Scientific sessions will be held at the:
Grand Sierra Resort
2500 East 2nd Street
Reno, NV 89595

DPS Paper Sorters
Paul Abell
Fran Bagenal
Kevin Baines
Nancy Chanover
Deborah Domingue Lorin
Amanda Hendrix
Lou Mayo
Jim Murphy
Vishnu Reddy
Scott Sheppard
Ellen Stofan

Session Numbering Key
100's Monday
200's Tuesday
300's Wednesday
400's Thursday
500's Friday

Sessions are numbered in the Program Book by day and time.
Changes after 10 September 2012 are included only in the online program materials.

Current DPS Officers
Daniel Britt	Chair
Rosaly Lopes	Vice-Chair
Athena Coustenis	Secretary
Andrew Rivkin	Treasurer
Nick Schneider	Education and Public Outreach
Vishnu Reddy	Press Officer
Tony Roman	Webmaster

Current DPS Committee Members
Jason Barnes	Term expires October 2012
Dale Cruikshank	Term expires October 2013
Melissa McGrath	Term expires October 2012
Ralph McNutt	Term expires November 2014
Robert Pappalardo	Term expires November 2014
Elizabeth (Zibi) Turtle	Term expires October 2013
Leslie Young	Term expires October 2012
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(Note: Secretary/Treasurer position split in 2003)

Webmaster

(The Webmaster is not really a proper officer at all, and the position was created in an ad-hoc manner in 1995 when public use of the Internet and Web sites were first being used to share information. The Webmaster is appointed by the DPS Chair and there is no set term.)
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The DPS sponsors five prizes:

The Gerard P. Kuiper Prize honors outstanding contributions to the field of planetary science.

The Harold C. Urey Prize recognizes outstanding achievement in planetary research by a young scientist.

The Harold Masursky Award acknowledges outstanding service to planetary science and exploration.

The Carl Sagan Medal recognizes and honors outstanding communication by an active planetary scientist to the general public.

The Jonathan Eberhart Planetary Sciences Journalism Award recognizes and stimulates distinguished popular writing on planetary sciences.

Current and Previous Winners

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### Exhibitors

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CRYSTAL BALLROOM

CRYSTAL 2

CRYSTAL 3

CRYSTAL 4

CRYSTAL 5

Corridor

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**Notes:**
- **Monday, 10/15:**
  - Session Chair Breakfast (7:15 AM - 8:00 AM, Crystal 2)

- **Tuesday, 10/16:**
  - Session Chair Breakfast (7:15 AM - 8:00 AM, Crystal 2)

- **Wednesday, 10/17:**
  - Session Chair Breakfast (7:15 AM - 8:00 AM, Crystal 2)

- **Thursday, 10/18:**
  - Session Chair Breakfast (7:15 AM - 8:00 AM, Crystal 2)

- **Friday, 10/19:**
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<td>Lecture: Orbital Dynamics of Extrasolar Planets, Eric B. Ford (University of Florida)</td>
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<td>6:00 PM-7:30 PM</td>
<td>Town Hall: Agency Night</td>
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<td>7:30 PM-9:00 PM</td>
<td>Public Talk: The Fascinating Quest of Asteroids: The Remnants of Planetary Formation, Patrick Michel (Lagrange Laboratory, University of Nice-Sophia Antipolis, CNRS, Côte d'Azur Observatory)</td>
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<td>DPS Banquet</td>
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*Plenary Session: 107 Exploring the Planet: 1.5 Years of MESSENGER Orbital Surveys, Sean C. Solomon (Lamont-Doherty Earth Observatory) 2:00 PM - 3:00 PM, Reno Ballroom*

*Plenary Session: 108 Exploring the Planet: Latest Results from Venus Express, Darrell Strobel as the 2012 Kuiper Prize Winner, Darrell Strobel (Johns Hopkins University) 1:30 PM - 2:05 PM, Reno Ballroom*

*Plenary Session: 109 Exploring New Worlds: Latest Results from the Kepler Mission, William J. Borucki (NASA Ames Research Center) 2:20 PM - 2:55 PM, Reno Ballroom*

*Plenary Session: 110 Exploring the Planet: The Remnants of Planetary Formation, Patrick Michel (Lagrange Laboratory, University of Nice-Sophia Antipolis, CNRS, Côte d'Azur Observatory) 2:55 PM - 3:30 PM, Reno Ballroom*
Monday, 15 October, 2012

100 Extrasolar Planetary Systems: Formation, Orbital Dynamics, and Habitability
Monday, 8:30 AM - 10:00 AM, Tahoe Room

100.01 Underlying Architecture of Planetary Systems Based on Kepler Data: Number of Planets and Coplanarity
- Julia Fang\(^1\), J. L. Margot\(^1\)
\(^1\)University of California, Los Angeles.

We investigated the underlying architecture of planetary systems by deriving the distribution of planet multiplicity (number of planets) and the distribution of orbital inclinations based on the sample of planet candidates discovered by the Kepler mission. The scope of our study included solar-like stars and planets with orbital periods less than 200 days and with radii between 1.5 and 30 Earth radii, and was based on Kepler planet candidates detected during Quarters 1 through 6. Our analysis improves on previous work by including all available quarters, extending to 200-day periods, and fitting models to observables such as normalized transit duration ratios that contain information on mutual orbital inclinations; these improvements lend to a deeper investigation of the intrinsic distributions of planetary systems. We created models of planetary systems with different distributions of planet multiplicity and orbital inclinations, simulated observations of these systems by Kepler, and compared the number and properties of the transits of detectable objects to actual Kepler planet detections. Based on the underlying distributions of our best-fit models, 75-80% of planetary systems have 1 or 2 planets with orbital periods less than 200 days. In addition, over 85% of planets have orbital inclinations less than 3 degrees. This high degree of coplanarity is comparable to that seen in our Solar System, with the exception of Mercury. These results provide important constraints and insights into theories of planet formation and evolution.

100.02 Dynamics of Kepler’s Multiple Planet Systems
- Jack J. Lissauer\(^2\), Kepler Science Team
\(^2\)NASA Ames Research Center.

Among the ~1800 Kepler targets that have candidate planets, 20% have two or more candidate planets. While most of these objects have not yet been confirmed as true planets, several considerations strongly suggest that the vast majority of these multi-candidate systems are true planetary systems. Virtually all candidate systems are stable, as tested by numerical integrations (assuming a physically motivated mass-radius relationship). The number of candidates in multiple candidate systems is more than 100 times as large as would be expected if planet candidates were distributed randomly among target stars, as would be the case for most types of false positives. Statistical studies performed on these candidate systems reveal a great deal about the architecture of planetary systems, including the typical spacing of orbits and flatness. The distribution of observed period ratios shows that the vast majority of candidate pairs are neither in nor near low-order mean motion resonances. Nonetheless, there are small but statistically significant excesses of candidate pairs both in resonance and spaced slightly too far apart to be in resonance, particularly near the 2:1 resonance. The characteristics of some of the confirmed Kepler multi-planet systems will also be discussed.

100.03 Planetary Assembly in Binary Systems
- Stefano Meschiari\(^1\)
\(^1\)University of Texas at Austin.

The existence of planets born in environments highly perturbed by a stellar companion represents a major challenge to the paradigm of planet formation. In numerical simulations, the presence of a close binary companion stirs up the relative velocity between planetesimals, which is fundamental in determining the balance between accretion and erosion. Aerodynamic drag from a putative protoplanetary disk exacerbates the issue by differentially phasing planetesimal orbits in a size-dependent fashion, ultimately interfering or halting altogether the delicate phase of assembly of planetary embryos in large regions of the protoplanetary disk. However, the
detection of several planets in tight binary systems and the recent discovery of circumbinary planets (Kepler 16-b, 34-b, and 35-b) establishes that planet formation in binary systems is clearly viable. We perform N-body and hydrodynamical simulations of planetesimals embedded in a protoplanetary disk, subject to the gravitational perturbation of a stellar companion, and follow the collision history among planetesimals. We identify a number of physical processes (including the hitherto unexplored complication of small-scale turbulence in the disk) that conspire to make the binary environment particularly hostile to planetary assembly.

100.04 Changes in One Planet's Mass or Semi-Major Axis Affects All Planets' Eccentricities
- Christa L. Van Laerhoven, R. Greenberg
  1The University of Arizona.

If one or more of the planets in a system undergoes a gradual change in either semi-major axis (e.g., by tides) or mass (e.g., by evaporation of a close-in planet) the underlying secular dynamics of the system change, such that the orbital eccentricities of all the planets are affected. In a non-resonant multi-planet system each planet's eccentricity is a sum of eigenmodes, described by classical secular theory. The planets' masses \(m\) and semi-major axes \(a\) set the underlying structure of the eigenmodes, while the eccentricities \(e\) and longitudes of pericenter set the modes' amplitudes and phases. If a physical process (whatever it may physically be) changes only an \(m\) or \(a\) value, but not \(e\), the underlying eigenmode structure will change, and also the eigenmode amplitudes (and phases) will respond. Thus, this process will change the range of values that each planet's eccentricity will take over a secular cycle, and how quickly secular eccentricity variation happens. Wu and Goldreich (ApJ 564, 1024, 2002) developed a theory that incorporates changing semi-major axis into secular theory, but an implicit assumption of their analysis was that only a single eigenmode has non-zero amplitude. Therefore, that result can only be applied to a system that has already damped to a "quasi-fixed-point", not to its interesting previous evolution; moreover, Van Laerhoven and Greenberg (C.M.&Dyn.Astr., 113, 215, 2012) showed that in the context of tidal evolution there are often modes that damp on similar timescales so there may be several long-lived eigenmodes. To address this issue, we have developed formulae to describe the more general solution for a system of any number of planets with multiple active eigenmodes incorporating externally driven change in any semi-major axis or mass. Such effects may have significant implications for some multi-planet systems.

100.05 Tidal Evolution of Multiple Planet Systems Around Brown Dwarfs
- Emeline Bolmont, S. N. Raymond, J. Leconte
  1Laboratoire d'Astrophysique de Bordeaux, France, 2Laboratoire de Météorologie Dynamique, France.

The tidal evolution of planets orbiting brown dwarfs (BDs) presents an interesting case study because BDs' terrestrial planet forming region is located extremely close-in. In fact, the habitable zones of BDs range from roughly 0.001 to 0.03 AU and for the lowest-mass BDs are located interior to the Roche limit. In contrast with stars, BDs spin up as they age. Thus, the corotation distance moves inward. We study the tidal evolution of planets around BDs using a standard tidal model and test the effect of numerous parameters such as the initial semi-major axis and eccentricity, the rotation period of the BD, the masses of both star and planet, and their tidal dissipation factor. We find that the most important parameter is the initial orbital distance with respect to the corotation distance. We find that all planets that form at or beyond the corotation distance and with initial eccentricities smaller than about 0.1 and are repelled from the star. Some planets initially interior to corotation can survive if their inward tidal evolution is slower than the BD's spin evolution, although most initially close-in planets fall onto the BD. Next we studied multiple planet systems with a N-body code altered to include tidal forces. We present a few interesting case studies for systems of planets orbiting BDs. In one example, a close-in planet pushes a more distant planet outward while locked in resonance. In another example, rapid outward tidal migration destabilizes a system of three planets. In another case, the combination of eccentricity forcing from an outer planet and dissipation within the inner planet drives the inner planet into the BD despite being exterior to the corotation radius. We thank the CNRS's PNP program for funding.

100.06 Orbital Stability of Moons around Giant Exoplanets and Free-Floaters in Planet-Planet Scattering
- Yu-Cian Hong, S. N. Raymond, J. I. Lunine
  1Astronomy Department, Cornell University, 2Laboratoire d'Astrophysique de Bordeaux, France.
Planet-planet scattering is the best current candidate for explaining the eccentric and inclined orbits of giant exoplanets. It is interesting to know if satellites can survive the violent dynamical history of extra-solar planetary systems. We have conducted a series of numerical simulations using a version of the Mercury symplectic integrator modified by J. Chambers to allow inclusion of moons bound to the giant planets. Through energy and momentum exchange between the perturbing planet and moons during close encounters, moons change orbit or become unbound, generally from outer to inner ones, depending on the geometry of close encounter. The smallest close encounter distance throughout the instability period, which typically ranges from orders of 0.001 to 0.01AU, places an upper bound on the semi-major axis of surviving moons. Whether a moon can survive as the perturber comes close depends strongly on the perturber mass. If a Neptune-mass perturber comes as close as 0.06HR, moons may still remain bound out to 0.35 Hill radii on a Saturn-mass host planet, whereas an equal-mass perturber is more likely to strip away all moons. If the less massive planet is ejected into interstellar space, the most distant moons that can survive have a much smaller semi-major axis. Moons that remain stable may enter orbital resonance with each other, providing a tidal source of heating. Simulated orbits of primordial moons lie partly within the detectable range of microlensing, which may be the best technique for determining the occurrence of exomoons.

100.07 Planet Hunters: A Status Report


The Planet Hunters (http://www.planethunters.org) citizen science project uses the power of human pattern recognition via the World Wide Web to identify transits in the Kepler public data. Planet Hunters uses the Zooniverse (http://www.zooniverse.org) platform to present visitors to the Planet Hunters website with a randomly selected ~30-day light curve segment from one of Kepler’s ~160,000 target stars. Volunteers are asked to draw boxes to mark the locations of visible transits with multiple independent classifiers reviewing each 30-day light curve segment. Since December 2010, more than 170,000 members of the general public have participated in Planet Hunters contributing over 12.5 million classifications searching the 1 1/2 years of publicly released Kepler observations. Planet Hunters is a novel and complementary technique to the automated transit detection algorithms, providing an independent assessment of the completeness of the Kepler exoplanet inventory. We report the latest results from Planet Hunters, highlighting in particular our latest efforts to search for circumbinary planets (planets orbiting a binary star) and single transit events in the first 1.5 years of public Kepler data. We will present a status report of our search of the first 6 Quarters of Kepler data, introducing our new planet candidates and sharing the results of our observational follow-up campaign to characterize these planetary systems. Acknowledgements: MES is supported by a NSF Astronomy and Astrophysics Postdoctoral Fellowship under award AST-1003258. This is research is supported in part by an American Philosophical Society Franklin Grant.

100.08 Habitability of Planet-Hosting Binary Star Systems: Calculating the Habitable Zone for Circumprimary Planets

- Lisa Kaltenegger, N. Haghighipour

We have developed a comprehensive approach to assess the influence of the secondary star on the limits of the habitable zone and habitability of terrestrial planets around the primary of an S-type binary system. We have considered different stellar spectral types for the primary and secondary stars, and have taken into account the interaction between the incoming radiation from the secondary and the atmosphere of an Earth-like planet. We have determined the contribution of the secondary to the total flux received by the planet, and by combining dynamical simulations with the influence of the additional flux, have derived the binary’s habitable zone as a function of its semimajor axis, eccentricity, and stellar energy distribution. We find that terrestrial planets can be
habitable and stable in S-type binaries for a variety of binary eccentricities. Our results indicate that in binaries where the stars have similar masses and spectral types, the effect of the secondary on the location of the primary’s habitable zone is generally small. However, when the stars have different spectral types, a luminous secondary can influence the extent of the habitable zone significantly when the binary’s separation is small, and can temporarily provide additional high flux levels when the binary is eccentric. We present the details of our model and the results of its applications to currently known S-type binary-planetary systems.

**100.09 Habitability of P-type Planet-Hosting Binary Star Systems: Calculating Habitable Zone for Known Circumbinary Planets**

- Nader Haghighipour¹, L. Kaltenegger²
  ¹Inst. for Astronomy, Univ. of Hawaii, ²Max Planck Institute for Astrophysics, Germany.

We have developed a detailed approach to determine the location of the habitable zone around a planet-hosting binary star system (P-type). Our approach takes into account the interaction between the incoming radiation from a star and the atmosphere of an Earth-like planet, and accounts for the fraction of the insolation from each star of the binary that contributes to the total flux received at the top of the planet’s atmosphere. Since these interactions depend on the spectral energy distribution of each star, we have considered different stellar spectral types for the primary and secondary of the binary, and included different cloud fractions for the atmosphere of the planet. By combining dynamical simulations with the influence of the additional flux, we have derived the binary’s habitable zone as a function of its semimajor axis, eccentricity, and stellar energy distribution. Our results suggest that in most cases in circumbinary (P-type) planetary systems, the flux of the two stars at the location of the planet can be added, and the system can be regarded as a more luminous single star. However, if the stellar separation of the binary is small, the eccentricities of the binary and planet can play an important role in the locations of the system’s habitable zone. We have applied our model to the currently known planet-hosting circumbinary systems detected by Kepler and have determined the possibility of the existence and detection of Earth-like planets in their habitable zones. We present the details of our model and discuss its applications to different binary-planetary systems.

**101 Icy Satellites 1**
Monday, 8:30 AM - 10:00 AM, Carson 1/2

**101.01 Polar Temperatures on Ganymede: Ray-Tracing Thermal Model Results**
- David A. Paige¹, K. Bennett², B. Greenhagen³, P. Hayne³, P. Schenk⁴
  ¹UCLA, ²ASU, ³JPL, ⁴LPI.

Temperatures in the polar regions of Ganymede are important for considering the thermal stability of cold-trapped volatiles as well as constraining the heat flow rate from the moon’s interior. We have developed a ray-tracing thermal model that can calculate surface temperatures that are in good agreement with LRO Diviner Lunar Radiometer measurements for the Moon. The Ganymede version of model includes the effects of multiply scattered solar and infrared radiation, one-dimensional heat conduction, and the radiative effects of Jupiter at solar and infrared wavelengths. We have used the model and DEMs derived from past flyby missions to calculate global diurnal and seasonal temperature variations, including temperature variations caused by local topography. The results show that the poles of Ganymede are significantly colder than those of Europa, and allow for the thermal stability of a wide range of potentially cold-trapped volatile and organic species.

**101.02 Strike-slip Faulting On Ganymede, Now And Then**
- Robert T. Pappalardo¹, B. R. Smith-Konter², M. E. Cameron³, L. C. DeRemer-Keeny⁴, F. Nimmo⁵
  ¹Jet Propulsion Laboratory, California Institute of Technology, ²University of Texas, El Paso, ³University of Texas, El Paso, ⁴DigitalGlobe, ⁵University of California, Santa Cruz.

Strike-slip tectonism is important to the structural development of Ganymede’s surface, and in the transition from dark to grooved terrain. Three distinct signatures of strike-slip faulting are recognized [1]: (1) en echelon
structures, (2) strike-slip duplexes, and (3) laterally offset pre-existing features. As strike-slip faulting progressed, *en echelon* fractures (in both dark and grooved terrains) merged to define *en echelon* swaths, which can become distinct tectonic domains. Three morphological categories of strike-slip “duplexes” (spindle-shaped lensoid regions bounded by strike-slip faults) occur, suggesting an evolutionary sequence from discontinuous fractures in dark terrain, to lensoid bounding structures, to lensoid regions with subparallel internal structure in grooved terrain. Ganymede’s 24 measured duplexes have an average length/width ratio of 2.4, on the low end of the terrestrial range [2]. Lateral offsets of pre-existing features betray the existence of some major strike-slip faults: Dardanus Sulcus (13°W, 18°S) is displaced ~45 km by a prominent NE-SW trending fault. We model Coulomb shear failure on Ganymede, considering nonsynchronous rotation (NSR), and diurnal stresses both for present (0.0013) and possible past high (~0.05) eccentricity [3]. We adopt NSR period 0.14 Ma; Love numbers \( h_2 = 1.52 \) and \( l_2 = 0.38 \); Young’s modulus 9.3 GPa; Poisson’s ratio 0.33; and fault depth 2 km. NSR shear stress resolved along the Dardanus fault is ~0.3 MPa, sufficient to induce failure to ~1.4 km for friction coefficient ~0.3. For past high eccentricity, diurnal stress would have modulated NSR stress by ~100 kPa through Ganymede’s tidal cycle. This could have induced shear heating [4] and tidal walking [5], as modeled for Europa. References: [1] DeRemer and Pappalardo (2003), *LPSC*, 34, #2033; [2] Aydin and Nur (1982), *Tectonics*, 1, 91; [3] Showman and Malhotra (1997), *Icarus*, 127, 93; [4] Nimmo and Gaidos (2002), *JGR*, 107, 10.1029/2000JE001476; [5] Rhoden et al. (2012), *Icarus*, 218, 297.

101.03 Ridges on Ridges: Extensions of Adjacent Topography onto the Flanks of Europan Ridges

- Richard Greenberg\(^1\), P. B. Sak\(^2\)
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At some locations along ridges on Europa, older ridges on adjacent terrain appear to extend up the flank of a more recent ridge. It has thus been suggested that the ridges may have formed by upturning of that adjacent terrain. However, the newer ridges generally appear to be material deposited over the older terrain. How might material that was pushed over and buried the earlier surface have inherited the topography of the underlying material? At some sediment-starved subduction zones on Earth, where the poorly consolidated material of a frontal prism of an overriding plate is pushed over preexisting ridges and seamounts on the downgoing plate, the overriding plate inherits the morphology of the downgoing plate even though the actual extension of that topography has been underthrust and buried. A well-studied example lies offshore of Costa Rica where the Caribbean plate overrides the Cocos plate. Experiments show other mechanisms as well: Mass-wasting down a flank can result in extensions of adjacent ridges thanks to the geometry imposed by a constant angle of repose. More pronounced extensions of the older ridges result if the new ridge grows as it is bulldozed from behind (i.e. from the central groove of a double ridge on Europa). The shapes of the ridge extensions are distinctly different in these latter two cases. If tidal pumping extrudes material to the surface at the center of a double ridge, it might drive the latter mechanism. The ridge extensions observed on the flanks of newer ridges may be a definitive, and perhaps crucial, diagnostic of dominant ridge-building mechanisms when additional images are obtained at high resolution from future exploration. In addition to their morphology, the distribution of ridge extensions at only isolated locales may also provide important constraints on the diversity of ridge formation processes.

101.04 Oceanography of Europa

- Krista M. Soderlund\(^1\), B. E. Schmidt\(^1\), D. D. Blankenship\(^1\), J. Wicht\(^2\)
  \(^1\)University of Texas Institute for Geophysics, \(^2\)Max Planck Institute for Solar System Research, Germany.

Europa maintains a global liquid water ocean located between a lower silicate mantle and an upper ice shell. If ice-ocean interactions affect the ice shell, oceanographic processes may be tested through their implications for surface geology. Chaos terrain, in particular, is thought to be a surficial indicator of high heat flow. These regions of disrupted ice occur over a wide range of spatial scales and tend to be concentrated at low latitudes, a puzzling result if they were formed by tidal heating. Here we present a three-dimensional numerical model of weakly-rotating thermal convection in a thin spherical shell and show that heat from the interior is preferentially emitted in a low latitude band. We further predict that oceanic thermal plumes are short-lived structures unlikely to remain intact between the silicate-ice and ocean-ice interfaces due to vigorous, poorly-organized convective motions. These flows cause the ocean to be well-mixed near the equator, while thermal and compositional
gradients may be maintained toward the poles. Our results imply that oceanic heat transfer may directly influence the thermo-compositional state of the ice shell, consistent with chaos terrain distribution.

101.05 Keck II NIRSPEC Observations of Hydrogen Peroxide on Europa
- Kevin P. Hand\textsuperscript{1}, M. Brown\textsuperscript{2}
\textsuperscript{1}Jet Propulsion Laboratory, Caltech, \textsuperscript{2}Caltech.

We observed Europa over four consecutive nights using the Keck II near-infrared spectrograph (NIRSPEC). Spectra were collected in the 3.14-4.0 μm range, allowing detection and monitoring of the 3.5 μm feature due to hydrogen peroxide (Bain and Giguere, 1955). Galileo Near-Infrared Spectrometer (NIMS) results revealed hydrogen peroxide on Europa in the anti-jovian region of the leading hemisphere at an abundance of 0.13± 0.07% by number relative to water (Carlson et al., 1999). We find comparable results for the two nights over which we observed the leading hemisphere, with reduced concentrations measured for observations that also incorporated sub- and anti-jovian hemispheres. Significantly, we also observed a small amount of hydrogen peroxide (∼ 0.04%) during a night of observations of Europa’s trailing to sub-jovian hemispheres. No hydrogen peroxide was detected during observations of just the trailing hemisphere.

101.06 The Thermal Chemistry Of H$_2$O$_2$ On Icy Satellites: Descent With Modification?
- Reggie L. Hudson\textsuperscript{1}, M. J. Loeffler\textsuperscript{1}
\textsuperscript{1}NASA Goddard Space Flight Center.

Magnetospheric radiation drives surface and near-surface chemistry on Europa, but below a few meters Europa’s chemistry is hidden from direct observation. As an example, surface radiation chemistry converts H$_2$O and SO$_2$ into H$_2$O$_2$ and (SO$_4$)$_2^-$, respectively, and these species will be transported downward (Green, Astrobiology, 2010, 10, 275) for possible thermally-driven reactions. However, while the infrared spectra and radiation chemistry of H$_2$O$_2$-containing ices are well documented, this molecule’s thermally-induced solid-phase chemistry has seldom been studied. Here we report new results on thermal reactions in H$_2$O + H$_2$O$_2$ + SO$_2$ ices at 50 - 130 K. As an example of our results, we find that warming H$_2$O + H$_2$O$_2$ + SO$_2$ ices promotes SO$_2$ oxidation to (SO$_4$)$_2^-$. These results have implications for the survival of H$_2$O$_2$ as it descends, with modification, towards a subsurface ocean on Europa. We suspect that such redox chemistry may explain some of the observations related to the presence and distribution of H$_2$O$_2$ across Europa’s surface as well as the lack of H$_2$O$_2$ on Ganymede and Callisto. [This work was supported by NASA’s Exobiology, Outer Planets, and Planetary Geology and Geophysics programs, and The Goddard Center for Astrobiology.]

101.07 Compositional Mapping of the Galilean Moons by Mass Spectrometry of Dust Ejecta
- Frank Postberg\textsuperscript{1}, E. Gruen\textsuperscript{2}, M. Horanyi\textsuperscript{3}, S. Kempf\textsuperscript{3}, H. Krüger\textsuperscript{4}, J. Lebreton\textsuperscript{5}, J. Schmidt\textsuperscript{6}, R. Srama\textsuperscript{1}, Z. Sternovsky\textsuperscript{1}, R. Thissen\textsuperscript{7}
\textsuperscript{1}IRS, University of Stuttgart, Germany, \textsuperscript{2}MPI for Nuclear Physics, Germany, \textsuperscript{3}LASP, University of Colorado, \textsuperscript{4}MPI for Solar System Research, Germany, \textsuperscript{5}LPC2E, France, \textsuperscript{6}University of Oulu, Finland, \textsuperscript{7}IPAG, France.

We present a method to measure composition and origin of ballistic dust particles populating the thin exospheres of the Galilean moons. The presence of such particles, generated by the ambient meteoroid bombardment that erodes the surface has already been detected by Galileo spacecraft. As these grains are almost unaltered samples from the moons’ surfaces, unique composition data can be obtained from a dust spectrometer. The ballistic trajectories can be traced back to their region of origin at the surface, which allows in situ compositional mapping at flybys or from an orbiter. The well-established approach of dust detection by impact ionization has recently shown its capabilities by analyzing ice particles expelled by subsurface salt water on Saturn’s moon Enceladus. Applying the method on micro-meteoroid ejecta of less active moons allow for the qualitative and quantitative analysis of samples from various surface areas, thus combining the advantages of remote sensing and a lander. The detection rates at 200-500 km altitude are on the order of thousand per orbit and hundreds per flyby. Thus an orbiter can create a compositional map of samples taken from a greater part of the surface, whereas flybys allow an investigation of certain areas of interest. The method provides chemical characterization of ice and dust particles encountered at speeds at 1 km/s and above. It measures the bulk composition of the ice and has ppm-
level sensitivity to hydrated salts, most rock forming materials, and organic compounds. Key chemical and isotopic constraints for varying provinces or geological formations on the surfaces lead to better understanding of the body’s geological evolution. Regions which were subject to endogenic or exogenic alteration (resurfacing, radiation, old/new regions) are distinguished and investigated. In particular exchange processes with subsurface oceans on the Galilean moons could be determined with high quantitative precision.

101.08 Saturn’s Irregular Moon Ymir
- Tilman Denk¹, S. Mottola²
 ¹Freie Universität Berlin, Germany, ²DLR, Germany.

Ymir (diameter ~18 km), Saturn’s second largest retrograde outer or irregular moon, has been observed six times by the Cassini narrow-angle camera (NAC) during the first 7 months in 2012. The observations span phase angles from 2° up to 102° and were taken at ranges between 15 and 18 million kilometers. From such a distance, Ymir is smaller than a pixel in the Cassini NAC. The data reveal a sidereal rotation period of 11.93 hrs, which is ~1.6x longer than the previously reported value (Denk et al. 2011, EPSC/DPS #1452). Reason for this discrepancy is that the rotational light curve shows a rather uncommon 3-maxima and 3-minima shape at least in the phase angle range ~50° to ~100°, which was not recognizable in earlier data. The data cover several rotations from different viewing and illumination geometries and allow for a convex shape inversion with possibly a unique solution for the pole direction. The model reproduces the observed light curves to a very good accuracy without requiring albedo variegation, thereby suggesting that the lightcurve is dominated by the shape of Ymir. Among Saturn’s irregular moons, the phenomenon of more than two maxima and minima at moderate to high phase angles is not unique to Ymir. At least Siarnaq and Paaliaq also show light curves with a strong deviation from a double-sine curve. Their rotation periods, however, remain unknown until more data can be taken. The light curve of Phoebe is fundamentally different to Ymir’s because it is mainly shaped by local albedo differences and not by shape. Other reliable rotation periods of irregular satellites measured by Cassini include: Mundilfari 6.74 h; Kari 7.70 h; Albiorix 13.32 h; Kiviuq 21.82 h. More uncertain values are: Skathi ~12 h; Bebhionn ~16 h; Thrymr ~27 h; Erriapus ~28 h.

101.09 Observations of the Phoebe Ring with Cassini & Herschel: How Seeing Nothing Can Yield a Signal Half the Time
- Dan Tamayo¹, M. M. Hedman¹, J. A. Burns¹, J. J. Kavelaars²
 ¹Cornell University, ²Herzberg Institute of Astrophysics, Canada.

Using the Spitzer Space Telescope, Verbiscer et al. (2009) detected a colossal dust ring surrounding Saturn, far beyond the main rings. This ring is believed to be derived from impact ejecta lost from the irregular satellite Phoebe. With only this thermal signal at 24 microns and a more recent one by WISE at 22 microns (Hamilton et al. 2012, AAS), it is important to extend the wavelength coverage of observations to better characterize the particle properties of this ring. We report here on two new studies. The first, at visible wavelengths, is an indirect detection in reflected light using the Cassini spacecraft orbiting Saturn. The main challenge is that the Phoebe ring is so large from Cassini’s vantage point that it covers the entire field of view and appears as a constant faint background. To circumvent this problem, we have made observations targeting Saturn’s shadow as it pierces the ring’s smooth haze. We have developed successful protocols to then extract the Phoebe ring’s signal from the deficit in brightness along Saturn’s conical shadow where particles are unilluminated and hence reflect no signal. In our second study we present new limits at 70 and 160 microns using the Herschel Space Observatory. The combination of all these data should provide firmer limits on the particle sizes in this colossal ring.
The Rosetta spacecraft has flown by two asteroids. Steins is a ~5 km diameter E-type asteroid, while Lutetia is ~100 km and C- or M-class. The MIRO instrument made continuum observations at wavelengths of 0.5 and 1.6 mm, probing 1 to 15 mm below the surface. We find Lutetia is covered by a very low-thermal inertia [< 20 J/(K m² s⁰.⁵)] and high-emissivity (>0.9) fine powder (Gulkis et al. 2011). The smaller Steins has a larger thermal inertia [~650 J/(K m² s⁰.⁵)] and lower emissivity (~0.8) indicative of a more rock-like surface material (Gulkis et al. 2010). The trend of larger asteroids having lower thermal inertias has been noted previously (e.g. Delbo et al. 2007). Our data support the hypothesis that any airless body with a gravity field strong enough to retain fine impact ejecta will become covered by a powder. A combined analysis of MIRO and VIRTIS (infrared) data indicates Lutetia’s surface roughness is consistent with >=50% areal coverage by unresolved craters (Keihm et al. 2012, submitted to Icarus). A consequence of large asteroids being covered by powder is that they will have extremely large temperature gradients, 50 K/cm, within their daytime surfaces. Submillimeter and longer wavelengths, sensing cooler regions at depth, will measure a much smaller flux than IR surface measurements. Some researchers, seeing this difference, postulated a drop in emissivity at long wavelengths relative to the IR (e.g. Muller and Barnes 2007). Reanalyzing observations of four large asteroids (Vesta, Ceres, Pallas, Hygiea) using thermal properties we derived for Lutetia, we can match the flux density measurements without invoking wavelength-dependent electrical properties. We find a fairly uniform emissivity of ~0.9 from IR to cm wavelengths. This research was carried out at JPL/Caltech, under a contract with NASA, and was funded by the NASA-Rosetta project.

102.02 Visible Spectroscopic Observation Of Asteroid 162173 (1999ju3) With The Gemini-s Telescope
- Seiji Sugita¹, D. Kuroda², S. Kameda³, S. Hasegawa⁴, S. Kamata¹, M. Abe⁴, M. Ishiguro⁵, N. Takato², M. Yoshikawa⁴
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Asteroid 162173 (1999JU3; hereafter JU3) is the target of the Hayabusa-2 mission. Its visible reflectance spectra have been observed a few times [1,2], and obtained spectra exhibit a wide variety of spectral patterns ranging from a spectra with absorption in the UV region (May 1999) to a flat spectrum with a faint broad absorption centered around 0.6 microns (September 2007) and that with UV absorption and strong broad absorption centered around 0.7 micron (July 2007). The apparent large spectral variation may be due to variegation on the asteroid surface. Such variegation would make a large influence on remote sensing strategy for Hayabusa-2 before its sampling operations. In order to better constraint the spectral properties of JU3, we conducted visible spectroscopic observations at the GEMINI-South observatory 8.1-m telescope with the GMOS instrument. We could obtain three different sets of data in June and July 2012. Although the JU3 rotation phases of two of the observation are close to each other, the other is about 120 degrees away from the two. Our preliminary analyses indicate that these three spectra are slightly reddish but generally flat across the observed wavelength range (0.47 - 0.89 microns). The observed flat spectra are most similar to the spectrum obtained in September 2007, which probably has the highest signal-to-noise ratio among the previous three spectra. This result suggests that material with a flat spectrum probably covers a dominant proportion of the JU3 surface and that the other two types of previously obtained spectra may not cover a very large fraction of the JU3 surface. [1] Binzel, R. P. et al. (2001) Icarus, 151, 139-149; [2] Vilas, F. (2008) AJ, 135, 1101-1105.

102.03 New Spectral Reflectance Observations of Hayabusa 2 Near-Earth Asteroid Target 162173 1999 JU3
- Faith Vilas¹
  ¹Planetary Science Institute.

The successful visit of the spacecraft Hayabusa to near-Earth asteroid 25143 Itokawa, and the successful return of samples of the asteroid’s material, have spurred the Japanese Space Agency (JAXA) to mount a second mission (Hayabusa 2) to Apollo asteroid 162173 1999 JU3. JAXA’s objective is to sample an asteroid having an unaltered or barely altered composition (C or D class). Asteroid 162173 1999 JU3 is targeted both for its easy accessibility from the Earth (a low ΔV of 3.238 km s⁻¹) and its spectral class. Spectral reflectance observations of 162173 during two apparitions in 2003 and 2007 are both tantalizing and potentially inconclusive, with the suggestion that mineralogical variegation is revealed on the asteroid’s surface. A spectrum from July 2007 suggests the presence of an absorption feature centered near 0.7 μm. The strength of the absorption feature suggests that the material
contributing to the spectrum is largely concentrated iron-bearing phyllosilicates, however, the SNR is limited. Other spectra do not show this feature, but could contain other subtle absorption features. During the final opportunity to observe 162173 before the proposed launch of Hayabusa 2, reflectance spectra were obtained of 162173 (V = ~18.5) using the facility ES2 spectrograph with a red-sensitive CCD at McDonald Observatory's 2.1-m telescope on UT June 12 and 13, 2012. A preliminary examination of these spectra suggests that absorption features could be present and the surface variegation is real, however, the SNR remains limited. These new spectral will be presented and discussed in the context of our prior knowledge of 162173 1999 JU3.

102.04 Characterization of Hayabusa II Target Asteroid (162173) 1999 JU3

- Nicholas Moskovitz\(^1\), S. Abe\(^2\), D. Osip\(^3\), S. J. Bus\(^4\), P. Abell\(^5\), F. DeMeo\(^6\), R. Binzel\(^6\)

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The Japanese Hayabusa II mission is planned to rendezvous with and return a sample from the near-Earth asteroid (162173) 1999 JU3. Previous mid-infrared studies have constrained the albedo and thermal properties of this object (Muller et al. 2011; Campins et al. 2011; Hasegawa et al. 2008). Visible wavelength spectra from 1999 and 2007 reveal a C-type asteroid that displays pronounced spectroscopic variability around 0.7 microns. Variability in the strength of a 0.7 micron band could be due to heterogeneous concentrations of iron-bearing phyllosilicates across its surface (Vilas 2008). We will present new observations from the favorable 2012 apparition to further characterize this object. In June of 2012 spectroscopic observations were conducted with the LDSS3 and FiRe instruments on the Magellan telescopes at Las Campanas Observatory in Chile. Between April and July of 2012 broadband visible-wavelength photometry was obtained with the Tenagra II telescope in Arizona and with the IMACS, Megacam and LDSS3 instruments on the Magellan telescopes. Our visible and near-infrared spectra confirm a C-type taxonomic classification, but do not show evidence for the presence of a 0.7 micron phyllosilicate band. Our time series of visible spectra cover approximately 60% of the rotational phases of 1999 JU3, but do not display any pronounced variability. We use our new optical light curves, combined with photometry from 2007, to refine a shape model of the asteroid. This shape model provides a means for mapping surface regions accessed by the spectroscopic observations from both 2007 and 2012, and thus to directly address the possibility of surface heterogeneity. This surface map, in conjunction with the newly measured photometric phase curve of the asteroid, will be used to make predictions regarding composition and surface properties that will ultimately be tested upon arrival of the Hayabusa II spacecraft.

102.05 Thermal and Physical Characterization of the OSIRIS-REx Target Asteroid (101955) 1999 RQ36

- Joshua P. Emery\(^1\), M. S. Kelley\(^2\), Y. R. Fernandez\(^3\), C. W. Hergenrother\(^4\), K. T. Crane\(^1\), J. Ziffer\(^5\), H. Campins\(^3\), D. S. Lauretta\(^1\), M. J. Drake\(^4\)

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The OSIRIS-REx mission, the third in NASA's New Frontier line, will launch in 2016, visit the near-Earth asteroid (101955) 1999 RQ\(_{36}\) and return samples of its regolith to Earth in 2023. Ground-based observations have already revealed a great deal about 1999 RQ\(_{36}\), including the spectral type (B-type), size, and rotation period. To further characterize the composition, surface grain size, and thermophysical properties, we observed 1999 RQ\(_{36}\) with the Spitzer Space Telescope during the time period 3-9 May 2007. Thermal spectra from 5.2 to 38 \(\mu\)m were measured with the Infrared Spectrograph (IRS) of opposite hemispheres of the body. Photometry at 3.6, 4.5, 5.8, and 8.0 \(\mu\)m was obtained with the Infrared Array Camera and at 16 and 22 \(\mu\)m with the IRS peak-up imaging mode. With the imaging modes, we targeted 10 equally distributed longitudes in order to search for rotational heterogeneities. The thermal inertia derived from the model fit is 600 +/- 150 J m\(^{-2}\) s\(^{-1}\) K\(^{-1}\). This moderately high thermal inertia suggests a regolith with grains less than ~2 cm in diameter. Thermal inertia an important parameter for estimating the strength of the Yarkovsky effect, and has been used with measurements of the semi-major axis drift rate to estimate the bulk density of 1999 RQ\(_{36}\) (Chesley et al. 2012). The inferred size of RQ\(_{36}\) is in excellent agreement with radar observations, and the geometric albedo is very low (pv~0.03). There is no evidence for spectral features larger than the noise (S/N~40) in the final spectrum. The imaging data show no evidence for dust around the asteroid. Additional observations with Spitzer are planned for September 2012. We will present the current results.
and new observations along with an analysis of the thermal lightcurve in the context of the shape model derived from radar data.

102.06 Arecibo and Goldstone Radar Observations of Binary Near-Earth Asteroid and Marco Polo-R Mission Target (175706) 1996 FG3


1JPL/Caltech, 2Arecibo Observatory, 3NRAO, 4UCLA, 5University of Maine at Farmington, 6Bloomsburg University.

We report Arecibo (2380 MHz, 13-cm) and Goldstone (8560 MHz, 3.5-cm) delay-Doppler radar observations of binary near-Earth asteroid and Marco Polo-R mission target (175706) 1996 FG3 that were obtained on nine dates between November 6-December 17, 2011. The images achieve resolutions as fine as 75 m in range and place hundreds of pixels on the primary. The images provide thorough rotational coverage by the primary and reveal a rounded, slightly elongated object with a visible extent of ~0.9 km. If the visible extent is about ½ of the actual extent, which would be true for a sphere, then the equatorial diameter is about 1.8 km. The primary has features along its leading edge that resemble the signature of the pronounced ridge on the equator of binary asteroid (66391) 1999 KW4. The images sample a wide range of orbital positions by the secondary, resolve it in range and Doppler frequency, show that it is elongated and roughly 500 m in diameter, and suggest that its rotation is synchronous (or nearly so) with the orbital period of 16.1 h estimated by Scheirich and Pravec (2009, Icarus 200, 531-547). We observe a maximum range separation of ~2.5 km that, combined with the nearly circular eccentricity found by Scheirich and Pravec from inversion of lightcurves, establishes a lower bound on the semimajor axis. 1996 FG3 has a circular polarization ratio SC/OC = 0.34±0.02 that is comparable to that of 25143 Itokawa (0.28±0.04), suggesting similar degrees of near-surface roughness. The radar data will yield a 3D model of the primary, possibly a coarse-resolution model of the secondary, more precise orbit fitting, and estimates of the system’s mass and bulk density.

102.07 Preliminary Results From The Neowise Post-cryogenic Mission


1JPL, 2Planetary Science Institute, 3IPAC, 4University of Arizona, 5MIRA, 6UCLA.

NASA’s Wide-field Infrared Survey Explorer mission surveyed the entire sky in four infrared wavelengths: 3.4, 4.6, 12 and 22 um (denoted W1, W2, W3, and W4 respectively). Images were collected in all four bands simultaneously using beamsplitters; cooling for all four detectors was provided by dual solid hydrogen tanks. Survey operations began on 14 January, 2010, and the first pass on the entire sky was completed six months later. However, coverage of the solar system was incomplete owing to the long synodic periods of near-Earth objects (NEOs) and many Main Belt asteroids. The hydrogen tank that provided cooling to the W3 and W4 Si:As detectors was exhausted on 5 August, 2010, resulting in the near-immediate loss of the 22 um channel that same day. As the remaining hydrogen in the second tank subsided away, both the detectors and the telescope temperature rose. During this period, the 12 um channel continued to operate (albeit with reduced sensitivity) until 29 September, 2010. On that day, the secondary tank’s hydrogen supply was finally exhausted, and the telescope temperature rose. Immediately thereafter, NASA’s Planetary Science Directorate funded a four month extension of the mission, the NEOWISE Post-Cryogenic Mission, to search for new asteroids and to fill in the gap in coverage of the solar system. The telescope temperature stabilized at 73.5 K, cold enough to allow observations in the two shortest wavelengths. The W1 and W2 arrays operated with minimal performance degradation. Survey operations concluded on 1 February, 2011. We present the preliminary results from the NEOWISE Post-Cryogenic Mission on NEOs.

102.08 Taxonomy Of The Cybeles, Hildas, And Jovian Trojans From WISE/NEOWISE

- Tommy Grav, A. Mainzer, J. M. Bauer, J. Masiero

2Planetary Science Institute, 3California Institute of Technology/Jet Propulsion Laboratory.
The populations of the region outside the Main Belt out to among the outer planets consist mainly of C-, P-, and D-type asteroids. All these taxonomic groups have dark visible albedos, however their albedos in the 3.4 and 4.6 micron band show interesting diversity. We have successfully used the near-infrared albedo to classify the large objects (larger than about 30km) in these populations and derive accurate taxonomic distributions. It is found that there is a trend of C- and P-types dominating the Cybeles and Hildas, while the D-types dominate the Jovian Trojan and irregular satellites of Jupiter and Saturn. Some interesting features are revealed in comparing the taxonomic distribution (as a function of diameter) between populations. We also report on the apparent fraction of interloper objects (S-, E-, M-, and other taxonomic types). This work uses data from the Wide-field Infrared Survey Explorer (a joint UCLA and JPL/Caltech mission in the NASA Explorer program) and NEOWISE (a JPL/Caltech project funded by the NASA Planetary Science Directorate).

102.09 Revising the Age for the Baptistina Family Using WISE/NEOWISE Data
- Joseph R. Masiero¹, A. Mainzer¹, T. Grav², J. M. Bauer¹, R. Jedicke³
  ¹JPL, ²PSI, ³IfA, U. Hawaii.

We present results from our simulations of the breakup and evolution of the Baptistina family using new data of the physical properties for family members available from the Wide-field Infrared Survey Explorer (WISE) and NEOWISE datasets. Measurements of the diameters of hundreds of family members allow us to refine the initial conditions for the evolution of the family and obtain more accurate results with our simulations. We also investigate the effect of varying the assumed physical and orbital parameters on the best-fitting age and discuss the effect of uncertainty in the density and thermal properties on the age determination, as well as possible methods of constraining these parameters. Funding for this work was provided by the NASA Postdoctoral Program, administered through Oak Ridge Associated Universities. WISE is a joint project between UCLA and JPL/Caltech funded by the NASA MIDEX program. NEOWISE is a project of JPL/Caltech funded through NASA’s Planetary Science Division.

103 Extrasolar Planets: Atmospheric Chemistry and Characterization
Monday, 10:30 AM - 12:00 PM, Tahoe Room

103.01 Chemical Characterization Of Extrasolar Planets
- Nikku Madhusudhan¹
  ¹Yale University.

Recent advances in observations and retrieval methods are leading to unprecedented constraints on chemical compositions of exoplanetary atmospheres. Molecular and elemental abundances derived from exoplanetary spectra provide critical clues on the chemical and dynamical processes in exoplanetary atmospheres, on the compositions of their interiors and formation environments, and, on the potential habitability of rocky exoplanets. In this talk, we will present new constraints on chemical abundances for an ensemble of exoplanetary atmospheres and will discuss their implications on our understanding of atmospheric processes, interiors, and formation conditions of exoplanets. We will present new constraints on the mixing ratios of carbon and oxygen based molecules and on the elemental C/H, O/H, and C/O ratios in several hot Jupiter atmospheres, based on latest observations using Spitzer, HST WFC3, and ground-based facilities. We will discuss how elemental abundance ratios can be used to characterize the atmospheric processes and formation mechanisms of giant extrasolar planets. We will discuss the influence of C/O ratio on equilibrium and non-equilibrium chemistry and thermal inversions in giant exoplanets, and the implications for interiors and atmospheres of planets in the super-Earth regime. We will end the talk with observing strategies for constraining elemental abundance ratios in exoplanetary atmospheres and predictions of molecules that are most likely to be observed in the near future with existing instruments.

103.02 The Chemistry of Metal-Rich Hot Neptunes
- Julianne I. Moses¹, M. R. Richardson², N. Madhusudhan³, M. R. Line⁴, C. Visscher⁵, J. J. Fortney⁶
  ¹Space Science Institute, ²Rice Univ., ³Yale Univ., ⁴Caltech, ⁵Southwest Res. Inst, ⁶UC Santa Cruz.
Neptune-mass planets with very high metallicities (100-3000 times solar) will exhibit an interesting continuum of atmospheric compositions in between the so-called “hot Neptune” and “Super Earth” exoplanet categories. If its metallicity is only slightly enhanced over solar, a Neptune-mass planet would have a photospheric composition similar to that predicted for any hydrogen-dominated, Jupiter-mass planet possessing a similar thermal structure and experiencing a similar incident stellar flux. Hydrogen-poor Super Earths, on the other hand, could have a variety of atmospheric compositions (e.g., Schaefer et al. 2011, arXiv:1108.4660), ranging from H$_2$O-, CO$_2$-, or N$_2$-dominated atmospheres, to more exotic high-temperature SiO and metal-rich atmospheres, depending on the planet’s mass, evolutionary history, incident stellar flux, and effective temperature. A Neptune-mass planet can become metal rich through efficient hydrogen escape (e.g., for less-massive, close-in planets) or through inefficient accretion of H$_2$, as has been suggested for our own solar-system “ice giant” Neptune, where carbon is enriched by 40-70 times solar (e.g., Karkoschka and Tomasko 2011, Icarus 211, 780) and oxygen may be enriched as much as 440 times solar (e.g., Lodders and Fegley 1994, Icarus 112, 368). We explore the predicted equilibrium and disequilibrium chemistry of generic hot Neptunes with metallicities varying from 1-3000 times solar and discuss observational consequences. The models are applied to the case of GJ 436b, where we find that methane will be the dominant carbon carrier until very high metallicities, near ~2000x solar, at which point the planet can have roughly equal proportions of CO, H$_2$, and CO$_2$, with methane becoming a more minor constituent. We compare our model results with Spitzer infrared secondary-eclipse data for GJ436b. This work was supported by the NASA PATM program.

103.03 Secondary Eclipse Spectral Retrievals: Trends in Chemistry
- Michael R. Line$^1$, E. Ellison$^2$, X. Zhang$^1$, Y. Yung$^1$
  $^1$California Institute of Technology, $^2$Flintridge Preparatory School.

Secondary eclipse spectra of exoplanets probe the thermal emission of the atmosphere and can therefore tell us about their composition and temperature. Here we will apply the optimal estimation retrieval approach (Lee et al. 2012, Line et al. 2012) to all available secondary eclipse spectra (in some cases multiple data sets per planet) in order to identify compositional trends amongst different atmospheres, such as the CH$_4$/CO ratio as a function of effective temperature etc. We will compare our retrieved results to what is expected from thermal equilibrium chemistry in order to assess how strongly out of equilibrium the planets as a whole agree with or deviate from thermal equilibrium.

103.04 Spitzer Transits Of The Super-Earth GJ1214b And Implications For Its Atmosphere
- Jonathan D. Fraine$^1$, D. Deming$^1$, M. Gillon$^2$, E. Jehin$^2$, B. Demory$^3$, B. Benneke$^3$, S. Seager$^3$
  $^1$University of Maryland, $^2$Universite de Liege, Belgium, $^3$Massachusetts Institute of Technology.

We observed the transiting super-Earth exoplanet GJ1214b using Warm Spitzer at 4.5 μm wavelength during a 20-day quasi-continuous sequence in May 2011. The goals of our long observation were to accurately define the infrared transit radius of this nearby super-Earth, to search for the secondary eclipse, and to search for other transiting planets in the habitable zone of GJ1214. We here report results from the transit monitoring of GJ1214b, including a re-analysis of previous transit observations by Desert et al. (2011). In total, we analyze 14 transits of GJ1214b at 4.5 μm, 3 transits at 3.6 μm, and 7 new ground-based transits in the I+z band. Our new Spitzer data by themselves eliminate cloudless solar composition atmospheres for GJ1214b, and methane-rich models from Howe & Burrows (2012). Using our new Spitzer measurements to anchor the observed transit radii of GJ1214b at long wavelengths, and adding new measurements in I+z, we evaluate models from Benneke & Seager (2012) and Howe & Burrows (2012) using a χ² analysis. We find that the best-fit model exhibits an increase in transit radius at short wavelength due to Rayleigh scattering. Pure water atmospheres are also possible. However, a flat line (no atmosphere detected) remains among the best of the statistically acceptable models, and better than pure water atmospheres. We explore the effect of systematic differences among results from different observational groups, and we find that the flat line model is the least sensitive to systematic error.

103.05 A Framework For Characterizing The Atmospheres Of GJ 1214b-type Low-mass Low-density Transiting Planets
The atmosphere of the low-mass low-density transiting planet GJ 1214b has been extensively characterized via transmission spectroscopy. Observations include spectra and photometric points from blue to mid-infrared wavelengths. The transmission spectrum appears relatively featureless, indicating an atmosphere that does not show strong molecular absorption features. It has been suggested that this "flat" spectrum could be due to an obscuring grey cloud/haze layer, or due to a high mean molecular weight (MMW) atmosphere. If the planet is similar to a scaled down version of Uranus or Neptune, as suggested by Nettelmann et al. (2011), both explanations could well be viable. To lift the degeneracy of these explanations, one can imagine characterizing a range of similar planets, which are now being found. Here we examine the structure and atmospheres of volatile-rich planets from 5-20 Earth masses and T_eq from 100 - 1500 K. Based on population synthesis models of core-accretion planet formation, we examine the expected Z_atmosphere and MMW these low mass planets. We examine how atmospheric escape of the outermost layers of such planets may expose deeper atmospheric layers with less hydrogen and a higher Z_atmosphere and MMW. We note that the hottest variants of these planets should feature atmospheres rich in CO, rather than CH4, potentially eliminating a pathway to photochemical haze formation. We provide a synthesis of these physical effects over a range of mass, temperature, and metallicity parameters. We highlight where in parameter space these GJ 1214b and Neptune-like planets are likely to have atmospheres that are most amenable to characterization from transmission spectroscopy.

103.06 Distinguishing Between Hydrogen-rich And Water-rich Exoplanets: Application To GJ1214b
- Bjoern Benneke1, S. Seager1
1 MIT.

One of the most profound questions about the newly discovered class of super-Earth exoplanets is whether these exoplanets are predominately hydrogen-dominated mini-Neptunes or water-rich planets with significant water vapor envelopes. Transit observations of the super-Earth GJ1214b rule out cloud-free hydrogen-dominated atmospheres but are currently not able to determine whether the lack of strong spectral features is due to high-altitude clouds or the presence of a high mean molecular mass atmosphere. Here we propose an efficient strategy to distinguish between cloudy mini-Neptunes and planets with high mean molecular mass atmospheres, such as water-dominated atmospheres, based on observations of the shapes of the molecular absorption features at NIR wavelengths near the luminosity peak of M-dwarfs. In a numerical retrieval study of synthetic transmission spectra, we demonstrate that a strong detection of water vapor (>5\sigma) in GJ1214b's atmosphere is possible, even for high mean molecular mass atmospheres, if the observational error bar can be reduced by a factor of 2-3 compared to the published HST WFC3 and VLT transit observations. The required reduction in observational uncertainty may be achievable by stacking repeated transit observations with currently available instrumentation. A set of ten or more transit observations could allow the distinction between a clear, water-rich atmosphere surrounding GJ1214b and cloudy, a hydrogen-rich atmosphere. We also present a retrieval reanalysis of the published transit observations of GJ1214b. We find that the observational data suggest water vapor absorption in the atmosphere of GJ1214b at a confidence of 1.8\sigma. The possible presence of water vapor was revealed by combining observational evidence from different data sets using a Bayesian atmospheric retrieval method. The observed spectrum is in agreement with the presence of a water-rich atmosphere. Hydrogen-dominated atmospheres are in agreement with the observations only if a hypothetical cloud deck is present at a fine-tuned pressure level.

103.07 Spitzer Observations of the Thermal Emission from WASP-43b
- Jasmina Blecic1, J. Harrington1, N. Madhusudhan2, K. B. Stevenson1, C. J. Campo1, R. A. Hardy1, P. Cubillos1, S. Nymeyer1, D. R. Anderson3, C. Hellier3, A. Collier Cameron4, A. M. S. Smith4
1 University of Central Florida, 2 Yale University, 3 Keele University, United Kingdom, 4 University of St. Andrews, United Kingdom.
WASP-43b (Hellier et al., 2011) is the closest-orbiting hot Jupiter (a = 0.0142 AU) with a period of only 0.81 days. However, its host star is the coolest and lowest-mass of any stars with a hot-Jupiter (K7V, $M_*$ = 0.58 $M_\odot$), emitting just enough energy that the planet gets to a modest equilibrium temperature of 1374 K. This configuration led to strong signal-to-noise (S/N) observations and deep eclipses in both Spitzer channels (3.6 and 4.5 μm). Planets with higher S/N ratio allow more accurate measurements of eclipse depths and brightness temperatures and tighter constraints on atmospheric composition and thermal structure. We present the eclipse depths and brightness temperatures, the possibility of thermal inversion and constraints on molecular abundances and thermal structure. The eclipse timings further refine orbital parameters.

**103.08 The Characterization of the Cool and Eccentric Exoplanet WASP-8b with Spitzer**


  1 University of Central Florida, 2 Yale University.

WASP-8b is one of the coldest hot-Jupiter planets observed during secondary eclipse (when the planet passes behind the star) with the Spitzer Space Telescope. We present our observations of WASP-8b at the 3.6, 4.5, and 8.0-micron wavebands with the Spitzer's IRAC instrument, during secondary eclipse. We will show the resulting light curves of our infrared observations, determining the planet-to-star flux ratios. With this spectral information we further characterized the planet’s dayside atmosphere, constraining its chemical composition, recognizing the absence of a thermal inversion, and estimating the energy redistribution regime over its surface. Although having a equilibrium temperature is only 950K, the large eccentricity of the orbit (e=0.31) should make the dayside temperature of WASP-8b oscillate with an amplitude of hundreds of degrees. We modeled these temporal variation of the temperature over the surface of the planet and set constrains on the rotational angular velocity and radiative timescale of the planet, based in the observed hemisphere-averaged brightness temperature during secondary eclipse. This planet is also dynamically interesting since it orbits the primary star of a binary system. Along with a large eccentricity, suggests the presence of an unseen planetary companion. A precise determination of the eclipse mid-times will help to constrain the orbit of such companion.

**103.09 Evaluating Potential Causes of the Two Observational Classes of Exoplanets**

- **Joseph Harrington**, J. J. Fortney, M. O. Bowman, UCF Exoplanets Team

  1 University of Central Florida, 2 University of California, Santa Cruz.

We compare Spitzer and ground-based broadband flux measurements for over 30 exoplanets by plotting brightness vs. equilibrium temperatures ($T_b$ vs. $T_{eq}$). $T_{eq}$ is a proxy for bolometric stellar flux; $T_b$ is measured flux expressed as a temperature. This model-free comparison shows two classes of planet (Harrington et al. 2007, Nature; 2011 DPS). Below ~1900 K, planets appear about as bright as their $T_{eq}$, calculated with 0 Bond albedo and uniform redistribution of received radiation over the entire planetary surface. However, above ~1900 K planets appear several hundred K brighter than the $T_b = T_{eq}$ line. There appears to be overlap between the two classes in the 1800 - 2000 K range, but the distinction is strong above 2000 K. Potential causes include clouds at cooler temperatures, permitting a deeper and therefore hotter view into the hotter planets; a reduced advection time scale for the hotter planets, causing more heat to be re-emitted on the dayside; ohmic heating for closer-in planets; the lack of a TiO cold trap for hotter planets, allowing this absorber to exist in gaseous form; and a mechanical ($K_z$) greenhouse that is more effective for hotter planets. We evaluate these mechanisms against the data. This work was supported by the NASA Science Mission Directorate’s Planetary Atmospheres Program under grant NNX12AI69G. Spitzer is operated by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with NASA, which also provided support for this work.

**104 Icy Satellites 2**

Monday, 10:30 AM - 12:00 PM, Carson 1/2

**104.01 The Orbits and Masses of Pluto's Satellites**
We have fit numerically integrated orbits of Pluto's satellites, Charon, Nix, Hydra, and S/2011 (134340) 1, to an extensive set of astrometric, mutual event, and stellar occultation observations over the time interval April 1965 to July 2011. We did not include the newly discovered satellite S/2012 (134340) 1 because its observation set is insufficient to constrain a numerically integrated orbit. The data set contains all of the HST observations of Charon relative to Pluto which have been corrected for the Pluto center-of-figure center-of-light (COF) offset due to the Pluto albedo variations (Buie et al. 2012 AJ submitted). Buie et al. (2010 AJ 139, 1117 and 1128) discuss the development of the albedo model and the COF offset. We applied COF offset corrections to the remainder of the Pluto relative observations where applicable. The dual stellar occultations in 2008 and 2011 provided precise Pluto_Charon relative positions. We obtain a well determined value for the Pluto system mass, however, the lack of orbital resonances in the system makes it difficult to determine the satellite masses. The primary source of information for the Charon mass is a small quantity of absolute position measurements which are sensitive to the independent motions of Pluto and Charon about the system barycenter. The long term dynamical interaction among the satellites yields a weak determination of Hydra's mass; the masses of the other two satellites are found to be small but indeterminate. We have delivered ephemerides based on our integrated orbits to the New Horizons project along with their expected uncertainties at the time of the New Horizons encounter with the Pluto system. Acknowledgments: The research described in this paper was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

104.02 Comparative Planetology between the Uranian and Saturnian Satellite Systems - Focus on Ariel
- Julie Castillo-Rogez1, E. P. Turtle2
  1Jet Propulsion Laboratory, California Institute of Technology, 2The John Hopkins University Applied Physics Laboratory.

The Uranian and Saturnian satellite systems present many similarities. Both systems have several mid-sized satellites as well as numerous irregular satellites and small moons embedded in their rings. Uranus' unusual obliquity and the absence of a Titan-sized satellite in the Uranian system are, of course, significant differences with implications for the dynamical history and evolution of each system. Of particular interest, Uranus' mid-sized satellite Ariel appears to share similar properties with Enceladus in terms of available radiogenic and tidal power. Moreover, Ariel's surface appears relatively young with evidence for potentially recent geological activity. These similarities raise the question of the potential of this satellite for endogenic activity and long-term preservation of a deep ocean. We will present models of the geophysical and dynamical evolution of Ariel and compare these results with our current understanding of Enceladus. Acknowledgements: Part of this work was carried out at the Jet Propulsion Laboratory, California Institute of Technology.

104.03 Hydrocarbons On Phoebe, Iapetus, And Hyperion: Quantitative Analysis
- Dale P. Cruikshank1, C. M. Dalle Ore3, Y. J. Pendleton1, R. N. Clark2
  1NASA Ames Research Center, 2U.S. Geological Survey.

We present a quantitative analysis of the hydrocarbon spectral bands measured on three of Saturn's satellites, Phoebe, Iapetus, and Hyperion. These bands, measured with the Cassini Visible-Infrared Mapping Spectrometer on close fly-bys of these satellites, are the C-H stretching modes of aromatic hydrocarbons at ~3.28 μm (~3050 cm⁻¹), and the are four blended bands of aliphatic -CH2- and -CH3 in the range ~3.36-3.52 μm (~2980-2840 cm⁻¹). In these data, the aromatic band, probably indicating the presence of polycyclic aromatic hydrocarbons (PAH) is unusually strong in comparison to the aliphatic bands, resulting in a unique signature among Solar System bodies measured so far, and as such offers a means of comparison among the three satellites. The ratio of the C-H bands in aromatic molecules to those in aliphatic molecules in the surface materials of Phoebe, NAro:NAliph ~24; for Hyperion the value is ~12, while Iapetus shows an intermediate value. In view of the trend of the evolution (dehydrogenation by heat and radiation) of aliphatic complexes toward more compact molecules and eventually to aromatics, the relative abundances of aliphatic -CH2- and -CH3- is an indication of the lengths of the molecular chain structures, hence the degree of modification of the original material. We derive CH2:CH3 ~2.2 in the
spectrum of low-albedo material on Iapetus; this value is the same within measurement errors to the ratio in the diffuse interstellar medium. The similarity in the spectral signatures of the three satellites, plus the apparent weak trend of aromatic/aliphatic abundance from Phoebe to Hyperion, is consistent with, and effectively confirms that the source of the hydrocarbon-bearing material is Phoebe, and that the appearance of that material on the other two satellites arises from the deposition of the inward-spiraling dust that populates the Phoebe ring.

104.04 Cassini/CIRS' View Of Dione And Rhea: The Search For Activity And Ring Infall

- Carly Howett, J. Spencer, T. Hurford, A. Verbiscer

SouthWest Research Institute, Goddard Spaceflight Center, University of Virginia.

No direct detection of activity on Dione has ever been made, but there are many indications that it may exist: for example recently mass loading of magnetospheric plasma flow from Dione’s surface was detected. The probably cause of this mass loading is surface outgassing, which in turn may have been caused by recent geological activity (Burch et al., 2007). Additionally, some of Dione’s surface plains appears to have been relatively recently resurfaced (Moore, 1984; Schenk and Moore, 2009). Cassini's Composite Infrared Spectrometer (CIRS) is well equipped for searching for Dione's activity, having taken many high spatial resolution thermal infrared observations (10 to 1100 cm-1) of Dione since its arrival in the Saturnian system in 2004. The progress that has been made in using this data set to search for activity on Dione will be reported. Around Rhea’s equator lies a blue linear discontinuous track, known as Rhea’s equatorial great circle or string of pearls, the origin of which is the subject of much speculation. Collisional diffusion in Rhea’s possibly current or former circumsatellite ring would broaden its disk radially, allowing some particles to strike the surface in preferentially the equatorial plane. Since many of Rhea’s blue features are indeed located on high topographic areas along the equator ring infall is a viable formation method, as these areas are more likely to catch or block these infalling ring particles as they approach the surface. The impacting material could then excavate the surface, revealing the observed older, bluer subsurface (Schenk et al., 2011). The variation in thermal surface properties across Rhea’s equatorial great circle will be reported, to help decipher whether it is formed by excavation of the surface by infalling ring material, as proposed. This work was funded by NASA/Cassini Data Analysis Program.

104.05 Far-ultraviolet Photometric Characteristics Of The Icy Moons Of Saturn

- Emilie M. Royer, A. R. Hendrix

JPL.

The icy moons of Saturn orbiting inside the E-ring experience weathering processes: E-ring grains as well as cold plasma ions, neutrals and energetic particles impact their surfaces. The Cassini UVIS instrument (UltraViolet Imaging Spectrograph), operating in the FUV wavelengths (118 - 190nm) probes the uppermost layers of the regolith and is uniquely suited to studying these exogenic processes, leading to a better understanding of the surfaces’ evolution and the saturnian environment. We present an analysis of ultraviolet disk-integrated phase curves of Tethys. We display phase curves for the leading and trailing hemispheres as well as for the Saturn and anti-Saturn ones. As expected, we find that the leading hemisphere is brighter than the trailing and at large phase angles, it seems that we directly observe these E-ring grains in forward scattering. Our analysis is completed by using a Hapke model to retrieve the photometric parameters of the surface, such as the single scattering parameters, the opposition effect parameters and information on the roughness, our data set covering a wide range of phase angles, from 6.8 to 163.9 degrees. We discuss implications for the exogenic processes involved.

104.06 The Spatial Distribution of Thermal Emission from Baghdad Sulcus, Enceladus, at 100 meter Scales


Southwest Research Institute, Catholic University of America, Goddard Space Flight Center, System & Software Designers, Inc (SSD).

The Cassini Composite Infrared Spectrometer (CIRS) has been observing endogenic thermal emission from the south pole of Enceladus since 2005. Best spatial resolution from conventional scans is about 1km, usually from distances >2000 km. When Cassini is closer to Enceladus, the spacecraft cannot rotate fast enough to track the surface, and the 5 seconds required to obtain a CIRS spectrum produces many kilometers of smear. However,
higher-resolution mapping can be done from much closer range by exploiting the 20 msec sampling of the CIRS raw interferograms. On April 14th, 2012, Cassini made a gravity pass of Enceladus at a range of 74 km. Spacecraft orientation was inertially fixed, and chosen so that the active tiger stripe Baghdad Sulcus passed through the CIRS and VIMS fields of view during the flyby. In the 7 to 17 μm region, CIRS uses linear arrays of ten detectors with IFOV of 0.29 mrad, which were oriented roughly perpendicular to the ground track and operated in pairs, giving five cross-track spatial resolution elements, each 43 meters wide. Along-track spatial resolution, defined by the 20 msec interferogram sampling time and the flyby speed of 7.5 km/sec, was 150 meters. At longer wavelengths, CIRS obtained a single-detector scan with a spatial resolution of 300 meters. The brief passage of the intense tiger stripe thermal emission through the field of view produced complex spikes in the CIRS interferograms. Though spectra cannot be reconstructed, we can use knowledge of the interferogram temporal response to reconstruct the time history of the incoming radiation and thus its spatial distribution. The resulting image will map tiger stripe thermal emission along a small part of Baghdad Sulcus at about ten times the spatial resolution of the best previous Cassini thermal images.

104.07 Cassini INMS Measurements of the Structure of Emissions from Enceladus
- Mark E. Perry¹, B. D. Teolis², B. A. Magee², H. T. Smith³, J. L. Westlake³, R. L. McNutt¹, J. H. Waite²
  ¹Johns Hopkins Applied Physics Lab, ²Southwest Research Institute.

Recent Cassini Ion and Neutral Mass Spectrometer (INMS) observations of plumes and jets from Enceladus have an order-of-magnitude higher temporal and spatial resolution than earlier INMS measurements. These higher-resolution observations show areas of both high-velocity jets and lower-velocity diffuse plumes, similar to the results from the Cassini Ultraviolet Imaging Spectrograph observations. Although INMS measures densities only along a single track during each encounter, the accumulated set of observations enables estimates of velocities, the angular spreading of the jets, and the overall rate of mass loss. The full-widths-half-maximum of the some jets are narrower than 30 degrees, indicating speeds of Mach 4 and above. Direct measurements of neutral-particle velocities are possible with INMS observations using the Open Source Neutral Beam (OSNB) mode. One set of OSNB measurements of the diffuse emissions showed neutral velocities below Mach 1. An observation during an earlier encounter measured an individual jet with particle velocities of 1.2 to 1.6 km/s relative to Enceladus, in agreement with the INMS results based on the width of the jets.

104.08 Cassini VIMS Observations Of Thermal Emission From The Warmest 'Tiger Stripes' Near The South Pole On Enceladus
- Jay D. Goguen¹, B. J. Buratti¹, R. H. Brown⁵, R. N. Clark¹, P. D. Nicholson⁴, M. M. Hedman⁴, C. Sotin¹, D. P. Cruikshank⁵, K. H. Baines¹, K. J. Lawrence¹, J. R. Spencer⁶, D. Blackburn¹
  ¹JPL, ²University of Arizona, ³US Geological Survey, ⁴Cornell University, ⁵NASA Ames Research Center, ⁶Southwest Research Institute.

The discovery and continuing investigation of the long linear fissures near Enceladus’ south pole is a major highlight of the Cassini mission to Saturn. Known as the ‘tiger stripes’, these fissures are the source of water dominated plumes and extensive thermal emission (Spencer et al, 2006; Porco et al, 2006). This paper presents new observational constraints on the highest temperature component of the tiger stripes thermal emission using VIMS (Visible and Infrared Mapping Spectrometer) spectra. Because VIMS detects the thermal emission at 4 to 5 micrometer wavelengths, VIMS is sensitive to the rising edge of Planck function for temperatures near 200 K, making the new VIMS spectra complementary to the CIRS observations acquired at longer wavelengths. Although the thermal emission spectra of the hottest areas is only a small piece of the Enceladus and tiger stripe puzzle, it is an important missing piece that we will use to model how and where the detected heat is generated and the physical processes that transport the heat to the observable surface. Our first definitive detection of thermal emission from Baghdad Sulcus was reported in Blackburn et al (LPSC 2012) from VIMS data acquired during E11 (August 2010). Due to seasonal change during the mission, the Enceladus S. pole region has entered the perpetual winter night and reflected sunlight does not interfere with VIMS measurements of the faint thermal emission as it did early in the mission. During the 75 km altitude targeted encounter E18 (April 2012), VIMS acquired a 2 minute long sequence of 25 ms integration time spectra through a single high resolution pixel as Cassini passed over the
South pole. The resulting data has the best spatial resolution of the thermal emission acquired to date. This work was supported in part by a grant from NASA’s Outer Planets Research Program.

104.09 Provenance Of CO2 Ice On Enceladus’ Surface

- Dennis L. Matson¹, A. G. Davies¹, T. V. Johnson¹, J. C. Castillo-Rogez¹, J. I. Lunine²
  ¹Jet Propulsion Laboratory, California Institute of Technology, ²Department of Astronomy, Cornell University.

Brown et al. (2006) identified CO2 ice within Enceladus’ South Polar Terrain using Cassini VIMS data and suggested that it resulted from an active replenishment process. Until now this process has been a mystery. Although there is a relatively small amount of CO2 in the water vapor erupted by the plumes, the spectra of the resulting deposits are expected to be dominated by water frost. We point out that CO2 frost deposits are a possible product of the water circulation model proposed by Matson et al. (2012). In this model, buoyant CO2-bubble-rich water rises up from the ocean and into fissures in the icy crust. When a neutral buoyancy level is reached, the water flows horizontally along the fissures under a relatively thin ice cap. Heat lost from the water beneath the ice supplies heat for the thermal anomalies identified on the surface. Even as the water is flowing horizontally, it continues to lose CO2 because bubbles continue to rise. Recesses and other irregularities on the bottom of the surface ice allow the bubble-gas to collect in pockets. When these are fissured by recurring tidal stresses, the CO2 gas can escape and condense nearby on surfaces that are cold enough. References: Brown et al. (2006) Science, 311, 5766; Matson et al. (2012) Icarus, in press, doi 10.1016/j.icarus.2012.05.031. This work has been conducted at the Jet Propulsion Laboratory, California Institute of Technology under contract to NASA. © 2012 Caltech. All rights reserved.

105 Asteroids 2: Asteroid Dynamics and Physical Properties

Monday, 10:30 AM - 12:00 PM, Reno Ballroom

105.01 The Capture of Exotic Asteroids Within the Fossilized Kirkwood Gaps of the Primordial Main Belt

- William Bottke¹, D. Vokrouhlicky², D. Nesvorny¹, H. Levison¹, D. Minton³
  ¹Southwest Research Inst., ²Charles, U., Czech Republic, ³Purdue U..

In the Nice model, the giant planets reside for hundreds of My on nearly-circular, co-planar orbits in a much more compact configuration than they have today (all between 5-12 AU). This implies that mean motion resonances linked to the orbits of these planets once resided within the primordial main belt, albeit in different locations than the present-day resonances. We hypothesize these putative “fossilized Kirkwood gaps” might still be noticeable within the current main belt. To test this, we first tracked how planetary perturbations affected a uniformly distributed population of main belt test bodies. Over 600 My, we found only limited gaps were created. We attribute this to two factors: (i) giant planets on circular, low inclination orbits produce weak resonances, and (ii) the chaotic nature of today’s main belt resonances is also a byproduct of overlapping mean motion and secular resonances. Second, we simulated how planetary perturbations affected test bodies started outside the main asteroid belt. Here we found that planetary encounters allowed test bodies to reach and enter into the primordial main belt resonances. From there, a significant fraction stayed until the end of the simulation, when presumably late giant planet migration would force them to drop out of resonance. This would leave the bodies permanently captured near the semimajor axis of their host resonances. Interestingly, our preliminary results suggest many large E-, M-, and K-type asteroids can be found near primordial Jovian resonances like the J4:1 (2.2 AU), J7:2 (2.42 AU), and J3:1 (2.67 AU). If true, Jupiter was located at 5.55 AU prior to the onset of late giant planet migration. We speculate that some of these asteroids, perhaps even (21) Lutetia, may have come from the terrestrial planet region.

105.02 Hungaria Family as the Source of Aubrites

- Matija Cuk¹, J. A. Burns², B. J. Gladman³, D. P. Hamilton³, D. Nesvorny⁵
  ¹SETI Institute, ²Cornell University, ³University of British Columbia, Canada, ⁴University of Maryland, ⁵Southwest Research Institute.
The Hungaria asteroids are just interior to the main asteroid belt, with semimajor axes between 1.8 and 2.06 AU, low eccentricities and relatively high inclinations, 16-30 degrees. Small asteroids in the Hungaria region are dominated by a collisional family centered on 434 Hungaria, while the multi-km ones appear to be of more diverse origins (Warner et al. 2009). Hungarias are a secularly declining population with a half-life of 600 Myr-1000 Myr (Milani et al. 2009, McEachern et al. 2010), and they may represent a remnant of a population that was much larger during the Late Heavy Bombardment (Cuk 2012, Bottke et al. 2012). The dominant spectral type of the Hungaria group is the E or X-type (Warner et al. 2009), mostly due to the E-type composition of Hungaria and its genetic family. It is widely believed the E-type asteroids are related to the aubrite meteorites, also known as enstatite achondrites (Gaffey et al. 1992). Could aubrites be fragments of the progenitor of the Hungaria family? Delivery routes of meteoroids from Hungarias to Earth are likely to be different than those for the main-belt asteroids, and their dynamics could be constrained through the meteorites’ cosmic-ray exposure (CRE) ages. Interestingly, aubrites have the oldest median CRE ages of all stony meteorites (Eugster et al. 2006). We are testing if the connection between aubrites and the Hungaria family is consistent with CRE ages using numerical integrations of the motion of meteoroids from the Hungaria region. Our model includes encounters with planets, collisional evolution and the Yarkovsky effect. Preliminary results indicate that the long delivery times of Hungaria-derived meteoroids are a good match for CRE ages of aubrites, as these bodies typically reach Earth though Mars-crossing orbits, rather than Jovian mean-motion resonances. This work is supported by NASA’s Planetary Geology and Geophysics program.

105.03 The Strength of Rubble Piles
- Daniel J. Scheeres¹, P. Sanchez¹

¹University of Colorado.

The measured size distribution of 1/d^3 for larger grains on asteroid Itokawa (Michikami et al., Earth Planets Space, 60, 13-20, 2008) and the presence of micron sized dust on that asteroid’s surface (Tsuchiyama et al., Science 333, 1125, 2011) provide a global indication of grain distribution within rubble piles. Even assuming a less steep distribution of 1/d^2 for dust grains smaller than 1 mm in size, the interior of Itokawa should still be dominated by the finest dust grains, with the mean grain size equal to ~ twice the smallest grain in the distribution. One implication of this result is that fines are present on the surface and thus should be distributed throughout rubble pile asteroids similar to Itokawa. This has important consequences for the strength of a rubble pile due to natural cohesion forces that are known to be present for such small grains, as evidenced by terrestrial experience. We calculate and simulate the effect of these forces for the strength of a rubble pile constituted of larger boulders embedded in a matrix of finer grains. This simple model predicts a yield strength that varies inversely with the mean particle size, and provides sufficient strength to a rubble pile to account for many of the fast spinning bodies seen in the population. If rubble pile asteroids are strengthened through cohesion between dust fines, there are several implications that can be tested and compared against the existing asteroid data. We present these tests and evaluate whether this model is consistent with them. Finally, based on the theoretical work behind this research we propose a reinterpretation of the spin limit for asteroids with size between 0.5 - 10 km in terms of mechanics models of strength and failure, predicting a larger mean density than the currently derived 2.3 g/cm^3 limit.

105.04 Asteroid Regolith Mechanical Properties: Laboratory Experiments With Cohesive Powders
- Daniel D. Durda³, D. J. Scheeres³, S. E. Roark³, R. Dissly³, P. Sanchez³

³Southwest Research Inst., ³University of Colorado, ³Ball Aerospace & Technologies Corporation.

Despite clear evidence that small asteroids undergo drastic physical evolution, the geophysics and mechanics of many of the processes governing that evolution remain a mystery due to a lack of scientific data, both on the sub-surface and global geophysics of these small bodies and on the mechanical properties of regoliths in the unique micro-gravity regime they inhabit. We are beginning a three-year effort to study regolith properties and processes on low-gravity, small asteroids by conducting analog experiments with cohesive powders in a 1-g laboratory environment. Based on a rigorous comparison of forces it can be shown that van der Waals cohesive forces between millimeter to centimeter-sized grains on asteroids ranging in size from Eros to Itokawa, respectively, may...
exceed their ambient weight several-fold. This observation implies that regoliths composed of impact debris of those sizes should behave on the microgravity surfaces of small asteroids like flour or other cohesive powders do in the 1-g environment here on Earth. Our goal is to develop an improved understanding of the role of cohesion in affecting regolith processes and surface morphology of small Solar System bodies, some the targets of ongoing and proposed NASA New Frontiers and Discovery missions, and to quantify the range of expected mechanical properties of such regoliths. Our experiments will be conducted in ambient and vacuum conditions within an environmental test chamber at Ball Aerospace & Technologies Corporation (BATC) in Boulder, CO. To aid in validating our experiment chamber and support equipment performance, and before proceeding with experiments on geologic regolith simulant materials, we will perform a series of comparative, ‘calibration’ experiments with micro glass spheres; all primary experiments will be performed with at least one non-idealized regolith simulant, like JSC-1, that more realistically simulates the angular particle shapes expected in actual geologic fragments generated from impact comminution.

105.05 Investigation of Shapes and Spins of Reaccumulated Remnants from Asteroid Disruption Simulations
- Patrick Michel\(^1\), R. Ballouz\(^2\), D. C. Richardson\(^2\), S. R. Schwartz\(^3\)

\(^1\)Lagrange Laboratory, University of Nice, Cote d’Azur Observatory, CNRS, France, \(^2\)University of Maryland, \(^3\)University of Maryland/University of Nice.

Evidence that asteroids larger than a few hundred meters diameter can be gravitational aggregates of smaller, cohesive pieces comes, for instance, from images returned by the Hayabusa spacecraft of asteroid 25143 Itokawa (Fujiiwara et al., 2006, Science 312, 1330). These images show an irregular 500-meter-long body with a boulder-strewn surface, as might be expected from reaccumulation following catastrophic disruption of a larger parent asteroid (Michel et al., 2001, Science 294, 1696). However, numerical simulations of this process to date essentially focus on the size/mass and velocity distributions of reaccumulated fragments, matching asteroid families. Reaccumulation was simplified by merging the objects into growing spheres. However, understanding shapes, spins and surface properties of gravitational aggregates formed by reaccumulation is required to interpret information from ground-based observations and space missions. E.g., do boulders on Itokawa originate from reaccumulation of material ejected from a catastrophic impact or from other processes (such as the Brazil-nut effect)? How does reaccumulation affect the observed shapes? A model was developed (Richardson et al., 2009, Planet. Space Sci. 57, 183) to preserve shape and spin information of reaccumulated bodies in simulations of asteroid disruption, by allowing fragments to stick on contact (and optionally bounce or fragment further, depending on user-selectable parameters). Such treatments are computationally expensive, and we could only recently start to explore the parameter space. Preliminary results will be presented, showing that some observed surface and shape features may be explained by how fragments produced by a disruption reaccumulate.

Simulations of rubble pile collisions without particle cohesion, and an investigation of the influence of initial target rotation on the outcome will also be shown. We acknowledge the National Science Foundation (AST1009579) and NASA (NNX08AM39G).

105.06 Numerical Simulations of Landslides Calibrated Against Laboratory Experiments for Application to Asteroid Surface Processes
- Derek C. Richardson\(^1\), J. Blum\(^2\), T. Weinhart\(^3\), S. R. Schwartz\(^1\), P. Michel\(^4\), K. J. Walsh\(^5\)

\(^1\)University of Maryland, \(^2\)University of Braunschweig, Germany, \(^3\)University of Twente, Netherlands, \(^4\)University of Nice-Sophia Antipolis, CNRS, Côte d’Azur Observatory, France, \(^5\)Southwest Research Institute.

Spacecraft images of asteroids show evidence of low-gravity granular flows. Interpretation of these flows requires numerical modeling, which in turn requires code validation at laboratory scales. We have implemented a soft-sphere discrete element method (SSDEM) for modeling granular flows in our numerical code (Schwartz et al. 2012, Granular Matter 14, 363). Here we present results from a study to calibrate our code against controlled landslide experiments in order to determine the SSDEM parameters that best match real materials, to see how changes in those parameters affect the flow, and to mimic effects such as those due to irregular particle shapes. The apparatus, designed at University of Braunschweig, is a 0.6 × 0.8 m enclosed bed with a surface comprised of 10 mm diameter glass spheres glued into precisely drilled holes in a metal plate. The exact positions and depths of each of these glued spheres are input to the simulations. The experiments consist of filling the apparatus with
loose glass beads (also 10 mm diameter) up to a set depth then gradually tilting the bed to note the angle of landslide initiation and the characteristics of the resulting flow. We reproduce this procedure in simulations, which we find are quite sensitive to the adopted SSDEM parameters, e.g., rolling friction and tangential damping delay landslide onset, while higher particle elasticity gives rise to faster, shorter-duration landslides. Preliminary results show a best match to the experiments (landslide initiation around 25 degrees) when adopting low static friction and no rolling friction in the simulations, but more experiments are in process. In future work, we will perform simulations in low-gravity environments representative of asteroid surfaces. This work is supported in part by grant NNX08AM39G from the NASA Office of Space Science. This study resulted from International Team collaboration #202 sponsored by ISSI in Switzerland.

105.07 A Numerical Investigation into Low-Speed Impact Cratering Events
- Stephen Schwartz¹, D. C. Richardson¹, P. Michel²
  ¹Univ. of Maryland, ²Laboratoire Lagrange, Observatoire de la Côte d’Azur, France.

Impact craters are the geological features most commonly observed on the surface of solid Solar System bodies. Crater shapes and features are crucial sources of information regarding past and present surface environments, and can provide indirect information about the internal structures of these bodies. In this study, we consider the effects of low-speed impacts into granular material. Studies of low-speed impact events are suitable for understanding the cratering process leading, for instance, to secondary craters. In addition, upcoming asteroid sample return missions will employ surface sampling strategies that use impacts into the surface by a projectile. An understanding of the process can lead to better sampling strategies. We use our implementation of the Soft-Sphere Discrete Element Method (SSDEM) (Schwartz et al. 2012, Granular Matter 14, 363-380) into the parallel N-body code PKDGRAV (cf. Richardson et al. 2011, Icarus 212, 427-437) to model the impact cratering process into granular material. We consider the effects of boundary conditions on the ejecta velocity profile and discuss how results relate to the Maxwell Z-Model during the crater growth phase. Cratering simulations are compared to those of Wada et al. 2006 (Icarus 180, 528-545) and to impact experiments performed in conjunction with Hayabusa 2. This work is supported in part by grants from the National Science Foundation under grant number AST1009579 and from the Office of Space Science of NASA under grant number NNX08AM39G. Part of this study resulted from discussions with the International Team (#202) sponsored by ISSI in Bern (Switzerland). Some simulations were performed on the YORP cluster administered by the Center for Theory and Computation of the Department of Astronomy at the University of Maryland in College Park and on the SIGGAM computer cluster hosted by the Côte d’Azur Observatory in Nice (France).

105.08 Binary-YORP Coefficients for Known Asteroid Shapes
- Jay W. McMahon¹, D. J. Scheeres¹
  ¹University of Colorado.

The binary YORP (bYORP) effect has been hypothesized to be a significant factor in the evolution of near-Earth binary asteroid systems (Cuk and Burns, Icarus, v.176, pp.418-431, 2005; McMahon and Scheeres, CMDA, v.106, pp.261-300, 2010). However, understanding of the coefficient values for realistic asteroid shapes is lacking due to the small number of shape models available for the generally smaller secondary asteroids. Until now, we have only calculated the coefficients based on the shape of 1999 KW4 Beta, although various studies by other authors have computed coefficients for artificially generated asteroids based on Gaussian Spheres and some shape models without self-shadowing (Steinberg and Sari, The Astronomical Journal, v.141, pp.55-64, 2011). We also scaled the 1999 KW4 Beta coefficients to other binary systems with no knowledge of the other systems’ secondary shapes in order to make evolutionary predictions (McMahon and Scheeres, Icarus Vol. 209, pp 494-509, 2010). In this study, we compute the bYORP coefficient for a range of asteroid shapes, using these as a stand-in for actual secondaries. This allows us to circumvent the lack of information on binary asteroid secondaries and to develop a richer database of realistic coefficients. While this approach may miss some key features of binary secondaries, at the least it provides some statistics on the expected variability of the bYORP coefficient. We analyze all available asteroid shape models on the PDS-SBN, including radar-based shape models and models estimated from past spacecraft missions. The coefficients are computed with an updated algorithm that includes the effects of self-shadowing. We also present the coefficients for perturbed versions of the available shape models, which give
effective error bars to the computed coefficients due to inexact shape models. Finally, we discuss the dynamical implications of the derived bYORP coefficients on binary asteroid evolution.

**105.09 Internal Stresses For Realistic Asteroid Shapes: The Case Of Kleopatra**
- Masatoshi Hirabayashi¹, D. J. Scheeres¹
  ¹University of Colorado at Boulder.

We will present updated results for the averaged-normal stress and stress state within the asteroid Kleopatra. In this study we introduce a new method for computing the mutual gravity attraction of two generalized bodies in contact, which is applicable for computing the generalized stress field at any point within an asteroid. This methodology is applied to the asteroid Kleopatra, although computations for other asteroids will also be presented at the conference. Our method fills the asteroid shape with small equal-sized parallelepipeds and computes the higher order mutual gravity for each cube-pair. Since the gravitational attractions for pairs close to each other cannot be accurately modeled by a point mass assumption, we control the order of the gravity attraction computation by the relative distance. A validation test using the shape of an ellipsoid gives good agreement with the results of Holsapple (2001). We base our analysis on the radar-derived Kleopatra shape model (Ostro et al., 2009) with the updated total size and density from the (Deschamps et al., 2011) observations. Specifically we use a Kleopatra spin period of 5.38 hours and density of 3.2 g/cm³. The current results show that the asteroid is very close to being in a tensile state across its “neck” region and clearly has a localized stress concentration in this region. We will present results on the internal yield criterion and what limits can be inferred from this information.

**107 Welcome, 2011 Urey Prize Lecture: Orbital Dynamics of Extrasolar Planets, Large and Small**
Monday, 1:30 PM - 2:20 PM, Reno Ballroom

**107.01 Urey Prize Lecture: Orbital Dynamics of Extrasolar Planets, Large and Small**
- Eric B. Ford¹
  ¹Univ. of Florida.

For centuries, planet formation theories were fine tuned to explain the details of solar system. Since 1999, the Doppler technique has discovered dozens of multiple planet systems. The diversity of architectures of systems with giant planets challenged previous theories and led to insights into planet formation, orbital migration and the excitation of orbital eccentricities and inclinations. Recently, NASA’s Kepler mission has identified over 300 systems with multiple transiting planet candidates, including many potentially rocky planets. Precise measurements of the orbital period and phase constrain the significance of mutual gravitational interactions and potential orbital resonances. For systems that are tightly-packed or near an orbital resonance, measurements of transit timing variations provide a new means for confirming transiting planets and detecting non-transiting planets in multiple planet systems, even around faint target stars. Over the course of the extended mission, Kepler is poised to measure the gravitational effects of mutual planetary perturbations for ~200 planets, providing precise (but complex) constraints on planetary masses, densities and orbits. I will survey the systems with multiple transiting planet candidates identified by Kepler and discuss early efforts to translate these observations into new constraints on the formation and orbital evolution of planetary systems with low-mass planets.

**108 Latest Results from the Kepler Mission**
2:20 PM - 2:55 PM, Reno Ballroom

**108.01 Latest Results from the Kepler Mission**
- William J. Borucki¹, Kepler Mission Team
  ¹NASA Ames Research Center.
As the Kepler Mission completes the end of its third year of science observations, calibrated time series data of increasing length are becoming available that make possible the detection of planetary candidates smaller than Earth and candidates with orbital periods nearing one year. Further, the greater capability and sophistication of the pipeline analyses improve the completeness of the results and provide better estimates of the parameter distributions. The most recent data release on 28 July 2012 (Quarters 6 through 9) adds an additional ¼ year of observations so that most planetary candidates with orbital periods as long as 273 days now show at least 3 transits. Data for an additional year (i.e., Quarters 10 through 13) are scheduled to be released on 28 October 2012. A first look at the size, period, and semi-major axis distributions of these data will be presented. Summaries of the planets confirmed, candidates that are being actively analyzed, and the methods being used to verify and confirm planets will be discussed. The Extended Kepler Mission operations begin on 1 October 2012 and many changes in mission focus and operations, data release, and science community participation are being implemented and will be outlined. Funding for this Discovery mission is provided by NASA’s Science Mission Directorate.

109 Exploring New Worlds: Dawn at Vesta
Monday, 2:55 PM - 3:30 PM, Reno Ballroom

109.01 Exploring New Worlds: Dawn at Vesta
- Carol Raymond¹, C. T. Russell², M. C. DeSanctis³, R. Jaumann⁴, A. Konopliv¹, H. Y. McSween⁵, A. Nathues⁶, T. Prettyman¹, M. T. Zuber⁸
  ¹Jet Propulsion Laboratory, California Institute of Technology, ²UCLA, Institute of Geophysics, ³INAF, Istituto di Astrofisica e Planetologia Spaziale, Italy, ⁴DLR, Planetary Research and Freie Universität, Germany, ⁵University of Tennessee, ⁶Max Planck Institute (MPS), Germany, ⁷Planetary Science Institute, ⁸Institute of Technology.

Dawn has completed its exploration of Vesta after spending more than a year mapping the surface and sensing the interior. Vesta is shown to be an object whose evolution is similar to the terrestrial planets, including full igneous differentiation, geologic layering, global tectonic features, and significant mass wasting. Vesta experienced a violent impact history, surviving near fatal collisions that left global scars. Its impact history provides critical constraints on dynamical models of early solar system formation due to its position near the center of the main asteroid belt. While Vesta is very bright on average, dark material is observed with uneven distribution across the body and appears to mix with, and darken, the original Vestan crust, resulting in a large range of albedo. Diversity in mineralogy exists at all scales, from hemispheric dichotomies to small-scale variations exposed by impact gardening. Elemental abundances have been mapped and reveal regional differences in bulk-regolith composition. Vesta’s composition and impact history confirm it to be the parent body of the HED meteorites. Vesta has a substantial iron core, and significant high-degree gravity anomalies that may reflect variations in crustal density and/or thickness. The nature of Vesta’s magmatic evolution, the strength and mechanical properties of its crust, and the sources of the enigmatic compositional layering are some of the topics being explored in depth with Dawn data. The spacecraft is now enroute to the dwarf planet Ceres, where it arrives in February 2015.

110 Asteroids: Spacecraft Missions, Radar Observations, and Spectroscopy
Monday, 3:30 PM - 6:00 PM, Exhibit Hall

110.01 Rosetta Lutetia Fly-by Attitude Reconstruction
- Stubbe Faurschou Hvíd¹
  ¹DLR, Germany.

On July 10th 2010 the ESA Rosetta spacecraft flew past the asteroid 21-Lutetia on the way to its 2014 rendezvous with Comet 67P/Churyumov-Gerasimenko. The closest distance to the asteroid was 3160 km. During the fly-by the asteroid was observed with all the remote sensing instruments of the Rosetta spacecraft. 21-Lutetia is the largest asteroid yet visited by a spacecraft. During the flyby the Rosetta spacecraft attitude was controlled by the onboard...
avionics system using optical navigation with the navigational cameras. It has proven challenging to reconstruct the precise attitude profile executed during the fly-by. The highest accuracy data available for reconstructing the pointing comes from the OSIRIS NAC camera system (18.6 μrad/px-1). This paper describes a method for reconstructing the fly-by attitude using high quality matching between the high-resolution shape model and the actual image data acquired during the fly-by. This method provides a precise attitude determination for the time step of every NAC image acquired during the fly-by. The same method can be applied to the upcoming primary mission of the Rosetta spacecraft. When 67P/Churyumov-Gerasimenko becomes active the predetermined accuracy of the orbit will decrease. During this phase systematic orbit reconstruction will have to be performed.

110.02 The Shape of OSIRIS-REx Mission Target 1999 RQ36 from RADAR and Lightcurve Data
- Michael C. Nolan1, C. Magri2, L. A. M. Benner3, C. W. Hergenrother4, E. S. Howell1, R. S. Hudson5, J. D. Giorgini3, D. S. Lauretta3, J. L. Margot6
1Arecibo Observatory/USRA, 2U. Maine, Farmington, 3JPL/Caltech, 4LPL/U. Arizona, 5Washington State U., Tricities, 6UCLA.

We used planetary radar images and visible lightcurves of asteroid (101955) 1999 RQ36 obtained in 1999 and 2005 to create a three-dimensional shape model of the asteroid and to constrain its surface properties. Radar images at 19-, 15- and 7.5-m resolution taken with the Arecibo and Goldstone planetary radar systems in September/October 1999 and September/October 2005, combined with lightcurves taken in 2005 by CWH and in 1999 by Krugly et al. (2002) were used to model the shape of 1999 RQ36 at 25-m resolution. The asteroid has a fairly smooth “spinning top” shape similar to the primaries of binary asteroids such as 1999 KW4, but with a less well-defined equatorial ridge. The shape appears fairly smooth at small scales, with some large-scale features. There is one 10-20 m boulder that appears in both the 1999 and 2005 radar images, but no other small-scale surface features are evident down to the radar resolution of 7.5 m. The asteroid has a disk-integrated circular polarization ratio of 0.18 ± 0.02 that varies by about 10% over the surface, which is somewhat lower than the polarization ratios obtained for (25143) Itokawa and (433) Eros, suggesting that the surface of 1999 RQ36 is smoother at cm-to-m scales than those objects. The model unambiguously shows the rotation to be retrograde and perpendicular to the orbit plane to within ~ 5° uncertainty, consistent with expectations for YORP spin-up. These results strongly support OSIRIS-REx mission planning. Detailed shape and spin-state information are essential for analysis of orbital stability and sample-targeting accuracy. The smooth surface, polarization ratio, and slope analysis (using the density from Chesley et al., 2012) all provide confidence in the presence of regolith on the surface of 1999 RQ36.

110.03 Observational Properties Of 1999 Ju3 - Hayabusa 2 Mission Primary Target
- Myung-Jin Kim1, Y. Choi1, H. Moon1, S. Mottola2, M. Ishiguro3, M. Kaplan3, D. Kuroda6, D. S. Warjurkar4, J. Takahashi7, Y. Byun1
1Yonsei University, Korea, Republic of, 2Korea Astronomy and Space Science Institute, Korea, Republic of, 3DLR, Germany, 4Seoul National University, Korea, Republic of, 5Akdeniz University, Turkey, 6NAOJ, Japan, 7Nishi-Harima Astronomical Observatory, Japan.

Near-Earth asteroid 162173 (1999 JU3) is the primary mission target of JAXA’s Hayabusa 2 mission, which is the first sample-return from C-type asteroids. It is also a backup target of NASA’s OSIRIS-REx mission. C-type asteroids are known to be parent bodies of carbonaceous chondrites, and offer unique opportunities to study hydrated and volatile-rich remnants of the early epoch in the Solar System. 1999 JU3 is thus the most remarkable asteroid over the next decade. Physical properties, such as rotational period, pole orientation and shape, are essential for the mission planning and the thermal design of the spacecraft. During the apparition in 2007 - 2008, the international observation campaign for 1999 JU3 was conducted. However, some of parameters need further improvements because of the restricted condition of past observation. In particular, there is a big uncertainty in the pole orientation, whether prograde rotation or not. We participated in an observational campaign of 1999 JU3 using several 1-2m class telescopes with Calar Alto 1.2m in Spain, UH 2.2m in Hawaii, Nishi-Harima 2m in Japan, TUG 1m in Turkey and HCT 2m in India. In total, we acquired the lightcurve data from single night in the period of 2011 and the beginning of June to 19th July in 2012 with a sufficient signal to noise ratio. The coverage of the phase angle is
between 6 and 54 degrees. Based on these data sets, we will report the rotational period and the amplitude. In addition, we plan to compare the results obtained from the observation in 2007 - 2008.

110.04 Observing Campaign for Potential Deep Impact Flyby Target 163249 (2002 GT)
- Jana Pittichova, S. R. Chesley, P. A. Abell, L. A. M. Benner

The Deep Impact spacecraft is currently on course for a proposed 2020-Jan-4 flyby of Potentially Hazardous Asteroid 163249 (2002 GT). The re-targeting will be complete with a final small maneuver scheduled for 2012-Oct-04. 2002 GT has a well-determined orbit and absolute magnitude 18.3 (~800m diameter). Little more is known about the nature of this object, but in late June 2013 it will pass 0.012 AU from Earth, affording an exceptional opportunity for ground-based characterization. At this apparition 2002 GT will be in range of Arecibo, which should provide radar delay observations with precisions of a few microseconds, potentially revealing whether the system is binary or not. The asteroid will reach magnitude V=16.1 and will be brighter than V=18 for over two months, facilitating a host of observations at a variety of wavelengths. Light curve measurements across a wide range of viewing perspectives will reveal the rotation rate and ultimately lead to strong constraints on the shape and pole orientation. Visible and infrared spectra will constrain the mineralogy, taxonomy, albedo and size. Radar and optical astrometry will further constrain the orbit, both to facilitate terminal guidance operations and, when combined with spacecraft flyby data, to potentially reveal nongravitational forces acting on the asteroid. Coordinating all of these observations will be a significant task and we encourage interested observers to collaborate in this effort. The 2013 apparition will be the last time 2002 GT will be brighter than magnitude 18 until after the 2020 spacecraft flyby and thus represents a unique opportunity to characterize a potential flyby target, which will aid planning and development of the flyby imaging sequence and interpretation of flyby imagery. The knowledge gained from this proposed flyby will be highly relevant to NASA’s human exploration program, which desires more information on the characteristics of sub-kilometer near-Earth asteroids.

110.05 Goldstone Radar Imaging of Near-Earth Asteroid 2003 MS2
- Kenneth J. Lawrence, L. Benner, S. Ostro, J. Giorgini, R. Jurgens, M. Brozovic, C. Magri, J. L. Margot

We report delay-Doppler radar images of 2003 MS2 that were obtained at Goldstone (8560 MHz, 3.5 cm) on three dates during this object’s close Earth flyby in July of 2003 within 0.025 AU (9.7 lunar distances). The asteroid was a strong radar target and we obtained images with resolutions as high as 19 m/pixel. The radar images reveal an unusually angular object with pronounced facets. Our longest sequence of images was obtained on July 4 when the asteroid rotated at least several tens of degrees in 2.7 hours. During that interval, the bandwidths varied by a factor of about 1.5 and clearly establish that this is an elongated object. The rotation and bandwidth variations evident in the radar images are consistent with the 7 hour rotation period and 0.5 magnitude lightcurve amplitude reported by Muinonen et al. 2006[1]. If we adopt the 7 hour period, then the maximum and minimum bandwidths place lower bounds on the maximum pole-on dimensions of (0.35 x 0.23) km/cos δ, where δ is the (unknown) subradar latitude. These constraints are consistent with the range extents of 0.25 km visible in the images. We obtain a circular polarization ratio of 0.28+/−0.02 that is comparable to 25143 Itokawa and suggests a similar degree of near-surface roughness at decimeter spatial scales. [1] Muinonen, K. et al. (2006). Spins, shapes, and orbits for near-Earth objects by Nordic NEON. Proceedings of the International Astronomical Union, 2, pp 309-320 doi:10.1017/S1743921307003377.

110.06 Modeling Asteroid Surface Properties Using Radar Albedos and Circular-Polarization Ratios
- Anne Virkki, K. Muinonen, A. Penttilä

A basic strategy for observing using radar is to transmit a fully circularly polarized wave in a specific polarization state and to measure the distribution of echo power in the same (SC) and opposite states of circular polarization (OC). The ratio of SC to OC (μ) is an important physical observable when using the radar technique, as it is
considered to provide the best indications for wavelength-scale geometric complexity of the surface (positive correlation with the complexity; S. J. Ostro, Rev. Mod. Phys. 65, 1993). The observed values are taxonomic-class dependent to some extent, varying from $\mu = 0.10$ (G class) to $\mu = 0.83$ (E class). The maximum value observed for an asteroid using radar is $\mu = 1.48 \pm 0.4$ for 2003 TH2. Circular polarization is studied for aggregates of spheres at backscattering. Exact electromagnetic scattering computations using the superposition T-matrix method are carried out to study how different parameters affect the value of $\mu$, e.g., the size distribution, the size parameters, and the refractive indices. Both scattering and absorption of the electromagnetic waves are treated using various monodisperse and polydisperse sphere aggregates. The simulations show striking interference structure at backscattering for $\mu$ as a function of the size parameter and the refractive index of the spherical particles. The structure comprises two sets of bands of maxima: the primary band, following the extinction efficiency of a sphere with the same size parameter as the monomers of the aggregate; and the secondary bands, a result of bi-sphere resonances between the monomers. Our goal is to relate the computed circular-polarization ratios and radar albedos for aggregates of spheres to the observational data of asteroid regoliths measured using radar.

110.07 Combining Thermal and Radar Observations of Near-Earth Asteroids


1Arecibo Observatory/USRA, 2JHU/Applied Physics Lab, 3U. Maine Farmington, 4U. Central Florida.

As we sample ever-smaller sizes of near-Earth asteroids (NEAs) we see a wide range of shapes, surface features, and rotation states. Infrared observations using SpeX at the NASA IRTF (0.8-4.1 microns) show a range of spectral types and thermal characteristics. The goal of our investigation is to combine radar-derived shape models with reflected and thermal near-IR spectra to better understand the regolith properties of different types of NEAs. We have observed 40 NEAs, including 25 S-complex, 10 X-complex and 4 C-complex objects, and one T object. All of these NEAs have been observed at several different viewing geometries. The sizes range from a few hundred meters to a few kilometers effective diameter. Our sample includes four binaries, one triple system, nine contact binaries and three spheroidal (non-binary) objects. The other objects are irregular shapes, or not yet determined. We have developed a shape-based thermophysical model, SHERMAN, which will take the asteroids' shape and spin into account when calculating the thermal emission. This is a self-consistent model that uses the observed reflectance, and allows variable thermal parameters across the asteroid surface. We compare SHERMAN to other thermal and thermophysical models to explore the effects of shape, composition and rotation rate for modeling NEAs.

110.08 Spectra And Albedos Of Small Koronis Family Members

- Cristina A. Thomas, D. E. Trilling, A. S. Rivkin

1NASA Goddard Space Flight Center, 2Northern Arizona University, 3Applied Physics Laboratory-Johns Hopkins University.

The space weathering process and its implications for the relationships between S- and Q-type asteroids and ordinary chondrite meteorites are long-standing problems in asteroid science. Although the visible and near-infrared spectra of S- and Q-type objects qualitatively show the same absorption features and quantitatively show evidence of the same minerals, the S-types display increased spectral slopes and muted absorption features compared to the Q-types. This spectral mismatch is consistent with the effects of the space weathering process. We investigated space weathering within the old Main Belt Koronis family using a spectrophotometric survey (Rivkin et al. 2011, Thomas et al. 2011). Rivkin et al. (2011) identified several potential Q-type objects within the Koronis family. We present followup spectral observations of two of these potential Q-type objects. In addition to our observations, we investigated the albedo distribution of small Koronis family members and will discuss whether albedo variations are due to space weathering or variations in regolith.

110.09 Color Variation Within Inner-belt Asteroid Families


1University of Southern Maine, 2University of Central Florida, 3University of Maryland, 4Instituto de Astrofisica de Canaries (IAC), Spain.
We studied the Sloan Digital Sky Survey (SDSS) colors of four inner-belt families: Flora, Baptistina, Erigone, and Nysa. Each of these asteroid families divides cleanly into two clusters in color space: one belonging to a primitive asteroid taxonomic class while the other to a non-primitive class. The clusters were determined using two techniques: Principal Component Analysis and AutoClass. We also found that the Wide-field Infrared Survey Explorer (WISE) albedos for each of the clusters were clearly different, which is nicely consistent with our SDSS clusters. These results indicate that there are at least two populations within each of the four families. This dichotomy within each family has two possible explanations. One possibility is that the two clusters represent contamination resulting from a purely dynamical definition of the family. This contamination can come from adjacent, yet distinct asteroid families or a non-family background population. Or a plausible, but less favored explanation, is that the color and albedo clusters within each family could represent surprisingly different compositional units within the parent body. Based upon a Yarkovsky analysis, significant contamination between families is the favored explanation for our results. These results may allow us to refine current methods of family definition and help minimize interlopers.

110.10 Near-IR Spectroscopy and Visual Broadband Photometry of Unbound Asteroid Pairs
- Stephen D. Wolters1, P. Weissman1, S. R. Duddy1, A. Christou1, S. F. Green1, S. C. Lowry2, B. Rozitis4
  1Jet Propulsion Laboratory, 2University of Kent, United Kingdom, 3Armagh Observatory, United Kingdom, 4The Open University, United Kingdom.

Over 62 pairs of asteroids have been identified with extremely similar orbits (Rożek, Breiter, and Jopek 2011, MNRAS 412, 987). Backwards integration of their orbits show that each pair probably experienced a very low-velocity close encounter, in many cases less than 1 Myr ago (e.g. Vokrouhlický and Nesvorný 2008, AJ 136, 280). Pravec et al. (2010, Nature, 466, 1085) examined 35 pairs and found that the secondary/primary mass ratio is <0.2. Also, as this ratio approaches 0.2, the rotation period of the primary increases. This is consistent with formation of the pairs through rotational fission of a parent rubble-pile asteroid (Scheeres 2007, Icarus 189, 370). However, the pairs were linked through dynamical considerations alone, and mass ratios were determined using catalogued visual magnitudes and the assumption that the albedos and bulk densities of the components are identical. We are undertaking a campaign of characterising the asteroids in these pairs using visual and NIR spectroscopy as well as thermal IR photometry. We present 0.8-2.5 micron spectroscopic observations of using SpeX on NASA-IRTF, and BVRI photometry using the 0.6-m Table Mountain Observatory telescope. Our goals are to assess the similarity of the spectra of the components’ surfaces (e.g. Duddy et al. 2012, A&A, 539, A36) and also to look for evidence of color variation as a function of rotational phase. Since dynamical studies have placed constraints on the formation ages, if the asteroids are completely resurfaced during formation, we can start to explore the timescales involved in space weathering. We report recent progress in our investigations. This work was supported in part by the NASA Planetary Astronomy Program and done in part at the Jet Propulsion Laboratory under contract with NASA.

110.11 Dunites In The Sky? VNIR Spectra Of Six Suspected A-class Asteroids
- Michael Lucas1, J. P. Emery1, D. Takir1
  1University of Tennessee.

Olivine-rich A-class asteroids are rare. They represent <1% of the ~2150 individual spectrally measured asteroids from the four major taxonomic surveys conducted during the last three decades. The most recent survey (DeMeo et al., 2009) observed 15 of 26 presumed A-class objects. Nine were found to be S-types (8 objects) or L-type (1 object) and were “declassified” with spectral data extended into the near-infrared (NIR). We present visible and near-infrared (VNIR) spectra of four more suspected A-class asteroids (982, 1509, 3352, and 4142). Spectra of 982 Franklina and 1509 Esclangona heretofore were recorded only in visible light. VNIR spectrum of 4142 Dersu-Uzala is from Binzel et al. (2004). Three of these suspected A-class objects reside interior to the main-belt. We also acquired NIR spectra of confirmed A-class asteroids 289 Nenetta and 863 Benkoela. We identified the taxonomic classification of each asteroid using the extended taxonomy of Bus-DeMeo. The asteroids 982 Franklina, 1509 Esclangona, 3352 McAuliffe, and 4142 Dersu-Uzala are not olivine-rich A-types but are S-type or S-subtypes. We performed spectral band-parameter measurements using the calibrations of Dunn et al. (2010) and band-parameter temperature corrections of Sanchez et al. (2012) to derive mineral abundances and mafic silicate
compositions for these four S-type objects. The presence of Band I and II strongly indicates the presence of pyroxene in the four S-type objects and in the A-type 863 Benkoela. Three asteroids (982, 3352, and 4142) plot in the S(IV) region of the S-asteroid subtypes plot of Gaffey et al. (1993) and above the orthopyroxene to clinopyroxene trend line of Adams (1974) indicating the presence of olivine. However, 1509 Esclangona plots in the S(III) region and below the trend line and may be more pyroxene-rich. The four S-type objects have ol/ol+px ratios of 0.60-0.65 and mafic mineral compositions of olivine (Fa19-31) and pyroxene (Fs16-25).

110.12 Near Infrared Spectroscopy of the Trojan Asteroids: Testing the Distribution of Spectral Types in the L4 and L5 swarms.

- Richard Ness  
  1University of Tennessee at Knoxville.

The Trojan asteroids are a collection of celestial bodies, inhabiting Jupiter's stable Lagrange points, of which little is known, yet they contain important information about the evolution of the early solar system. Trojans are not large enough to have differentiated, and therefore their composition is vital in describing primordial conditions in the region(s) of the solar nebula in which they formed. Although visible and near-infrared spectroscopy of Trojans has continually failed to uncover any diagnostic spectral features, recent work has identified two spectral groups characterized by differing spectral slopes. Those results suggest that the spectral groups occur in equal relative abundances in the two Trojans swarms, but the observations were heavily weighted toward the L4 swarm. Here, we present new near-infrared (0.7 to 2.5 μm) spectra of 20 Trojan asteroids, mostly from the L5 swarm. We used the SpeX instrument on the NASA Infrared Telescope Facility for these observations. The new spectra are all featureless with red spectral slopes (increasing reflectance with increasing wavelength), similar to previously published Trojan spectra. The asteroids' spectra are summarized by compressing the data into color indices to investigate the presence of spectral groups. Analysis of the color indices demonstrates that there are two groups of spectrally different Trojan asteroids in the new sample of Trojans from the L5 swarm. The relative proportion of the “redder” and “less-red” spectra groups appears to be the same for the L5 group as for the L4 group, supporting the hypothesis that a specific spectral type of asteroid is not concentrated in one particular Lagrange point. These results indicate that there is no systematic compositional difference between L4 and L5 Trojans. This work provides important information about the little known Trojan asteroids and ultimately offers a stepping stone toward the discovery of their composition.

110.13 A Spectroscopic And Photometric Survey Of Selected Near-earth Asteroids: Results From 2008-2012.

- Michael D. Hicks  
  1JPL, 2Moorepark College, 3Victor Valley College, 4Los Angeles City College, 5California State University, Los Angeles, 6University of California, Berkeley, 7Los Angeles Valley College, 8University of Southern California.

Over the past four years we have used the dual-channel optical spectrometer (DBSP) at the Palomar 200-inch telescope (P200) to collect low-resolution spectroscopy of Near-Earth Asteroids (NEAs) and have been awarded, on average, three nights per semester. Additionally, we have ample access to the JPL Table Mountain 0.6-m (TMO) telescope for time-resolved Bessel BVRI photometry. Undergraduate students from the CURE program (Consortium for Undergraduate Research Experience) have provided a large fraction of the observing effort at TMO. With these two telescopes, we strive to characterize all bright (V<17) objects of interest, limited primarily by weather, as they become available at our latitude. Our focus has been Potentially Hazardous Asteroids (PHAs), planetary radar targets, and low delta-V near-Earth asteroids (as potential mission targets). In this paper we will present our observational results for ~150 NEAs. Our data products are diverse, and can include taxonomic classification, broad-band colors, rotational period, solar phase behavior and absolute magnitude, and 3-d shape/pole models derived from lightcurve inversion. We will discuss the variability between main-belt and near-Earth spectral families, quantify differences between PHA and background near-Earth populations, and present our first attempts to generate a spectral photometry using solely near-Earth asteroids. This research was funded by NASA. The student participation was supported by the National Science Foundation under REU grant 0852088 to Cal State LA.
110.14 Photometry of 10 Jovian Trojan Asteroids
Robert D. Stephens¹, L. M. French², D. R. Coley¹, R. Megna³, L. H. Wasserman³
¹Center for Solar System Studies, ²Illinois Wesleyan Univ., ³Lowell Observatory.

Lightcurves for 10 Jupiter Trojan asteroids were obtained from GMARS Observatory from August 2010 to March 2012. The objects studied include (911) Agamemmnon, (1867) Deiphobus, (4709) Ennomos, (11397) 1998 XX93, (23135) 2000 AN146, (4138) Kalchas, (10247) Ampiaros, (12714) Alkimos, (16070) 1999RB101, and (24470) 2000 SJ310. Most objects are in the 50-100 km diameter range. Results will be compared with any previous period and amplitude determinations.

110.15 Eight Years in the Hungarias
Brian D. Warner¹, A. Harris²
¹Palmer Divide Obs./MoreData!, ²MoreData!

Since 2005, the Palmer Divide Observatory has run an observations and analysis program concentrating on the Hungaria asteroids. These are small (D < 13 km) inner main belt asteroids with high orbital inclinations, with many having high albedos (pV ~ 0.4). As such, they were easily studied by smaller telescopes as a control group against which to test theories regarding rotation statistics and binary population among the near-Earth population. We will review some previously reported but important results: 1) the rotation rate distribution is essentially flat in the range 1/day &lt; f &lt; 12/day, similar to the NEA population; 2) there is a strong excess of slow rotators (P &gt; 24 h) within the group, slightly more pronounced than in the NEA population; 3) the binary population of the NEAs and Hungarias is statistically identical, giving support to YORP spin-up as the primary mechanism for binary formation and not planetary tidal encounters; and 4) the Hungaria collisional family age is on the order of 0.2 - 0.5 Gyr. We also include an update on our efforts to determine the distribution of spin axis orientations, which are hampered by the lack of sparse data of sufficient quality to support dense data sets (lightcurves).

110.16 Spin State and Moment of Inertia Characterization of 4179 Toutatis
Yu Takahashi¹, M. Busch², D. J. Scheeres³
¹University of Colorado at Boulder, ²UCLA/National Radio Astronomy Observatory.

The 4.6 km long contact-binary near-Earth asteroid 4179 Toutatis has made close Earth flybys every four years between 1988 and 2012, and has been observed with high-resolution radar imaging during each approach since 1992 (Ostro et al. 1995, Hudson et al. 1995, Ostro et al. 1999, Hudson et al. 2003, Busch et al. 2012). These observations have provided the asteroid orientation and angular velocity during each apparition with varying degrees of uncertainty. Using these observations, Toutatis’ spin state dynamics were fitted in a least-squares sense, with solar and terrestrial tidal torques incorporated in the dynamics model. The tidal torques greatly influence the spin state of Toutatis due to their being a function of the gravitational spherical harmonics, which are linearly related to the moments of inertia and the center-of-mass offset of the body. The moments of inertia and the initial spin state at an epoch in 1996 are used as initial conditions for a least-squares batch filter estimate of Toutatis’ Euler angles, angular velocity, moments of inertia, and the center-of-mass offset. The spin state dynamics as well as the uncertainties of the Euler angles and angular velocity of the converged solution are then propagated to December 2012, which is the next apparition of the asteroid. The data collected during the 2012 flyby will be used to validate our results. Toutatis’ moments of inertia about its short and intermediate principal axes as compared to that about the long axis are 3 ± 1% and 4 ± 1% larger respectively than the values expected if the asteroid had uniform density. Based on the estimated moments of inertia, we find that Toutatis has a non-uniform internal density distribution consistent with a 15% greater density in the asteroid’s “head” (the smaller lobe).

110.17 Investigating Near Earth Asteroids Spectra Using Meteorites And Lunar Sample Measurements
Mirel Birlan¹, C. Feller², M. Popescu³
¹IMCCE Observatoire de Paris, France, ²Universite Paris 7, France, ³University, Romania.
Asteroid spectra are affected by space weathering (SW) processes. Taxonomic classes in the S-complex (DeMeo et al, Icarus, 202, 2009) are in relative good agreement to measurements obtained on irradiated samples of silicates. One of the models proposed for quantifying the space weathering influence of silicates is proposed by Brunetto et al (Icarus, 184, 2006). This model of SW was implemented into the on-line application M4AST (Modeling for Asteroids). M4AST consists into a spectral database of asteroids and a set of applications for spectral analysis (Popescu et al, A&A, 2012 in press). M4AST allows also obtaining of mineralogical solutions using laboratory spectra from RELAB and mineralogical modeling using space weathering effects corroborated with radiative transfer laws. Our scientific goal was to evaluate the SW influence for a sample of 50 S-type Near-Earth Asteroids (NEAs). For the de-redening process of asteroids’ spectra we used the model of Brunetto et al as (2006) implemented into the M4AST. The comparison to the meteorites and lunar samples contained in the RELAB database were further performed for the original and de-redened spectra of asteroids. The main conclusion of this statistical analysis is the dissociation of spectral lunar samples inside the best-fit match of de-weathered S-type asteroids spectra. Indeed, the number of occurrences of laboratory measurements contained on average 10% of lunar samples for each spectrum of S-type asteroids. After the application of SW model, the best fit spectra of laboratory measurements contains on average 10 times less lunar samples. This result is consistent to the conclusion that asteroids and the Moon experienced different mechanisms of space weathering.

110.18 Taxonomic Size Frequency Distributions By Dynamical Zone
Amy Murphy1, J. Ziffer1, H. Campins2, M. S. Kelley3, D. H. Wooden4
1University of Southern Maine, 2University of Central Florida, 3University of Maryland, 4NASA Ames Research Center.

We investigate the size-frequency distribution of major asteroid taxonomic classes by combining data from the recent Wide-field Infrared Survey Explorer (WISE) and Carvano et al.’s (2010) Sloan Digital Sky Survey (SDSS) based taxonomy. Prior to WISE the limited scope of albedo and diameter studies restricted our understanding of taxonomic size frequency distributions. Our research using the new WISE database extends the number of asteroids analyzed from 4,000 to over 8,000 and expands on previous work by focusing on asteroid classes S, C, X (and its subclasses), and D. We remove asteroids belonging to the major asteroid families as defined by Nesvorny (2010) and control for collisional environment by using dynamical zones as defined by Cellino et al. (1991). Understanding the taxonomic size frequency distributions provides insight into the collisional evolution of asteroids in each class. Our results can be extrapolated to infer the overall volume of each class.

110.19 On Identifying Clusters Within the C-type Asteroids of the Sloan Digital Sky Survey
Renae Poole1, J. Ziffer1, T. Harvell1
1University of Southern Maine.

We applied AutoClass, a data mining technique based upon Bayesian Classification, to C-group asteroid colors in the Sloan Digital Sky Survey (SDSS). Previous taxonomic studies relied mostly on Principal Component Analysis (PCA) to differentiate asteroids within the C-group (e.g. B, G, F, Ch, Cg and Cb). AutoClass’s advantage is that it calculates the most probable classification for us, removing the human factor from this part of the analysis. In our results, AutoClass divided the C-groups into two large classes and six smaller classes. The two large classes (n=4974 and 2033, respectively) display distinct regions with some overlap in color-vs-color plots. Each cluster’s average spectrum is compared to ‘typical’ spectra of the C-group subtypes as defined by Tholen (1989) and each cluster’s members are evaluated for consistency with previous taxonomies. Of the 117 asteroids classified as B-type in previous taxonomies, only 12 were found with SDSS colors that matched our criteria of having less than 0.1 magnitude error in u and 0.05 magnitude error in g, r, i, and z colors. Although this is a relatively small group, 11 of the 12 B-types were placed by AutoClass in the same cluster. By determining the C-group sub-classifications in the large SDSS database, this research furthers our understanding of the stratigraphy and composition of the main-belt.

110.20 The Evidence in Asteroids for Chemical and Physical Trends in the Solar Nebula
Guy Consolmagno1, R. J. Macke2, D. T. Britt3
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Inspired by the Nice model, several modelers have suggested that the asteroid belt is populated primarily by material that originated well inside or outside its current boundaries. We have devised a novel way of illustrating this distribution: we bin asteroids in the main belt by semimajor axis and in each bin calculate the volume fraction of asteroids of a given spectral class, as defined for 1447 asteroids by Binzel and Bus. (The four largest asteroids, Ceres, Vesta, Pallas, and Hygeia, are removed as they would dominate their bins and thus mask distribution trends.) For example, we see S and C asteroid concentrations are highest at the inner and outer belt boundaries, respectively, and vary smoothly as a function of distance from those boundaries. Typical S type asteroids are 20%-30% macroporous; C type asteroids, 40%-60% macroporous; and icy bodies (comets and TNOs) may be as much as 80% macroporous. The meteorite analogs of those asteroids show parallel chemical and physical trends.

Microporosity increases linearly with percentage matrix from the almost zero-porosity enstatite chondrites (inner belt asteroid analogs) up to about 35% for CI's with ~99%-+ matrix (outer belt analogs). Porosity also increases, nonlinearly, with degree of oxidation from the reduced enstatite chondrites to the highly oxidized carbonaceous chondrites. Finally, porosities trend with petrographic type (based on the average porosity per petrographic type), with the most thermally altered meteorites (enstatite chondrites) at the lowest porosity while the most aqueously altered meteorites (CI, CM) are the most porous. Given these distributions, we conclude that asteroid macroporosity, microporosity, matrix, and oxidation state all increase with heliocentric radius. This suggests that heliocentric distance within the solar nebula controls not only the composition of the material accreting into planets, but the physical nature of how that material accreted and evolved.

110.21 Outgassing Activity of 176P/LINEAR Observed with Herschel/HIFI: An Upper Limit for the Water Production Rate

- Miguel de Val-Borro1, L. Rezac1, P. Hartogh1, N. Biver2, D. Bockelée-Morvan3, J. Crovisier1, M. Küppers3, D. C. Lis4, S. Szutowicz5, G. A. Blake6, M. Emprechtinger7, C. Jarchow7, E. Jehin6, M. Kidger7, L. M. Lara8, E. Lellouch1, R. Moreno1, M. Renegel1

1Max Planck Institute for Solar System Research, Germany, 2Observatoire de Paris, France, 3Rosetta Science Operations Centre, Spain, 4Caltech, 5Space Research Centre, Poland, 6Université de Liège, Belgium, 7Herschel Science Centre, Spain, 8Instituto de Astrofísica de Andalucía, Spain.

176P/LINEAR is a member of the new cometary class known as main-belt comets (MBCs). It displayed cometary activity during its 2005 perihelion passage that was found suggestive of the presence of sublimating sub-surface ices. We have therefore searched for emission of the water ground state rotational line at 557 GHz toward 176P/LINEAR with the Heterodyne Instrument for the Far Infrared (HIFI) on board the Herschel Space Observatory on UT 8.78 August 2011, about 40 days after its most recent perihelion passage, when the object was at a heliocentric distance of 2.58 AU. No H2O line emission was detected in our observation, from which we derive sensitive 3-sigma upper limits for the water production rate and column density of < 4e25 molec/s and of < 3e10 cm⁻², respectively. From the peak brightness measured during the object’s active period in 2005, this upper limit is lower than predicted by the relation between production rates and visual magnitudes observed for a sample of comets by Jorda et al. (2008). Thus, 176P was likely less active at the time of our observation than during its previous perihelion passage. The retrieved upper limit for the water production rate is generally lower than values derived from the spectroscopic search for CN emission in other MBCs.

111 Everything Asteroids

Monday, 3:30 PM - 6:00 PM, Exhibit Hall

111.01 The Near-Earth Object Human Space Flight Accessible Targets Study (NHATS) List of Near-Earth Asteroids: Identifying Potential Targets for Future Exploration


1NASA Johnson Space Center, 2NASA Goddard Space Flight Center, 3Aerospace Consultant, 4NASA Langley Research Center, 5NASA Headquarters, 6Jet Propulsion Laboratory, California Institute of Technology.
Introduction: Much attention has recently been focused on human exploration of near-Earth asteroids (NEAs). Detailed planning for deep space exploration and identification of potential NEA targets for human space flight requires selecting objects from the growing list of known NEAs. NASA therefore initiated the Near-Earth Object Human Space Flight Accessible Target Study (NHATS), which uses dynamical trajectory performance constraints to identify potentially accessible NEAs. Accessibility Criteria: Future NASA human space flight capability is being defined while the Orion Multi-Purpose Crew Vehicle and Space Launch System are under development. Velocity change and mission duration are two of the most critical factors in any human spaceflight endeavor, so the most accessible NEAs tend to be those with orbits similar to Earth’s. To be classified as NHATS-compliant, a NEA must offer at least one round-trip trajectory solution satisfying purposely inclusive constraints, including total mission change in velocity ≤ 12 km/s, mission duration ≤ 450 days (with at least 8 days at the NEA), Earth departure between Jan 1, 2015 and Dec 31, 2040, Earth departure C3 ≤ 60 km2/s2, and Earth return atmospheric entry speed ≤ 12 km/s. Monitoring and Updates: The NHATS list of potentially accessible targets is continuously updated as NEAs are discovered and orbit solutions for known NEAs are improved. The current list of accessible NEAs identified as potentially viable for future human exploration under the NHATS criteria is available to the international community via a website maintained by NASA’s NEO Program Office (http://neo.jpl.nasa.gov/nhats/). This website also lists predicted optical and radar observing opportunities for each NHATS-compliant NEA to facilitate acquisition of follow-up observations. Conclusions: This list of NEAs will be useful for analyzing robotic mission opportunities, identifying optimal round trip human space flight trajectories, and highlighting attractive objects of interest for future ground-based observation opportunities.

111.02 An Experimental Demonstration of the Importance of Cohesion in Electrostatic Dust Lofting
   - Christine Hartzell1, X. Wang2, D. Scheeres3, M. Horanyi2
   1California Institute of Technology, 2University of Colorado.

Electrostatic dust lofting has been hypothesized to occur on the Moon since the Lunar Horizon Glow was observed by the Surveyor spacecraft. The hypothesis was naturally extended to asteroids, due to their much smaller surface gravity. In the past, electrostatic dust lofting was said to be feasible if the electrostatic force (pulling the grain off the surface) was greater than the gravity force (holding the dust on the surface). However, cohesion, which is significant for small dust grains, was neglected. When cohesion is included and the charge on the dust is approximated by Gauss’ law, it can be seen that small dust particles require a larger electric field to be lofted than intermediately sized grains. This hypothesis was tested by measuring the spreading of piles of uniformly sized polystyrene dust grains resting on a biased plate in small plasma chamber. If the electric field at the edge of the pile was large enough to overcome gravity and cohesion, the dust pile spread. We saw that piles of 15 micron grains exhibited significant spreading, while the spreading of 5 and 25 micron grains was negligible. Moderate spreading was observed for 10 and 20 micron grains. Thus, we have experimentally demonstrated the dominance of cohesion in determining the electric field required for lofting small dust grains. The preferential lofting of intermediately sized grains has important implications for our understanding of the evolution of the surfaces of airless bodies and the design of future landing spacecraft. C.M.H. acknowledges support from the NASA Earth and Space Science Fellowship, Grant NNX09AR51H. D.J.S. acknowledges support from the NASA Discovery Data Analysis Program and Planetary Geology and Geophysics program. This work was partially supported by the NASA Lunar Science Institute’s Colorado Center for Lunar Dust and Atmospheric Studies (CCLDAS).

111.03 Asteroids@Home
   - Josef Durech1, J. Hanus1, R. Vanco2
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We present a new project called Asteroids@home (http://asteroidsathome.net/boinc). It is a volunteer-computing project that uses an open-source BOINC (Berkeley Open Infrastructure for Network Computing) software to distribute tasks to volunteers, who provide their computing resources. The project was created at the Astronomical Institute, Charles University in Prague, in cooperation with the Czech National Team. The scientific aim of the project is to solve a time-consuming inverse problem of shape reconstruction of asteroids from sparse-in-time photometry. The time-demanding nature of the problem comes from the fact that with sparse-in-time photometry the rotation period of an asteroid is not apriori known and a huge parameter space must be densely
scanned for the best solution. The nature of the problem makes it an ideal task to be solved by distributed computing - the period parameter space can be divided into small bins that can be scanned separately and then joined together to give the globally best solution. In the framework of the the project, we process asteroid photometric data from surveys together with asteroid lightcurves and we derive asteroid shapes and spin states. The algorithm is based on the lightcurve inversion method developed by Kaasalainen et al. (Icarus 153, 37, 2001). The enormous potential of distributed computing will enable us to effectively process also the data from future surveys (Large Synoptic Survey Telescope, Gaia mission, etc.). We also plan to process data of a synthetic asteroid population to reveal biases of the method. In our presentation, we will describe the project, show the first results (new models of asteroids), and discuss the possibilities of its further development. This work has been supported by the grant GACR P209/10/0537 of the Czech Science Foundation and by the Research Program MSM0021620860 of the Ministry of Education of the Czech Republic.

111.04 A New Approach for Computing Yarkovsky and YORP Forces on Asteroids
    - Jacob Adler¹, D. Paige¹
    ¹University of California.

We examine the effects of non-gravitational forces by tracking photon momentum through a three dimensional ray-tracing thermal model. The ray-tracing model accounts for the momentum transfer associated with absorption, shadowing, rescattering and emission of solar and infrared photons. This new model calculates the Yarkovsky and YORP effects, which are extremely important in midsize asteroids, by summing the forces on each facet of the shape model and integrating over time. The availability of a high quality topographic model as well as the physical properties of the asteroid Itokawa, mainly its non-symmetric shape and rubble pile consistency, made it a prime target for the evaluation of the effectiveness of the new model. We used R. Gaskell’s Itokawa shape model from Hayabusa data and found the momentum vectors and forces on each of the 3,145,728 triangular facets. We compare our results with those predicted from previous Yarkovsky and YORP studies such as Scheeres 2007 and Breiter 2009. Our generalized approach can be applied to any body to refine ephemerides and assess the effects of non-gravitational forces on the evolution of small solar system bodies.

111.05 Ejection of Satellites of Asteroids by Koziński-Related Resonances
    - Julien Frouard¹, T. Yokoyama¹
    ¹UNESP, Brazil.

We investigate how satellites of asteroids can suffer ejections or collisions while migrating away from their primary due to tides and BYORP. We are in particular interested in the region contained in 10-100 times the radius of the primary, thus well before the instability limit caused by solar perturbation only. It is well known that the orbital problem of a satellite with oblateness and solar perturbation is much more complex than the classical Koziński mechanism, in terms of resonances and how they appear. Large orbital instabilities can eject satellites at the critical semi-major axis (where oblateness and solar perturbation equalize), provided that the obliquity of the primary is high enough. We numerically integrate the averaged evolution of typical binary NEAs and MBAs, taking into account the obliquity of the primary, a realistic solar orbit, and slow dissipative drifts that can drive the system inside resonances and chaotic regions. Stability of sufficiently small satellites (~ 1E-4, 1E-5 primary mass) is only dependent on the maximum obliquity attained by the primary, and ejections (or collisions) appear for obliquities > 60°-70°. On the other hand, satellites massive enough can easily destabilize the motion of the equator of the primary while migrating outwards, and ejections are a more common fate.

111.06 Proper Elements, Asteroid Families, Resonances: An Extralarge Dataset
    - Andrea Milani¹, Z. Knežević², A. Cellino³, B. Novaković³, I. Shevchenko⁵, E. A. Smirnov⁵
    ¹Università di Pisa, Italy, ²Astronomical Observatory of Belgrade, Serbia, ³Astronomical Observatory of Torino, Italy, ⁴University of Belgrade, Serbia, ⁵Pulkovo Observatory, Russian Federation.

As part of the maintenance of the AstDyS online information system, we continue to accumulate proper elements computed by the synthetic method (Knežević and Milani 2000, 2003) for Main Belt Asteroids (including high eccentricity and inclination ones), Jupiter’s Trojans, and Trans Neptunian Objects. The most recent proper
elements catalogs contain more than 300,000 objects. We have started the largest ever classification of asteroids into dynamical families. The much increased number density implies that it is difficult to use directly the standard method of hierarchical clustering (Zappala’ et al 1994). We use a two stage procedure to define core families, then add smaller objects from a larger catalog of smaller bodies; the second step can be repeated periodically, thus ensuring the classification remains up to date. We have applied such a method to both the low and the high inclination regions of the main belt, obtaining a family classification with more than 60,000 member asteroids. We also started the identification of asteroids affected by mean motion resonances, by using three criteria: stability of the proper semimajor axis, Lyapounov exponents and actual libration of critical arguments. We obtain information on the two and three-body resonances, on apocentric vs. pericentric libration, and on the stability of the resonance, for each individual asteroid. We show figures combining information from all three datasets: proper elements, family membership, and resonances. These show clearly the role of families in feeding small asteroids into weak resonances, mostly by non-gravitational perturbations, and the role of these resonances in pushing asteroids to higher eccentricities thus supplying both the Near Earth and the Near Jupiter region. Thus the data we are computing, although based on a comparatively recent dynamical behavior (the last 2 Myr covered by numerical integrations), provide information on the long term transport mechanisms and collisional evolution.

111.07 A Method for Rejection of Astrometric Outliers based on the Peirce Criterion
- Marco Micheli\textsuperscript{1}, D. J. Tholen\textsuperscript{1}, G. T. Elliott\textsuperscript{1}
\textsuperscript{1}Institute for Astronomy - University of Hawaii.

In the last decade the growing number of telescopes dedicated to NEO surveys, together with a rapid increase of the number of amateur-level observatories, resulted in a dramatic increase in the number of astrometric observations reported to the Minor Planet Center. The most accurate stations are now capable of obtaining astrometry of asteroids with random errors around 0.1”. On the other hand, the increase in the number of available data points is sometimes associated with an increasing occurrence of outliers, biases and erroneous observations, which may affect the correctness of scientific results obtained from those data, especially in cases of high-precision computations (impact monitoring, detection of non-gravitational effects, mission planning, ...). For well-calibrated professional settings, the dominant source of error is usually the astrometric catalog bias; debiasing methods have been developed (Chesley et al. 2010) based on the specific catalog used in the astrometric reduction. However, for astrometric positions coming from less-controlled sources, larger sources of error are often present (timing errors, improper handling of trailed sources, incorrect astrometric solutions, even misidentification of the target in some cases), and a complete but rigorous rejection of certain datapoints may become necessary. We recently developed a rejection method (Micheli et al. 2012) based on the little known Peirce criterion (Peirce 1852), that allows a mathematically founded approach to the rejection of observational data, specifically tailored for Rayleigh-distributed quantities (such as the optical astrometric residuals). We will present the basis of the method, together with its advantages over more common rejection algorithms, such as the ones based on the better known Chauvenet criterion. We will also present updated results on our application of this method to small-sized NEOs, that allows us to detect subtle non-gravitational effects (such as radiation pressure) even on short-arc single-opposition objects. Work funded by the NSF grant AST 0709500.

111.08 Radiation Recoil Effects on the Dynamical Evolution of Asteroids
- Desiree Cotto-Figueroa\textsuperscript{2}, T. S. Statler\textsuperscript{1}, D. C. Richardson\textsuperscript{2}, P. Tanga\textsuperscript{3}
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The rotation rate of asteroids obtained from optical lightcurves has given strong evidence to support the idea that most asteroids are aggregates. Numerical simulations of the dynamical evolution of aggregates have assumed a constant YORP torque that continuously spins up the object past the point where mass shedding and possible re-accumulations of the shedded mass occur. As a result, the YORP effect is a preferred candidate for the formation of binary asteroids. However, from the results found by Statler [2009] we know that this scenario is not realistic (Icarus 202, 501-513). The YORP effect has an extreme sensitivity to the topography of the asteroids and a minor change in the surface of an aggregate can stochastically change the YORP torques. Moreover, Holsapple [2010] showed (in the continuum limit) that if an object is spun up and allowed to deform continuously, the deformation increases the moment of inertia sufficiently, such that the increase in the angular momentum results in a
decreasing spin rate (Icarus 205, 430-442). We self-consistently model the YORP effect on the spin states of dynamically evolving aggregates. The time scales over which mass reconfiguration occur are much shorter than the time scales over which YORP changes the spin states. If the continuous reconfiguration leads to a shape of the aggregate that is nearly symmetric, the YORP torques could become negligibly small or even vanish. This would imply a self-limitation in the evolution of the spin state due to YORP and the objects would not follow the classical YORP cycle. Moreover, subsequent reconfigurations could lead to a random walk in the YORP torques making the evolution of the spin state completely stochastic. This analysis will let us test whether the YORP acceleration is self-limiting and whether the shape changes interrupt the YORP cycle and make the spin evolution stochastic.

111.09 Determination of Multiple Asteroid Orbits With a Genetic-Based Algorithm

- Frederic Vachier1, J. Berthier1, F. Marchis2
  1IMCCE, France, 2SETI Institute.

Over the past decade, discoveries of multiple asteroid systems have played a significant role in our general understanding of small solar system bodies. Direct observations of satellites of asteroids are rare and difficult since they require the use of already over-subscribed facilities such as adaptive optics (AO) on large 8-10 m class telescopes and the Hubble Space Telescope (HST). The scarcity of data and the long temporal baseline of observations (up to 10 years) significantly complicate the determination of the mutual orbits of these systems. We implemented a new approach presented in Vachier et al. (A&A, 2012), for determining the mutual orbits of directly-imaged multiple asteroids using a genetic-based algorithm. This approach was applied to several known binary asteroid systems (22 Kalliope, 3749 Balam, and 50 000 Quaoar) observed with AO systems and HST. From 10 years of observation, we derived an orbital solution for Linus, companion of (22) Kalliope, with an accuracy close to the astrometric limit provided by the AO observations, assuming a purely Keplerian orbit. A search for non-Keplerian orbit confirmed that a J2 ~ 0 is the best-fitting solution. We show that the precession of the nodes could be detected without ambiguity, implying that Kalliope's primary may have an inhomogeneous internal structure. HST astrometric observations of Weywot, companion of the trans-Neptunian object (50 000) Quaoar, were used to derive its mass and its bulk density, which appears to be higher than the density of other TNOs. Finally, we derived a bundle of orbital solutions for (3749) Balam, with equally good fits, from the limited set of astrometric positions. They provide a realistic density between 1.3 and 3.7 g/cm3 for this S-type asteroid. We will present additional mutual orbits determined using our method as they become available. This work has been supported by NASA grant NNX11AD62G

111.10 The Asteroid 2000 ET70

- Alberto Q. Vodniza1, M. R. Pereira1
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The asteroid 2000 ET70 (162421) was discovered by Lincoln Laboratory ETS (LINEAR) in New Mexico on March 8, 2000. Whiteley (2001) classified 2000 ET70 as an X-type object: This asteroid belongs to an ambiguous group that includes objects that are large and dark, metallic. The composition of this asteroid is unknown. The asteroid was at 0.0454430 U.A from the Earth on February 19.85956 (2012) and it will be at approximately 0.1503270 A.U from the Earth on August 21.07061 (2012). The asteroid 2000 ET70 was studied by radar in Arecibo and Goldstone. Shantanu Naidu and Jean-Luc Margot studied this object by Arecibo radar (Feb 13-2012) and they suggest that 2000 ET70 is roughly 1.5 km in diameter and that it has a period of rotation of about 9.5 hours. It has an orbital period of 0.92 years. From our Observatory, located in Pasto-Colombia, we captured several pictures, videos and astrometry data during three days. Our data was published by the Minor Planet Center (MPC) and also appears at the web page of NEODyS. Our observatory’s code at the MPC is “H78”. Pictures of the asteroid were captured with the following equipment: 14” LX200 GPS MEADE (f/10 Schmidt-Cassegrain Telescope) and STL-1001 SBIG camera. Astrometry was carried out, and we calculated the orbital elements. We obtained the following orbital parameters: eccentricity = 0.1243231, semi-major axis = 0.94541495 A.U, orbital inclination = 22.32919 deg, longitude of the ascending node = 45.20913 deg, argument of perihelion = 9.5 years (335.76 days), mean motion = 1.07218658 deg/d, perihelion distance = 0.82787796 A.U, aphelion distance = 1.06295195 A.U. The parameters were calculated based on 71 observations (2012 Mar. 1-7) with mean residual = 0.262 arcseconds.
111.11 Absolute Magnitudes of Pan-STARRS 1 Asteroids

- Peter Veres1, R. Jedicke1, L. Denneau1, A. Fitzsimmons2, B. Bolin1, R. Wainscoat1, PS1 Science Consortium
  1Institute for Astronomy, University of Hawaii at Manoa, 2Queen’s University, United Kingdom.

It is well known that the absolute magnitudes (H) in the MPCORB and ASTORB orbital element catalogs suffer from a systematic offset. Jurić at al. (2002) found ~0.4 mag offset in the SDSS data and detailed light curve studies of WISE asteroids by Pravec et al. (2012) revealed size-dependent offsets of up to 0.5 mag. The offsets are thought to be caused by systematic errors introduced by earlier surveys using different photometric catalogs and filters. The next generation asteroid surveys provide an order of magnitude more asteroids and well-defined and calibrated magnitudes. The Pan-STARRS 1 telescope (PS1) has observed hundreds of thousands asteroid detections to the Minor Planet Center (MPC) and discovered almost 300 NEOs since the beginning of operations in late 2010. We transformed the observed apparent magnitudes of PS1-detected asteroids from the \( g_{P1},r_{P1},i_{P1},y_{P1},z_{P1} \) and \( w_{P1} \)-bands into Johnson photometric system by assuming the mean S and C-type asteroid color (Fitzsimmons 2011 - personal communication, Schlafly et al. 2012, Magnier et al. 2012 - in preparation) and calculated the absolute magnitude (H) in the V-band and its uncertainty (Bowell et al., 1989) for more than 200,000 known asteroids having on average 6.7 detections per object. The H error with respect to the MPCORB catalog revealed a mean offset of -0.49±0.30 mag in good agreement with published values. We will also discuss the statistical and systematical errors in H and slope parameter G.

111.12 Recovery and Evidence for Rapid Rotation of Manned Mission Candidate 2001 QJ142

- David J. Tholen1, M. Micheli1, G. T. Elliott1
  1Univ. of Hawaii.

The near-Earth asteroid 2001 QJ142 falls high on the list of candidates for a manned mission due to the low delta-V needed to reach the target. The object was observed for only 32 days in 2001, leading to a three-sigma ephemeris uncertainty region spanning over 6 deg as of 2012 March 6, when the asteroid reached a peak brightness of V=22.6 during the opposition. We attempted recovery observations on February 16 using the Megaprime instrument on the Canada-France-Hawaii Telescope. Initial examination of the data did not reveal the target. A repeated recovery attempt was performed on February 27 using the Tektronix 2048 CCD camera on the University of Hawaii 2.24-m telescope. This latter attempt was successful, the object being found about 34 arcmin east of the nominal ephemeris position. Multiple 300 sec exposures consistently revealed the asteroid. We reexamined the Megaprime images to determine why the object was not found during the initial recovery attempt. The object was clearly detected in just one of the 140 sec exposures, but could be barely seen in the other two exposures at a signal-to-noise ratio of just 2. Apparently the asteroid has a large lightcurve amplitude and a short rotation period. The 300 sec exposures on February 27 apparently averaged over enough of the lightcurve to produce a fairly uniform brightness, while the 140 sec exposures on February 16 did not. These results suggest a rotation period of about 10 min, making a manned mission problematic, except for regions of the surface near the poles. We are working on integrating sample lightcurves over the known exposure times in an attempt to refine the rotation period. It should be noted that another observational window occurs in late November when the asteroid reaches V=20.9 during its next opposition. This work was supported by NSF.

111.13 Reinvestigation of Low-Signal Small Bodies

- Nathaniel B. Lust1, D. T. Britt1
  1University of Central Florida.

Using a tool kit of newly developed and refined techniques we reinvestigate small bodies from the asteroid lightcurve database. These tools include, improved centering techniques, Bayesian denoising, phase dispersion minimization, and Szego polynomial and wavelet period analysis. Our investigations are twofold. First we reanalyze well defined light curves to compare our results with the standard analysis. These tests not only compare the precision to which the derived results agree, but the methodology and scale of determined confidence regions. Second we investigate low signal bodies looking to improve detection of physical properties such as rotation period, binary detection, and shape inversion. Improved lightcurve data will address a range of issues including (1) Better estimates on binary system mass to improve our understanding of their structure, formation,
density/porosity, and size-spin statistics. (2) Improved spin state data on NEOs that are potential targets for human missions to support mission planning and decision making. (3) Improved spin state data on rapid rotators near the transition zone of the asteroid spin-size distribution and complex axis rotators to facilitate the understanding of the evolution of these scientifically interesting NEOs. We will measure the performance differences of our method with standard analysis for three high signal well sampled lightcurves. The established routines are then used to reinvestigate five low signal sparsely sampled lightcurves establishing better estimates on their physical parameters. These results will guide our further investigation of existing low signal small body lightcurves, and determine the most interesting targets for further investigation.

111.14 Where Did Ceres Accrete - In Situ in the Asteroid Belt, Among the Giant Planets, or in the Primordial Transneptunian Belt?

- William B. McKinnon
  Washington Univ.

Ceres appears to be in rotational hydrostatic equilibrium and its density implies a substantial water ice fraction (20±5% by mass). Thermal evolution arguments strongly favor an icy outer shell as opposed to bound water throughout (Castillo-Rogez et al., Icarus 2001). Such iciness is unusually large for asteroids (or meteorites) as we know them. If Ceres formed in situ, this could be consistent with temporal evolution of the nebular snow-line across the asteroidal zone; icy planetesimals from further out could also contribute, prior to Jupiter formation. In the “grand tack” elaboration of the Nice model, Jupiter and Saturn undergo a two-stage, inward-then-outward, migration (Walsh et al., Nature 2011). Because Jupiter reverses migration direction close in, the primordial asteroid belt is emptied and then repopulated with bodies from both the inner and outer solar system. At Ceres’ position the majority of icy, outer solar system bodies derive from between the giant planets (out to ~8 AU in the initial configuration). This new asteroid belt is predicted to be highly dynamically agitated, however, which may not be consistent with 39Ar/40Ar age constraints from meteorites. In the Nice model proper, KBOs/comets are embedded in large numbers into the jovian Trojan clouds and the outer asteroid belt (>2.6 AU) (Levison et al., Nature 2009). Although the model embedded cometary population does not include large bodies (>180 km diameter), the size-frequency distribution can be extended according to various proposed population indices. Without violating the Trojan population constraint, I find that embedding and retaining large (500-to-1000 km diameter) KBOs in the outer asteroid belt generally cannot be statistically ruled out at the 2σ level (though the original steep differential power-law index of Levison et al., -6.5, is not consistent with an embedded Ceres). Chemical and isotopic measurements (especially D/H) will be important future tests of Ceres’ provenance.

112 Satellites: Irregular, Icy and Io

Monday, 3:30 PM - 6:00 PM, Exhibit Hall

112.01 The Saturnian Satellite Tethys Observed By Cassini-VIMS

- Katrin Stephan,1 R. Jaumann,1 R. Wagner,1 R. N. Clark,2 D. P. Cruikshank,3 C. Dalle Ore,3 G. B. Hansen,4 R. H. Brown,5 B. Giese,1 T. Roatsch,1 D. Matson,6 K. Baines,7 G. Filacchione,8 F. Cappacino,8 S. Rodriguez,9 B. J. Buratti,6 P. D. Nicholson,10 C. Sotin6

1 German Aerospace Center (DLR), Germany, 2 USGS, 3 NASA Ames, 4 Univ. of Washington, 5 Univ. of Arizona, 6 JPL, 7 SSEC, 8 INAF-IASF, Italy, 9 Univ. Paris, France, 10 Cornell Univ.

We present a detailed analysis of the variations in spectral properties across the surface of Saturn’s satellite Tethys using Cassini/VIMS data and their relationships to geological and/or morphological characteristics as seen in the Cassini/ISS images. Despite the spectral dominance of water ice on Tethys’ surface distinct spectral variations could be detected, which are surprisingly very different from what was expected from the visible albedo derived from Voyager and Cassini camera data. The abundance of water ice usually follows the visible surface albedo as seen on many other satellites. Although on Tethys, the weakest water ice signature could be also measured on the trailing hemisphere as known from Dione and Rhea [1-3], the detailed mapping, however, shows a more complex pattern. Two relatively narrow N/S-trending bands characterized by larger ice particle sizes rather than the higher abundance of water ice separate the Saturn-facing and the anti-Saturnian hemisphere of Tethys. So far, larger ice

112.02 Crater Clusters on the Saturnian Satellite Dione
- Roland Wagner1, G. Neukum1, N. Schmedemann1, T. Roatsch1, T. Denk2, C. C. Porco3
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Double craters, crater chains and crater clusters occur on the terrestrial planets, on the Galilean satellites and on satellites of Saturn. Such craters can form by nearly simultaneous impacts of tidally split projectiles, of mutually orbiting bodies, and by material ejected from, and escaping, one satellite and re-impacting on another. The most abundant types of multiple craters found in ISS images from the Saturnian satellites Enceladus, Tethys, Dione and Rhea are double craters and chains. Clusters are less common. In this paper we discuss the morphology and spatial abundance of multiple craters on Dione and examine if age determinations obtained from counting every crater in a cluster as if it was formed by one impactor could significantly affect the derivation of surface ages. To examine such a possible influence, we use the following procedure: (a) within a mapped geologic unit, crater clusters are separately mapped; (b) the crater distribution of all craters outside the clusters is measured; (c) the crater distribution in each cluster is measured; (d) for each cluster, a crater scaling law is used to recalculate the diameter of the unsplit projectile and the crater diameter which would have been formed by this projectile; (e) two crater size distributions are constructed, one with all craters, and one with the craters outside the clusters and the craters created from the unsplit projectiles. This procedure was tested for a cratered plains unit on Enceladus. About 10% of all craters are clustered impacts. There is a slight difference in age between the two distributions but it is still within measurement uncertainties. This procedure is being tested for units on Dione. We anticipate similar results if the percentage of multiple craters is not larger than 10% as on Enceladus.

112.03 Mimas And Enceladus: Formation And Interior Structure From Astrometric Reduction Of Cassini Images
- Radwan Tajeddine1, V. Lainey1, N. Rambaux1, N. J. Cooper2, S. Charnoz3, C. D. Murray2
1IMCCE/UPMC - Observatoire de Paris, France, 2Queen Mary University of London, United Kingdom, 3Université Paris Diderot / CEA, France.

The origin and evolution of the Saturnian satellites is still debated. While the canonical formation model creates many main moons in Saturn’s subnebulae, a new model suggests a possible formation at the outer edge of a past massive ring (Charnoz et al. 2011). Furthermore, many interior structure models were suggested for Enceladus in order to explain the geysers observed in its South polar region. For instance, Nimmo and Pappalardo (2006) suggest the existence of a low density anomaly in the ice crust, and Collins and Goodman (2007) explain these geysers by an internal local "sea" with higher density than the ice crust. It is also noteworthy that in the model of Charnoz et al. (2011), the core of the satellites is not necessarily symmetric, due to the accretion of icy material onto large silicate chunks (> 10 - 100 Km). All these previous models may result in a shift between the center of mass and the center of figure of the satellites. We used the astrometry of Cassini ISS NAC images of Mimas and Enceladus to attempt to quantify such a shift considering, on one hand, the satellite's observed position as the center of figure and, on the other hand, its predicted position from the orbital ephemeris as the center of mass. In studying such a shift, we may add new constraints to the existing models and possibly discriminate between the various interior and formation models of the Saturnian system.

112.04 Enceladus Plumes: A Boiling Liquid Model
- Miki Nakajima1, A. P. Ingersoll1
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Following the discovery of H₂O vapor and particle plumes from the tiger stripes at the south pole of Enceladus (Porco et al., 2006), observational and theoretical studies have been conducted to understand the plume mechanism (e.g., Schmidt et al., 2008; Kieffer et al., 2009; Ingersoll and Pankine, 2010). Although the “Ice Chamber Model”, which assumes that ice sublimation under the stripes causes the plumes, has successfully explained the plume mass flux (e.g., Nimmo et al., 2007; Ingersoll and Pankine, 2010), it cannot explain the high salinity in the plume (Postberg et al., 2009). Ice particles condensing from a vapor are relatively salt free, but ice particles derived from a salty liquid can have high salinity. Therefore we have investigated the “Boiling Liquid Model”, which assumes that liquid H₂O under the stripes causes the plumes. With conservation of mass, momentum and energy, we built a simple atmospheric model that includes controlled boiling and gas-ice wall interaction. We first assumed that the heat radiated to space comes entirely from the heat generated by condensation of the gas onto the ice wall. We varied the width (0.1-1 m) and the height (5-4000 m) of the crack as parameters. We find that the escaping vapor flux can be relatively close to the observed value (250±100 kg/s, Hansen et al., 2006, 2008) but the radiated heat flux is only ~1 GW, which is much less than the observed value (15.8 GW, Howett et al., 2011). Other models (Nimmo et al., 2007; Abramov and Spencer, 2009) also have the same difficulty accounting for the observed value. We then investigated the additional heat radiated by the particles after they come out of the crack. We built a simple model to estimate the size distributions of these condensed ice particles and their radiative properties.

112.05 A Hybrid DSMC/Free-Molecular Model of the Enceladus South Polar Plume
- Seng Keat Yeoh¹, T. A. Chapman¹, D. B. Goldstein¹, P. L. Varghese¹, L. M. Trafton¹
  ¹University of Texas at Austin.

Cassini first detected a gas-particle plume over the south pole of Enceladus in 2005. Since then, the plume has been a very active area of research because unlocking its mystery may help answer many lingering questions and open doors to new possibilities, such as the existence of extra-terrestrial life. Here, we present a hybrid model of the Enceladus gas-particle plume. Our model places eight sources on the surface of Enceladus based on the locations and jet orientations determined by Spitale and Porco (2007). We simulate the expansion of water vapor into vacuum, in the presence of dust particles from each source. The expansion is divided into two regions: the dense, collisional region near the source is simulated using the direct simulation Monte Carlo method, and the rarefied, collisionless region farther out is simulated using a free-molecular model. We also incorporate the effects of a sublimation atmosphere, a sputtered atmosphere and the background E-ring. Our model results are matched with the Cassini in-situ data, especially the Ion and Neutral Mass Spectrometer (INMS) water density data collected during the E2, E3, E5 and E7 flybys and the Ultraviolet Imaging Spectrograph (UVIS) stellar occultation observation made in 2005. Furthermore, we explore the time-variability of the plume by adjusting the individual source strengths to obtain a best curve-fit to the water density data in each flyby. We also analyze the effects of grains on the gas through a parametric study. We attempt to constrain the source conditions and gain insight on the nature of the source via our detailed models.

112.06 Multi-plume Modeling Of Enceladus' Neutral Atmosphere
- Valeriy Tenishev¹, M. R. Combi¹, J. H. Waite², C. Hansen³, M. Rubin¹
  ¹University of Michigan, ²Southwest Research Institute, ³Planetary Science Institute.

In addition to being the major source of neutral gas and dust particles for the Saturnian E-ring and, ultimately, heavy ions for the Saturnian inner magnetosphere, Enceladus exhibits geological activity that made it an object of recent study. As a part of the study its atmosphere has been intensively observed with the INMS and UVIS instruments onboard the Cassini spacecraft. The goal of the presented work is to link both data sets by means of numerical modeling in order to improve understanding of Enceladus’ atmosphere. Located at the origins of the observed dust jets (Spitale & Porco, 2007), gas vents are the major source of the atmosphere. Neglecting Enceladus’ gravity and assuming the vents to be point sources, the state of the atmosphere can be described by the sum of the gas flows injected from eight major independent vents, a uniform source, and the background torus. We then verify the model parameters using a Monte Carlo test particle model that includes gravity. This approach has been implemented in our multi-plume model (Tenishev et al., 2010), where parameters of the gas
sources were obtained by fitting E2 UVIS, and E3 and E5 INMS measurements. In this study we will update our model by assimilating the E7 INMS observation (Dong et al., 2011) as well as the results of occultations obtained by the UVIS instrument on October 24, 2007 (Hansen et al., 2008), and May 18, 2010 (Hansen et al., 2011). Although the model necessarily gives a time-averaged picture of the relative source rates of the individual plumes over the several flybys, the detailed comparison of the model fit with data from each flyby does provide clues to the time variation of individual plumes from flyby to flyby. Acknowledgements This work was supported by grant NNX12AG83G from Cassini Data Analysis program.

112.07 The Dust-pickup Alfvén Wing at Enceladus Identified by the Cassini Field and Plasma Instruments

- Ying-Dong Jia1, K. K. Khurana1, C. T. Russell1, N. Krupp2, J. S. Leisner2, A. M. Persoon3, M. K. Dougherty4
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The corotating saturnian magnetosphere overtakes Enceladus at 26.4 km/s, generating plasma and field perturbations along its orbit. At the end of 2011, Cassini on flyby pass E15 examined the particle and field distribution 6 Enceladus radii downstream of the moon. During this pass, the total electron density, electron counts in various energy channels, and magnetic field data unambiguously identify a long, thin and displaced absorption wake. We find that the low energy electrons are still depleted at this distance, and that only electrons with energy higher than 100 keV are refilled. The location of this absorption wake is shifted transversely by one Enceladus radius (RE) outward from the Enceladus orbit. In addition, perturbations of the magnetic field are seen at a different location, which is several RE toward Saturn. Such a unique structure is likely to reveal the Alfvén wing structure, which is different from the Alfvén wing at Io.

112.08 Statistical Study On The Perturbations In The Wake Of Enceladus: Implications On Flow Convection

- Hanying Wei1, J. S. Leisner2, Y. Jia3, C. T. Russell1, M. K. Dougherty3
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Due to the strong mass loading from Enceladus’ plume, the magnetospheric plasma flow slows near the mass-loading center and the initially southward pointing field lines drape around it. On the downstream side, the slow flow and bent field lines persist until the plasma returns to the corotation speed. We look for the bending of field lines and magnetic fluctuations due to the plume-magnetosphere interaction, by analyzing the magnetic field data during Enceladus flybys and also during the crossings of the orbit of the moon far downstream. The location and width of the wake are studied statistically with eight-years of Cassini observations. This study lets us determine how far the wake signature extends, how it varies with downstream distance, and how much the wake moved inward or outward of the Enceladus orbital distance. It can also allow us to understand Enceladus’ effects on the global convection patterns along its orbit, such as causing the wake to bend inward of the moon’s orbital distance, and generating a radial as well as azimuthal flow perturbation.

112.09 Modeling The Enceladus Spectrum As Measured By Cassini-VIMS With Complex Layered Water Ice Models

- Gary B. Hansen1
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We have been working on layered water ice models that fit the measured spectra of Enceladus by the Cassini Visual and Infrared Mapping Spectrometer (VIMS). Our original inspection using two observations (equatorial and South Pole) showed that good fits could be made using fractional monolayers of 2-μm frost over 20 μm for the polar ice and about 1 monolayer of 1-μm frost over 7 μm for the equatorial ice. We then ran ~200 general models that could be used for any analysis. In fitting these two observations, we found that The spectrum short of 3 μm was fit better using a thick layer of sub-μm particles, but that the longer wavelengths were fit best with thinner layers of larger particles. It appears that very good fits may be had with two layers over a micron-sized sub-layer (with the coarser grained layer over the finer grained layer). We are now implementing this model and will present the two-layer fits. This layering is undoubtedly due to Enceladus orbit in the E-ring of micron sized water ice.
particles whose source is the geysers on Enceladus' south pole. The multiple layering could be the signature of a process where the particle size in the E-ring changes over time, or perhaps a mixture of incoming particles is sorted over time with the largest sizes on top. Of interest also is the variation of layers over Enceladus' surface that should be consistent with E-ring and geyser exposure.

112.10 Photometric Properties of Enceladus' South Polar Terrain

- Andrew Annex¹, A. J. Verbiscer¹, P. Helfenstein²

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Cassini images reveal in exquisite detail the complex and varied terrains within the geologically active south pole of Enceladus. The region is dominated by four parallel rifts or sulci, informally known as tiger stripes, from which plumes comprised primarily of water vapor erupt [1,2]. The rich data set of Cassini images acquired at high spatial resolution (< 0.5 km/pixel) and a variety of viewing and illumination geometries enables the quantitative analysis of surface scattering properties through disk-resolved photometry. Here we investigate the photometric properties of individual terrain units [3] through fits of the Hapke photometric model [4] to data acquired in the clear (CL1 CL2), UV3, GRN, and IR3 filters, centered at 0.61, 0.34, 0.57, and 0.93 μm, respectively. Terrain units include the tiger stripe smooth and platy planks formations, tiger stripe medial dorsum structures, relict tiger stripe structures, south pole funicular (ropy) plains, south pole lateral fold-and-wedge formations, and the south pole reticulated plains. Despite the constant, ubiquitous infall of plume particles onto the surface, differences in scattering properties, texture, and albedo among terrain units can be discerned. Work supported by NASA's Cassini Data Analysis Program. [1] Porco et al. 2006 Science 311, 1393-1401. [2] Hansen et al. 2008 Nature 456, 477-479. [3] Spencer et al. 2009 in Saturn from Cassini-Huygens (M. K. Dougherty et al. Eds.) 683-724. [4] Hapke 2002 Icarus 157, 523-534.

112.11 Relaxed Craters Across Enceladus Signal Widespread High Heat Flows

- Kelsi Singer¹, M. T. Bland¹, W. B. McKinnon², P. M. Schenk²

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We present a comprehensive map of viscously relaxed craters on Enceladus, which when combined with finite element modeling, indicates unexpectedly high heat flows (similar to those observed by CIRS at the south pole) also affected cratered terrains. Apparent crater depths were measured in the regions where accurate topography from stereo-controlled photoclinometry could be created. Measurements extend over 18% of Enceladus' surface (52% of the visible cratered terrains, limited due to deep shadows in many craters). The craters show a range of relaxation states, but modeling to match the observed degrees of relaxation requires high heat flows in all cases, in excess of 150 mW m-2 over 2 Ga (assuming an insulating surface layer yields an effective surface temperature of 120 K). This implies even higher heat fluxes for shorter heat pulses, given orbital mechanics constraints. The predicted deposition rates of particles from the current south polar jets cannot explain the magnitude of crater shallowing observed, thus relaxation is presumed to be the main cause, and morphologies consistent with viscous relaxation are observed. The current estimate of power emanating from South Polar Terrain is 15.8 GW, and is mainly concentrated over small areas of the tiger stripes themselves (Howett et al., 2011, JGR, 116, E03003). However, if averaged over the entire south polar terrain (area south of 55°), this power output would yield a heat flow of 220 mW m-2. Thus, it is plausible that more distributed heat flux could have relaxed the craters in the mid-latitude and northern terrains. This is also consistent with other large, highly tectonized regions present at equatorial and mid-latitudes, which have lead to inferences about previous episodes of high heat flow on Enceladus.

112.12 Infrared Spectroscopic Characterization of the Low-Albedo Materials on Iapetus

- Cristina M. Dalle Ore¹, D. P. Cruikshank², R. N. Clark³


Iapetus, one of the large satellites of Saturn, has been studied over the centuries for its trademark brightness contrast, light on one side and dark on the opposite. On the basis of multicolor images from the Cassini imaging system, Denk et al. (2010, Science 327, 435) have suggested that the dark material is a combination of native and
**exogenous** materials with distinct histories. We present a Cassini VIMS analysis of parts of the Cassini Regio, the darkest region on the leading hemisphere of Iapetus, focusing on the hydrocarbon signature with a view to detect and investigate differences in the material(s). We find variations in the hydrocarbon bands with geographic location, one type predominantly located on the leading hemisphere. A comparison with the equivalent spectral features on Phoebe and Hyperion reveals a predictable resemblance between the leading hemisphere material and Phoebe and an unexpected likeness between Hyperion’s darkest material and Iapetus’ trailing hemisphere surface. The slope in the visible part of the spectrum, from which Denk’s analysis is derived, is strongly affected by a rise in the continuum (~0.35 - 0.65 μm) attributed to Rayleigh scattering from nano-size particles (Clark et al. 2012, Icarus 218, 831). The continuum rise varies in strength with albedo and H2O ice content, and when it is properly accounted for, the overall slope in all the identified spectral units is the same over the interval 0.35 - 2.3 μm, independent of albedo or ice abundance. The interpretation of current and previous results offers two different scenarios illustrated by the presence of one vs. two dark materials distributed over Iapetus’ surface. The appearance and relative strengths of the aromatic and aliphatic absorption bands make this spectral signature unique, enabling the comparison among the satellites. The authors acknowledge support from Cassini Science Team funding and NASA grant NNX11AN90G.

### 112.13 Spitzer/IRAC Photometry Of The Four Largest Uranian Satellites
- **Richard Cartwright**, J. Emery, A. Rivkin, D. Trilling


The surfaces of the four largest Uranian satellites are dominated by water ice and a spectrally neutral constituent that is likely carbonaceous in composition. CO2 ice has been detected on Ariel, Umbriel, and Titania, with no detection on the furthest regular Uranian satellite, Oberon (Grundy et al., 2003, 2006). Whether CO2 ice is primordial or is actively produced in the Uranian system is unclear; however, it seems unlikely that primordial CO2 ice would remain exposed on an icy satellite surface over the age of the Solar System. One possible mechanism for producing CO2 ice is bombardment of water ice and carbonaceous material by charged particles caught in Uranus’ magnetic field. Unlike the other large Uranian satellites, Oberon spends part of its orbit outside the confines of Uranus’ magnetic field. Unlike the other large Uranian satellites, Oberon spends part of its orbit outside the confines of Uranus’ magnetic field, which might help explain why CO2 ice has yet to be detected on Oberon. We are using photometric data gathered by the Infrared Array Camera (IRAC), onboard the Spitzer Space Telescope (SST), in order to search for the signature of CO2 ice on Oberon, and confirm its presence on Ariel, Umbriel, and Titania at longer wavelengths than previous studies. IRAC collects data in four different channels, which are centered roughly at 3.6, 4.5, 5.8, and 8.0 μm. Additionally, we are gathering spectroscopic data using SpeX on IRTF, at similar longitudes to the IRAC observations, in order to characterize the distribution of CO2 ice on these icy satellites over a wide range of near-infrared wavelengths. Our preliminary photometry results for Oberon indicate that there is a steep reduction in reflected solar flux from channel 1 to channel 2, suggesting that surface materials are absorbing photons at wavelengths within the bandpass of channel 2. We will present the results of our photometric analysis of the four largest Uranian moons.

### 112.14 A New Exploration Of Miranda’s Dynamical History
- **Benoit Noyelles**, E. Verheylewegen, A. Lemaitre

1. University of Namur, Belgium.

We consider the N-body problem of Uranus with its five main satellites Miranda, Ariel, Umbriel, Titania and Oberon. Previous studies have already treated the problem and explained in details the geophysical observations of the surface structure by the modifications on orbital elements of the satellites. These modifications are consequences of the passage through a mean-motion resonance in the past history of the system. The main responsible is the high inclination of Miranda (4.338°), probably due to a mean-motion resonance 3:1 with Umbriel. We re-analyse the problem with new computing tools and improve some previous results by a new global visualization with chaos and orbital scales maps. This new type of representations allows us to detect numerous secondary resonance zones confirmed by frequency analysis. We already know the important role of the secondary resonances in the problem: they cause the escape from the primary resonance and explain the high value of the current inclination of Miranda. We highlight the frequencies of the secondary resonance arguments and clearly identify the associated libration. These numerical results are validated by an analytical model allowing...
us to approximate the libration arguments in the primary resonance zones. A commensurability between the 
libration period and the circulation period of the following primary resonance explains the presence of a secondary 
resonance zone.

112.15 Modelling The Thermal Emission From Airless Planetary Surfaces And Sub-surfaces
- Cedric Leyrat\(^1\), A. Le Gall\(^2\), A. Stolzenbach\(^3\), E. Lellouch\(^1\)

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Thermal emission from airless planetary bodies hold important clues on the thermo-physical and compositional 
characteristics of their surfaces. At short wavelengths, in the mid-infrared domain, thermal emission arises from 
the first layers of the regolith (a few microns). In contrast, radiometric measurements obtained at larger 
wavelengths can probe deeper below the surface as the material becomes more “transparent”. At such 
wavelengths thermal emission probes several tens of cm up to a few meters below the surface, depending on the 
absorbing properties of the body’s regolith. The radiometric data obtained by spacecraft can be used to constrain 
the electrical and thermal properties of surface bodies, thus providing clues on their physical state (roughness, 
porosity) and composition (dielectric constant). This will help identifying the geological endogenic or exogenic 
processes that have affected these bodies. Both the Cassini (NASA/ESA/ASI) and Rosetta (ESA) spacecrafts have 
onboard a radiometer operating at relatively large wavelengths, respectively in the microwave and sub-millimetric 
domains. At such wavelengths, these instruments sense the thermal emission not only from the surface but also 
from a section of the sub-surface of the targeted bodies. As a consequence, the interpretation of radiometric data 
collected over the airless icy satellites of Saturn by Cassini and over the comet 67P/Churyumov-Gerasimenko by 
the Rosetta orbiter requires a good knowledge of the temperature profile below the surface, down to several 
meters. We have developed a new thermal model of surfaces that takes into account for conductive heat 
transport, local variations of the insolation on both diurnal and seasonal timescales, multiple sources of heating, 
and geometry computations based on SPICE/NAIF kernels. This new thermal model could be used to interpret 
Cassini radar/radiometer data recorded over some of Saturn’s icy satellites and Miro/Rosetta future 
measurements of the thermal emission of the comet 67P/Churyumov-Gerasimenko.

112.16 Planet Mass Dependence Of Rates And Source Region Of Temporary Capture Of Planetesimals By A 
Planet
- Ryo Suetsugu\(^1\), K. Ohtsuki\(^1\)

\(^1\)Department of Earth & Planetary Sciences, Kobe University, Japan.

When planetesimals encounter with a planet, in some cases they can be captured by the planet's gravity and orbit 
about the planet for an extended period of time, before they escape from the vicinity of the planet. This 
phenomenon is called temporary capture, and may have played an important role in the origin and dynamical 
evolution of small bodies in the Solar System. Recently, we investigated temporary capture of planetesimals 
initially on eccentric orbits, and found that temporary capture orbits can be classified into four types (Suetsugu et 
al. 2011). Their orbital size and direction of revolution around the planet change depending on planetesimals’ 
initial eccentricity and energy. We obtained rates of temporary capture of planetesimals and found that the rate of 
long capture increases with increasing eccentricity at low and high eccentricity but in intermediate values of 
eccentricity decreases with increasing eccentricity. In the above study, we performed three-body orbital 
integrations under Hill’s approximations, where the masses of the planet and planetesimals are assumed to be 
much smaller than the solar mass. In this case, the effect of the curvature of their guiding-center orbits is 
neglected. This assumption is valid for the case of a low mass planet, but the effect of the curvature may be 
important for temporary capture by a high mass planet, like Jupiter. In the present work, we use a simple three-
body system that consists of the Sun, a planet, and a test particle, and perform global orbital integration to 
examine temporary capture by a high mass planet. We will present the rates of temporary capture obtained by our 
global calculation, and also discuss the effect of the curvature on source region of temporary capture.

112.17 Exploring Io’s Atmosphere Chemistry With APEX And ALMA (sub)millimeter Spectroscopy
The Galilean volcanic moon Io holds a tenuous atmosphere (1-10 nbar pressure), originating primarily from the eruption of volcanic plumes, and that feeds the plasma torus in orbit around Jupiter. It is the only known SO2-dominated atmosphere, where only a handful of other species (SO, NaCl, S2) have been detected. Detailed modeling of volcanic plumes thermochemistry (e.g., Fegley and Zolotov, 2000; Schaefer and Fegley, 2004) shows that other trace species may be present. Measuring their abundances would provide constraints on their lifetime in the atmosphere and on the Ionian volcanic regimes. We present here the results of a chemical search project performed on the Atacama Pathfinder EXperiment antenna (APEX) in 2010, targeting several rotational (sub)millimeter lines of expected yet undetected volcanic species. The obtained data allows us to set an upper limit on SiO abundance, that, while it cannot confirm the existence of silicate-based volcanism, constrains the range of temperatures in volcanic conduits. We also present an upper limit on KCl abundance of ~1e-4, consistent with the Na/K atomic ratio observed in Io’s corona. Finally, the combination of several observed 34SO2 lines was used to obtain the first estimation of the 34/32 sulfur isotopic ratio in gas phase, suggesting a high value - about 10%, compared to ~5% on Earth - that needs confirmation. A similar chemical search project has been accepted for the first observation cycle on the Atacama Large Millimeter Array (ALMA), that is expected to offer a signal to noise increased by a factor greater than 10 with respect to APEX observations, as well as moderate spatial resolution (0.5") allowing to localize SO2 and SO emission on Io’s disk. If available at the time of the meeting, ALMA observations will be presented.

We present the SUDA (Surface Dust Analyzer) instrument that will provide detailed answers to the main goals of ESA’s JUICE mission about habitability, surface composition and exchange processes with the interior. The surfaces of the icy moons of Jupiter can be analyzed to unprecedented mass resolution and sensitivity down to the ppm level using modern dust analyzer instruments. The measurement method is based on analyzing the chemical composition of dust particles released from the surfaces of the moons. These dust particles populate the exosphere with densities sufficient for obtaining a valuable compositional picture even from a few flybys. The SUDA instrument is well suited for the detection of water ice particles with traces of the expected hydrated minerals such as sodium carbonates and magnesium sulphates, hydrated sodium chloride, and of organic materials. The value of a dust analyzer is well demonstrated by Cassini’s Cosmic Dust Analyzer that has analyzed Enceladus’s plume particles and E ring grains. SUDA is a time-of-flight, reflectron-type impact mass spectrometer, optimized for high mass resolution. The small size (268×250×171 mm3), low mass (< 4 kg) and large sensitive area (220 cm2) makes the instrument well suited for the challenging demands of the JUICE mission. A full-size prototype was used to demonstrate the performance through calibration experiments with a variety of cosmochemically relevant dust analogues. The effective mass resolution of m/Δm of 150- 200 is achieved for mass range of interest m = 1-150.

Asteroids 1 Ceres, 2 Pallas, and 4 Vesta and Galilean satellites Ganymede, Callisto, and Europa were observed in February and March, 2012 near 1 cm with the Green Bank Telescope in order to look for and characterize any deviations from a blackbody curve. The Caltech Continuum Backend instrument on that telescope provides uniquely useful information by simultaneously measuring 4 continuum bands between 7 and 11 mm, thus enabling...
the direct measurement of continuum slope. Ceres and Vesta are both successfully detected and show non-zero slopes in brightness temperature. Vesta's 1 cm continuum also shows some change with longitude that may be related to the previously detected light-curve at 3 mm (Müller and Barnes 2007). Observing the icy Galilean satellites is complicated by contamination from Jupiter's presence in the sidelobes of a single dish telescope. A technique for detecting and removing this contamination is applied. Overall, brightness temperature numbers are in agreement with previous observations at other wavelengths, but non-zero slopes in brightness temperature are also detected which require further analysis.

112.20 Shake, Rupture And Flow: Hydraulic Constraints On The Formation Of Europa's Chaos
- Britney E. Schmidt¹, B. T. Gooch¹, D. D. Blankenship¹, K. M. Soderlund¹
  ¹UT Austin, Institute for Geophysics.

Europa’s chaos terrains may have formed above shallow water lenses formed by melting of the upper ice shell with ascending thermo-compositional plumes. A key factor in the creation of chaos terrain may be dramatic disruption and collapse of the ice lid above the forming melt lens along with potentially violent mixing upon its rupture; this is analogous to the collapse of terrestrial ice shelves in which massive ice bodies disintegrate in a few days. At Thera Macula, there is evidence for modification by water immediately external to the scarp that bounds the collapsed region. Since water runs either subaerially down hill or from high pressure to low when below or within ice, the swollen appearance of bands entering Thera Macula, which are uphill in terms of hydraulic and topographic gradients, raises the possibility that this steep scarp represents the place where the lens initially broke. As the ice lid ruptures, the overpressure within the lens may create sufficient pressure within the fracture to drive water through it, allowing water to escape into and modify surrounding terrain. Similar effects are seen when aquifers or subglacial water sources are tapped: water flows up the pipe until the pressure in the water body is relieved and the hydraulic “pressure head” in the pipe is lowered. We have modeled the hydraulic potential associated with a rupturing lens in order to investigate the range of parameters for overpressure, fracture width, and lid thickness that could produce such modification as is observed at Thera Macula. These place important constraints on the pressure within the lens and the energetics of a collapse event. These estimates may explain how ice masses within chaos are initially disrupted and provide a means for quantifying the vigor of surface-subsurface mixing that could be critical to Europa’s habitability.

112.21 Improving Tidal Measurements about Europa Using the Properties of Unstable Periodic Orbits
- Dylan Boone¹, D. J. Scheeres¹
  ¹University of Colorado at Boulder.

The NASA Jupiter Europa Orbiter mission requires a circular, near-polar orbit to measure Europa’s Love numbers, geophysical coefficients which give insight into whether a liquid ocean exists. This type of orbit about planetary satellites is known to be unstable. The effects of Jupiter’s tidal gravity are seen in changes in Europa's gravity field and surface deformation, which are sensed through doppler tracking over time and altimetry measurements respectively. These two measurement types separately determine the h and k Love numbers, a combination of which bounds how thick the ice shell of Europa is and whether liquid water is present. This work shows how the properties of an unstable periodic orbit about Europa generate preferred measurement directions in the orbit determination process for estimating science parameters. We generate an error covariance over seven days for the orbiter state and science parameters and then disperse the orbit initial conditions in a Monte Carlo simulation according to this covariance. The dispersed orbits are shown to have a bias toward longer lifetimes and we discuss this as an effect of the stable and unstable manifolds of the periodic orbit. The stable manifold represents contraction forward in time and the unstable manifold represents expansion forward in time. However, using an epoch formulation of a square-root information filter, measurements aligned with the unstable manifold mapped back in time add more information to the orbit determination process than measurements aligned with the stable manifold. This corresponds to a contraction in the uncertainty of the estimate of the desired parameters, including the Love numbers. Low altitude, near-polar periodic orbits with these characteristics are discussed along with the estimation results for the Love numbers, orbiter state, and orbit lifetime. These results are applicable to other measurements and planetary satellites since the mathematical model is the same.
Counter-Orbitals: Another Class of Co-Orbitals

Anthony R. Dobrovolskis
NASA Ames Research Center.

Co-orbital companions share the same orbital period and semi-major axis about a primary (star or planet). Heretofore there have been three recognized classes of co-orbitals: (1) Trojans librate in tadpole-shaped orbits about the equilateral Lagrange points L4 and L5, 60 degrees ahead of or behind the secondary (planet or satellite). (2) Horse-shoe companions librate about both L4 and L5, as well as the L3 Lagrange point diametrically opposite the secondary. (3) “Quasi-satellites” appear to be in distant retrograde orbits about the secondary, but actually are in prograde orbits about the primary with the same period as the secondary. Quasi-satellite orbits lie outside the secondary’s Hill sphere, and enclose both L1 and L2, and sometimes L4 and L5 as well. In addition, some asteroids and comets are found in hybrid orbits which alternate among the above three classes, or combine some of their features. New research now reveals a fourth class of co-orbitals, which does not appear to be known before, and may be called “counter-orbitals”. Imagine reversing the inertial velocity of a distant quasi-satellite. Then it remains in orbit about the primary, with the same period, semi-major axis, eccentricity, and orbital plane, although retrograde. But instead of remaining relatively close to the secondary, now it passes the secondary twice per orbit, near periapsis and apoapsis. The attractive impulses at these conjunctions tend to stabilize this arrangement. Numerical simulations of the general three-body problem verify that counter-orbitals can persist for over 10,000 orbits, with small vertical excursions, but a wide range of eccentricities and mass ratios. For example, Charon can maintain counter-orbital companions at least up to 3 percent of its own mass, in eccentric orbits extending from about 7050 km out to 41700 km from the center of Pluto. This may present a collision hazard to the New Horizons spacecraft.

Extrasolar Planets and Systems

Monday, 3:30 PM - 6:00 PM, Exhibit Hall

Characterising the Kepler Survey Completeness: First Full Focal Plane Results

Jessie Christiansen, Kepler Science Office, Kepler Science Operations Center
NASA Ames Research Center/SETI Institute.

The primary goal of the Kepler mission is to determine the frequency of Earth-size planets in the habitable zones of solar-like stars. The mission has published a growing catalogue of planet candidates, but there are two key attributes of the catalogue that we need to understand before we can determine the underlying planet population - the rate of false negatives (completeness) and the rate of false positives (reliability). I will discuss our efforts towards determining the completeness of the survey, in particular characterising the behaviour of the automated transit detection software. I will present results from the first characterisation of the software across the full focal plane. Kepler was selected as the 10th mission of the Discovery Program. Funding for this mission is provided by NASA’s Science Mission Directorate.

A Framework for Characterizing the Performance of the Kepler Exoplanet Search and Data Products

Jon Michael Jenkins, J. Christiansen, C. Burke, S. McCauliff, J. Van Cleve, Kepler SO, Kepler SOC
SETI Institute, Orbital Sciences Corp., USRA.

Since launch in March 2009, the Kepler spacecraft has delivered >8.5 billion brightness measurements over a set of ~200,000 stars at a 29.4 minute cadence of phenomenal quality and completeness. Over 2,300 planet candidates and ~2,000 eclipsing binaries have been identified to date and a great wealth of astrophysics has been exposed to plain view that was previously unavailable to the community. The detailed behavior of the instrument and the stunning variety of the intrinsic stellar variations exhibited in the data have caused major rework and development of new algorithms for extracting the photometric time series from the data, correcting instrumental effects, searching for planets and constructing diagnostic metrics for the candidate planetary signatures. It has also proven to be a very intensive process to manually review the science pipeline output to generate the planet candidate catalogs. The effort to characterize the fidelity of the light curves and the reliability and completeness of the
exoplanet candidates identified in the data requires a broad spectrum of activities. Some of these activities are in early stages of development, including a machine learning approach to identifying Kepler Objects of Interest automatically from an analysis of diagnostics and information from the Kepler data themselves. Another example is the capability to inject transit signatures and stellar variability signatures into the data to learn to what degree these signatures are preserved in the output light curves. We describe a framework for laying out the activities required to accomplish these goals to ensure that the various tasks completely cover the problem space. Kepler was selected as the 10th mission of the Discovery Program. Funding for this mission is provided by NASA’s Science Mission Directorate.

113.03 $\chi^2$ Discriminators for Transiting Planet Detection in Kepler Data
- Shawn Seader$^1$, P. Tenenbaum$^1$, J. Jenkins$^1$
  $^1$SETI.

The Kepler Mission continuously observes a host of target stars in a 115 square-degree field of view to discover Earth-like planets transiting Sun-like stars through analysis of photometric data. The Kepler Science Operations Center at NASA Ames Research Center processes the data with the Science Processing Pipeline, which is composed of several modules including the Transiting Planet Search (TPS). To search for transit signatures, TPS employs a bank of wavelet-based matched filters that form a grid on a three dimensional parameter space of transit duration, period, and epoch. Owing to non-stationary and non-Gaussian noise, uncorrected systematics, and poorly mitigated noise events of either astrophysical or non-astrophysical nature, large spurious Threshold Crossing Events (TCE's) can be produced by the matched filtering performed in TPS. These false alarms waste resources as they propagate through the remainder of the Pipeline, and so a method to discriminate against them is crucial in maintaining the desired sensitivity to true events. Here we describe four separate $\chi^2$ tests which represent a novel application of the formalism developed by Allen for false alarm mitigation in searches for gravitational waves. The basic idea behind these vetoes is to break up the matched filter output into several contributions and compare each contribution with what is expected under the assumption that a true signal is present in the data. Vetoes can then be constructed which, under certain assumptions, have been shown to be $\chi^2$ distributed with expectation values that are independent of whether or not a true signal is present, thereby making them useful discriminators. The four different ways of breaking up the output and forming $\chi^2$ vetoes illustrated here, allow discrimination against different classes of false alarms. Kepler was selected as the 10th mission of the Discovery Program. Funding for this mission is provided by NASA’s Science Mission Directorate.

113.04 Confirmation and Mass Measurements for Exoplanets found by Gravitational Microlensing
- David P. Bennett$^1$, MOA Collaboration, OGLE Collaboration, MicroFUN Collaboration, PLANET Collaboration
  $^1$Univ. of Notre Dame.

We present the results of HST and ground-based adaptive optics observations of several microlensing events with signals of exoplanets. These observations are able to detect the exoplanet host star and measure its motion away from the source. In some cases, this measurement confirms the relative proper motion predicted by the modeling of the planetary signal in the light curve, thereby indirectly confirming the planet discovery. When combined with the microlensing light curve data, these observations also yield precise masses for the planets and their host stars.

113.05 Precision Near-Infrared Radial Velocities
- Peter Plavchan$^1$, NIRRVs
  $^1$Caltech.

We have built a single gas absorption cell for precision spectroscopic radial velocity measurements in the near-infrared. We are currently carrying out a survey with the CSHELL spectrograph at the NASA InfraRed Telescope Facility to detect exoplanets around red, low mass, and young stars. We discuss the current status of our survey, with the aim of ~20 m/s long-term photon-noise limited radial velocity precision at 2.3 microns. We present the design of a near-infrared fiber scrambler with first light in May 2012 with CSHELL at IRTF. The fiber scrambler makes use of non-circular core fibers to stabilize the illumination of the slit and echelle grating against changes in
seeing, focus, guiding and other sources of systematic radial velocity noise, complementing the wavelength
calibration of a gas cell.

113.06 Efficient Geometric Probabilities of Multi-transiting Systems, Circumbinary Planets, and Exoplanet Mutual Events
- Joshua Brakensiek\(^1\), D. Ragozzine\(^2\)
  \(^1\)Homeschool, \(^2\)University of Florida.

The transit method for discovering extra-solar planets relies on detecting regular diminutions of light from stars
due to the shadows of planets passing in between the star and the observer. NASA's Kepler Mission has
successfully discovered thousands of exoplanet candidates using this technique, including hundreds of stars with
multiple transiting planets. In order to estimate the frequency of these valuable systems, our research concerns
the efficient calculation of geometric probabilities for detecting multiple transiting extrasolar planets around the
same parent star. In order to improve on previous studies that used numerical methods (e.g., Ragozzine & Holman
2010, Tremaine & Dong 2011), we have constructed an efficient, analytical algorithm which, given a collection of
conjectured exoplanets orbiting a star, computes the probability that any particular group of exoplanets are
transiting. The algorithm applies theorems of elementary differential geometry to compute the areas bounded by
circular curves on the surface of a sphere (see Ragozzine & Holman 2010). The implemented algorithm is more
accurate and orders of magnitude faster than previous algorithms, based on comparison with Monte Carlo
simulations. Expanding this work, we have also developed semi-analytical methods for determining the frequency
of exoplanet mutual events, i.e., the geometric probability two planets will transit each other (Planet-Planet
Occultation) and the probability that this transit occurs simultaneously as they transit their star (Overlapping
Double Transits; see Ragozzine & Holman 2010). The latter algorithm can also be applied to calculating the
probability of observing transiting circumbinary planets (Doyle et al. 2011, Welsh et al. 2012). All of these
algorithms have been coded in C and will be made publicly available. We will present and advertise these codes
and illustrate their value for studying exoplanetary systems.

113.07 Self-consistent Model Of Debris Discs Coupling Dynamics And Collisions
- Quentin Kral\(^1\), P. Thebault\(^1\), S. Charnoz\(^2\)
  \(^1\)LESIA, France, \(^2\)CEA/Paris 7, France.

I will present the first attempt at developing a fully self-consistent code coupling dynamics and collisions to study
debris discs. So far, these two crucial mechanisms were studied separately, with N-body and statistical codes
respectively, because of stringent computational constraints. In particular, incorporating collisional effects
(especially destructive collisions) into an N-body scheme was deemed an impossible task because of the
exponential increase of particles it would imply. We present here an alternative approach, based on the LIDT code
developed by Charnoz et al.(2012) for protoplanetary discs, and strongly upgraded to account for the complexity of
debris disc physics (high velocity collisions, radiation-pressure affected orbits, etc.). In this 3D Lagrangian-Eulerian
code, grains of given size at a given location in a disc are grouped into "super-particles" (SPs), whose orbits are
tracked with an N-body code and whose mutual collisions are treated using a particle-in-a-box scheme. To keep
the number of super-particles from diverging, a reassignment routine reallocates redundant SPs to regions where
they are needed. Our code is under development but already working for simple astrophysical cases. I will present
some preliminary results for simple disc configurations, as well as some perspectives for the close-future.

113.08 Planet Formation in the Habitable Zone of a Triple Stellar System
- Othon Cabo Winter\(^1\), R. Domingos\(^1\), A. Izidoro\(^1\)
  \(^1\)UNESP, Brazil.

In the present work we evaluate some possible conditions needed in order to form rocky planets in the habitable
zone around a binary star disturbed by a third companion star. First, we identify the location of the habitable zone
and verify if it is inside a stable region of massless particles. Then, for the cases were that happens, we numerically
simulate the whole system taking into account a distribution of planetesimals and embryos that interact with each
other producing larger bodies. This study is made considering a range of different values for the separation of the
binary (d) and also for the semi-major axis \(a_3\) and eccentricity \(e_3\) of the perturbing star. The results are presented in terms of the final mass and location of the remaining bodies as a function of \(d, a_3, e_3\). We also make a discussion on the conditions needed for the formation of terrestrial planets in the habitable zone for this kind of triple star systems. Acknowledgment: This work is being funded by CNPq and FAPESP.

**113.09 The Stability of the Kepler 30 System and the Survivability of Kepler 30 Exomoons**

- R. Mitch Verboncoeur\(^1\), C. Fuse\(^1\)
- \(^1\)Rollins College.

The Kepler mission has revealed characteristics about a variety of planetary systems. Kepler 30, a system of three confirmed planets, is one such system. The close proximity of the three planets coupled with the large masses of Kepler 30c and Kepler 30d provide us with an opportunity to investigate the orbital stability of the system as well as the survivability and evolution of exomoons. An N-body planetary code was first used to test the viability of the mass estimates provided by Fabrycky et al. (2012) in the initial discovery paper. The masses that yielded the most stable planetary configurations were then used as the conditions for a set of simulations analyzing satellite survivability around Kepler 30d. Stability and exomoon simulations were run for 500,000 years. The initial conditions for the satellite survivability simulations included 100 proto-moons. We find that the Kepler 30 system is most stable when the planets are about 50 percent of the maximum mass estimated by Fabrycky et al. (2012). Regardless of the initial masses of the bodies in our simulations, Kepler 30b was consistently unstable over long durations. We also find that one or two satellites typically survive around Kepler 30d after 500,000 years. We discuss the possible habitability of these satellites.

**113.10 Chemical Timescales in the Atmospheres of Highly Eccentric Exoplanets**

- Channon Visscher\(^1\)
- \(^1\)Southwest Research Institute.

Close-in exoplanets with highly eccentric orbits are subject to large variations in incoming stellar flux between periapse and apoapse. These variations may lead to large swings in atmospheric temperature, which in turn may cause changes in the chemistry of the atmosphere from relatively higher CO abundances at periapse to relatively higher CH4 abundances at apoapse. Here we examine chemical timescales for CO<->CH4 interconversion compared to orbital timescales and vertical mixing timescales for the highly eccentric exoplanets HAT-P-2b and CoRoT-10b. As exoplanet atmospheres cool, the chemical timescales for CO<->CH4 tend to exceed orbital and/or vertical mixing timescales, leading to quenching. The relative roles of orbit-induced thermal quenching and vertical quenching depend upon mixing timescales relative to orbital timescales. For both HAT-P-2b and CoRoT-10b, vertical quenching will determine disequilibrium CO<->CH4 chemistry at faster vertical mixing rates, whereas orbit-induced thermal quenching may play a significant role at slower mixing rates. The general abundance and chemical timescale results - calculated as a function of pressure, temperature, and metallicity - can be applied for different atmospheric profiles in order to estimate the quench level and disequilibrium abundances of CO and CH4 on hydrogen-dominated exoplanets. Observations of CO and CH4 on highly eccentric exoplanets may yield important clues to the chemical and dynamical properties of their atmospheres.

**113.11 Glints As Indicators Of Water On The Surfaces And In The Atmospheres Of Exoplanets**

- Ludmilla Kolokolova\(^1\), A. Borovoi\(^2\), A. Konoshonkin\(^2\)
- \(^1\)Univ. of Maryland, \(^2\)Zuev Institute of Atmospheric Optics, Russian Federation.

Glints, bright flashes of light resulted from a specular reflection, have been widely discussed in the literature (e.g., Icarus, 195, 927, 2008) as indication of water basins (oceans or lakes) on exoplanets. However, not only liquid water can produce glints. Glints can be also produced as the starlight reflects from icy surfaces and cirrus clouds, thus, also indicating a water-bearing planet. The cirrus glints are well known to the Earth atmospheric scientists; they were also detected by EPOXI mission. We compare water and icy, specifically cirrus, glints to find out how we can distinguish between them and what the conditions are at which they can be observed and identified. For this, we consider the glints uniformly describing them by the probability density of the facet tilts; shadowing is included into consideration. Describing the specular reflection, we use the concept of the differential scattering cross.
section (DSCS) for rough surfaces instead of the conventional bidirectional reflectance distribution function (BRDF).
This allows us to derive simple equations, which connect DSCS and the probability densities for facet tilts (see DOI 10.1016/j.jqsrt.2012.06.011 for details). We show that the glints from particulate icy layers (cirrus) and wavy surfaces (ocean) are similar at small angles of incidence. However, at oblique incidence, the broader tilt distribution and the shadowing of wavy surface distort essentially the shape of the scattering domain broadening the angular distribution of the scattered light and removing part of the surface from the interaction with the light. These two effects make the glints from icy clouds and oceans look very different at large incident angles. The resulted difference can be used to discriminate between different types of glints. It also allows us to determine the observational conditions at which ocean and cirrus glints can be most efficiently observed.

- Robert Zellem¹, C. A. Griffith¹, P. Deroo², M. R. Swain³, I. Waldmann³, M. Zhao²
  ¹Lunar and Planetary Laboratory, University of Arizona, ²Jet Propulsion Laboratory, California Institute of Technology, ³University College London, Department of Physics & Astronomy, United Kingdom.

We present primary and secondary eclipse infrared H- and K-band emission spectra of the exoplanet HD 209458b observed with Palomar/TripleSpec. We have used a principal component analysis and bin wavelength channels in Fourier space to decrease the flux variance by \( \sim 3 \) orders of magnitude resulting in a final mean variance of \( \sim 300 \) ppm. Most of the secondary eclipse data points are consistent with a null detection, which renders them unusable for further constraining HD 209458b’s atmospheric chemical abundances and temperature profile. However in a few wavelength bands where Earth’s atmosphere is particularly clear, we detect the exoplanet above the error levels. Here we derive an exoplanet’s flux that is consistent with the Hubble/NICMOS secondary eclipse spectrum, within our achieved precision. Despite challenging data due to poor observing conditions that included clouds and autoguider failure, our data suggest that Palomar/TripleSpec has the capability to make significant spectroscopic measurements of eclipsing hot Jupiters.

113.13 C/O Ratios of Stars with Transiting Hot Jupiters: Connecting Stars to Planets
- Johanna Teske¹, S. Schuler², C. Griffith¹
  ¹Steward Observatory, University of Arizona, ²NOAO, ³Lunar and Planetary Lab, University of Arizona.

A planet's C/O ratio can influence its formation and evolution, with a C/O>0.8 resulting in a carbon-rich composition (Kuchner & Seager 2005; Bond et al. 2010) versus the silicate-dominated composition of Earth (C/O_solar≈0.5). Models of planet formation via core accretion indicate that close-in giant planets likely originate farther out in the disk from icy planetesimals that coalesce to form the core, followed by gas accretion and inward migration (e.g., Pollack et al. 1996). Since the abundances of C and O are expected to be enhanced equally during this process, the initial gas composition - that of the star - can also be expected for material incorporated into the planet. However, measurements of Jupiter challenge this prescription, suggesting differences in the disk composition with time and distance from the star (Lodders 2004). While most exoplanet theories & models assume a solar C/O ratio and an O-rich planet, relaxing this assumption leads to drastically different planet - a low atmospheric abundance of H2O, with the atmospheric oxygen is concentrated in CO rather than H2O, an interior dominated by carbon-rich compounds, and the photochemical production of hydrocarbon chains. Recent results suggest a C/O ratio &gt;1 in the atmosphere of one of the most highly irradiated exoplanets (Madhusudhan et al. 2011). This is particularly peculiar, however, given the C/O ratio of the host star is subsolar (~0.40; Petigura et al. 2011), and introduces the possibility of a sample of carbon-rich exoplanets. This finding highlights the question, "Does the same material comprise exoplanets and their host stars, and if not, what makes them different?" Here we present observations of the stellar C/O ratios for a sample of exoplanet host stars, and use these data and models of their corresponding exoplanet atmospheres by ourselves and others to investigate the connection between star and planet compositions.

113.14 Catastrophic Mass Loss Histories of Disintegrating Kepler Planets
- Eugene Chiang¹, D. Perez-Becker¹
  ¹UC Berkeley.
Short-period rocky extrasolar planets can have dayside temperatures surpassing 2000K, hot enough to sublimate rock and create a high-metallicity atmosphere. This atmosphere can escape via a thermal wind. As the atmosphere expands and cools, micron-sized dust can recondense out of the escaping high-Z gas. Dust absorbs a fraction of the incident starlight and heats the gas by gas-grain collisions. We present a hydrodynamic model of atmospheric escape from low-mass rocky planets that includes tidal gravity, variable grain condensation, and realistic heating and cooling of gas. We find that the mass loss rate depends so strongly on planet mass that the planet can lose the majority of its primordial mass within the last 1% of its lifetime. This calculation is of interest in light of the recently discovered planet candidate KIC 12557548b in the Kepler data. Stellar occultations for this source occur every 15.7 hours but vary in depth from a maximum of 1.3% to less than 0.2% in an apparently stochastic fashion. This source may represent a disintegrating rocky planet in its final death throes. Occultations are not caused by the planet itself, but by a time-variable dusty outflow enshrouding the planet. Our radiative/hydrodynamic calculations further secure this interpretation and give a planet mass 5 Gyr ago of 0.07 M⊕, and a mass of 0.01 M⊕ today.

113.15 Improvements in Equations of State and the Interpretation of Giant Impacts in Exoplanetary Systems
- Richard Kraus1, D. C. Swift2, S. T. Stewart1
1Harvard Univ., 2Lawrence Livermore National Laboratory.

Giant impacts in main sequence exoplanetary systems are inferred by the presence of amorphous warm dust and non-equilibrium gases with short dynamical lifetimes. The dust and gas are thought to be produced by an impact-generated vapor cloud. These signatures of impacts are evidence of a recent energetic event in an extra-solar system. More information about such impact events, such as the energy of the event and composition of the bodies involved, may be extracted by consideration of the mechanics and thermodynamics of the process that produced the observed dust and gas. Our understanding of giant impacts is limited by our knowledge of the material properties during the impact event, where the bodies are shock compressed to pressures of hundreds of gigapascals and temperatures of tens of thousands of Kelvin and then decompressed to vapor. Here we present new high-accuracy experimental data and wide-ranging equation of state models for MgO and SiO2, which represent end-member chemical components in the mantles of rocky planets. With these improved material models, we will be able to simulate giant impacts and obtain a bound on the type of impact and target composition that could produce the observed signatures of extrasolar giant impacts.

113.16 Ellipsoidal Variation Analysis of Kepler Observations Using the EVIL-MC Model
- Brian Jackson1, J. K. Carlberg1
1Carnegie DTM.

Follow-up and confirmation of the thousands of planetary candidates from the Kepler mission requires a sizable investment of astronomical resources. Thus, it is essential to identify signals already present in the data that can elucidate the nature of the transiting objects. Tidal distortion of a star by a close companion produces such a signal: as a short-period companion orbits, the tidal bulge raised on the primary rotates in and out of view, and the amplitude of these “ellipsoidal variations” (EVs) depends, among other things, on the mass ratio between the primary and companion. For example, a few Jupiter-mass planet orbiting 4 stellar radii from a solar mass star can induce brightness variations ~ 30 parts per million, small but measurable for some Kepler targets. EVs induced by such low-mass companions have been observed for only a handful of Kepler (and CoRoT) targets. Here we report the discovery of EVs in another Kepler system with a candidate transiting companion. The Kepler Input Catalog suggests the host star is an evolved red giant, and the star shows signs of solar-like oscillations, similar to p-mode acoustic oscillations observed in the Sun. Such oscillations have been observed for ~ thousand other red giants observed by Kepler, providing tight constraints on the stars’ masses and radii, if the effective temperatures are known. In this presentation, we will discuss constraints on the transiting companion’s mass and brightness temperature derived from analysis of the transits and EVs present in the publicly available Kepler data using the recently developed EVIL-MC model. Preliminary results suggest the candidate transiting object has a mass comparable to Jupiter’s but a radius many times larger, while the apparent lack of a secondary eclipse suggests its brightness temperature is less than 2700 K. BKJ acknowledges support from Carnegie DTM.
113.17. Removal of Cosmic Ray-Induced Noise from Kepler Data
- Robert L. Morris¹, J. M. Jenkins¹, J. Twicken¹
  ¹SETI Institute.

NASA’s Kepler Mission is designed to detect transiting exoplanets by measuring stellar brightness attenuation as small as 84 parts per million. Attaining the required photometric precision depends partly on the ability of ground-based data processing algorithms to mitigate the effects of significant noise sources. Among these is the charge released in the photometer’s CCDs by cosmic rays and solar energetic particles (we loosely refer to all such particles as “cosmic rays”, regardless of their origin), which continuously bombard the instrument with an estimated mean flux of of 5 cm⁻² s⁻¹. Cosmic ray strikes appear in pixel time series as a sequence of positive impulses affecting roughly one in five long cadence measurements (Kepler’s primary data collection mode). The problem of separating cosmic ray-induced signal from other signal components is complicated both by the ~30 min effective integration period of a long cadence measurement and by the fact that high-frequency stellar variations and image motion can also produce impulse-like features in pixel flux time series. We present an algorithm for detecting and removing the effects of cosmic rays on Kepler pixel time series. Given the pixels comprising a target star’s aperture, each variance-normalized and lightly detrended time series is modeled as a combination of the effects of intrinsic stellar variability, image motion, and cosmic ray strikes. The cosmic ray signal component is modeled as a Poisson process in which the magnitude of each event is drawn from a known distribution, while stellar variability is modeled as the sum of an autoregressive process and a small set (possibly empty) of salient harmonic components. Both simulation tests and analysis of results from Kepler flight data demonstrate the algorithm’s effectiveness. Kepler was selected as the 10th mission of the Discovery Program. Funding for this mission is provided by NASA’s Science Mission Directorate.

113.18. Using Light Travel Time Effect To Detect Circumbinary Planets with Ground-Based Telescopes
- Tobias Cornelius Hinse¹, N. Haghighipour²
  ¹Korea Astronomy & Space Science Institute, Korea, Republic of, ²Institute for Astronomy, University of Hawaii.

In the past few years, two-planet circumbinary systems (e.g., HW Vir, NN Ser, DP Leo and HU Aqr) have been detected around short-period eclipsing binaries using ground-based telescopes. The existence of these planets has been inferred by interpreting the O-C variations of their mid-eclipse timings. We propose to use Light Travel Time Effect (LITE) to detect such circumbinary planets from the ground. We generated, synthetically, the LITE signal of a two-planet circumbinary system with the aim to apply an analytic LITE model to recover the underlying synthetic system. To mimic a degree of realism inherent to ground-based observations, we added to the synthetic LITE data white noise with a Gaussian distribution and sampled the synthetic LITE signal randomly. We successfully recovered the original system demonstrating that two-planet circumbinary systems can be detected using ground-based telescopes, provided the timing measurements of the mid-eclipses are sufficiently accurate and the observing baseline is long enough to ensure a sufficient coverage of all involved periods. We used HU Aqr as a test system and applied our model to its proposed planetary bodies considering near-circular orbits. We present the results of our calculations and discuss the LITE-detectability of a HU Aqr-like system. (TCH acknowledges support from KRCF and KASI grant number 2012-1-410-02).

113.19. The Anelastic Equilibrium Tide In Giant Planets
- Françoise Remus¹, S. Mathis², J. Zahn³, V. Lainey³
  ¹CEA/DSM/IRFU/SAp, France, ²Observatoire de Paris - LUTH, France, ³Observatoire de Paris - IMCCE, France.

Once a planetary system is formed, its dynamical evolution is governed by gravitational interactions between its components, be it a star-planet or planet-satellite interaction. By converting kinetic energy into heat, the tides perturb their orbital and rotational properties. The rate at which the system evolves depends on the physical properties of tidal dissipation. Therefore, to understand the past history and predict the fate of a binary system, one has to identify the dissipative processes that achieve this conversion of energy. Planetary systems display a
large diversity of planets by their composition. Since tidal mechanism is closely related with the internal structure of the perturbed body, one has to investigate its effects on either its fluid and solid layers. Studies have been carried out on tidal effects in fluid bodies such as stars and envelopes of giant planets. However, the planetary solid regions may also contribute to tidal dissipation, be it the mantles of Earth-like planets that have been investigated by many works, or the cores of giant planets. The purpose of our study is to determine the tidal dissipation in the solid central regions of giant planets, taking into account the presence of a fluid envelope. We derive the different Love numbers that describe the anelastic deformation and discuss the dependence of the quality factor $Q$ on the rheological parameters and the size of the core. Taking plausible values for these parameters, and discussing the frequency-dependence of the solid dissipation, we show how this mechanism may compete with the dissipation in fluid layers, when applied to Jupiter- and Saturn-like planets. We also discuss the case of the icy giants Uranus and Neptune. Finally, we present the way to implement the results in the equations that describe the dynamical evolution of planetary systems.

114.01 The Fascinating Quest of Asteroids: The Remnants of Planetary Formation
- Patrick Michel
  
  1Lagrange Laboratory, University of Nice-Sophia Antipolis, CNRS, Côte d'Azur Observatory, France.

Asteroids are the leftover building blocks of the terrestrial planets and offer clues to the chemical mixture from which the planets formed. Current studies suggest that asteroid impacts in the early history of our planet may have delivered the necessary material for the emergence of life. In our current epoch, collisions of asteroids with the Earth pose a finite hazard and the design of efficient mitigation strategies relies on our knowledge of their physical properties. For all these reasons, the exploration of asteroids is a fascinating quest. This presentation will provide a basic overview of our current knowledge of asteroids, thanks in particular to space missions, observations and numerical models that allow exploring the different processes that they undergo during their evolutions. What are asteroids? Are they our friends or enemies? Amazing real images and movies of asteroids, which are stunning in their diversity, will be shown and discussed, as well as movies of numerical simulations of collisions and surface evolutions. Among other things, the first detailed images of a Near-Earth Asteroid, Eros, obtained by NASA’s NEAR mission in 2000-2001, will be presented, as well as images of Vesta, the second largest asteroid, from NASA’s Dawn mission. The fantastic adventure of the Japanese mission Hayabusa, which successfully returned to Earth a sample from the smallest asteroid ever visited in 2010, will also be discussed. Missions under development at NASA (OSIRIS-Rex), JAXA (Hayabusa 2), and under study at ESA (MarcoPolo-R), each with the goal of returning a sample from a possibly organic-rich asteroid, will also be presented. This fascinating quest continues and it is already clear that the next visits to asteroids will keep turning our understanding on its head and provide a wealth of exciting data to future generations of researchers.

Tuesday, 16 October, 2012

200 Extrasolar Planets: Kepler Outlook and Exoplanet Characterization
Tuesday, 8:30 AM - 10:00 AM, Tahoe Room

200.01 The Kepler Extended Mission
- Martin D. Still
  
  1NASA Ames Research Center.

Kepler is approaching the end of its primary 3.5 year primary mission, collecting space-based time-series photometry of near-uniform cadence to determine the frequency of Earth-sized planets within the habitable zone of stars. With NASA approving a further 4 years of operation, Kepler has the opportunity to detect increasingly smaller planet candidates in increasingly wider orbits using transit-detection and transit-timing methods, sampling the full habitable zone of solar-like stars and sampling the inner habitable zone of F stars. To foster greater community participation and optimize the scientific return of the extended mission, the Kepler Science Center will be committed to supporting community exploitation of the Kepler data. All Kepler time-series products will be
available to the entire community immediately after observation and pipeline processing. All previously proprietary data within the Kepler archive will be made public by Oct 28, 2012. All potential planet candidate events detected in multi-year light curves by the project will be published without delay at the NExScI Exoplanet Archive, and their disposition into planet candidates, eclipsing binaries and false positives can be followed in near-real time. This presentation describes how the scientific community can enter the process at any point - identifying new transit-like events in the time-series, categorizing events, confirming or validating planets, and characterizing the properties of planetary systems, either directly using Kepler archive products or through observational follow-up using ground-based or space-based facilities.

200.02 Terrestrial, Habitable Exoplanet Projection from Kepler
- Wesley A. Traub
  1Jet Propulsion Laboratory.

The Kepler exoplanet candidate list, allowing for explicit and implicit biases, is extrapolated to give the estimated end-of-mission value of eta-sub-Earth, the frequency of terrestrial planets in the habitable zones of stars like the Sun.

200.03 Transit Timing Variations of Resonant Three-planet Systems
- Anne-Sophie Libert, S. Renner
  1University of Namur, Belgium, 2LAL-IMCCE, France.

The transit timing variations (TTV) method is a powerful technique to infer the existence of additional non-transiting planets. This is especially the case for resonant systems where the variations can be strongly enhanced. Here we focus on resonant 3-planet systems and assume that the inner body transits the star. We show that the TTV curve exhibits three periodicities related to the resonant evolution of the system. We perform a dynamical study for different mass values of the three planets, with a special attention to the detection of terrestrial planets. A very interesting result is that the existence of two terrestrial companions can be deduced from the TTV curve only. We also highlight the degeneracy in the characterization of non-transiting planets: a system of two giant planets in mean-motion resonance can hide a third terrestrial planet in a multi-resonant configuration. The work of A-S L is supported by an F.R.S.-FNRS Postdoctoral Research Fellowship.

200.04 The Very Compact Five Exoplanet System KOI-500: Mass Constraints from TTVs, Resonances, and Implications
- Darin Ragozzine
  1University of Florida.

NASA’s Kepler Mission has discovered thousands of planet candidates, including nearly 900 in systems with multiple transiting planet candidates. Such multi-transiting systems are extremely valuable for understanding the combined physical and orbital characteristics of planetary systems. Most of these candidates are in Systems with Tightly-packed Inner Planets (STIPs), which are characterized by a concentration of dynamically tight planets near 0.1 AU. There are about 10 Kepler systems that show 5 or more planets transiting, though it is not yet fully clear whether these are unusual or just a high multiplicity tail of a continuous distribution of STIPs. The first known 5-candidate system was KOI-500 and we here present results which confirm and/or validate all 5 planets and discuss its several distinct properties. Even for a STIP, KOI-500 has a very compact architecture, with all 5 planets within 0.1 AU. The estimated radii of the 1.0, 3.1, 4.6, 7.1, and 9.5-day period planets are 1.3, 1.4, 1.5, 2.4, and 2.6 Earth radii, respectively. The outer four planets are very near unique and interlocking three-body resonances. The outer planets also show Transit Timing Variations (TTVs), allowing for good mass constraints and helping to fill in the exciting small planet mass-radius relation. The inclinations of the planets are generally well constrained, which, in combination with TTVs, allow for an investigation into the true mutual inclinations of this system. We will present an overview of the results of our analysis of the KOI-500 system and place it in context of other STIPs discovered by Kepler and Doppler surveys.

200.05 Ground-based Transmission Spectroscopy Of The Carbon-rich Hot Jupiter Wasp-12b
Contrary to early theoretical predictions, WASP-12b is thought to have a carbon-to-oxygen ratio (C/O) greater than unity. This ratio is significantly higher than the canonical solar-abundance ratio (0.54) and hints at a formation scenario beyond the H2O snowline. Our objective is to measure the transmission spectrum of WASP-12b in the red optical to reveal the strength of expected water absorption features and, hence, constrain the atmospheric C/O.

We observed two transits of WASP-12b using the GMOS detector at Gemini-North and will present the results from our analyses of these high-quality data. Additionally, we will combine our data with those from transit observations using the Hubble and Spitzer space telescopes to present our best-fit models of the transmission spectrum.

200.06 Two ‘b’s in the Beehive: The Discovery of the First Hot Jupiters in an Open Cluster
- David W. Latham\(^1\), S. N. Quinn\(^2\), R. J. White\(^2\)
\(^1\)Harvard-Smithsonian, CfA, \(^2\)Georgia State University.

We report the discovery of two giant planets orbiting stars in Praesepe (also known as the Beehive Cluster), the first known hot Jupiters in an open cluster. \( \text{Pr0201b} \) orbits a \( \text{V}=10.52 \) late F dwarf with a period of 4.4264 days and has a minimum mass of 0.540 M\( \text{Jup} \), while \( \text{Pr0211b} \) orbits a \( \text{V}=12.06 \) late G dwarf with a period of 2.1451 days and has a minimum mass of 1.844 M\( \text{Jup} \). Because they reside in a cluster, the ages of these planets are amongst the best-determined of any planet outside our own solar system. As we endeavor to learn more about the frequency and characteristics of planets, the environment in which most stars form -- open clusters like Praesepe -- may provide essential clues.

200.07 Constraining the Masses and Effective Temperatures of the Young Directly Imaged Exoplanets HR 8799 b, c, and d.
- Mark S. Marley\(^1\), D. Saumon\(^2\), M. Cushing\(^3\), J. Fortney\(^4\), A. Ackerman\(^5\)
\(^1\)NASA Ames Research Center, \(^2\)LANL, \(^3\)U. Toldedo, \(^4\)UCSC, \(^5\)NASA GISS.

The near-infrared colors of the planets directly imaged around the A star HR 8799 are much redder than most field brown dwarfs of the same effective temperature. Previous theoretical studies of these objects have concluded that the atmospheres of planets b, c, and d are unusually cloudy or have unusual cloud properties. Some studies have also found that the inferred radii of some or all of the planets disagree with expectations of standard giant planet evolution models. Here we report on our comparison of the available data to the predictions of our own set of atmospheric and evolution models with varying cloud properties and atmospheric composition. Unlike some previous studies we require mutually consistent choices for effective temperature, gravity, cloud properties, and planetary radius. This procedure thus yields plausible values for the masses, effective temperatures, and cloud properties of all three planets. We find that the cloud properties of the HR 8799 planets are not unusual but rather follow previously recognized trends, including a gravity dependence on the temperature of the L to T spectral transition--some reasons for which we discuss. We also confirm that, as in L and T dwarfs and solar system giant planets, non-equilibrium chemistry driven by atmospheric mixing is also important for these objects. Given the preponderance of data suggesting that the cloud clearing found at the L to T spectral type transition is gravity dependent, we present an exploratory evolution calculation that accounts for this effect and predict colors for future directly imaged exoplanets.

200.08 Hydrodynamic Vs. Evaporative Escape: Exoplanets And The Ex-planet
- Robert E. Johnson\(^1\), A. Volkov\(^1\), J. Erwin\(^1\), O. Tucker\(^2\)
\(^1\)Univ. of Virginia, \(^2\)Univ. of Michigan.

In studies of exoplanets, early terrestrial atmospheres, and even Pluto's atmosphere it has been convenient to use the equations of fluid dynamics, rather than a more detailed molecular kinetic model, to describe the loss of atmosphere over long time periods. However, the boundary conditions in the far field are always problematic. Therefore, it is assumed that the upward flow either goes through a sonic point or that the loss is Jeans-like at the
exobase. The so-called energy limited loss rate, an approximation obtained from the fluid equations, is also often used. Therefore, in a series of molecular kinetic studies of Pluto’s atmosphere, we confirmed that the energy limited loss rate gives a reasonable estimate over a broad range of solar heating conditions, but the flow did not go sonic although the Jeans parameter was relatively small and the escape rates large (Tucker et al. 2012; Erwin et al. 2012). Because the nature of the flow, and not just escape rate, determines the structure of the upper atmosphere, and because the simulation results scale (Volkov et al. 2011), we developed a criterion for determining when the flow associated with atmospheric escape goes sonic or remains Jeans-like. This criterion is verified in a series of kinetic simulations performed using a range of heating rates. In this talk we will discuss the validity of the energy limited escape rate and the nature of the criterion with applications to escape from a variety of exoplanet atmospheres. Erwin, J. et al. Icarus submitted (2012); Tucker, O.J. et al. Icarus 217, 408 (2012); Volkov et al. ApJLettts 729,L24 (2012)

200.09 WASP-29b: Another Cool Exoplanet With Abundant CO?

- Matthew Hardin1, J. Harrington1, K. Stevenson2, J. Bleicic1, O. Bowman1, P. Cubillos1, S. Nymeyer3, WASP Consortium
- 1University of Central Florida, 2University of Chicago, 3UCLA.

Stevenson et al. (2010, Nature 464, 1161-1164) made the surprising discovery of a lack of methane (CH4) and abundant carbon monoxide (CO) on the cool exoplanet GJ 436b. This was based on a nondetection at 4.5 microns (CO band), a strong detection at 3.6 microns (CH4 band), and a weak signal at 8.0 microns (CH4 band). At GJ 436b’s equilibrium temperature of 770 K, CH4 is thermochemically favored over CO. We present a second cool exoplanet that also features a detection at 3.6 microns and a nondetection at 4.5 microns, suggesting strong CO absorption. The transiting extrasolar planet WASP-29b was discovered by the Wide Angle Search for Planets by Hellier et al. (2010, ApJL 723, L60-L63). WASP-29b is a hot Saturn with a equilibrium temperature of 980 K. It orbits a K4 dwarf star every 3.922 days at a distance of 0.0457 AU. We analyze lightcurves from two Spitzer 3.6 micron secondary eclipses taken in August 2010 and January 2011, and one Spitzer 4.5 micron secondary eclipse taken in January 2011. We detect no eclipse in the 4.5 micron observation. This mirrors the results of Stevenson et al. for GJ 436b and suggests that WASP-29b may also have abundant CO. We strongly detect eclipses in the 3.6 micron observations, which provide timing constraints for all three observations. The lack of an 8.0 micron observation prevents us from confirming a lack of methane. K-band observations would help to address its abundance. These observations are part of the Spitzer Exoplanet Target of Opportunity program. Spitzer is operated by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with NASA, which provided support for this work.

201 Surface Processes on Titan

Tuesday, 8:30 AM - 10:00 AM, Carson 1/2

201.01 Global surface roughness of Titan

- Priyanka Sharma1, S. Byrne1
- 1University Of Arizona.

Investigations of Titan’s surface topography have shown little relief and gentle slopes. However, a global view of Titan’s surface roughness has not emerged from these studies. To address this, we have utilized 46 altimetry profiles from the Cassini Radar instrument to calculate median absolute slopes, average relief (difference of centroid and leading edge height estimates gives a measure of intra-footprint relief) and the Hurst exponent for the surface of Titan. Overall, we find median absolute slopes of ~0.023-0.086°, ~0.013-0.08° and ~0.006-0.069° over baselines of 45 km, 90 km and 180 km, respectively; intra-footprint relief in the range of ~50-180 m and Hurst exponents in the range of ~0.07-0.94. We detect a clear trend with latitude in all of these roughness parameters for Titan’s surface. Equatorial regions had the smallest slopes and lowest values of H, compared to the mid-latitudes and polar regions of Titan, at these baselines. These regions also showed smaller intra-footprint relief, whose magnitude is consistent with that expected of the equatorial dune fields. No discernible trends in spatial variation of surface roughness with longitude were detected. 28 altimetry profiles overlap sections of Cassini
Synthetic Aperture Radar (SAR) swaths that provide visual context. We find isolated positive relief features are generally brighter in SAR (rounder) than their surroundings. We report relief for a number of interesting topographic features covered by SAR data.

**201.02 The Surface Composition of Titan**


Mapping the surface composition of Titan with the Cassini Visual and Infrared Mapping Spectrometer (VIMS) requires knowledge of the atmospheric absorption in the windows through which VIMS can observe the surface as well as the spectral properties of candidate materials. Recent atmospheric models are refining that knowledge. Titan's surface, in the VIMS spectral range, is seen in only a few spectral windows, near 0.94, 1.1, 1.3, 1.6, 2.0, 2.68-2.78, and 4.9-5.1 microns. Atmospheric models fail to fit the observed spectra on the long wavelength side of the 2-micron window without invoking surface absorption at 2.1 microns. This new knowledge, along with the spectral shapes of the 2.68-2.78-micron, and 5-micron windows provide powerful constraints on Titan's surface composition. Water ice is incompatible with the observed 2.78/2.68 micron I/F ratio but likely exists below the surface. Many organic compounds have absorptions that are not seen in spectral windows of Titan, eliminating them as possible major components at the surface, including many polycyclic aromatic hydrocarbons (PAH). We find that some ring compounds and compounds with single N-H bonds have a close match to Titan's overall spectrum and can explain the relative intensities observed in the spectral windows, including the 2.68 and 2.78-micron double window, the low 3-5 micron reflectance, and increased absorption near 2.1-microns. Glycine is the only NH₂ compound we have found that is also compatible. Combinations of coronene (C24H12), phenanthrene (C14H12), indole (C8H7N), uracil (C4H4N2O2), and glycine (NH₂CH₂C00H) match the overall spectral structure of Titan spectra. We are searching for additional compounds that are also compatible. Indole, cytosine, and uracil, have 1.5-micron bands that are similar to the feature observed in Huygens DISR spectra of Titan's surface. These compounds, if present, can also help explain the pyrolysis results from the Huygens probe.

**201.03 Cassini/VIMS Data Analysis Of Potentially Geologically Varying Regions On Titan**

- Anezina Solomonidou¹, M. Hirtzig², E. Bratsolis³, G. Bampasidis³, A. Coustenis⁵, K. Kyriakopoulos³, S. Le Mouélic⁶, S. Rodriguez⁷, R. Jaumann⁸, K. Stephan⁸, R. M. C. Lopes⁹, P. Drossart⁵, C. Sotin¹⁰, R. H. Brown¹¹, K. S. Seymour¹², X. Moussas³

  ¹LESIA-Observatoire de Paris / National & Kapodistrian University of Athens, Greece, ²LESIA - Observatoire de Paris / Fondation La Main à la Pâte, France, ³National & Kapodistrian University of Athens, Greece, ⁴LESIA - Observatoire de Paris / National & Kapodistrian University of Athens, Greece, ⁵LESIA - Observatoire de Paris, CNRS, UPMC Univ. Paris 06, Univ. Paris-Diderot, France, ⁶Université de Nantes, Laboratoire de Planétologie et Géodynamique, France, ⁷Laboratoire AIM, Université Paris Diderot, Paris 7/CNRS/CEA-Saclay, DSM/IRFU/SAp, Centre de l’Orme des Merisiers, France, ⁸DLR, Institute of Planetary Research, Germany, ⁹Jet Propulsion Laboratory, ¹⁰Université de Nantes, Laboratoire de Planétologie et Géodynamique / Jet Propulsion Laboratory, ¹¹Lunar and Planetary Laboratory, University of Arizona, ¹²Concordia University, Department of Geography / University of Patras, Department of Geology, Greece.

We present a study of Titan's geology with a view to enhance our current understanding of some particular regions on the satellite’s surface, which may be varying in brightness and/or in color etc. We apply here a statistical method, the Principal Component Analysis (PCA) [1] and a radiative transfer code (RT) [1,2] on three such potentially “active” regions: Tui Regio, Hotei Regio, and Sotra Facula, within which we isolate specific regions of distinct and diverse chemical composition with PCA. Then, with our follow-up RT method, we retrieve the surface albedo of these specific isolated regions and of the surrounding terrains exhibiting different spectral responses. We thus evaluate the atmospheric contribution and can constrain the real surface alterations, by comparing the spectra of these regions. We search for the temporal surface variations of Hotei Regio (as reported by Nelson et al. 2009 [3]), with our RT code and the same data from 2004-2006, and do not find any significant surface albedo.

201.04 Thermal and Structural Evolution of a Partially Differentiated Titan
- Michael T. Bland1, W. B. McKinnon1
  1Washington University.

Titan’s moment of inertia (C/MR2) has been measured by Cassini to be ~0.34, indicating either partial differentiation, or full differentiation with a low-density (hydrated) silicate core. Fully differentiated models have been constructed [Castillo-Rogez and Lunine, 2010], but require specific geochemical assumptions (e.g., rapid accretion, minimal core dehydration). In contrast, the alternative, partially differentiated models have not yet been fully vetted. Here we investigate the thermal stability of such partially differentiated internal structures by evaluating whether complete differentiation can be avoided. Our model assumes an initial three-layer internal structure consisting of a pure ice layer, mixed ice-rock layer, and silicate core, and calculates the temperature of each layer following the numerical approach in Bland et al. (2008, 2009). The model allows melting in the pure ice and mixed layer, and dehydration of the initially hydrated silicate core (leading to densification and absorption of latent heat). Melting of the mixed layer liberates silicate material, which is assumed to sink to the top of the silicate layer over time scales short relative to simulation time scales (in reality some may mix back into the convecting mixed ice-rock layer). Simulations so far indicate that melting of Titan’s pure ice shell is common early in Solar System history, and that melting frequently extends into Titan’s nominal mixed ice-rock layer. Such melting leads to irreversible unmixing of some of the mixed ice-rock layer. Nearly complete dehydration of the silicate core occurs when condritic K is retained in the rock component. The structural evolution decreases Titan’s initial moment of inertia; however, long-lived radiogenic species are generally incapable of completely melting and separating Titan’s mixed layer. To date, thermally stable structural models with C/MR2 as large as ~0.33 have been achieved. We continue to investigate how realistic ocean and ice shell compositions affect Titan’s structural evolution.

201.05 Formation and Cooling Of Impact Oases On An Early Titan
- Carpy Sabrina1, N. Marounina2, G. Domingues1, G. Tobie2, J. Monteux2, O. Grasset2
  1Laboratoire De Planetologie Et De Geodynamique, France, 2Laboratoire De Plantetologie Et De Geodynamique, France.

Melting of H2O ice after an impact is a widespread phenomenon during the early history of an icy satellite. The main objective of this study is to treat the cooling and freezing process of a liquid reservoir on Titan crater floors during its accretionary stage. The impact melt generated after an impact is mixed with complex organics compounds, thus forming a liquid deposit on the crater floor where prebiotic chemical reactions could take place. The crater geometry and initial conditions are determined by the impact parameters (velocity, radius, angle, ...). We focus on two different methods to model the crystallization process: (i) an enthalpic method and (ii) a study of the solidification front position with time. The first one permits the development of fast and simple 2D radiative models. The second one is based on a finite element method and model a moving interface between ice and water. First results obtained for pure liquid water crystallization with an ambient atmosphere temperature of 95 K show that freezing timescale ranges between 100 yr and 400 yr for crater diameters ranging between 10 km and 20 km. Because the surface conditions on early Titan may be different from nowadays (colder or hotter), we consider various target composition and surface temperature, in order to predict post-impact lifetime of liquid pool and evolution of the liquid composition during the freezing.

201.06 Titan’s “Hot Cross Bun”: A Titan Laccolith?

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Cassini’s RADAR instrument acquired Synthetic Aperture Radar data during the T83 flyby on May 22, 2012. The data showed a feature centered at ~38.5N, 203W that resembles a “hot cross bun”. This type of feature has not been seen on Titan before, even though ~52% of Titan’s surface has been imaged using SAR. The feature, approximately 100 km across, is mostly radar bright but the cross pattern, interpreted to be extensional fractures, located roughly at the center of the brighter area, appears darker at radar wavelengths (2.3 cm). Radar illumination of the image indicates that the fractures are lower in elevation than the surrounding bright region. The morphology of the region is markedly similar to that of a 30-km dome-shaped feature on Venus that lies at the summit of the Kunapipi volcano. The Venus feature is interpreted to be the result of intrusion of magma at the summit of the volcano [1]. A similar feature, interpreted as a laccolith, is seen on the Moon near the crater Ramsden [2]. The lunar feature, imaged by the Lunar Reconnaissance Orbiter, shows the cross-shaped depression over a 300 m high rise. No topographic data for the feature on Titan are available at this time, but the morphology seen by the SAR data suggests that the feature may have been formed by material pushing up from below. Laccoliths form when an igneous intrusion splits apart two strata, resulting in a domeline structure. This previously unknown type of structure on Titan may be yet another indication of cryovolcanism. [1] Stofan, E.R., et al, Icarus, 152, 75-95, 2001. [2] Wichman, R.W. and Schultz, P. H. (1996). Icarus, 122, Issue 1, July 1996, pages 193-199. doi:10.1006/icar.1996.0118

201.07 Coexistence Of Dunes And Humid Conditions At Titan’s Tropics
1Brigham Young University, 2Johns Hopkins Applied Physics Laboratory, 3Cornell University, 4United States Geological Survey, 5IRSPS - Univ. G.d’Annunzio, Italy, 6Jet Propulsion Laboratory, 7LATMOS - UVSQ, France, 8Observatoire de Paris, France, 9Observatoire Aquitain des Sciences de l’Univers, France, 10Proxemy Research, 11Wheeling Jesuit University.

At Titan’s equatorial latitudes there are tens of thousands of dunes, a landform typical of desert environments where sand does not become anchored by vegetation or fluids. Model climate simulations predict generally dry conditions at the equator and humid conditions near the poles of Titan, where lakes of methane/ethane are found. However, moderate relative methane humidity was observed at the Huygens landing site, recent rainfall was seen by Cassini ISS near the Belet Sand Sea, and a putative transient lake in Shangri-La was observed by Cassini VIMS, all of which indicate abundant fluids may be present, at least periodically, at Titan’s equatorial latitudes. Terrestrial observations and studies demonstrate dunes can exist and migrate in conditions of high humidity. Active dunes are found in humid climates, indicating the movement of sand is not always prohibited by the presence of fluids. Sand mobility is related to precipitation, evaporation and wind speed and direction. If dune surfaces become wetted by rainfall or rising subsurface fluids, they can become immobilized. However, winds can act to dry the uppermost layers, freeing sands for saltation and enabling dune migration in wet conditions. Active dunes are found in tropical NE Brazil and NE Australia, where there are alternating dry and wet periods, a condition possible for Titan’s tropics. Rising and falling water levels lead to the alteration of dune forms, mainly from being anchored by vegetation, but also from cementation by carbonates or clays. Studies of Titan’s dunes, which could undergo anchoring of organic sediments by hydrocarbon fluids, could inform the relative strength of vegetation vs. cementation at humid dune regions on Earth. Furthermore, a comprehensive survey of dune morphologies near regions deemed low by SARTopo and stereo, where liquids may collect in wet conditions, could reveal if bodies of liquid have recently existed at Titan’s tropics.

201.08 Searching for the Remnants of Southern Seas: Cassini Observations of the South Pole of Titan
1Proxemy Research, 2California Institute of Technology, 3Cornell University, 4U.S. Geological Survey, 5Jet Propulsion Laboratory, 6JHU-APL, 7Brigham Young University, 8Wheeling Jesuit University.
The north polar region of Titan is home to three large seas along with hundreds of smaller lakes, while the south pole apparently has only two partially filled basins of liquid hydrocarbons. Aharonson et al. [2009] has suggested that cycles analogous to Croll-Milankovich cycles on Earth cause long-term cyclic transfer of hydrocarbons from pole to pole, with the north pole now containing the bulk of the liquids. Less than 50,000 years ago, the cycle would have been reversed, suggesting that the south polar region should contain remnants of southern seas. To identify such seas, we search for features enclosed by an apparent remnant shoreline, with an interior region of smooth (radar-dark) plains. Two such features can be readily identified, each with areal extents of over 100,000 km², along with several other possible candidate remnant seas or large lakes. One of the possible seas now contains Ontario Lacus. Analysis of the morphologic and topographic characteristics of the two candidate remnant seas can help constrain the possible depth and basin characteristics of the northern seas, as well as possible rates of surface modification in the time since the seas have (largely) dried up. In addition, analysis of the radar characteristics of the remnant sea basins may help us to determine if such processes also acted at equatorial regions where evidence of rainfall [Turtle et al., 2011] and a possible lake has recently been presented [Griffith et al., 2012], and at the more homogeneous mid-latitudes on Titan. References: Aharonson, O. et al., Nature Geoscience 2, 851-854; Griffith, C. et al., Nature 486, 237-239; Turtle, E.P. et al., Science 331, 1414-1417.

201.09 Cassini RADAR observations of Ligeia Mare: Radiometric Properties and Stereo Topography

Ligeia Mare is the best-mapped of Titan’s three seas, and has attracted particular interest as the target of the proposed TiME (Titan Mare Explorer) mission. Here we summarize radar observations of this ~400km wide feature and its environs from Cassini flybys T25, T28, T29 and T65. As noted in studies of Ontario Lacus (Hayes ref), radar reflectivity can be used with assumptions to assess liquid depth in shallow areas. Most of Ligeia is well below the noise floor of our observations (which varies across the scene - we use the most sensitive central beam where available to pose the tightest sigma-0 constraint) indicating depths likely >~10m, although we delineate some possibly shallow margins to aid in future modeling of tidal currents. In addition, the brightness temperature measured by passive radiometry (Janssen et al., 2009) places a joint constraint on the surface temperature and the emissivity, suggesting an upper limit of ~10% on suspended solid material. Combination of SAR imaging from the flybys permits construction of a stereo Digital Elevation Model. This stereo topography is compared with SARTopo measurements and shows a number of ~1km high mountains in the surrounding terrain: the peaks of these mountains would be above the horizon as seen from much of Ligeia. The model also places constraints on the watershed of Ligeia and thus on the hydrological balance of precipitation and evaporation. We will also report on further observations of Ligeia planned in the T86 flyby, shortly before the DPS meeting.

202 Asteroids 3: Taxonomy and Composition
Tuesday, 8:30 AM - 10:00 AM, Reno Ballroom

202.01 New Analysis Of The Baptistina Asteroid Family: Implications For Its Link With The K/t Impactor
- Marco Delbo, D. Nesvorny, J. Licandro, V. Ali-Lagoa

The Baptistina Asteroid Family (BAF) is the result of the breakup of an asteroid roughly 100 million years ago. This family is the source of meteoroids and near-Earth asteroids and likely caused an asteroid shower of impactors on our Earth. Bottke et al. (2007) proposed a link between the BAF and the K/T impactor, based on the favorable timing, large probability of a terrestrial impact of one 10-km BAF asteroid, and the Sloan colors of the BAF.
members, indicating that the BAF may have composition consistent with the K/T impactor (CM2-type carbonaceous meteorite, as inferred from chromium studies at different K/T boundary sites; Alvarez et al. 1980, Kring et al. 2007). The relationship between the BAF and K/T impactor is now controversial. Masiero et al. (2011) found that the albedo of BAF family members is ~0.15, significantly higher than expected for a dark carbonaceous parent body. Also, Reddy et al. (2011) reported the spectroscopic observations of (298) Baptistina and objects in the general neighborhood of the BAF, and suggested the BAF includes a mixture of spectroscopic types that is not very different from the background (mostly S-type asteroids in the background Flora family). Unfortunately, Reddy et al. observed only the large asteroids near (298) Baptistina, and not the K/T-impactor-size BAF members with D ~ 10 km. Using WISE albedos, Sloan colors and newly obtained spectroscopic observations of BAF members, here we show that (1) the large objects in the BAF are mostly BAF interlopers, (2) that BAF has an homogeneous composition consistent with an X-type class. We discuss the implications of the link between the BAF and the K/T impactor.

202.02 Does the Solar Wind Create OH on NEO Surfaces?: Observations of 433 Eros and 1036 Ganymed

- Andrew S. Rivkin, E. S. Howell, J. P. Emery, J. M. Sunshine
  1JHU/APL, 2Arecibo Observatory, 3University of Tennessee, 4University of Maryland.

The discovery of water/OH in the lunar regolith (Sunshine et al., Clark, Pieters et al. 2009) overturned years of conventional wisdom. The origin of this solar wind water/OH is thought to be via interactions between the solar wind and lunar regolith, a form of space weathering/maturation processes. It was recognized by Sunshine et al. (and earlier proposed by Starukhina 2001) that these processes should also be occurring on asteroidal surfaces. Hydroxylated minerals have been found on many objects though most are associated with the carbonaceous chondrite meteorites (Rivkin et al. 2003). Those meteorites can contain water/OH bound into their minerals, and it would be difficult to disentangle solar wind-created water/OH from native asteroidal material. However, there are other asteroids more suitable for comparison with the lunar regolith than these carbonaceous asteroids. In particular, two large S-class NEOs, 1036 Ganymed and 433 Eros, made good apparitions in 2011-2012 and are excellent targets for several reasons: These specific asteroids, based on their mineralogies and meteorite analogs, are not expected to have 3-μm bands from native material. Their solar distances vary from 1.1-1.8 AU while they are bright enough to observe and their phase angles also cover a wide range, but they do not exactly vary together allowing them to be disentangled. They provide an opportunity for observations over a long span, providing constraints on how solar wind could create water on surfaces in conditions similar to lunar conditions. The varying conditions experienced by the NEOs will allow any band variation to be characterized. Alternately, if there is no band or no variation, that will provide constraints that modeling and theory of the lunar water must explain. We will present our 3-μm spectral observations of 1036 Ganymed and 433 Eros and discuss our results. This work funded by NSF Planetary Astronomy

202.03 Cracking the Space Weathering Code: Ordinary Chondrite Asteroids in the Near-Earth Population

  1MIT, 2Univ. Massachusetts, 3Laboratoire d'Astrophysique de Marseille, France, 4Wellesley College.

202.04 Evidence for the Nature of Space Weathering Spectral Signatures on Low Albedo Asteroids
- Beth Ellen Clark¹, C. Lantz², M. A. Barucci²
  ¹Ithaca College, ²Paris Observatory, France.

We address an existing problem in understanding the reflected light spectral signatures of carbonaceous (low-albedo) asteroids. We know from observations of the moon and high-albedo asteroids that interplanetary surface processes (solar wind and micrometeorite bombardment) can alter the spectral properties of silicates. The problem is that we don’t understand how carbonaceous surfaces respond to surface processes. The question is, what are the spectral signatures of surface processes on low albedo asteroids? To answer this question, we need to study reflected light spectra of asteroid subsurface materials, and compare them with asteroid surface materials. In this work, we assume that primitive asteroids are the parent bodies of carbonaceous chondrites. We begin with a fairly well-established meteorite-asteroid link: several studies have found evidence that links the CM meteorites with the Ch/Cgh asteroids [Hiroi et al. 1996; Fornasier et al. 1999]. Assuming this link, we reason that differences between spectra of particulate samples of the CM meteorites and spectra of the regolith of the asteroids can be due to either differences in textural properties, or differences caused by surface processes on the asteroid. Previous work has resulted in contradictory predictions. Asteroid color survey data analyzed by Lazzarin et al. (2006) predicted spectral reddening for low albedo asteroids. Laser irradiation experiments by Moroz et al. (1996; 2004; 2004b) indicated both reddening and blueing of various degrees. Our initial results indicate spectral blueing of up to 50%, with little to no concurrent albedo change. We used telescopic observations of 43 Ch and Cgh-type asteroids (0.4 to 2.5 microns) from Binzel, DeMeo, et al. (MIT) and Fornasier et al. (Obs. Paris). We compare them statistically with 106 CM meteorite spectra from RELAB. The goal of this work is to predict what the OSIRIS-REx mission will see at B-type asteroid (101955) 1999RQ36.

202.05 The Bias-corrected Mass Distribution Of Compositional Classes In The Main Asteroid Belt
- Francesca E. DeMeo¹, B. Carry²
  ¹Massachusetts Institute of Technology, ²European Space Astronomy Centre, Spain.

Each compositional class of asteroid is a relic of the temperature and composition conditions in which it formed. The current distribution reveals the history of the Solar System, and each body acts as a marker of any mixing that occurred since formation. The remnant of a primordial temperature gradient, seen as transition from the S class to C class dominating in different regions of the asteroid belt has been a paradigm for three decades (Gradie & Tedesco 1982, Science, 216, 1405). In this work, we reexamine the architecture of the asteroid belt by determining the bias-corrected distribution of 99.99% of its mass based on compositional information provided by ground-based and space-based measurements. We report an updated view of the distribution of asteroid compositions. This material is based upon work supported by the National Science Foundation under Grant No. 0907766.

202.06 Comparative Analyses of Carbonaceous Chondrites and Additional Outer Main Belt Asteroids Using Near-Infrared (2-4 μm) Spectroscopy
- Driss Takir¹, J. P. Emery¹, R. N. Clark², H. Y. McSween Jr.¹, N. Pearson²
  ¹University of Tennessee Knoxville and Planetary Geosciences Institute, ²U.S. Geological Survey.

CM carbonaceous chondrites (CCs) are widely thought to come from C-complex asteroids. If so, the two should have very similar mineralogies. Both have been found to contain abundant phyllosilicates. However, comparisons in the 3-μm region have been difficult because laboratory spectra have generally been measured under ambient conditions and therefore contaminated by adsorbed water. Here in addition to V-NIR spectra, which include the 0.7-μm band (Fe²⁺/Fe³⁺ charge transfer), we used 3-μm spectra of CCs, measured under dry conditions and vacuum to remove adsorbed water and mimic the space environment, for subsequent comparison with reflectance spectra of asteroids and fuller understanding of the linkage between CCs and outer Main asteroids. We have measured more than 32 spectra of outer Main Belt asteroids (2.5 < a < 4.0 AU), using the LXD mode of NASA IRTF SpeX. We also measured spectra of 10 CCs and a few minerals under dry conditions and vacuum. In comparing these
laboratory spectra of CCs and minerals with telescopic spectra of asteroids, we have found some intriguing matches, suggesting that some of these meteorites and asteroids have similar mineralogies, and possibly experienced analogous aqueous alteration processes.

202.07 Optical Spectroscopy of Unbound Asteroid Pairs

- **Samuel Duddy**¹, S. C. Lowry¹, A. Christou², S. D. Wolters³, C. Snodgrass⁴, A. Fitzsimmons⁵, J. F. Deller¹, O. R. Hainaut⁶, B. Rozitis⁷, P. R. Weissman³, S. F. Green⁷

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The recently discovered unbound asteroid pairs have been suggested to be the result of the decoupling of binary asteroids formed either through collision processes or, more likely, rotational fission of a rubble-pile asteroid after spin-up (Vokrouhlicky et al. 2008, AJ 136, 280; Pravec et al., 2010, Nature, 466, 1085). Much of the evidence for linkage of the asteroids in each pair relies solely on the backwards integrations of their orbits. We report new results from our continuing spectroscopic survey of the unbound asteroid pairs, including the youngest known pair, (6070) Rhineland - (54827) 2001 NQ8. The survey goal is to determine whether the asteroids in each unbound pair have similar spectra and therefore composition, expected if they have formed from a common parent body. Low-resolution spectroscopy covering the range 0.4-0.95 microns was conducted using the 3.6m ESO NTT+EFOSC2 during 2011-2012 and the 4.2m WHT+ACAM. We have attempted to maintain a high level of consistency between the observations of the components in each pair to ensure that differences in the asteroid spectra are not the result of the observing method or data reduction, but purely caused by compositional differences. Our WHT data indicates that the asteroids of unbound pair 17198 - 229056 exhibit different spectra and have been assigned different taxonomies, A and R respectively. Initial analysis of our data from the NTT suggests that the asteroids in unbound pairs 6070 - 54827 and 38707 - 32957 are likely silicate-dominated asteroids. The components of pair 23998 - 205383 are potentially X-type asteroids. We present final taxonomic classifications and the likelihood of spectral similarity in each pair.

202.08 Collisional Histories of Comets and Trojan Asteroids: Diopside, Magnesite, and Fayalite Impact Studies

- **Susan M. Lederer**¹, E. A. Jensen², D. H. Wooden³, S. S. Lindsay⁴, K. Nakamura-Messenger⁴, D. C. Smith⁶, L. P. Keller¹, M. J. Cintala¹, M. E. Zolensky¹

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Comets and asteroids have weathered dynamic histories, as evidenced by their rough surfaces. The Nice model describes a violent reshuffling of small bodies during the Late Heavy Bombardment, with collisions acting to grind these planetesimals away. This creates an additional source of impact material that can re-work the surfaces of the larger bodies over the lifetime of the solar system. Here, we investigate the possibility that signatures due to impacts (e.g. from micrometeoroids or meteoroids) could be detected in their spectra, and how that can be explained by the physical manifestation of shock in the crystalline structure of minerals. All impact experiments were conducted in the Johnson Space Center Experimental Impact Laboratory using the vertical gun. Impact speeds ranged from ~2.0 km/s to ~2.8 km/s. All experiments were conducted at room temperature. Minerals found in comets and asteroids were chosen as targets, including diopside (MgCaSi₂O₆, monoclinic pyroxene), magnesite (MgCO₃, carbonate), and fayalite (FeSiO₄, olivine). Impacted samples were analyzed using a Fourier Transform Infrared Spectrometer (FTIR) and a Transmission Electron Microscope (TEM). Absorbance features in the 8-13 μm spectral region demonstrate relative amplitude changes as well as wavelength shifts. Corresponding TEM images exhibit planar shock dislocations in the crystalline structure, attributed to deformation at high strain and low temperatures. Elongating or shortening the axes of the crystalline structure of forsterite (Mg₂SiO₄, olivine) using a discrete dipole approximation model (Lindsay et al., submitted) yields changes in spectral features similar to those observed in our impacted laboratory minerals. Results on forsterite and orthoenstatite can be found in Jensen, et al., this meeting. Funding was provided by the NASA PG&G grant 09-PGG09-0115, NSF grant AST-1010012, and a Cottrell College Scholarship through the Research Corporation.
A new paradigm has emerged where 3.9 Gyr ago, a violent reshuffling reshaped the placement of small bodies in the solar system (the Nice model). Surface properties of these objects may have been affected by collisions caused by this event, and by collisions with other small bodies since their emplacement. These impacts affect the spectroscopic observations of these bodies today. Shock effects (e.g., planar dislocations) manifest in minerals allowing astronomers to better understand geophysical impact processing that has occurred on small bodies. At the Experimental Impact Laboratory at NASA Johnson Space Center, we have impacted forsterite and enstatite across a range of velocities. We find that the amount of spectral variation, absorption wavelength, and full width half maximum of the absorbance peaks vary non-linearly with the velocity of the impact. We also find that the spectral variation increases with decreasing crystal size (single solid rock versus granular). Future analyses include quantification of the spectral changes with different impactor densities, temperature, and additional impact velocities. Results on diopside, fayalite, and magnesite can be found in Lederer et al., this meeting. Funding was provided by the NASA PG&G grant 09-PGG09-0115, NSF grant AST-1010012, and a Cottrell College Scholarship through the Research Corporation.

**205 Jupiter: Spots, Waves, Jets and Structure**

**205.01 Chromophores from Photolyzed Ammonia Reacting with Acetylene: Application to Jupiter’s Great Red Spot**

- **Robert W. Carlson**\(^1\), K. H. Baines\(^1\), M. S. Anderson\(^1\), G. Filacchione\(^2\)

\(^1\)JPL, \(^2\)IAPS, Italy.

The production mechanisms of chromophores at Jupiter, and notably at the Great Red Spot (GRS), have been long-standing puzzles. A clue to the formation of the GRS coloring agent may be the great height of this storm, which can upwell ammonia to pressure levels of a few hundred mbar where solar photons capable of dissociating NH3 penetrate. Acetylene formed at higher altitudes can diffuse down and react with the NH3 photodissociation products, forming a deposit that absorbs in the ultraviolet and visible region (Ferris and Ishikawa, J. Amer. Chem. Soc. 110, 4306-4312, 1988). We have investigated the system NH3 + C2H2 + CH4 using a Zn lamp emitting at 214 nm to produce NH2 + H and subsequent reaction products. The deposits produced in these reactions were analyzed by optical and infrared spectroscopy and soft-ionization (He*) time-of-flight mass spectroscopy. The combination of NH3 + CH4 produced no visibly absorbing material, but NH3 + C2H2 and NH3 + C2H2 + CH4 mixtures both produced a yellow-orange film whose transmission spectra are similar to that of the GRS obtained by Cassini VIMS. Infrared spectra show a strong band at 2056 wavenumbers which may arise from nitrile (-CN), isonitrile (-NC), or diazide (-CNN) functional groups. The high-resolution mass spectra are consistent with compounds of the form CnH2n+1Nm, similar to the products formed in NH3 + CH4 spark discharges (Molton and Ponnampерuma, Icarus 21, 166-174, 1974). We thank NASA’s Planetary Atmospheres Program for support.

**205.02 Investigation of Jupiter’s Equatorial Hotspots and Plumes using Cassini ISS Observations**

- **David S. Choi**\(^1\), A. P. Showman\(^2\), A. R. Vasavada\(^3\), A. A. Simon-Miller\(^4\)

\(^1\)ORAU/NASA GSFC, \(^2\)University of Arizona, \(^3\)JPL, \(^4\)NASA/GSFC.

We present an updated analysis of Jupiter’s equatorial meteorology from Cassini observations. For two months preceding the spacecraft’s closest approach, the ISS onboard regularly imaged the atmosphere. We created time-lapse movies from this period in order to analyze the dynamics of equatorial hot spots and their interactions with adjacent latitudes. Hot spots are relatively cloud-free regions that emit strongly at 5 microns; improved knowledge
of these features is crucial for fully understanding Galileo probe measurements taken during its descent through one. Hot spots are quasi-stable, rectangular dark areas on visible-wavelength images, with defined eastern edges that sharply contrast with surrounding clouds, but diffuse western edges serving as nebulous boundaries with adjacent equatorial plumes. Hot spots exhibit significant variations in size and shape over timescales of days and weeks. Some of these changes correspond with passing vortex systems from adjacent latitudes interacting with hot spots. Strong anticyclonic gyres present to the south and southeast of the dark areas appear to circulate into hot spots. Compact cirrus-like ‘scooter’ clouds flow rapidly through the plumes before disappearing within the dark areas. These clouds travel at 150-200 m/s, much faster than the 100 m/s hot spot and plume drift speed. This raises the possibility that the scooter clouds may be more illustrative of the actual jet stream speed at these latitudes. Most previously published zonal wind profiles represent the drift speed of the hot spots at their latitude from pattern matching of the entire longitudinal image strip. If a downward branch of an equatorially-trapped Rossby waves controls the overall appearance of hot spots, however, the westward phase velocity of the wave leads to underestimates of the true jet stream speed. This research was supported by a NASA JDAP grant and the NASA Postdoctoral Program.

### 205.03 Discovery Of A Rossby Wave In Jupiter's South Equatorial Region

- **Amy A. Simon-Miller**, D. S. Choi, J. H. Rogers, P. J. Gierasch
  
  1NASA's GSFC, 2ORAU/NASA's GSFC, 3British Astronomical Association, United Kingdom, 4Cornell University.

A detailed study of the chevron-shaped dark spots on the strong southern equatorial wind jet near 7.5 deg S planetographic latitude shows variations in velocity with longitude and time. The chevrons move with velocities near the maximum wind jet velocity of ~140 m/s, as deduced by the history of velocities at this latitude and the magnitude of the symmetric wind jet near 7 deg N latitude. Their repetitive nature is consistent with an inertia-gravity wave (n = 75-100) with phase speed up to 25 m/s, relative to the local flow, but the identity of this wave mode is not well constrained. However, high spatial resolution movies from Cassini images show that the chevrons oscillate in latitude with a ~7-day period. This oscillating motion has a wavelength of ~20 deg and a speed of ~100 m/s, following a pattern similar to that seen in the Rossby wave plumes of the North Equatorial Zone, and possibly reinforced by it, though they are not perfectly in phase. The transient anticyclonic South Equatorial Disturbance (SED) may be a similar wave feature, but moves at slower velocity. All data show chevron latitude variability, but it is unclear if this Rossby wave is present during other epochs, without time series movies that fully delineate it. In the presence of multiple wave modes, the difference in dominant cloud appearance between 7 deg N and 7.5 deg S may be due to the presence of the Great Red Spot, either through changes in stratification and stability or by acting as a wave boundary.

### 205.04 Jets and Water Clouds on Jupiter

- **Yuan Lian**, A. P. Showman
  
  1Ashima Research, 2Lunar and Planetary Lab, the University of Arizona.

Ground-based and spacecraft observations show that Jupiter exhibits multiple banded zonal jet structures. These banded jets correlate with dark and bright clouds, often called "belts" and "zones". The mechanisms that produce these banded zonal jets and clouds are poorly understood. Our previous studies showed that the latent heat released by condensation of water vapor could produce equatorial superrotation along with multiple zonal jets in the mid-to-high latitudes. However, that previous work assumed complete and instant removal of condensate and therefore could not predict the cloud formation. Here we present an improved 3D Jupiter model to investigate some effects of cloud microphysics on large-scale dynamics using a closed water cycle that includes condensation, three-dimensional advection of cloud material by the large-scale circulation, evaporation and sedimentation. We use a dry convective adjustment scheme to adjust the temperature towards a dry adiabat when atmospheric columns become convectively unstable, and the tracers are mixed within the unstable layers accordingly. Other physics parameterizations included in our model are the bottom drag and internal heat flux as well as the choices of either Newtonian heating scheme or gray radiative transfer. Given the poorly understood cloud microphysics, we perform case studies by treating the particle size and condensation/evaporation time scale as free parameters. We find that, in some cases, the active water cycle can produce multiple banded jets and clouds. However, the
equatorial jet is generally very weak in all the cases because of insufficient supply of eastward eddy momentum fluxes. These differences may result from differences in the overall vertical stratification, baroclinicity, and moisture distribution in our new models relative to the older ones; we expect to elucidate the dynamical mechanisms in continuing work.

205.05 Radiative Forcing of the Stratosphere of Jupiter from Cassini Observations
- Xi Zhang¹, C. A. Nixon², R. Shia¹, R. A. West¹, R. Morales-Juberias¹, R. Cosentino⁴, P. G. Irwin⁵, T. Dowling⁶, M. A. Allen¹, Y. L. Yung¹
¹Caltech, ²NASA GSFC/University of Maryland, ³JPL, ⁴New Mexico Institute of Mining and Technology, ⁵University of Oxford, United Kingdom, ⁶University of Louisville.

In this study we present a detailed analysis of the instantaneous zonally averaged radiative forcing of the Jovian stratosphere during the Cassini flyby in Dec. 2000. It provides the necessary data for an accurate simulation of the state of the stratosphere of Jupiter. First, we retrieved the global map of stratospheric temperature field and hydrocarbon species based on the measurements from the Cassini Composite Infrared Spectrometer (CIRS). The associated uncertainties are carefully characterized. From the simultaneous observations by the multiple filters of Cassini Imaging Science Subsystem (ISS), a global map of stratospheric aerosol is obtained via a nonlinear optimization approach. Large difference between the scattering properties of aerosols and clouds in the equatorial region and polar region indicate different types of aerosol and clouds in the two regions. Secondly, based on the retrieved data, a line-by-line radiative transfer model including the Non-LTE effect is introduced to calculate the solar heating and mid-infrared cooling rates for each latitude and altitude. The fractal aggregated multisphere particles with monomer radius of tens of nanometers contribute to the heat source in the upper stratosphere of the polar region. Finally, preliminary results of a stratospheric circulation model driven by the radiative forcing and a two-dimensional chemical transport model forced by the circulation will be presented.

205.06 A Three-dimensional Non-spherical Calculation Of The Rotationally Distorted Shape And Internal Structure Of A Model Of Jupiter With A Polytropic Index Of Unity
- Keke Zhang¹, D. Kong¹, G. Schubert², J. Anderson³
¹University of Exeter, United Kingdom, ²UCLA, ³JPL.

An accurate calculation of the rotationally distorted shape and internal structure of Jupiter is required to understand the high-precision gravitational field that will be measured by the Juno spacecraft now on its way to Jupiter. We present a three-dimensional non-spherical numerical calculation of the shape and internal structure of a model of Jupiter with a polytropic index of unity. The calculation is based on a finite element method and accounts for the full effects of rotation. After validating the numerical approach against the asymptotic solution of Chandrasekhar (1933) that is valid only for a slowly rotating gaseous planet, we apply it to a model of Jupiter whose rapid rotation causes a significant departure from spherical geometry. The two-dimensional distribution of the density and the pressure within Jupiter is then determined via a hybrid inverse approach by matching the a priori unknown coefficient in the equation of state to the observed shape of Jupiter. After obtaining the two-dimensional distribution of Jupiter's density, we then compute the zonal gravity coefficients and the total mass from the non-spherical Jupiter model that takes full account of rotation-induced shape changes. Our non-spherical model with a polytrope of unit index is able to produce the known mass and zonal gravitational coefficients of Jupiter. Chandrasekhar, S. 1933, The equilibrium of distorted polytropes, MNRAS 93, 390.

206 Mars Atmosphere: Exosphere to Surface
Tuesday, 1:30 PM - 3:30 PM, Carson 1/2

206.01 Time-variability Of Martian Water Loss, Observed With SPICAM On Mars Express
- Michael S. Chaffin¹, J. Chaufray², I. Stewart³, N. Schneider¹
¹University of Colorado, ²LATMOS-IPSL, France.
There is a great deal of evidence indicating that the amount of surface liquid water on Mars has decreased dramatically over the course of Martian history. One factor controlling this decline is the thermal loss to space of hydrogen, which is produced from water in the ionosphere. This work demonstrates that hydrogen (and therefore water) loss from the Martian atmosphere is much more time-variable than previously thought, with exobase temperature and density varying by a factor of at least two over a period of two months in the fall of 2007, as observed by the UV spectrometer SPICAM on the ESA Mars Express spacecraft. In preparation for NASA's MAVEN mission, scheduled to launch in 2013 and observe the loss of hydrogen from Mars beginning in 2014, the number of analyzed Mars hydrogen corona observations has been quadrupled, revealing the new and unexpected behavior. While the mechanism responsible for the changes in exobase temperature and density has yet to be analyzed, the data show little correlation with available solar input measurements, indicating that some unmonitored mechanism is responsible for dramatic changes in the thermal escape rate of hydrogen at present, and possibly throughout Martian history. This work is supported by NASA Earth and Space Science Fellowship Grant Number 11-Planet11F-0060.

206.02 The Effects of Hydrogen on the Ionosphere of Mars

Majd Mayyasi-Matta1, P. Withers1, M. Mendillo1
1Boston University.

A 1-D model is used to study the effects of Hydrogen chemistry on the composition of the Martian ionosphere. The presence of H and H2 neutral species in the atmosphere of Mars lead to the production of several hydrogenated ions. We simulate different conditions and find that the topside ionosphere can contain appreciable amounts of hydrogenated species such as H3+, OH+ and HCO+. Comparisons of a subset of the modeled non-hydrogenated ions are made with Viking ion density measurements. Future comparisons will be available from the Neutral Gas and Ions Mass Spectrometer (NGIMS) measurements when the Mars Atmosphere and Volatile EvolutioN (MAVEN) mission arrives at Mars.

206.03 Evaluating the Importance of Pickup Oxygen Ion Precipitation to the Martian Thermosphere

Xiaohua Fang1, S. Bougher2, R. Johnson3, J. Luhmann4
1University of Colorado, 2University of Michigan, 3University of Virginia, 4University of California.

Ionization of Martian neutral species and the subsequent pickup by the solar wind provides not only a non-thermal atmospheric loss process, but also a significant source to the thermospheric energy budget, depending on whether the ions ultimately return or leave to the planet. This study represents the first attempt to quantify the importance of returning energetic pickup ions to the Martian thermosphere on a global scale. To accomplish this, two global models are coupled: the Monte Carlo Pickup Ion Transport model (MCPIT) for evaluating particle precipitation at the exobase, and the Mars Thermosphere General Circulation Model (MTGCM) for the response in the upper atmosphere. Three cases are selected to explore the ion precipitation importance under nominal quiet, active, and extreme solar wind conditions at solar maximum, respectively. It is found that under quiet conditions, the particle input results in small but noticeable thermospheric temperature enhancement (by up to 8 K) at some place in the hemisphere that is opposite to the upstream convection electric field direction. In an active case in which the solar wind speed is as high as 1200 km/s with all the other parameters kept the same, the temperature is significantly enhanced by up to 14 K, which is large enough to be experimentally detected. We also examine the responses of the thermosphere to an extreme case, in which the impinging solar wind has greatly elevated dynamic pressure and magnetic field. In the extreme scenario, the thermosphere reacts dramatically: heating from pickup ion bombardment can totally overwhelm the solar EUV heating on the dayside, and the horizontal winds become much faster as well. It is suggested that precipitating pickup ions represent an important energy source to the Martian thermosphere and should be taken into account in global atmospheric modeling, particularly during disturbed solar wind conditions.

206.04 Evidence for Significantly Enriched Heavy Oxygen in Mars Atmosphere

Timothy A. Livengood1, T. Kostiuk1, T. Hewagama1, R. L. Smith2, G. Sonnabend3, M. Sornig5, T. Stangier5
1CRESST/UMD/GSFC, 2NASA/GSFC, 3U of Cologne, Germany, 5Rhenish Institute for Environmental Research, Germany.
The loss of primordial atmosphere from Mars should have resulted in significant enrichment of heavy isotopes in Mars carbon dioxide, which has not previously been observed. Atmospheric isotope ratios provide important context in which to interpret the geochemistry of Mars meteorites and future returned samples. Biotic and abiotic isotope-fractionation occur relative to the available chemical reservoirs, enabling a tool to interpret chemical fossils for Mars astrobiology. We report on high-resolution infrared spectroscopy of Mars obtained in October 2007 from the NASA IRTF, targeting the sub-solar latitude in late southern summer. The measured spectra include fully-resolved pressure-broadened absorption features due to cool tropospheric carbon dioxide above the warm surface and an absorption feature that is definitively due to the isotopologue that is singly-substituted with oxygen-18. The ratio of oxygen-18 to the normal isotope can be recovered from fitting the whole spectrum in absorption against the warm surface. The mean value of the retrieved oxygen-18 fraction differs insignificantly from the terrestrial VSMOW standard, consistent with prior in situ and remote-spectroscopy efforts, which found only modest differences from VSMOW. Comparison between the retrieved isotope ratio and the surface temperature reveals that the concentration of isotopically heavy carbon dioxide is correlated with the local surface temperature, suggesting that the heavy gas is preferentially adsorbed by the regolith at low night temperatures and released in warm day temperatures. The minimum retrieved isotope fraction is consistent with the solar wind ratio measured by the Genesis mission, indicating that any accuracy error in the spectroscopic parameters used for the retrieval must have resulted in underestimating heavy-isotope enrichment. The maximum retrieved isotope ratio is significantly enhanced relative to VSMOW and relative to prior retrievals on Mars. We provide additional evidence that enhancement has been previously observed but was unrecognized, and briefly present follow-up observations from May 2012.

206.05 Latitudinal Maps of [HDO]/[H2O] During Mars’ Aphelion Season
- Robert E. Novak1, M. J. Mumma2, G. L. Villanueva2
  1Iona College, 2NASA’s GSFC.

We report latitudinal maps of HDO and H2O taken at three seasonal points during Mars’ aphelion season. These observations were taken at Ls = 50° (26 March 2008) and Ls = 72° (2 April 2010) using CSHELL at NASA’s IRTF and Ls = 117° (28 May 2012) using NIRSPEC at the Keck II Telescope. The spectrometers, with the entrance slit positioned N-S on Mars centered at the sub-Earth point, produced spectral/spatial images. Spectra were extracted at 0.6 arc-second intervals. Individual spectral lines were measured near 3.67 μm (HDO) and 3.29 μm (H2O). The column densities were obtained by comparing the observed lines to those of a multi-layered, radiative transfer model. The model includes solar Fraunhofer lines, two-way transmission through Mars’ atmosphere, thermal emission from Mars’ surface and atmosphere, and a one-way transmission through the Earth’s atmosphere. Latitudinal maps of HDO, H2O, and their ratios were then constructed. The [HDO]/[H2O] ratios have been found to be larger than those on Earth and they vary with both latitude and season. For the Ls = 50° observations, the ratio peaks near the sub-solar latitude (19°N, [HDO]/[H2O] ~ 6.9 VSMOW ) and decreases towards both the North and South polar-regions. At Ls = 72° and Ls = 117°, column densities of both HDO and H2O and their ratios increase from the Southern hemisphere to the North polar-region. Our results for H2O column densities will be compared to TES results. The results for HDO and the [HDO]/[H2O] ratios will be compared to model results. This work was partially funded by grants from NASA’s Planetary Astronomy Program (344-32-51-96), NASA’s Astrobiology Program (344-53-51), and the NSF-RUI Program (AST-805540). We thank the administration and staff of the NASA-IRTF and the Keck Observatory for awarding observing times and coordinating our observations.

206.06 Ancient Martian Atmosphere: The Oxidizing–Reducing Transition
- Justin Deighan1, A. D. Howard1, R. E. Johnson1
  1University of Virginia.

Modern Mars is a cold, dry world where weathering is slow and volcanic activity is dormant. This allows for the accumulation of 0.13% O2 in the thin CO2 dominated atmosphere, making it relatively oxidizing. In contrast, during the Noachian and Hesperian eras > 3 Gya, Mars is thought to have had extended warm periods with persistent liquid water and intense volcanic eruptions. The atmosphere was likely much thicker, though still CO2 dominated, and oxidizing atmospheric species were either weathered out or reduced by volcanic gases. We examine here the
photochemical transition of the atmosphere between these two extremes—oxidizing and reducing—as driven by
to quantity dominant processes and plausible O loss rates. These are compared with the
rates of photochemical H₂ production and escape to space to determine the redox state of the atmosphere. Our
atmospheric photochemistry model is coupled to a 1D radiative-convective model to capture temperature profile
feedback due to the production of O₃ in oxidizing atmospheres. Studying the transition between an oxidizing and
reducing atmosphere on Mars is of interest for understanding weathering mineralogy, loss of atmosphere, and
habitability for life. This work was supported by a grant from the NASA Planetary Atmosphere program.

206.07 Winds and Temperatures in the Martian Middle Atmosphere from Infrared Heterodyne Spectroscopy

- Guido Sonnabend¹, D. Stupar¹, C. Reinerth¹, M. Sornig², M. Herrmann¹, T. Stangier², T. Kostiuk³, T.
  Livengood⁴, K. Fast⁵

¹University of Cologne, Germany, ²Rhenish Institute for Environmental Research at the University of
  Cologne, Germany, ³NASA GSFC, ⁴CRESST/UMD/GSFC, ⁵NASA.

We present observations of mesospheric zonal winds and temperatures on Mars around northern hemisphere
Summer solstice. Data was gathered using ground based ultra-high resolution spectroscopic observations of CO₂
features around 10 μm wavelength. Observations were carried out during October 2007 using the NASA GSFC
instrument HIPWAC at the NASA IRTF and March 2012 using the Cologne Tuneable Heterodyne Infrared
Spectrometer (THIS) at the McMath-Pierce Solar Telescope on Kitt Peak, Arizona. During this times Mars was in
late Northern winter (Ls=330°, 2007) to and close to the northern hemisphere Summer Solstice (Ls=90°, 2012).
Non-LTE processes in the atmosphere of Mars lead to an enhanced mesospheric emission of CO₂ molecules in the
9 and 10 μm band. These narrow emission features can be used to measure Doppler-shifts induced by winds. At
the same time the linewidth provides temperature information. The non-LTE emission is contributed from the
Mesosphere (50-90 km). Heterodyne techniques allow a spectral resolution of more than 10⁷ and thus the
observation of fully resolved molecular features and the retrieval of Doppler shifts down to ~1 MHz. In the case of
our observations this coresponds to an accuracy of 10 m/s while temperatures can be retrieved to an accuracy
of ~5 K. Spectra of the fully resolved CO₂ P(12) line were taken on the day side of Mars at various positions on the
disk to provide a good latitudinal and longitudinal coverage. This work was funded by the Deutsche
Forschungsgemeinschaft through grant SO879/3-1.

206.08 Modelling the Martian CO₂ Ice Clouds

- Constantino Listowski¹, A. Määttänen¹, F. Montmessin¹, F. Lefèvre¹

¹LATMOS, France.

Martian CO₂ ice cloud formation represents a rare phenomenon in the Solar System: the condensation of the main
component of the atmosphere. Moreover, on Mars, condensation occurs in a rarefied atmosphere (large Knudsen
numbers, Kn) that limits the growth efficiency. These clouds form in the polar winter troposphere and in the
mesosphere near the equator. CO₂ ice cloud modeling has turned out to be challenging: recent efforts (e.g. [1]) fail
in explaining typical small sizes (80 nm-130 nm) observed for mesospheric clouds [2]. Supercold pockets (T<< T₉₉)
which appear to be common in the mesosphere [3],might be exclusively responsible of the formation of such
clouds, as a consequence of gravity waves propagating throughout the atmosphere [4]. In order to understand by
modeling the effect CO₂ clouds could have on the Martian climate, one needs to properly predict the crystal sizes,
and so the growth rates involved. We will show that Earth microphysical crystal growth models, which deal with
the condensation of trace gases, are misleading when transposed for CO₂ cloud formation: they overestimate the
growth rates at high saturation ratios. On the other hand, an approach based on the continuum regime (small Kn),
corrected to account for the free molecular regime (high Kn) remains efficient. We present our new approach for
modelling the growth of Martian CO₂ cloud crystals, investigated with a 1D-microphysical model. [1] Colaprete, A.,

206.09 A Search for Localized Water Vapor Sources on Mars Utilizing Viking MAWD Data
Recent spacecraft results suggest there may be multiple locations in the mid-latitude regions of Mars currently experiencing hydrological activity. We are investigating whether these locations may be surface sources of atmospheric water vapor that are observable from orbit. The Viking Mars Atmospheric Water Detector (MAWD) instrument acquired a unique column water vapor dataset which samples a wide range of local times, seasons, latitudes and longitudes. We have searched the MAWD data set for localized spikes of column water vapor content at mid-latitude regions, and have found 72 raster-averaged data points showing localized regions with significantly elevated column water, with values between 13 and 71.5 precipitable microns at latitudes ranging from 38.94 to -52.24 degrees. These observations occurred primarily between 6-10 and 14-18 hours Mars local time, and predominately during the Martian northern summer season. We are currently validating these measurements and correlating their locations with surface features and with orbital brightness temperature measurements.

206.10 Precipitation Rates in a Stable Warm and Wet Climate on Early Mars
- Richard Urata¹, O. B. Toon²
  ¹University of Colorado, Boulder.

The Noachian river valley networks on Mars are thought to have formed under warm and wet conditions. Two conditions need to be met. The surface temperatures must have been warm enough to allow liquid water at the surface, and enough precipitation must have fallen to the surface on a yearly basis to maintain at least a seasonal flow of water, or flash floods over a long period of time. Using a general circulation model, we find that a warm climate could have been sustained by the greenhouse effect created by the hydrological cycle on early Mars with a 500 mb CO₂ atmosphere, and a reduced solar constant. The required conditions for such a climate are: an initial injection of atmospheric water or a low-albedo ice cap, relatively high clouds with particle sizes near 10 μm that do not precipitate efficiently, and horizontally extensive clouds that trap outgoing infrared radiation. We also find that to have significant precipitation at latitudes where the river valleys are found requires local sources of water at the surface. In the case of a large initial injection of atmospheric water, such local sources of water can form as snow deposits when the planet is in high obliquity (≥45°). Oceans can also act as a local source of water. We present simulation results with oceans that reach to -2550 m (Arabia shoreline in the northern hemisphere, Hellas basin, and Argyre basin in the southern hemisphere). Such oceans freeze quickly and form ice layers that are meters thick. However the amount of water sublimated from the ice is sufficient to create significant precipitation in non-polar latitudes at all obliquities. With oceans, the obliquity determines the latitude for highest precipitation. Then the obliquity cycle explains why the river valleys are found across such a wide range of latitudes.

206.11 Winds, Waves and Shorelines from Ancient Martian Seas
- Don Banfield¹, M. Donelan², L. Cavaleri³
  ²Cornell Univ., ³U. Miami, ³ISMAR-CNR, Italy.

We have explored possible atmospheric and oceanic conditions on early Mars (i.e. pressure, wind speed, fetch, salinity/viscosity, etc.) under which waves, hence shorelines, would be created. To estimate the wind-driven wave spectra on ancient martian seas under various conditions, we have adapted terrestrial ocean wave generation models to allow for significant changes in air density (pressure, temperature, composition), fluid viscosity and gravity. These extreme changes to simulate early Mars push the models well beyond the conditions for which they were built and tested. To validate the models under these exotic conditions, we also conducted wave flume experiments using the NASA Ames MARSWIT low-pressure wind tunnel facility. In these experiments, we altered the air density (via changing pressure) and recorded the waves produced at various wind speeds for fetches up to 5.6 m. Our findings differ from those of a similar earlier study (Lorenz et al., 2004), which found essentially no waves at pressures less than about 500 mbar. Instead, under sufficiently strong winds (>25 m/s), we found evidence of waves produced at pressures as low as 40 mbar (the lowest we tested). We attribute the difference to the greater depth and fetch in our flume, which both favor a more realistic experiment in wave generation over open water. With estimates of wave spectra for various early Mars environmental conditions in hand, we then use
an approach similar to that in Kraal et al. (2006) to estimate their shoreline forming capabilities. We will report the boundary separating conditions where waves (and shorelines) are expected to form from those where they are not. We will also report on the scenario of “ice-push” as an alternative method of shoreline creation for ice-covered seas. This work was funded by NASA’s Mars Fundamental Research Program.

206.12 Science of Global Climate Modeling: Confirmation from Discoveries on Mars
- William K. Hartmann
  *Planetary Science Institute.*

As early as 1993, analysis of obliquity changes on Mars revealed irregular cycles of high excursion, over 45°. Further obliquity analyses indicated that insolation and climatic conditions vary with time, with the four most recent episodes of obliquity >45° occurring about 5.5, 8, 9, and 15 Myr. Various researchers applied global climate models, using Martian parameters and obliquity changes. The models (independent of Martian geomorphological observations) indicate exceptional climate conditions during the high-obliquity episodes at >45°, with localized massive ice deposition effects east of Hellas and on the west slopes of Tharsis. At last year’s DPS my co-authors and I detailed evidence of unusual active glaciation in Greg crater, near the center of the predicted area of ice accumulation during high obliquity. We found that the timescale of glacial surface layer activity matches the general 5-15 Myr timescale of the last episodes of high obliquity and ice deposition. Radar results confirm ice deposits in debris aprons concentrated in the same area. Less direct evidence has also been found for glacial ice deposits in the west Tharsis region. Here I emphasize that if the models can be adjusted to Mars and then successfully indicate unusual, specific features that we see there, it is an argument for the robustness of climate modeling in general. In recent years we have see various public figures casting doubt on the validity of terrestrial global modeling. The successful match of Martian climate modeling with direct Martian geological and chronometric observations provides an interesting and teachable refutation of the attacks on climate science.


207 Asteroids: Dawn at Vesta
Tuesday, 1:30 PM - 3:30 PM, Reno Ballroom

207.01 Vesta: A Geological Overview
  1DLR, Institute of Planetary Research, Germany, 2UCLA, Institute of Geophysics, 3Jet Propulsion Laboratory, California Institute of Technology, 4Brown University, 5Planetary Science Institute, 6Arizona State University, 7Johns Hopkins University Applied Physics Laboratory, 8Lunar and Planetary Institute, 9Istituto Nazionale di Astrofisica, Italy, 10Westfälische Wilhelms-Universität, Germany, 11Universität Braunschweig, Germany, 12NASA Lunar Science Institute, 13Bear Fight Institute, 14University of Tennessee, 15Max Planck Institute (MPS), Germany, 16Freie Universität Berlin, Germany, 17Institute of Technology.

The Dawn spacecraft has collected over 28,000 images and a wealth of spectral data providing nearly complete coverage of Vesta’s surface with multiple views. These data enable analysis of Vesta’s diverse geology including impact craters of all sizes and unusual shapes, a variety of ejecta blankets, large troughs extending around the equatorial region, impact basins, enigmatic dark material, and considerable evidence for mass wasting and surface alteration features. Two large impact basins, Veneneia (400km) underlying the larger Rheasilvia basin (500km) dominate the south pole. Rheasilvia exhibits a huge central peak, with total relief of -22km to 19km, and steep scarps with mass wasting features. Vesta’s global tectonic patterns (two distinct sets of large troughs almost parallel to the equator) strongly correlate with the locations of the two south polar impact basins, and were likely created by their formation. Numerous unusual asymmetric impact craters and ejecta indicate the strong role...

207.02 Vesta Mineralogy after Dawn global Observations

- Maria Cristina De Sanctis1, E. Ammannito1, F. Capaccioni1, M. T. Capria1, F. Carraro1, S. Fonte1, A. Frigeri1, A. Longobardo1, G. Magni1, S. Marchi1, E. Palomba1, F. Tosi1, F. Zambon1, J. P. Combe2, T. B. McCord2, L. A. Mc Fadden3, H. McSween4, D. W. Mittlefehldt4, C. M. Pieters5, R. Jaumann7, K. Stephan7, C. A. Raymond8, C. T. Russell9
1Istituto Nazionale di Astrofisica, Italy, 2Bear Fight Institute, 3NASA - GSFC, 4Department of Earth and Planetary Sciences - University of Tennessee, 5NASA - JSC, 6Department of Geological Sciences - Brown University, 7DLR, Germany, 8NASA - JPL, 9Institute of Geophysics and Planetary Physics - University of California.

The Dawn mission has completed its mapping phases at Vesta and millions of spectra have been acquired by the Visible and InfraRed Mapping Spectrometer, VIR(1). VIR characterizes and maps the mineral distribution on Vesta - strengthening the Vesta HED linkage- and provides new insights into Vesta’s formation and evolution(2,3). VIR spectra are dominated by pyroxene absorptions near 0.9 and 2.0 μm and large thermal emission beyond 3.5 μm. Although almost all surface materials exhibit howardite-like spectra, some large regions can be interpreted to be richer in eucritic (basaltic) material and others richer in diogenitic (Mg-orthopyroxenitic) material. The Rheasilvia basin contains Mg-pyroxene-rich terrains for example. Vesta’ s surface shows considerable diversity at local scales. Many bright and dark areas(3,4) are associated with various geological features and show remarkably different morphology. Moreover, VIR detected statistically significant, but weak, variations at 2.8 μm that have been interpreted as indicating the presence of OH-bearing phases on the surface(5). The OH distribution is uneven with large regions lacking this absorption feature. Associations of 2.8 μm band with morphological structures indicate complex process responsible for OH. Vesta exhibits large spectral variations that often correlate with geological structures, indicating a complex geological and evolutionary history, more similar to that of the terrestrial planets than to other asteroids visited by spacecrafts. Grateful Support of the Dawn Instrument, Operations, and Science Teams is acknowledged. This work is supported by an the Italian Space Agency (ASI) grant n°I/004/12/0, a DLR grant, and by NASA through the Dawn project and the Dawn at Vesta Participating Scientist grant. References: (1) De Sanctis M.C. et al., Space Sci. Rev., 2010. (2) Russell C.T et al., Science, 336, 684 2012. (3) De Sanctis M.C. et al., Science, 336, 697, 2012 (4) McCord, Nature, submitted (5) De Sanctis M.C. et al., Science, submitted.

207.03 Chemical mapping of Vesta

1Planetary Science Institute, 2NASA Johnson Space Center, 3Johns Hopkins University Applied Physics Laboratory, 4Smithsonian Institution, 5University of Tennessee, 6United States Geological Survey, 7University of Toulouse, France, 8Jet Propulsion Laboratory, Caltech, 9Institute of Geophysics and Planetary Physics - University of California Los Angeles.

Vesta’s surface mineralogy and composition have been studied for decades via telescopic spectroscopy and laboratory analyses of the howardite, eucrite, and diogenite (HED) meteorites, which are thought to originate from Vesta. Visible and infrared reflectance measurements by Dawn have broadly confirmed the paradigm established by Earth-based work, strengthening the Vesta-HED connection. The Dawn mission has achieved a milestone by
completing the first chemical measurements of a main-belt asteroid using nuclear spectroscopy. Dawn’s Gamma Ray and Neutron Detector (GRaND) has globally mapped the composition of Vesta, including the portions of the northern hemisphere not illuminated by solar radiation. GRaND is sensitive to the composition of the bulk regolith to depths of several decimeters. Abundances and/or detection limits for specific elements and elemental ratios, such as H, Fe, Si, Fe/O, Fe/Si, and K, have been measured. Variations in the average atomic mass and neutron macroscopic absorption cross section have been characterized. The measurements constrain the relative proportions of HED whole-rock end-members, providing measurements of the pyroxene and plagioclase content of the regolith, thereby constraining the processes underlying Vesta’s differentiation and crustal evolution. The spatial resolution of GRaND is sufficient to determine basin-average compositions of Veneneia and Rheasilvia, which may contain outcrops of Vesta’s olivine-rich mantle. While the elemental composition of Vesta’s regolith is similar to the meteorites, there are notable departures from HED whole-rock compositions. While these differences are not sufficient to topple the Vesta-HED paradigm, they provide insight into global-scale processes that have shaped Vesta’s surface. Questions addressed by the analysis of GRaND data include: (i) Is Vesta the source of the Fe-rich mesosiderites? (ii) Are evolved, igneous lithologies present on Vesta’s surface? (iii) What are the origins of exogenic materials found in Vesta’s regolith? (iv) Is the vestan mantle exposed within the southern basins?

207.04 Comparison Of Dawn, Hubble Space Telescope, And Ground-based Observations Of Vesta: What We Learned So Far?


Max Planck Institute for Solar System Research, Germany, Planetary Science Institute, University of California Los Angeles, USGS Flagstaff, Jet Propulsion Laboratory California Institute of Technology, Univ. of North Dakota.

NASA’s Dawn spacecraft observations of asteroid Vesta have revealed a surface that shows highest diversity in albedo, color and composition than any asteroid visited by a spacecraft so far. Ground-based and HST observations of Vesta showed hemispherical and rotational variations attributed to igneous and impact processes that have shaped Vesta’s surface since its formation. Here we compare interpretation of Vesta’s rotation period, pole position, albedo, color, and compositional properties from ground-based telescopes, HST and Dawn. Our goal is to provide ground truth for prior observations and help identify the limits of ground/HST-based studies of asteroids. We also present HST and Dawn albedo and color maps of Vesta in the Claudia (used by the Dawn team) and IAU (similar to Thomas et al. 1997) coordinate systems. These maps should help observers orient themselves and identify compositional and albedo features from prior studies. We have linked several albedo features identified on HST maps to morphological features on Vesta using Dawn Framing Camera data. Rotational spectral variations observed from ground-based studies are also consistent with those observed by Dawn. While past interpretation of some of these features was tenuous, they were reasonable for the limitations set by the data and our knowledge of Vesta and HED meteorites at that time. Our analysis shows ground-based and HST observations are critical for our understanding of small bodies and provide valuable support ongoing and future spacecraft missions. This research was supported by NASA Dawn Participating Scientist Program Grant NNX10AR22G-DAVPS, and NASA Planetary Geology and Geophysics Grant NNX07AP73G.

207.05 Nature of Orange Ejecta Around Oppia and Octavia Craters on Vesta from Dawn Framing Camera


Max Planck Institute for Solar System Research, Germany, USGS, PSI, JHUAPL, UCLA.

NASA’s Dawn spacecraft entered orbit around asteroid (4) Vesta in July 2011 for a year-long mapping orbit. The Dawn Framing Camera (FC) discovered enigmatic orange material on Vesta. FC images revealed diffuse orange ejecta around two impact craters, 34-km diameter Oppia, and 30-km diameter Octavia, as well as numerous sharp-edge orange units in the equatorial region. This orange material is seen in FC ratio images similar to those used in the Clementine mission (R=0.75/0.45 microns, G=0.75/0.92 microns, and B=0.45/0.75 microns). The G channel helps quantify the pyroxene band depth at 0.90 micron (greener areas have higher ratio i.e. deeper band). The two
other channels depend on the visible spectral slope (redder areas have positive visible slope; bluer areas have negative visible slope). Here we explore the composition and meteoritical analogs for this material on Vesta. Interestingly the orange ejecta around Oppia correspond to olivine-rich unit observed by Gaffey (1997). Clementine ratio images reveal that orange material around the craters forms an asymmetric ejecta preferentially extending southeast for Oppia and northwest for Octavia. The non-circular shape of Oppia crater coupled with preferential ejecta distribution suggests an impact on a slope. Color properties of Oppia ejecta show a steep visible spectral slope (creating the orange color in Clementine ratios images) and a weak 0.75/0.92 microns band ratio, thus having a shallow 0.90-micron pyroxene band compared to global average. The steep visible slope and weaker 0.90-micron pyroxene absorption implies that another component or process has modified the original surface. Comparison with laboratory of HEDs suggests that impact melt can mimic the color characteristics of orange material around Oppia crater. Further investigations are underway to constrain the origin and nature of this orange material. NASA Dawn Participating Scientist Program Grant NNH09ZDA001N-DAVPS, and NASA Planetary Geology and Geophysics Grant NNX07AP73G supported parts of this research.

207.06 The Roughness and Albedo of 4 Vesta and Vestoids
- Bonnie J. Buratti1, M. D. Hicks1, J. Y. Li2, D. G. Blackburn3, J. K. Hillier4, M. V. Reddy5, S. E. Schroder5, A. Nathues5, C. A. Raymond1, C. T. Russell6, S. Mottola7, T. Roatsch7
1 JPL, 2 PSI, 3 Univ. Arkansas, 4 Grays Harbor College, 5 MPI, Germany, 6 UCLA, 7 DLR, Germany.

Dawn measurements of 4 Vesta represent the first detailed investigation of a V-type asteroid. When combined with ground-based observations of vestoids, which are believed to be fragments of Vesta, these data enable a comparison of the surface properties of this class of asteroid with other small bodies. Such comparisons have been made with two important photometric parameters: roughness and albedo. We find that the macroscopic roughness, which includes everything from large features such as craters, mountains, and ridges, down to small clumps of particles, differs for Vesta and vestoids. Vestoids are rougher than their parent body, and furthermore, Vesta appears to be smooth mainly at small size scales. This result suggests that small craters and clumps of particles are infilled with dust from ejecta which is kept on the surface by Vesta’s planet-like gravity. In addition, Vesta could accrete dust from its surroundings in the asteroid belt. Analysis of the global albedo of Vesta shows that the variegations on this body are far greater than any asteroid studied so far by a spacecraft. The albedo seems to be bifurcated into two distinct regimes. This bifurcation appears to be exogenous in origin.

207.07 Impact Crater And Basin Morphologies On Vesta In Solar System Context
- Paul M. Schenk1, D. P. O’Brien2, J. Vincent3, S. Marchi4, D. Williams5, M. Sykes5
1 Lunar & Planetary Inst., 2 Planetary Science Institute, 3 Max Planck Institute, Germany, 4 NASA Lunar Science Institute, 5 Arizona State University.

Vesta occupies a unique niche as the smallest silicate body large enough to retain complex crater morphologies that has been observed to date. Dawn global imaging and topographic mapping (@ 20-70 m scales) reveals that the 505-km-wide impact basin Rheasilvia has a large central complex, steep rim scarp and bowl-shaped floor, elements similar to large impact basins on midsize icy satellites of Saturn. Impact melt and debris volumes are generally lower on Vesta and on icy satellites than on lunar basins. These similarities suggest that the Rheasilvia morphology may be a consequence of large impacts into lower gravity objects. Lower impact velocities and planetary curvature may also be important. A number of pre-Rheasilvia impact basins occur but are degraded and original morphologies may be difficult to determine. Post-Rheasilvia impact craters are relatively pristine but are no larger than 70 km across. Flow-like morphologies occur within ejecta blankets but melt volumes within crater floors are low, allowing floor structures to be mapped. Low melt volumes are consistent with low melt production due to lower impact velocities on Vesta. The radial extent of ejecta deposits appears to scale similarly on Vesta and the Moon, though some cases occur where ejecta appears to be more extensive. Rheasiliva ejecta covers at least all of the southern hemisphere and may be more than 5 km thick near the rim. Depths of post-Rheasilvia impact craters are broadly consistent with simple lunar craters but also suggest that the transition diameter between simple and complex craters on Vesta may be smaller than expected. Recent revisions of simple-complex transitions on the Saturnian icy satellites also suggest smaller than expected transition diameters. These new trends may indicate a weaker dependency on gravity that previously thought.
207.08 Exploration of Saturnalia Fossa and Associated Structures in Vesta’s Northern Hemisphere

Jennifer Scully¹, C. T. Russell¹, A. Yin¹, D. L. Buczkowski², D. A. Williams³, H. Hiesinger⁴, W. B. Garry⁵, R. A. Yingst⁵, D. T. Blewett⁵, T. Roatsch⁶, R. W. Gaskell⁷, F. Preusker⁸, L. Le Corre⁷, E. Ammannito⁹, R. Jaumann⁶, C. M. Pieters⁹, C. A. Raymond¹⁰

¹University of California Los Angeles, ²JHU-APL, ³Arizona State University, ⁴Wilhelm Westfalisch University, Germany, ⁵PSI, ⁶DLR, Germany, ⁷Max Planck Institute, Germany, ⁸INAF/IFSI, Italy, ⁹Brown University, ¹⁰Jet Propulsion Laboratory, California Institute of Technology.

Since its arrival at Vesta on July 16th 2011, NASA’s Dawn spacecraft has collected spectacular imaging, compositional and geophysical data. Dawn is scheduled to depart Vesta on August 26th and during this eventful year many unexpected discoveries have been made about this diverse asteroid. One such discovery is the Saturnalia Fossa trough in Vesta’s northern hemisphere. Saturnalia Fossa is the chief structure of at least 5 parallel troughs, many of which partly coalesce into one another at various locations. The sizeable Saturnalia Fossa dominates Vesta’s northern hemisphere and lends its name to the Saturnalia Ridge and Trough Terrain. Saturnalia Fossa has a maximum width of ~39 km, making it almost twice the width of the ~ 22 km wide Divalia Fossa equatorial trough. Currently Saturnalia Fossa (~366 km long) is shorter than Divalia Fossa (~465 km long) (Buczkowski et al., 2012, submitted to GRL). But, Saturnalia Fossa extends into the currently shadowed northern region and its length will increase as Dawn gains coverage in this enigmatic area. The northern troughs are covered in an obscuring layer of regolith, which makes identifying their specific form challenging. Comparative planetology, along with the analysis of Dawn data, helps to indicate whether the troughs are graben or another structure. The orientation of the troughs makes it likely that their formation is linked to that of the southern Veneneia basin (Buczkowski et al., 2011, AGU). There are many smaller structures, which include grooves, pit crater chains and small ridges that are preferentially oriented sub-parallel or sub-perpendicular to the troughs. This suggests that they have a related formation mechanism. An initial analysis of the distribution of the troughs and smaller structures indicates that they are oriented as if they were formed by large-scale shearing. This shear is possibly a result of the Veneneia-forming impact.

207.09 The Crater Chains of Vesta - a Morphological Study

Uri Carsenty¹, B. W. Denevi², R. J. Wagner¹, P. Schenk³, S. F. Hviid¹, D. L. Buczkowski², R. Jaumann¹, C. A. Raymond⁵, C. T. Russell⁵

¹DLR, Germany, ²Johns Hopkins University APL, ³LPI, ⁴JPL, California Institute of Technology, ⁵UCLA, Institute of Geophysics.

The Dawn spacecraft spent 141 days in the Low Mapping Orbit (LAMO) around Vesta obtaining 10251 images with an average resolution of 20m per pixel. The surface of Vesta displays a diverse geological structure - numerous impact craters, extensive ejecta blankets, giant troughs around the equator, impact basins, and regions with enigmatic dark as well as bright material (1). The LAMO imaging data set has been used to search, over the entire illuminated surface, for crater chains, which are groups of depressions (round or elongated) in mostly linear alignments - resembling a chain of pearls. More than 300 features were identified as crater chains most of which have an East - West orientation. Based on morphology the observed crater chains were divided into 5 subgroups. 1) Single crater chain (A) - a linear alignment of craters associated with other types of linear features (e.g. grooves, faults, troughs, ridges, or trenches). 2) Single crater chain (NA) - a linear alignment of craters not associated with other types of linear features. 3) Crater chain families - segments of short crater chains aligned parallel to each other. Some are associated with lineaments and some are not. 4) Swarm - a wide “band” of craters stretching in the East - West direction. 5) Special cases which do not fit in the other groups or are mixtures of the other types. The global distribution of crater chains and crater counts will be used to analyze the various morphological groups. Hypotheses for the formation mechanisms of the different groups will be explored. (1) Jaumann, et al, 2012 - Science 336,687-690.

207.10 High Resolution Topography for Thermal Modeling on Vesta

Eric Palmer⁴, M. V. Sykes⁴, R. W. Gaskell⁵, J. Li⁴

For more than a year, NASA’s Dawn mission has been providing fascinating data on Vesta. Surface temperatures and thermal parameters are being derived using measurements by the Visual and Infrared Spectrometer (VIR) (Capria et al., 2012). However, the spatial distribution of temperatures is complex due to significant albedo variations over short distance scales and extensive cratering that generates shadows and complex surface features over small spatial scales. This results in VIR pixels that have sub-pixel variations in the temperature that are difficult to deconvolve. Here we report the benefits of using high-resolution topographic modeling when interpreting the thermal component of the VIR observations. Stereo-photoclinometry has been used for years to derive accurate shape models of planetary surfaces. It uses high-resolution images to determine both the surface reflectance and the incidence and emission angles for every pixel of every image. Using this data, we construct both the local surface topography (known as maplets) as well as reflectance values for the Cornelia crater on Vesta (-9.7 Lat, 225 Lon), a fresh crater that has sharp relief and significant variations in albedo. Using this terrain model, we construct high-resolution, time-resolved insolation maps accounting for Bond albedo, incidence angle and shadowing effects of near-by features. From these maps, we calculate the temperature of the surface and subsurface using a 1-D thermal conduction model. This time-resolved model allows us to calculate the temperature at ~3 times the spatial resolution for all regions of Cornelia crater at the time when VIR collected its observations. By combining the thermal flux for all the high-resolution points within a single VIR pixel element, we generate a thermal spectrum that accurately models the VIR data because they reflect slope inflections that are generated by sub-pixel temperature variations.

207.11 Thermal Properties Of Unusual Local-scale Features On Vesta
  1INAF-IAPS, Rome, Italy, 2Bear Fight Institute, 3University of Maryland, 4U.S. Geological Survey, 5NASA Johnson Space Center, 6University of California at Los Angeles, 7NASA/Jet Propulsion Laboratory and California Institute of Technology.

On Vesta, the thermal behavior of areas of unusual albedo seen at the local scale can be related to physical properties that can provide information about the origin of those materials. We used Dawn’s Visible and Infrared Mapping Spectrometer (VIR) hyperspectral cubes to retrieve surface temperatures and emissivities, with high accuracy as long as temperatures are greater than ~180 K. Data acquired in the Survey phase (23 July through 29 August 2011) show several unusual surface features: 1) high-albedo (bright) and low-albedo (dark) material deposits, 2) spectrally distinct ejecta and ‘pitted’ materials, 3) regions suggesting finer-grained materials. Some of the unusual dark and bright features were re-observed by VIR in the subsequent High-Altitude Mapping Orbit (HAMO) and Low-Altitude Mapping Orbit (LAMO) phases at increased pixel resolution. In this work we present temperature maps and emissivities of several local-scale features that were observed by Dawn under different illumination conditions and different local solar times. Data from VIR’s IR channel show that bright regions generally correspond to regions with lower thermal emission, i.e. lower temperature, while dark regions correspond to areas with higher thermal emission, i.e. higher temperature. This behavior confirms that many of the dark appearances in the VIS mainly reflect albedo variations, and not, for example, shadowing. During maximum daily insolation, dark features in the equatorial region may rise to temperatures greater than 270 K, while brightest features stop at roughly 258 K, local solar time being similar. However, ‘pitted’ materials, showing relatively low reflectance, have significantly lower temperatures, as a result of differences in composition and/or structure (e.g., average grain size of the surface regolith, porosity, etc.). To complement this work, we provide preliminary values of thermal inertia for some bright and dark features.

207.12 Reconciling HED Collisional Ages with the Lunar Late Heavy Bombardment
  1NASA Lunar Science Institute, 2NLSI/SwRI, 3NASA Marshall Space Flight Center, 4Museum fur Naturkunde, Germany, 5Observatoire de la Core d’Azur, France, 6INAF, Italy, 7NLSI/USRA, 8University of Tennessee, 9PSI, 10LP, 11JPL, 12UCLA.
The nature of the lunar Late Heavy Bombardment (LHB), a period of increased bombardment of the Moon ~3.9Gyr ago, continues to be debated because many lunar samples provide only circumstantial evidence about the epoch of large basin formation. Independent constraints can be placed by meteorite 40Ar-39Ar ages reset in asteroid impact events. The best examples are perhaps offered by the howardite, eucrite and diogenite (HED) meteorites long suggested to come from asteroid Vesta, a paradigm that has been strengthened by recent findings of NASA’s Dawn mission. The distribution of HED impact ages shows a spike near ~4.45Gyr, an apparent gap, and then numerous ages between ~3.4-4.1Gyr. Intriguingly, the overall HED impact age distribution shares several common aspects with lunar data, and prompted us to further investigate these similarities. The starting consensus was that the HED impact age pattern should reflect the bombardment history of Vesta and main belt asteroids, which are constantly surrounded by impactors. However, if that were true, then why should HEDs impact ages show a gap from 4.1 to 4.45Gyr, when collisions in the main belt were commonplace according to dynamical models? We found -thanks to hydrocode simulations- that impacts among main belt asteroids are very inefficient in resetting the Ar-Ar clock due to their low average impact velocity (~5km/s). We suggest that the HED impact ages were reset by impacts from Earth-crossing impactors on highly eccentric orbits located outside the current boundary of the main asteroid belt. The advantage of this model is that it naturally explains the similar age distribution of HEDs and lunar samples. In particular, we conclude that HED ages between ~3.4-4.1Gyr record a “vestan” heavy bombardment, analogous to the lunar LHB. We also infer that the oldest impact ages recorded in HEDs constrain the leftover planetesimal population in the terrestrial planet region.

208 Extrasolar Planets: Atmospheric Circulation and Dynamics
Tuesday, 2:30 PM - 3:30 PM, Tahoe Room
208.01 Atmospheric Circulation of Hot Jupiters: Dependence on Stellar Irradiation and Rotation Period
- Adam P. Showman⁺, N. K. Lewis⁻, J. J. Fortney²
  ¹Univ. of Arizona, ²UC Santa Cruz.

Efforts to characterize and model extrasolar giant planet (EGP) atmospheres have so far emphasized planets within 0.05 AU of their stars. Despite this focus, known EGPs now populate nearly a continuum of orbital separations from canonical hot Jupiter values (~0.03-0.05 AU) out to 1 AU and beyond. Unlike typical hot Jupiters, these more distant EGPs will not in general be synchronously rotating and may exhibit a range of rotation rates. In anticipation of observations of this wider population, we here present three-dimensional atmospheric circulation models exploring the dynamical regime that emerges over a broad range of rotation rates and incident stellar fluxes appropriate for warm and hot Jupiters. We adopt a state-of-the-art general circulation model (GCM) that couples the dynamics to realistic non-grey radiative transfer. We find that, depending on the parameters, the circulation resides in one of two basic regimes. In agreement with previous studies, the circulation for canonical hot Jupiters exhibits a broad, fast superrotating (eastward) equatorial jet driven by the strong day-night heating contrast, with westward mean flow at high latitudes and significant day-night temperature differences. At faster rotation rates and lower incident fluxes, however, the circulation transitions to a vastly different regime: the day-night heating gradient becomes less important, and baroclinic instabilities emerge as a dominant player, leading to eastward jets in the midlatitudes, with significant equator-to-pole temperature differences, minimal temperature variations in longitude, and, in many cases, weak windflow at the equator. Our most rapidly rotating and least irradiated models exhibit multiple eastward jets in each hemisphere—similar to the jets on Jupiter and Saturn—and illuminate the dynamical continuum between highly irradiated EGPs and the weakly irradiated giant planets of our own Solar System. The regime transition identified here has important implications for observations of infrared lightcurves and spectra, which we will discuss.

208.02 Atmospheric Heat Redistribution on Hot Jupiters
- Daniel Perez-Becker⁺, A. P. Showman⁻
  ¹UC Berkeley, ²University of Arizona.
Hot Jupiters are expected to be tidally locked exoplanets, possessing permanent daysides and nightsides. Infrared observations of transiting hot Jupiters, which allow detailed estimates of longitudinal temperature variations, suggest that planets receiving moderate stellar irradiation exhibit modest fractional day-night temperature differences, while planets under extreme stellar irradiation have large fractional day-night temperature differences. This indicates a systematic trend wherein hotter planets are less efficient in redistributing the absorbed stellar flux from dayside to nightside. To this day, no atmospheric models have been published that identify which dynamical mechanisms determine the atmospheric heat redistribution efficiency on hot Jupiters or explain the aforementioned trend. To address this issue, we present a two-layer shallow-water model of the atmospheric dynamics on synchronously rotating planets. Our model shows that planets with weak friction and weak irradiation (i.e., long frictional and radiative time constants) exhibit a banded zonal flow with minimal day-night temperature differences, while models with strong irradiation and/or strong friction (i.e., short frictional or radiative time constants) exhibit a day-night flow pattern with large (order-unity) fractional day-night temperature differences. This is the first self-consistent dynamical model to explain the emerging observational trend. Strong radiation and strong drag play different roles, which we will describe, in inducing such a dynamical transition. We also show that day-night gravity-wave propagation timescales play a role at least as important as day-night advection timescales in controlling the transition; this indicates that canonical comparisons of radiative time constants with advection time constants are, at best, overly simplified. Interestingly, our models show that the regime transition from small-to-large day-night temperature difference is related, but not equivalent, to a transition from banded zonal flows under weak irradiation and weak drag to a day-to-night flow regime under strong irradiation and/or strong drag.

208.03 Modeling The Atmospheric Circulation Of Gj 1214b: Dependence On Atmospheric Composition
- Tiffany Kataria¹, A. P. Showman¹, J. J. Fortney², M. S. Marley³, R. S. Freedman³
  ¹University of Arizona, ²University of California at Santa Cruz, ³NASA Ames Research Center.

The next decade will see a growth in the detection and characterization of super Earths, planets with masses 1-10 times the mass of the Earth. Already, ground- and space-based transit surveys (e.g. Kepler, MEarth) have detected super Earths, which allow for the potential of follow-up observations to constrain their atmospheric composition and understand their circulation. Here we present three-dimensional atmospheric circulation models of GJ 1214b, a 6.55 Earth-mass planet detected by the MEarth survey, using the SPARC/MITgcm, a model that couples the MITgcm dynamical core with a fully non-grey, two-stream radiative transfer scheme (Marley and McKay 1999). In particular, we study the effect of varying atmospheric compositions on the planet’s temperature structure and circulation, including H2-dominated, H2O-dominated, and CO2-dominated compositions (Miller-Ricci and Fortney 2010). For each case, we identify and compare major dynamical features of the flow, including jet streams and waves. We also use these model results to generate synthetic lightcurves and spectra to understand what role, if any, the circulation plays in planet observations from transit to secondary eclipse.

208.04 Three-dimensional Atmospheric Circulation and Climate of Terrestrial Exoplanets and Super Earths
- Yohai Kaspi¹, A. P. Showman²
  ¹Weizmann Institute of Science, Israel, ²University of Arizona.

The recent discovery of super Earths and terrestrial exoplanets extending over a broad region of orbital and physical parameter space suggests that these planets will span a wide range of climatic regimes. Characterization of the atmospheres of warm super Earths has already begun and will be extended to smaller and more distant planets over the coming decade. The habitability of these worlds may be strongly affected by their three-dimensional atmospheric circulation regimes, since the global climate feedbacks that control the inner and outer edges of the habitable zone—including transitions to Snowball-like states and runaway-greenhouse feedbacks—depend on the equator-to-pole temperature differences, pattern of relative humidity, and other aspects of the dynamics. Here, using an idealized moist atmospheric general circulation model (GCM) including a hydrological cycle, we study the dynamical principles governing the atmospheric dynamics on such planets. In this presentation we will review how the planetary rotation rate, planetary mass, heat flux from a parent star and atmospheric mass affect the atmospheric circulation and temperature distribution on such planets. We will elucidate the possible climatic regimes and diagnose the mechanisms controlling the formation of atmospheric jet streams, Hadley cells,
and the equator-to-pole temperature differences. Finally, we will discuss the implications for understanding how
the atmospheric circulation influences the global-scale climate feedbacks that control the width of the habitable
zone.

208.05 3d Mixing In Hot-jupiter Atmospheres: Application To Tio Clouds On Hd209458b
- Vivien Parmentier¹, A. P. Showman², Y. Lian³
  ¹Observatoire de la côte d’azur, France, ²The University of Arizona, ³Ashima Research.

Like brown dwarfs, hot Jupiters exhibit atmospheric temperatures ranging from hundreds to thousands of Kelvins.
But unlike them, they are highly 3D objects with strongly asymmetric heating and a huge day/night temperature
contrast. Thus, many chemical species that can exist in gas phase on the dayside can condense and gravitationally
settle on the nightside. The abundance of such species in the atmosphere therefore depends whether or not the
atmospheric circulation can loft them vertically despite their tendency to gravitationally settle on the nightside. To
understand the three-dimensional distribution of such species, we present global circulation models of HD209458b
including passive tracers that advect with the three-dimensional flow, including a source/sink on the nightside to
represent condensation and gravitational settling. We show that global advection patterns produce very strong
vertical mixing that can keep particles lofted as long as the particles sizes are a few microns or less. A key point is
that the region being vigorously mixed is stably stratified; the vertical mixing results not from small-scale
convection but from the large-scale circulation driven by the day-night heating contrast. Although this vertical
mixing is not diffusive in any rigorous sense, a comparison of our results with idealized diffusion models allows a
rough estimate of the effective vertical eddy diffusivities in these atmospheres; we will present these diffusivities,
which can be used in 1D models of the atmosphere. Moreover, we show that the models produce strong spatial
and temporal variability in the tracer concentration that could result in observable variations in the secondary
eclipse depth of hot Jupiters. Finally, we focus on TiO in HD209458b and show that the day-night cold trap would
deplete TiO if it condenses into particles bigger than a few microns on the planet’s night side, making it unable to
create the observed stratosphere of the planet.

208.06 The Longevity of Oceans on Terrestrial Exoplanets
- Mark Alan Bullock¹, D. H. Grinspoon²
  ¹Southwest Research Inst., ²Denver Museum of Nature & Science.

Near the inner edge of stellar habitable zones, terrestrial planet habitability will be determined by how long water
can remain on the surface before the onset of a water vapor runaway greenhouse. This is known because of what
has been learned from the exploration of Venus. We have developed a one-dimensional, two-component
radiative-convective model, with clouds, in order to explore how variables such as distance from the star,
planetary mass, and stellar type affect the onset of a water vapor runaway greenhouse on planets around other
stars. The model uses a non-ideal equation of state for steam atmospheres with CO2 and N2 background gases.
We will show how the formation of water clouds in terrestrial exoplanet atmospheres can extend the longevity of
oceans on planets that are close to the inner edge of the conventionally defined habitable zone. Applied to Venus,
our results show that surface water may have been stable for up to 2 billion years before the atmosphere entered
a moist runaway state.

209 Asteroids: Dawn Results and Future Observations
Tuesday, 3:30 PM - 6:00 PM, Exhibit Hall

209.01 Vesta’s Pinaria Region (Av-11): Interpretation of Surface Mineralogy
- Lucy-Ann A. McFadden¹, C. De Sanctis², E. Ammannito², A. Netheus³, F. Capaccioni², E. Palomba², F. Tosi²,
  F. Zambon², L. Le Corre³, V. Reddy³, R. Jaumann⁴, K. Stephan⁴, F. Preusker⁴, T. Hoogenboom⁵, S. Marchi⁶,
  C. A. Raymond⁷, C. T. Russell⁸
  ¹NASA/GSFC, ²INAF, Italy, ³MPI-Lindau, Germany, ⁴DLR, Institute of Planetary Research, Germany, ⁵LPI,
  ⁶SWRI, ⁷JPL, Caltech, ⁸IGPP-UCLA.
The Pinaria Region of Vesta is bounded by 0-90 longitude, and -21 to -66 latitude, in the Claudia coordinate system. The region, named after the Roman vestal virgin (c. 600 B.C.) includes two, large craters, Pinaria (37km) and Aquilia (26.8 km). A prominent scarp is part of the 180 km long, 20 km high, Matronalia Rupes. It forms the western rim of the 505 km south pole impact basin, Rheasilvia. The feature forms a boundary between two terrains, the high altitude plateau and the groove and ridge terrain of the Rheasilvia basin where the lowest point is 14 km below the reference sphere. Mineralogical maps are derived using hyperspectral data from Visible and Infrared Mapping Spectrometer on NASA’s Dawn spacecraft. Spectral data show that Vesta's surface is dominated by pyroxenes. The band centers and depths of the two major pyroxene absorptions suggest mineralogical variations in both composition and/or texture. The position of the long wavelength absorption of pyroxene at 2 μm of the exposed scarp of Matronalia Rupes suggests low-Ca orthopyroxene consistent with a diogenitic composition. Band centers in the grooved terrain are within the eucrite and howardite range, due to their longer wavelength band centers. Support of the Dawn Instrument, Operations, and Science Teams is gratefully acknowledged. This work is supported by an Italian Space Agency (ASI) grant, a DLR grant, and by NASA through the Dawn project and the Dawn at Vesta Participating Scientist grant.

209.02 Compositional And Lithological Variations Of Vesta From Dawn Framing Camera (fc)

- Thangjam Guneshwar¹, L. Le Corre¹, V. Reddy⁷, A. Nathues¹, H. Sierks¹, M. Hoffmann¹
  ¹Max-Planck Institute for Solar System Research, Germany, ²University of North Dakota.

Dawn observations of Vesta have confirmed the heterogeneous mineralogy and geology with a north-south and east-west dichotomy. The study of howardite-eucrite-diogenite (HED) meteorites, believed to be fragments of Vesta, gives us an insight to its geological processes and nature. Here, we attempt to analyze compositional variations from Dawn FC seven color data using 1-μm pyroxene band parameters (band curvature, band tilt and band strength). Higher band curvature means a shorter wavelength 1-μm band center, which is typical of low-calcium pyroxenes seen in diogenites. Band tilt is the ratio of 830nm to that of 980nm. Higher band tilt is observed when the 1-μm band center is at longer wavelength. This is especially the case for high-calcium pyroxenes, and can be used to identify eucrites. Band strength (980nm/750nm) is generally sensitive to variations in depth (strength) of 1-μm absorption feature. Band depth is a function of iron abundance, particle size, temperature, abundance of opaques (metal/carbon) and phase angle. A false composite color assigning band curvature as red, band tilt as green and band strength as blue gives a qualitative analysis to identify and map the lithological and compositional variations. Using Dawn FC data we have confirmed north-south and east-west dichotomy reported first by Reddy et al. (2012). Parts of Rheasilvia basin and south polar regions are more reddish indicating the dominance of diogenite-rich material. Parts of Rheasilvia basin and some equatorial regions with more greenish, which is indicative of eucrite-type material. The Max Planck Society and the German Space Agency, DLR financially support the Framing Camera project.

209.03 SPC Shape and Topography of Vesta from DAWN Imaging Data

- Robert W. Gaskell¹
  ¹Planetary Science Institute.

The DAWN spacecraft has now left Vesta, leaving a legacy of more than 16000 clear filter images of the asteroid. During the last month of Dawn's stay at Vesta, the sun slowly crept northward, enabling the spacecraft to view topography closer to the north pole. We have used these images with our stereophotoclinometry (SPC) software to construct topography for most of Vesta's surface to 50 meter resolution, and below about 60 degrees south to 20 meter resolution. We present this topography as a 1/64 degree gridded map (about 70 m resolution), as a stereographic projection of the south polar region at 25 m resolution and as a global shape model with 1.57 million vectors. In addition, we present solutions for the s/c position and camera pointing at all imaging times during DAWN's entire stay at Vesta.

209.04 Solar Ice Caps on Ceres: Predictions for Dawn

- Paul Hayne⁷, O. Aharonson¹
  ¹California Institute of Technology.
Observations of Mercury and Earth’s Moon support the presence of substantial deposits of water ice and other volatile species in polar regions persistently shadowed by topography. This motivates investigation into whether similar thermal regimes exist on the dwarf planet Ceres. We investigated the effects of topographic shadowing using models for the temperatures inside craters at different latitudes, placing constraints on the extent and total surface areas that may be occupied by water ice and other volatile species. The model calculates heat diffusion subject to the effects of Ceres’ obliquity and orbital eccentricity, as well as multiple scattering of solar and infrared radiation between surface elements. Our results indicate that peak surface temperatures in perennially shadowed parts of craters are always below the ~110 K cutoff for water ice to be stable on billion-year time scales. For an obliquity of 3° and depth-to-diameter ratio of 1/6 typical of simple craters, perennial shadow occurs at latitudes > 53°. We therefore expect that Ceres could harbor substantial ice deposits on shadowed crater slopes down to this critical latitude, provided non-thermal losses are slow compared to the influx of molecules to the cold traps. Furthermore, a hemispherical asymmetry exists due to the timing of Ceres’ perihelion passage, which would lead to ice buildup in the southern hemisphere if the orbital elements vary slowly relative to the accumulation rate. Our model results are potentially testable by the Dawn mission during its expected 2015 encounter with Ceres.

210 NEOs, Surveys, and Asteroid Dynamics

Tuesday, 3:30 PM - 6:00 PM, Exhibit Hall

210.01 Physical Property Requirements of a Target Asteroid for a Mitigation Demonstration Mission
- Line Drube1, H. Alan1, A. Barucci1, M. Fulchignoni1, D. Perna2
1DLR Institute of Planetary Research Berlin, Germany, 2LESIA-Observatoire de Paris, France.

As part of the NEOShield project we are carrying out a statistical investigation of the properties of the known NEO population, using the latest published data, with the aim of estimating the most likely mitigation-relevant physical properties of the first threatening NEO to trigger a space-borne mitigation campaign. A major aim of NEOShield is to pave the way for a mitigation demonstration mission, including an appropriate and realistic choice of target NEO. Our investigation focuses on the physical properties of the most frequent serious impactors. We define a serious impactor to be one with the potential to lead to major loss of life and damage to infrastructure. At the low end of the size range our definition includes atmospheric events such as the 1908 Tunguska explosion, caused by a body with a diameter of around 50 m. We consider the upper limit of our diameter range of interest to be around 200 m: for objects above this size the impact frequency drops below 1 per 10 000 years. The small sizes of the NEOs in question present technical difficulties for mitigation planning. The complexity and chances of failure of a mitigation mission increase with decreasing diameter below a few hundred meters due to, e.g., the difficulties of targeting and maneuvering around an optically faint, low-gravity object. Further complications arise due to the fact that rotation rates and shapes tend to be more extreme in the case of such small NEOs. Very little is known about the mitigation-relevant properties of small NEOs. An important aspect of our study is to determine to what extent common assumptions about NEO physical properties are justified for mitigation planning, and identify the most critical areas of ignorance. We present and briefly discuss results obtained to date. Funded under EU FP7 program agreement no. 282703.

210.02 Asteroid Apophis From Past, Present And Future Observations
- David Bancelin1, D. Hestroffer1, W. Thuillot1
1IMCCE-Paris Observatory, France.

Since its discovery in 2004, asteroid (99942) Apophis became a study case. It was the first asteroid to have reached the level 4 on Torino scale for a possible collision with the Earth in 2029. Since, new optical and radar data enabled to remove the 2029-threat. Some impacts are still possible in the future but with lower probability. As a matter of fact, some regions located in the target plane of Apophis in 2029 are called keyholes because they are small regions where the asteroid has to pass in order to collide the Earth in the future. Those keyholes can be qualified as primary when they are spawned by one close encounter, and secondary when they are spawned by two consecutives close encounters. The impact probability is directly linked to the size of the uncertainty on the location of Apophis on 2029 but also to the location and size of keyholes. Besides, some other sources of
uncertainty, mainly the Yarkovsky effect can also slightly modify this probability (see table below). This non
gravitational effect, leading to a secular semi-major axis drift, is poorly known for Near-Earth asteroids in general
because it depends on physical values. Thus, it is difficult to compute the accurate influence of this effect. We
propose in this work to study the keyholes location versus the size of the ellipse uncertainty. This will involve
several orbit propagation of orbital solution from various sets of observations from past and present data,
including also a Yarkovsky model. Moreover, we will analyse the contribution of future space data from the Gaia
mission which will provide unprecedented observations.

Impact probabilities : $IP_y$ refers to the probability using a Yarkovsky model.

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<td>2077</td>
<td>$2.1 \times 10^{-7}$</td>
<td>$2.8 \times 10^{-7}$</td>
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210.03 Numerical Study of the Asteroid Deflection Efficiency of the Kinetic Impactor Approach in the NEOShield Project

- Martin Jutzi\textsuperscript{1}, P. Michel\textsuperscript{2}, W. Benz\textsuperscript{1}
\textsuperscript{1}Physics Institute, University of Bern, Switzerland, \textsuperscript{2}Lagrange Laboratory, University of Nice, Côte d’Azur Observatory, CNRS, France.

Due to their impact potential, Near-Earth Objects present a scientifically well-founded threat to our civilization.
Several ideas have been proposed to deflect a small body on a collision route to the Earth. Here we focus on the
kinetic impactor method. This technique consists of impacting the small body with a projectile (spacecraft) and
using the transfer of momentum provided by the impact and the resulting ejecta to deviate the object. The
momentum transferred in such an impact is usually characterized by a factor $\beta \ (\geq 1)$ known as the momentum
multiplication factor. $\beta$ is a crucial quantity which determines the deflection efficiency of the kinetic impactor
approach. Its value depends on the target characteristics (material properties, internal structure, surface structure,
size) and also on the velocity of the impactor. In addition to impact experiments and scaling laws, numerical
simulations of impacts are needed to determine $\beta$ under various conditions at asteroid scales. In the context of the
European NEOShield project, we started to investigate the $\beta$ values as a function of impact conditions and target
material properties. This study is performed using a 3D SPH code including a model for porous material and
recently improved strength models (Benz and Asphaug 1995, Computer Physics Communications 87; Jutzi et al.
2008, icarus 198; Jutzi et al, in prep). Our first aim was to compare simulations with data presented by Housen and
Holsapple (LPSC 2012). Preliminary results for porous materials show a good agreement with laboratory
experiments. We will present new results of this study where we focus on the dependence of $\beta$ on the impact
velocity. Funded under EU FP7 program agreement No. 282703. M.J. and W.B acknowledge partial support from
the Swiss National Science Foundation.

210.04 Limits On The Production Rate Of Tidally Disrupted Neo Families

- Eva Schunova\textsuperscript{1}, K. J. Walsh\textsuperscript{2}, R. Jedicke\textsuperscript{2}, M. Granvik\textsuperscript{2}, R. J. Wainscoat\textsuperscript{3}
\textsuperscript{1}Comenius University Bratislava, Slovakia, \textsuperscript{2}Southwest Research Institute, \textsuperscript{3}Institute for Astronomy
University of Hawaii, \textsuperscript{3}Department of Physics University of Helsinki, Finland.

We calculate the upper limit on the flux $F(H)$ of tidally disrupted families into the NEO population and their
detection efficiency $\varepsilon(H,t)$ (including observational bias) as a function of the absolute magnitude $H$ of the parent
body and time $t$ since the disruption. Tidal disruption during a close encounter with Earth or Mars is the most likely
family-creation mechanism in the NEO region. Our results are based on the N-body disruption simulations of
rubble-pile parent NEO’s followed by a numerical integration of the fragments, a simulation of the observational
selection effects using the Pan-STARRS Moving Object Processing System (MOPS), and then attempting to identify
the family at different times after the disruption.
210.05 NEAs’ Satellites Under Close Encounters with Earth
- Rosana Araujo¹, O. C. Winter¹
  ¹UNESP - Univ Estadual Paulista, Brazil.

In the present work we took into account the gravitational effects experienced by a NEA (Near-Earth Asteroid), during a close encounter with Earth, in order to estimate the stability regions of NEAs’ satellites as a function of the encounter conditions and for different primary-satellite mass ratio values. Initially, the methodology consisted on numerically simulating a system composed by the Sun, the planets of the Solar System, and samples of NEAs belonging to the groups Apollo, Atens and Amor, for a period of 10 Myr. All encounters with Earth closer than 100 Earth’s radius were registered. The next step consisted on simulating all those registered close encounters considering the Earth, the asteroid that perform the close encounter, and a cloud of satellites around the asteroid. We considered no-interacting satellites with circular orbits, random values for the inclination, longitude of the ascending node and true anomaly, and with radial distribution going from 0.024 to 0.4 Hill’s radius of the asteroid. The largest radial distance for which all the satellites survive (no collision or ejection) is defined as the critical radius. We present a statistical analysis of the registered encounters and the critical radius found, defining the stable regions as a function of the impact parameter - d, and of the relative velocity - V. For the case of massless satellites, we found that all satellites survived for encounters with d>0.3 Earth Hill’s radius. For impact parameter d<0.13 Earth Hill’s radius, we found that particles with radial distance greater than 0.24 Hill’s radius of the asteroid, are unstable, for any relative velocity. The results for the other considered cases will be presented and discussed. We also discuss the implications of the regions found, specially in the NEAs-binary scenarios.

210.06 The NEOShield Project: Understanding the Mitigation-Relevant Physical Properties of Potentially Hazardous Asteroids
- Alan W. Harris¹, L. Drube¹, NEOShield Consortium
  ¹DLR Inst. Planetary Research, Germany.

NEOShield is a European-Union funded project to address impact hazard mitigation issues, coordinated by the German Aerospace Center, DLR. The NEOShield consortium consists of 13 research institutes, universities, and industrial partners from 6 countries and includes leading US and Russian space organizations. The primary aim of the 5.8 million euro, 3.5 year project, which commenced in January 2012, is to investigate in detail promising mitigation techniques, such as the kinetic impactor, blast deflection, and the gravity tractor, and devise feasible demonstration missions. Options for an international strategy for implementation when an actual impact threat arises will also be investigated. Our current scientific work is focused on examining the mitigation-relevant physical properties of the NEO population via observational data and laboratory experiments on asteroid surface analog materials. We are attempting to narrow the range of the expected properties of objects that are most likely to threaten the Earth and trigger space-borne mitigation attempts, and investigate how such objects would respond to different mitigation techniques. The results of our scientific work will flow into the technical phase of the project, during which detailed designs of feasible mitigation demonstration missions will be developed. We briefly describe the scope of the project and report on results obtained to date. Funded under EU FP7 program agreement no. 282703.

210.07 Structural Modeling Of Rubble Piles In Two And Three Dimensions
- Donald Korycansky¹
  ¹University of California Santa Cruz.

One of the puzzles about the structure of asteroids and other small bodies of the solar system is amount void space that is apparently present, from measurements of their bulk densities as compared to the mineral grain densities of their surfaces. In many cases, void fractions of 40% or more are inferred. The question arises as to whether this large void fraction is the result of large-scale internal structure ("macroporosity") or small-scale grain-density effects ("microporosity"). In this work I present results from modeling rubble piles. In particular, rubble piles are modeled as assemblages of irregular polyhedra. Modeling is done by a so-called "penalty method" where repulsive forces are applied to prevent interpenetration of the constituent blocks. Displacements are proportional
to the forces, so this is a first-order dynamics method (i.e. there is no inertia). Collision detection among the elements is done via Minkowski summation: compilation of the pairwise differences of the polyhedra vertices, followed by the application of a convex hull. Minkowski summation provides the minimum distance required to resolve a collision, but the location of the overlap region is lost. Thus, further operations are done to recover this information. Given the depth of overlaps and their locations, the positions and orientations of polyhedra are adjusted to reduce the overlap until a structure with minimal interpenetration is produced. Initial calculations done with 100 polyhedra derived from voronoi decomposition of a cube yield results with void fractions in the range of 20-25%. Further results will be reported at the DPS conference. This work was supported by NASA PG&G award NNX07AQ04G.

210.08 Modeling Global-Scale Craters in Rubble Piles

- Travis SJ Gabriel, D. G. Korycansky, E. Asphaug

 UNIVERSITY OF CENTRAL FLORIDA, UNIVERSITY OF CALIFORNIA, SANTA CRUZ.

We model large craters in rubble piles by initiating a velocity field according to the Maxwell Z-Model in a simulated rubble pile. Open Dynamics Engine (ODE, www.ode.org), as used in similar studies (Korycansky and Asphaug 2009, Korycansky and Plesko 2011), is used here to simulate icosahedra of varied dimensions bound by self-gravity and friction. ODE employs sophisticated collision detection and constraint-force solvers in addition to solving equations of rigid body motion. The engine has been benchmarked in situations where the solutions are readily available through laboratory studies or analytical calculation such as the angle of repose of polyhedra in an open-walled box and a rectangular box sliding on an inclined plane (Korycansky and Asphaug 2010 LPSC). Using solutions of the Z-Model as an initial condition for crater excavation greatly reduces the number of parameters to study. Dynamical evolution of the velocity field is followed to several gravitational timescales. Our simple study, a precursor to using explicit SPH-derived flow fields, does not consider the time dependent nature of the radial velocity flow strength term, α(t), nor the Z-Model’s velocity field contribution beyond t=0. A constant value of Z=2.7 is used. The simulation serves as a laboratory for investigating the flow strength term in observed craters such as the Stickney crater on Phobos, and as a testbed for exploring the physical effects of shear bulking and other aspects of granular flow in asteroid and comet collisional evolution.

210.09 What Separates the Greeks From the Trojans?


 GEORGIA STATE UNIVERSITY, ILLINOIS WESLEYAN UNIVERSITY, GMARS.

The Greek and Trojan asteroids, trapped at their respective L4 and L5 Lagrange points of Jupiter, represent a poorly understood and exceptional population of minor bodies. Their unique orbital situation makes them a relatively accessible, potentially primordial population that can provide vital clues as to the origin and evolution of the Solar System. A close examination of the similarities and differences between the two camps could suggest the mechanisms responsible for their capture and, in turn, confine the parameters of the Nice Model. Furthermore, these objects could bridge the gap between the Main Belt and the icy minor bodies of the Outer Solar System. Here we present updated photometry of the 113 intrinsically brightest (H ≤ 10.0) Greeks and Trojans. These data are part of our continuing program to obtain multi-epoch photometric observations for these objects, as well as phase curves and multi-band light curves for the brightest 25 members. While each dataset individually gives us physical properties of these specific Greeks and Trojans, through a combined analysis, wider reaching trends might be revealed not only between the camps, but linking these populations to other minor body populations in the Solar System.

210.10 A Dynamical Origin Of The Leading/trailing Asymmetry In Jupiter’s Trojan Swarms?

- David P. O’Brien

 PLANETARY SCIENCE INSTITUTE.

The cataloged population of Jupiter Trojans has long shown a puzzling asymmetry between the leading (L4) and trailing (L5) swarms down to the smallest observable sizes. Estimates from the Sloan Digital Sky Survey (SDSS) place the leading/trailing ratio at 1.6 ± 0.1 [1], survey observations with the Subaru telescope give a leading/trailing ratio

210.11 Revisited Study On The Survival Regions Of Classical Kbos

- Helton Da Silva Gaspar¹, D. Nesvorný², A. Morbidelli³
  ¹UNESP - FEG, Brazil, ²Southwest Research Institute, ³Observatory of Nice, France.

Many studies has been dedicated to explain the complex Kuiper Belt structure. In a recent study, Dawson & Murray-Clay (2012) propose an assembly model that forms hot classical KBOs interior to Neptune and delivers them to the classical region where the cold populations forms in-situ. By using the survival map by Lykawka & Mukay (2005), their theory is supported by the absence of objects inside a stable region in the space of initial semimajor axis versus eccentricity. They argue that such region should contain excited in-situ original objects. We reproduce the 4Gy survival map but in terms of proper semimajor, eccentricity and inclination instead. By superimposing the classical KBOs over our survival map, we find out that cold objects cover uniformly the whole survival region. This result agrees with a scenario in which in-situ nearly circular objects had eccentricities excited then yielding an uniform distribution all over the survival region.

210.12 ATLAS: Asteroid Terrestrial-impact Last Alert System

- Robert Jedicke¹, J. Tonry¹, P. Veres¹, D. Farnocchia², F. Spoto³, A. Rest⁴, R. J. Wainscoat¹, E. Lee⁵
  ¹University of Hawaii, ²SpaceDyS, s.r.l., Italy, ³University of Pisa, Italy, ⁴Space Telescope Science Institute, ⁵Friends of the IfA.

The Asteroid Terrestrial-impact Last Alert System (ATLAS) could survey the entire visible night sky to V~20 four times each night to detect asteroids on an Earth-impacting trajectory. We plan on using existing image analysis and moving object detection software; mostly off-the-shelf telescopes, mounts and observatories; and readily available computation and data storage nodes. We will present our survey simulations showing the evolution of the impact probability for objects on an impact trajectory as a function of time before impact for different ATLAS implementations. e.g. with two observatories at one location or separated by about 100 km. ATLAS should provide about a month’s advance notice of impact for 300m diameter objects and about a week’s notice for Tunguska scale impactors of ~50m diameter.

210.13 The Catalina Sky Survey: Current and Future Work

- Eric Christensen¹, S. Larson¹, A. Boattini¹, A. Gibbs¹, A. Grauer¹, R. Hill¹, J. Johnson¹, R. Kowalski¹, R. McNaught²
  ¹Lunar and Planetary Laboratory, ²Australian National University, Australia.

The Catalina Sky Survey (CSS) continues to be the most productive Near Earth Object (NEO) survey in operation, accounting for nearly two-thirds of all NEO discoveries since 2005. We present a review of the current status of the survey operations, and highlight recent and future upgrades to our instrumentation. Recently, CSS has refurbished a 1.0-m telescope on Mt. Lemmon, Arizona, adjacent to the 1.5-m survey telescope. This telescope will be primarily used for NEO follow-up, recovery, and physical characterization of NEOs including colors and light curves. It will be capable of remote or robotic operations, programmed by adaptive queue-planning software of our own design. We expect to complete commissioning activities and begin full-time operations by the end of this year. A
large-format camera featuring a single 10k x 10k detector is in the process of being fabricated for the 1.5-m survey
telescope. The new camera system will increase the field-of-view from 1.2 to 5.0 square degrees, and the nightly
coverage rate from ~180 to ~750 square degrees, to limiting magnitude V~21.5. This telescope is already the most
productive for NEO discovery, accounting for approximately 40% of new NEOs since 2008, at an average rate of
over 350 NEOs per year. We anticipate a significant increase in its discovery rate after commissioning, which will
begin in late 2013. The Catalina Sky Survey gratefully acknowledges the support of NASA’s Near Earth Object
Observation program (grant no. NNH12ZDA001N-NEOO).

210.14 Spacewatch Observations of Near-Earth Objects
   - Robert S. McMillan¹, T. H. Bressi², J. V. Scotti¹, J. A. Larsen², M. L. Perry¹
   ¹Univ. of Arizona, ²U. S. Naval Academy.

We have enhanced Spacewatch’s (McMillan et al. 2007 IAU Symp. 236) astrometry and photometry of Near-Earth
Objects (NEOs). We specialize in follow-up of the Congressionally-mandated "large" NEOs (absolute mag H≤22) as
they recede from Earth after discovery and become fainter, as well as NEOs on impact risk pages, Potentially
Hazardous Asteroids, and NEOs observed by WISE (Mainzer et al. 2012 ApJ 752, id 110). Spacewatch was the pre-
eminent follower-up of NEOs discovered by WISE within 2 weeks of their discovery. We have observed at
elongations as small as 46°. Follow-up on longer orbital arcs improves understanding of the statistics of the orbits
and absolute magnitudes of the population as well as the recoverability of individual objects. The new CCD which
we began operating on our 1.8-m telescope on 2011 Oct 16 makes 23rd mag asteroids more frequently accessible.
Faster readout and smaller pixels yield 67% more observations of NEOs per year and astrometric residuals of ±0.3
arcsec, vs. ±0.6 arcsec on NEOs with the old CCD. To reach more distant objects with H≥22, we now also use the
Bok 2.3-meter telescope of Steward Observatory and the Kitt Peak National Observatory (KPNO) 4-m Mayall
telescope. About 2800 tracklets of NEOs were accepted by the MPC from Spacewatch in the interval 2011 Jul 1 -
2012 Jun 30. The archive of images collected with our mosaic of CCDs on the 0.9-m telescope of Steward
Observatory now approaches 15 TB in size and spans almost 10 years of uniformly conducted surveying. It
contributes incidental followup astrometry and precoversies of NEOs. This work is funded by NASA/NEOO grants
NNX11AB52G and NNX12AG11G, the Brinson Foundation of Chicago, IL, the estates of R. S. Vail and R. L. Waland,
and other private donors. Spacewatch uses facilities of KPNO and services of the IAU’s Minor Planet Center.

210.15 Evaluation of the Gravity Field and the Dynamic Environment of Asteroid 216 Kleopatra
   - Thierry Chanut¹, O. C. Winter¹
   ¹FEG-UNESP, Brazil.

Recent observations and spacecraft rendezvous with asteroids in orbit close to the Earth (NEAs) have shown binary
and triple systems. The existence of satellites orbiting these asteroids can be explained by their non-homogeneous
shape. One of the main techniques, used in the last decade to rebuild the shape and determinate the gravity field
of irregularly shaped asteroids, is the polyhedral model. We use the model of polyhedron in this work to find the
spherical harmonic gravity coefficients of 216 Kleopatra, Then, taking the rotation of asteroid into account,
pseudo-potential energy and Zero velocity curves were used to analyze the environment of orbit dynamics around
the asteroid. Finally, we compare our results with those found using observational data to build the physical model
of 216 Kleopatra.

210.16 On The Attitude Dynamics Of Central Bodies Of Triples Systems 87 Sylvia, 45 Eugenia And 2001sn263.
   - Luiz Augusto Boldrin¹, O. C. Winter¹, E. Vieira Neto¹
   ¹Unesp, Brazil.

The study of multiple asteroids is a great key for knowledge of our solar system past, since they are remaining
objects of the formation of planets. Starting from that motivation, in a previous work on the system (87) Sylvia we
studied the dynamics of Sylvia’s satellites perturbed by the Sun and Jupiter. In that work it was shown that
Romulus and Remus experience strong secular perturbations from the Sun and Jupiter, which could destabilize
them. We also found out that the flatness (J2) of the central body is of extreme importance in the stability of the
orbits of the satellites. From these results, we decided to do a study on the attitude motion of the main body of
this kind of system and analyze its influence on the orbital motion of its satellites. The attitude motion of the central body of the triples systems 87 Sylvia, 45 Eugenia and 2001SN263 have been studied taking into account the torques from its satellites, the Sun and Jupiter. Analyzing the results through the temporal variation of the right ascension and declination of the central body's pole, we found that the satellites induce short period and low amplitude oscillations, and the Sun and Jupiter only provide large oscillations observed in long timescales. It was also observed a coupling between the orbital plane of the satellites and the equator plane of the central body, in such a way that the orbital plane always follows the equatorial plane of the central body, even with the latter experiencing great variations. Acknowledgements: CAPES, FAPESP and CNPq.

210.17 Progress on the Size Frequency Distribution of Small Main-belt Asteroids
- Brian Burt¹, D. E. Trilling², D. C. Hines², K. R. Stapelfeldt², L. M. Rebull³, C. I. Fuentes¹, A. Hulsebus⁵
  ¹Northern Arizona University, ²STSCI/SSI, ³NASA/GSFC, ⁴IPAC, ⁵Iowa State University.

The asteroid size distribution informs us about the formation and composition of the Solar System. We build on our previous work in which we harvest serendipitously obtained Spitzer data of the Taurus region and measure the brightness and size distributions of Main-belt asteroids. This is accomplished with the highly sensitive MIPS 24 micron channel. We expect to catalog ~ 10⁴ asteroids, giving us a statistically significant data set. Results from this investigation will allow us to characterize the total population of small, Main-belt asteroids. Here we will present new results on the completeness of our study and the presence of size distribution variations with inclination and radial distance in the belt. We acknowledge and thank funding from PMDAP through NASA.

210.18 The Yarkovsky Drift’s Influence on NEAs: Trends and Predictions with NEOWISE Measurements
- Carolyn Nugent¹, A. Mainzer², J. Masiero², T. Grav³, J. Bauer²
  ¹University of California, Los Angeles, ²Jet Propulsion Laboratory, California Institute of Technology,

The Yarkovsky effect is a non-gravitational force that perturbs the orbits of small bodies, including near-Earth asteroids (NEAs). Despite its small magnitude, it must be included in the calculation of precise asteroid trajectory predictions (Giorgini et al. 2002; Milani et al. 2009), and it is believed to be a key mechanism in the process that delivers asteroids from the main belt to near-Earth space (Bottke et al. 2006). The Wide-field Infrared Survey Explorer (WISE) (Wright et al. 2010) has observed over 150,000 minor planets (including ~ 600 NEAS) at infrared wavelengths (Mainzer et al. 2011). Combining WISE measurements with published reliable diameters determined from in situ spacecraft visits, stellar occultations, and radar gives a list of NEOs with well-determined diameters and geometric albedos. These diameters and geometric albedos were combined with the mathematical formulation of the diurnal Yarkovsky effect developed by Vokrouhlický et al. (2000) to produce Yarkovsky drifts estimates for 540 NEAs. We identify the candidates likely to have the strongest Yarkovsky drifts, however, none currently have sufficient radar or optical measurements to allow for Yarkovsky detection (Chesley et al. 2003, Nugent et al. 2012). We list future observation opportunities for these targets, and we encourage observers to obtain more astrometry of these objects when possible. WISE is a joint project between UCLA and JPL/Caltech funded by the NASA MIDEX program. NEOWISE is a project of JPL/Caltech funded through NASA's Planetary Science Division.

210.19 Chaotic diffusion of the Vesta family
- Jacques Laskar¹, J. Delisle³
  ¹Observatoire de Paris, France.

The Vesta family is a known source of near-Earth asteroids (NEAs). Members of this family first slowly migrate in the main belt until they enter in the nu_6 or the 3:1 resonance with Jupiter. Their life time is then very short, and they often become NEAs before reaching hyperbolic orbits (Migliorini et al. 1997). The Yarkovsky effect is considered as the main explanation for the slow migration of Vesta family asteroids towards both resonances (Carruba et al. 2003). We numerically estimate the semi-major axis diffusion of Vesta family members induced by close encounters with 11 massive main-belt asteroids: (1) Ceres, (2) Pallas, (3) Juno, (4) Vesta, (7) Iris, (10) Hygiea, (15) Eunomia, (19) Fortuna, (324) Bamberga, (532) Herculina, (704) Interamnia. We find that most of the diffusion
is due to Ceres and Vesta. We extrapolate our results to constrain the global effect of close encounters with all main-belt asteroids. We show that for asteroids whose diameter is larger than about 40 km, the diffusion due to close encounters dominate the Yarkovsky effect (Delisle & Laskar 2012). Since Vesta family members are all smaller than 8 km, we confirm that the main mechanism of its diffusion is the Yarkovsky effect. We also show by extrapolations on the closest distance of approach during encounters that 10 over the 13800 known Vesta family objects (Nesvorny, 2010) may have had an encounter with Vesta within one diameter over the age of the family. Such an event may have resulted in a semi-major axis jump of about 1 AU. Thus, even if the mean effect of close encounters is secondary compared to the Yarkovsky effect, they considerably affect some individual orbits. Ref: Delisle, J.-B., & Laskar, J.: 2012, Chaotic diffusion of the Vesta family induced by close encounters with massive asteroids, A&A, 540, A118

210.20 Measuring the YORP Effect of Asteroid 4660 Nereus

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1University of Aizu, Japan, 2National Central University, Taiwan, 3Seoul National University, Korea, Republic of, 4Japan Aerospace Exploration Agency, Japan.

We present analysis of the YORP-induced change in spin rate of Nereus using its lightcurves obtained from 1997 to 2010. The detailed shape model of Nereus has been derived from the radar observations, which predicts that a detectable change could occur in a few years (Brozovic et al., 2009). We compared the observed lightcurves and modeled ones with the radar shape model, and find that a decelerating model provides a significantly better fit than the constant-period model.

211 Mars Satellites: Phobos and Deimos

Tuesday, 3:30 PM - 6:00 PM, Exhibit Hall

Results from the Mars Express (MEX) Radio Science (MaRS) team who analyzed MEX radio tracking data for the purpose of determining the gravitational attraction of the moon Phobos on the MEX spacecraft, and hence the mass of Phobos shall be presented. Accurate new values for the mass, an estimate of the degree two (C20) gravity field harmonic and the density of Phobos from three close flybys provide meaningful constraints on the corresponding range of the body's macroporosity, providing a basis for interpretation of the internal structure. When applied to various hypotheses bearing on the origin of Phobos, these results support the proposition that Phobos formed from a debris disk in orbit about Mars and is not a captured asteroid. Estimates on the tidal evolution of the Phobos orbit provide clues on the formation distance and its fate in a few ten million years.

211.01 Ashes To Ashes, Dust To Dust: Phobos, The Life And Fate Of An Inhomogeneous Moon Of Second Generation

Martin Paetzold1, T. Andert2, B. Haeusler2, S. Tellmann1, G. Tyler3

1Rheinisches Institut Fuer Umweltforschung, Abt. Planetenforschung, Germany, 2Universitaet der Bundeswehr Muenchen, Germany, 3Stanford University.

Results from the Mars Express (MEX) Radio Science (MaRS) team who analyzed MEX radio tracking data for the purpose of determining the gravitational attraction of the moon Phobos on the MEX spacecraft, and hence the mass of Phobos shall be presented. Accurate new values for the mass, an estimate of the degree two (C20) gravity field harmonic and the density of Phobos from three close flybys provide meaningful constraints on the corresponding range of the body's macroporosity, providing a basis for interpretation of the internal structure. When applied to various hypotheses bearing on the origin of Phobos, these results support the proposition that Phobos formed from a debris disk in orbit about Mars and is not a captured asteroid. Estimates on the tidal evolution of the Phobos orbit provide clues on the formation distance and its fate in a few ten million years.

211.02 Dynamics Of The Moons Of Mars, From Orbital To Surface

Julie Bellerose1

1Carnegie Mellon University.
The interest in exploring the moons of Mars, Phobos and Deimos, comes from both science and human exploration perspectives. The moons’ origin is still debated, and their current evolution and associated dynamical processes are topics of various studies and theories. From a human exploration perspective, the moons provide a stepping-stone to crewed missions before reaching the surface of Mars. Prior to this, a number of data need to be gathered. The Mars Exploration Program Analysis Group (MEPAG) has identified goals and measurements over the last two decades, and recently defined Strategic Knowledge Gaps for human exploration, i.e. requirements for robotic precursor missions. The measurements pertinent for the Mars moons relate to their small body properties and their importance in dust exchange in the Martian atmosphere, also critical input to NASA science goals. This work builds on previous work and investigates the dynamics in the vicinity of Phobos and Deimos, down to their surface. In proximity of the moons, the low-gravity regime is perturbed by the Mars gravity potential, the solar radiation pressure, and the mass distribution of the moons. For surface dynamics, surface constraints and dynamical impacts are integrated to the overall dynamics, and account for surface friction and restitution. There are similarities to small bodies, although the Martian environment and the moons respective shape provide much richer dynamics. Analytical methods and dynamical simulations are shown in the vicinity of both moons, from orbit to surface impact. We investigate possible dust transfers between the moons and Mars. The findings are also applied to both spacecraft applications and debris hazards mitigation.

211.03 A New Reduction Of USNO Photographic Plates Of The Martian Satellites
- Vincent Robert\textsuperscript{1}, D. Pascu\textsuperscript{2}, J. E. Arlot\textsuperscript{1}, V. Lainey\textsuperscript{1}
\textsuperscript{1}IMCCE, France, \textsuperscript{2}USNO retired.

Thanks to the new technologies, a new astrometric reduction of old photographic plates can provide a better knowledge of the orbital motion of planetary satellites. In the cadre of the FP7 european project, USNO plates were digitized with the new generation DAMIAN scanning machine. The procedure was applied to various photographic plates and in particular to the USNO photographic plates of the Galilean satellites. The astrometric results are the most precise. Here we consider a set of a few hundred photographic plates of the Martian satellites, taken at the USNO, and covering the years 1969-1997. A specific procedure was developed to obtain a high precision and we expect an accuracy better than 100 mas in (RA,Dec) positions of each moon. Since the position of Mars may also be deduced from the observed RA and Dec positions of Phobos and Deimos, we can also assess the accuracy of Mars' ephemeris. First astrometric results will be presented.

212 Meteoroids and Meteorites
Tuesday, 3:30 PM - 6:00 PM, Exhibit Hall

212.01 Density, Porosity and Internal Structure of Unmelted Micrometeorites
- Tomas Kohout\textsuperscript{1}, J. Suuronen\textsuperscript{2}, A. Kallonen\textsuperscript{2}, J. Čuda\textsuperscript{3}, D. D. Badjukov\textsuperscript{4}, R. Skala\textsuperscript{5}
\textsuperscript{1}Academy of Sciences of the Czech Republic / University of Helsinki, Czech Republic, \textsuperscript{2}University of Helsinki, Finland, \textsuperscript{3}Palacky University Olomouc, Czech Republic, \textsuperscript{4}Russian Academy of Sciences, Russian Federation, \textsuperscript{5}Academy of Sciences of the Czech Republic, Czech Republic.

Physical properties and internal structure of ~100-300 μm-sized melted and unmelted micrometeorites from Novaya Zemlya glacier, Russia, were investigated using x-ray microtomography (XMT) at the Department of Physics, University of Helsinki. Due to its high-voltage (20-180 kV) nanofocus x-ray tube and variable imaging geometry, the XMT equipment allows scans 10 cm to 50 μm sized samples with sub-micron resolution. XMT results indicate predominantly silicate composition of our micrometeorites. The internal structure of the unmelted micrometeorites varies from vesicular, highly porous, to compact with abundant sulphides or magnetite. Melted micrometeorites are affected by atmospheric entry and their structure varies from glassy to barred olivine with sulphides metamorphosed into metal or iron oxides. Porosity of the unmelted micrometeorites varies from ~1% up to over 33 % while the grain density is in range of 2.5-3.2 g/cm³. The melted micrometeorites are compact with porosity mostly below 3% and increased grain density in range of 3.4-3.5 g/cm³. One melted micrometeorite contains large metal inclusion. This is also reflected in its higher grain density of 5.7 g/cm³ similar to stony-iron.
Magnetic studies of the melted micrometeorites reveal further ~4 wt% fraction of submicron-sized iron oxides which are too finely grained to be detected in the XMT scans. Generally melted micrometeorites have lower porosities and higher grain densities compared to unmelted ones and compositionally similar, carbonaceous chondrites. Porosity decrease is most likely a result of meteoroid melting and recrystallization during atmospheric entry. An increase in grain density is most likely due to the loss of volatiles or sulfur evaporation from iron bearing sulphides as troilite or pyrrhotite. XMT proves to be a capable 3D non-destructive investigation tool suitable for extraterrestrial material studies and for quantitative evaluation of its physical properties and represents a significant improvement over the SEM based methods used in earlier studies.

212.02 Strength And Flow Effects In The Atmospheric Breakup Of Meteoroids
- **Damian Swift**, L. Chen, R. Kraus, R. Mulford, B. El-Dasher, D. Milathianaki, B. Remington, D. Eakins
  **Lawrence Livermore National Laboratory, Imperial College, United Kingdom, Harvard University, Los Alamos National Laboratory, SLAC-LCLS.**

When meteoroids enter a planetary atmosphere, the breakup process is governed by the Rayleigh-Taylor instability, mitigated by the strength of the meteoritic material. Particle sizes in the breakup cascade depend on the perturbation length scales exhibiting growth, and on the spatial variation of strength in the body. The physics of meteoroid entry is thus related closely to high-pressure strength experiments using lasers, where strength is inferred by studying the Rayleigh-Taylor growth of perturbations. There are significant discrepancies between predicted and observed breakup altitudes of meteoroids, which in turn reduce the accuracy of assessments of the impact threat from asteroids. We have found that samples of Fe-Ni meteorite material exhibit significantly higher static and dynamic strength than previously reported, largely eliminating the discrepancy. Simulations of stress and flow within and around a meteor describe the onset and evolution of the breakup process in reasonable detail, including the transport of small particles into the lower atmosphere. These results can be used to calibrate compact expressions describing the breakup conditions.

212.03 Space Debris in Low Earth Orbits: Orbital Dynamics and Resonance Effects
- **Jarbas Sampaio**, E. Wnuk, R. Vilhena de Moraes, S. da Silva Fernandes
  **UNESP, Brazil, AMU, Poland, UNIFESP, Brazil, ITA, Brazil.**

The increasing number of space debris orbiting the Earth justifies the attention and interest in the observation, spacecraft protection and collision avoidance. Considering 10000 cataloged objects around the Earth, one can verify the distribution of objects as: 27% of operational spacecraft, 22% of old spacecraft, 41% of miscellaneous fragments, 17% of rocket bodies and about 13% of mission-related objects. The uncatalogued objects larger than 1 cm are estimated in some value between 50000 and 600000. In this work, the 2-line element set of the NORAD (North American Defense) are studied observing irregular and resonant orbital motions in Low Earth Orbits. Several resonant angles influence, simultaneously, the orbital motions of these objects and the time behavior of the inclination and the frequency analysis confirm the irregularities in their orbits. It is possible to observe the complexity in the orbital dynamics of some objects that, sometimes, they are influenced by several resonant angles but, after some days, the regular motion seems to dominate. Most of resonant space debris are observed in the 14:1 resonance and this region is a special way to analyze these objects.

212.04 Infrared Spetroscopy of Extraterrestrial Materials
- **William T. Reach**, M. Yesaltis, G. Rossman
  **USRA/SOFIA, University of Central Florida, Caltech.**

Infrared spectroscopy is diagnostically of the mineralogy and structural properties of nearly all materials, whether terrestrial, planetary, interplanetary, or interstellar. Astronomical observations of extrasolar planetary system debris as well as features in the interstellar medium have revealed some mineralogical signatures, which are generally interpreted in comparison to predictions based on pure minerals. To complement those studies, we are measuring the infrared spectra of a wide range of extraterrestrial materials in the laboratory. The goals are (1) to form a new basis for interpreting extrasolar and interstellar material by comparison to the parent bodies of meteorites rather than pure minerals and (2) to determine the infrared properties of meteorites of as wide a range
of types as possible in order to study which parent body properties and histories and physical processes can affect infrared spectra. Attenuated total reflectance (ATR) spectroscopy provides convenient measurement capabilities over the range of wavelengths and signal-to-noise that are directly comparable to the remote telescopic observations, 3-150 microns. The materials for the laboratory study were obtained from the NASA Antarctic Meteorite Curatorial Facility and supplemented by terrestrial crater rocks and tektites from private sources. The mid-infrared diagnostic features of silicate minerals are richly present in most samples. The far-infrared measurements, to date, indicate a dependence of absorbance on the degree of shock history. We will examine this effect with future experiments. If confirmed, the results could have implications for understanding mineralogy of extrasolar and interstellar dust, which is likely to have experienced shocks from hypervelocity collisions.

212.05 Öpik-type Collision Probability For High-inclination Orbits
- Petr Pokorny¹, D. Vokrouhlicky¹
  ¹Astronomical Institute, Charles University, Czech Republic.

The classical Öpik theory provides an estimate of the collision probability between two bodies on bound, heliocentric or planetocentric orbits under restrictive assumptions of: (i) constant eccentricity and inclination, and (ii) uniform circulation of the longitude of node and argument of pericenter. Here we develop a generalization of this formalism that is valid even for highly inclined and/or eccentric orbits of the projectile. We assume that the orbit of the target is circular and in the local Laplace plane. Such a generalized setting is necessary, as an example, for more precise estimation of terrestrial impact fluxes of sporadic micrometeoroids on high-inclined orbits (notably those from the toroidal source and the associated helion and anti-helion arcs). We perform N-body simulations with artificial populations of particles, where the results show a significant difference between the original and the generalized formalism. The classical Opik formalism predicts a characteristic timescale at which particles are eliminated different from the simulation results, the new values are in satisfactory accordance with the numerical simulations. Another significant difference are the radiant position of the impactors. For given values of Hamiltonian and z-component angular momentum the classical theory predicts infinite number of radians due to the evolution of orbital elements e, i and ω during the Kozai-Lidov cycle. However, in the more general case we obtain only 4 (or 8) possible impact configurations with the target. These results may lead to significant differences in estimation or processing of collisions between planets and dust, or asteroid,s and also in estimation of collisions in young planetary systems (e.g. LHB in the Solar System). This work has been supported by the grant SVV-265301

212.06 Isotopic Anomalies in Primitive Solar System Matter: Spin-state Dependent Fractionation of Nitrogen and Deuterium in Interstellar Clouds
- Steven B. Charnley¹, E. S. Wirstrom¹, M. A. Cordiner¹, S. N. Milam¹
  ¹NASA Goddard Space Flight Center.

Organic material found in meteorites and interplanetary dust particles is enriched in D and ¹⁵N. This is consistent with the idea that the functional groups carrying these isotopic anomalies, nitriles and amines, were formed by ion-molecule chemistry in the protosolar core [1]. Theoretical models of interstellar fractionation at low temperatures predict large enrichments in both D and ¹⁵N and can account for the largest isotopic enrichments measured in carbonaceous meteorites. However, more recent measurements have shown that, in some primitive samples, a large ¹⁵N enrichment does not correlate with one in D, and that some D-enriched primitive material displays little, if any, ¹⁵N enrichment. By considering the spin-state dependence in ion-molecule reactions involving the ortho and para forms of H₂, we show that ammonia and related molecules can exhibit such a wide range of fractionation for both ¹⁵N and D in dense cloud cores. We also show that while the nitriles, HCN and HNC, contain the greatest ¹⁵N enrichment, this is not expected to correlate with extreme D enrichment. These calculations therefore support the view that Solar System ¹⁵N and D isotopic anomalies have an interstellar heritage. We also compare our results to existing astronomical observations and briefly discuss future tests of this model. [1] Mumma, M. J. and Charnley, S.B. (2011), ARA&A, 49, 471.

212.07 Dynamical Modelling of Meteoroid Streams
Accurate simulations of meteoroid streams permit the prediction of stream interaction with Earth, and provide a measure of risk to Earth satellites and interplanetary spacecraft. Current cometary ejecta and meteoroid stream models have been somewhat successful in predicting some stream observations, but have required questionable assumptions and significant simplifications. Extending on the approach of Vaubaillon et al. (2005)\textsuperscript{1}, we model dust ejection from the cometary nucleus, and generate sample particles representing bins of distinct dynamical evolution-regulating characteristics (size, density, direction, albedo). Ephemerides of the sample particles are integrated and recorded for later assignment of frequency based on model parameter changes. To assist in model analysis we are developing interactive software to permit the “turning of knobs” of model parameters, allowing for near-real-time 3D visualization of resulting stream structure. With this tool, we will revisit prior assumptions made, and will observe the impact of introducing non-uniform cometary surface attributes and temporal activity. The software uses a single model definition and implementation throughout model verification, sample particle bin generation and integration, and analysis. It supports the adjustment with feedback of both independent and dependent model values, with the intent of providing an interface supporting multivariate analysis. Propagations of measurement uncertainties and model parameter precisions are tracked rigorously throughout. We maintain a separation of the model itself from the abstract concepts of model definition, parameter manipulation, and real-time analysis and visualization. Therefore we are able to quickly adapt to fundamental model changes. It is hoped the tool will also be of use in other solar system dynamics problems.\textsuperscript{2} Vaubaillon, J.; Colas, F.; Jorda, L. (2005) A new method to predict meteor showers. I. Description of the model. Astronomy and Astrophysics, Volume 439, Issue 2, August IV 2005, pp.751-760.

\textsuperscript{2}Mössbauer Study and Magnetic Measurement of Troilite Extract from Natan Iron Meteorite

\textbf{- Jan Cuda}\textsuperscript{1}, T. Kohout\textsuperscript{1}, J. Tuček\textsuperscript{1}, R. Zbořil\textsuperscript{1}

\textsuperscript{1}Palacky University, Czech Republic, \textsuperscript{2}Department of Physics, University of Helsinki, Helsinki, Finland and The Institute of Geology, Academy of Sciences of the Czech Republic, Czech Republic.

We focused our on the troilite in-field Mössbauer spectrum at 5 K in order to confirm or rule out the interpretation of two sextets for other troilite system extracted from the Natan IIICD iron meteorite. Beside the Mössbauer spectroscopy investigation, the global magnetic response of troilite extract was measured. Detailed analysis of field-cooled (FC) induced magnetization (10 mT) showed a similar profile to daubreelite (FeCr\textsubscript{2}S\textsubscript{4}) at temperatures below \textasciitilde170 K. Induced-FC, temperature dependence of remanent magnetization, and room temperature saturation isothermal remanent magnetization (RT SIRM) magnetization do not show any significant change at low temperatures (\textasciitilde70 K) related to prior magnetic studies for troilite. In order to quantify a magnetic response of the troilite extract from the Nantan IIICD iron meteorite, the hysteresis loops at 5 and 300 K were measured in external magnetic fields up to 7 T. Hysteresis parameters of coercive field ($B_C$) and saturation magnetization ($M_S$) were found to be 56 mT and 2 Am\textsuperscript{2}/kg at 5 K, respectively. At room temperature, the values of these parameters are lower ($B_C \sim 14$ mT and $M_S \sim 1.44$ Am\textsuperscript{2}/kg). Keywords: Troilite, zero- and in-field Mössbauer spectroscopy, magnetization measurements, Natan IIICD iron meteorite.

\textbf{213 Mars: Surface and Interior}

Tuesday, 3:30 PM - 6:00 PM, Exhibit Hall

\textbf{213.01 Mars Precession Rate And Moment Of Inertia Estimated From Radio Tracking Of The Mars Exploration Rover, Opportunity}

\textbf{- Petr Kuchynka}\textsuperscript{1}, W. M. Folkner\textsuperscript{1}, R. S. Park\textsuperscript{1}, A. S. Konopliv\textsuperscript{1}, S. Le Maistre\textsuperscript{2}, V. Dehant\textsuperscript{2}

\textsuperscript{1}Jet Propulsion Laboratory, California Institute of Technology, \textsuperscript{2}Royal Observatory of Belgium, Belgium.

The geological history of Mars is strongly related to the planet’s current interior structure. Until seismometer measurements of wave propagation through the planet’s interior become available, the structure can be studied only indirectly from dynamical parameters such as polar moment of inertia. For a homogeneous distribution of
density within a sphere, the normalized moment of inertia, MOI = C/MR^2, equals to 0.4. Lower values indicate the presence of a dense core. More generally, the estimation of MOI provides quantitative constraints on interior model parameters such as core and mantle size, density or composition. The polar moment of inertia is directly related to the planet’s precession rate, which may be accurately determined from Doppler tracking of landers on the surface. Viking lander data were previously used to constrain the Mars precession rate with an uncertainty of 300 mas/yr (Yoder and Standish, 1997). Combining Viking and Mars Pathfinder tracking reduced the uncertainty to 35 mas/yr (Folkner 1997). Tracking of Mars orbiters has also allowed the estimation of the precession rate through its effect on the orientation of the Mars gravity field. The most recent analysis, based on Viking, Pathfinder and orbiter tracking, has determined the precession rate to an accuracy of 10 mas/yr, constraining MOI to 0.3644 ±0.0005 (Konopliv et al. 2011). We present a preliminary estimate of the Mars precession rate based on recent Doppler tracking of the Opportunity rover combined with Pathfinder and Viking data. The new measurements are provided by the Mars Exploration Rover (MER) Science Radio experiment over the time period January to May 2012. During this period, Opportunity stood motionless on the surface awaiting the end of Martian winter. The combined data set covers a total of 36 years, allowing thus an improved estimation of the precession rate.

213.02 Studies of Lava Flows in Mars' Tharsis Region Using SHARAD Radar
  ^1University of Chicago, ^2NASA Goddard Space Flight Center, ^3Smithsonian Institution, ^4Southwest Research Institute, ^5CO.RI.S.T.A, Italy.

The Tharsis region of Mars is covered in volcanic flows that stretch for tens to hundreds of kilometers and are 30-70 m thick. We surveyed the Tharsis region to better understand the nature of these flows using SHARAD, the shallow radar instrument on the Mars Reconnaissance Orbiter. SHARAD operates at 20 MHz with a 10 MHz bandwidth. It has a free-space vertical resolution of 15 m and a 5-10 m vertical resolution in common geologic materials. SHARAD is able to determine dielectric properties of lava flows, provided that it can detect a subsurface interface. Radar measurements of the dielectric properties of these flows can provide information regarding their composition and density. A survey of SHARAD data over the Tharsis region revealed subsurface interfaces northwest of Ascræus Mons, and south and west of Pavonis Mons. These interfaces correspond to rift zone flows that occurred during the late stages of Tharsis volcanism. We estimated the permittivity of the flows, and also the loss tangent in some cases. The determined permittivity values range from 7.6 to 11.6, while the loss tangent values range from 4.5x10^-3 to 1.5x10^-2. These permittivity and loss tangent values are consistent with the measured values for terrestrial basaltic flows. This confirms that the Tharsis region flows are basaltic. Also, the low-loss composition and locations of these flows compels us to consider what makes these basaltic flows detectible by SHARAD, while other flows remain undetectable by the radar. To better understand the answer to this question further research is being conducted.

213.03 Search For Organic Molecules On Mars With The Gas Chromatograph-mass Spectrometer Of The Sample Analysis At Mars Experiment Onboard The Msl 2011 Curiosity Rover
- Cyril Szopa^1, P. Francois^2, P. Coll^3, M. Cabane^4, D. Coscia^1, S. Teinturier^1, F. Stalport^4, A. Buch^3, C. Freissinet^3, J. Eigenbrode^4, D. Glavin^4, P. Mahaffy^4, SAM team
  ^1LATMOS University Pierre & Marie Curie Paris 6, France, ^2LISA Université Paris Diderot UPEC CNRS, France, ^3LGPM Ecole Centrale Paris, France, ^4NASA GSFC.

In past times, life might have emerged under Martian conditions milder than the present ones, and left some remnants at the surface. Even if this did not happen, prebiotic molecules may have been preserved in the soil, and they might be similar to those that prevailed on the Earth surface some 3.5 to 4 billion years ago. NASA’s MSL2011 rover Curiosity will explore the surface and subsurface of Mars, seeking traces of prebiotic or biological activity. Organic signatures are among the main signatures of interest in this frame, and they will be among the main targets of the Gas Chromatograph Quadrupole Mass Spectrometer (GC-QMS) which constitutes the core of the Sample Analysis at Mars (SAM) analytical laboratory, developed by the NASA/GSFC in collaboration with the University of Paris (Fr) and the JPL. The main goal of this instrumentation is indeed to determine molecular abundances and isotopic ratios of organic molecules present in the collected samples, by analyzing gases either sampled from the atmosphere, or obtained from soil processing, either by physical heating or chemical reactions.
In order to prepare for the interpretation of the data obtained in situ with the GCQMS of SAM, and due to the complexity of this instrumentation, a number of calibrations are required to determine the exact behaviour of each part of this instrumentation, that is required to correctly treat the signal and obtain a correct interpretation of it. This paper will present an overview of the analytical capabilities of the GC-QMS, with a focus on the GC part. This will include calibration data obtained prior to the launch on the flight model, but also on individual spare components of the GC, as well as on a laboratory model similar to the flight model, and used to perform end to end calibration of the GC part.

213.04 Raman Spectroscopic Study Of The Dehydration Of Sulfates Using An Acoustic Levitator

- Stephen Brotton, R. Kaiser

Department of Chemistry, University of Hawaii at Manoa.

The martian orbiters, landers, and rovers identified water-bearing sulfates on the martian surface. Furthermore, the Galileo mission suggests that hydrated salts such as magnesium sulfate are present on the surface of Europa and Ganymede. To understand the hydrologic history of Mars and some of Jupiter’s and Saturn’s moons, future missions need to identify in situ the hydration states of sulfates including magnesium sulfate (MgSO₄ · nH₂O; n = 7, 6, . . . , 0), gypsum (CaSO₄ · 2H₂O), bassanite (CaSO₄ · 0.5H₂O) and anhydrite (CaSO₄). Raman spectroscopy is ideally suited for this purpose, since the Raman spectrum for each different degree of hydration is unique. To obtain laboratory Raman spectra for comparison with the in situ measurements, we have developed a novel apparatus combining an acoustic levitator and a pressure-compatible process chamber. Particles with diameters between ~10 μm and a few mm can be levitated at the pressure nodes of the ultrasonic standing wave. The chamber is interfaced to complimentary FTIR and Raman spectroscopic probes to characterize any chemical and physical modifications of the levitated particles. The particles can be heated to well-defined temperatures between ~300 K and ~1000 K using a carbon dioxide laser; the temperature of the particle will be probed via its black-body spectrum. The present apparatus enables (i) the production of high particle temperatures, (ii) precise measurement of the temperature, and (iii) accurate control of the environmental conditions (gas pressure and composition) within the chamber. Using this apparatus, we have studied the dehydration of sulfates including gypsum and epsomite (MgSO₄ · 7H₂O) in an anhydrous nitrogen atmosphere. We will present spectra showing the variation of the Raman spectra as gypsum, for example, is dehydrated to form anhydrite.

213.05 The Electric Potential Generated By The Origins Of Life

- Laura Zwicker

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The study of the origins of life here on Earth provides insight into the possible environmental and evolutionary constraints the emergence of life may face on extraterrestrial worlds. NASA has made it a goal to investigate this area of interest so that the information gathered might one day be utilized in the search for life in our universe. One particular topic of note is the potential connection between the deep-sea hydrothermal vents and the possible setting for the formation of the first life on Earth. Near volcanically active plates where the Earth’s crust is moving apart, an alkaline solution from the vent is fed into the acidic ocean, forming a self-assembling structure that carries an electric potential that could possibly be sufficient to drive prebiotic chemistry and allow life to evolve at such a location. These early conditions are replicated in the laboratory in experiments known as Chemical Gardens, in which these self-assembling structures are created by injecting either an acidic iron chloride solution into an alkaline silicate solution, or an alkaline silicate/sulfide solution is injected into an acidic iron chloride solution. Voltage is then measured between the inside and outside solutions to determine the electric potential generated by the precipitation process. Average voltage for a sodium silicate garden is -0.2mV, while average voltage for an iron sulfide garden is 0.6mV. This type of system is believed to hold true on any world with an acidic ocean, atmosphere high in carbon dioxide, and possessing a rock/water boundary at its ocean floor. Examples include early Mars, Europa, and possible Exosolar planets yet to be studied in detail. (Funded by the NASA Astrobiology Institute icy Worlds team.)

214 Mars Atmosphere: Corona to Surface
We present an analysis of HST ACS/SBC UV images of the extended H Ly alpha emission from the Martian hydrogen corona obtained over Oct/Nov 2007. The observations have been presented previously. This work will present a comparison of the distribution of the coronal Lyman alpha emission with simulations of the distribution of H atoms in the martian exosphere based on a monte carlo code for particle trajectories. It is assumed that all emission is produced by resonant scattering of solar Lyman alpha. We limit the comparison to the optically thin emission regions above the martian exobase, and vary the H temperature, the presence of a superthermal population, and the variation of source rate with angle from the sub-solar point to fit the observations. Constraints that we can derive on the number, the velocities, and the distribution of fast atoms leaving the martian exobase will provide important information on the escape flux of hydrogen, with relevance to the escape of water from Mars.

The production of energetic particles results in the formation of hot atom coronae on the Martian atmosphere. We have carried out the study of the hot carbon in Mars’ upper thermosphere and exosphere using our Monte Carlo calculations. The most important reactions for producing hot atomic carbon are expected to be photodissociation of CO and dissociative recombination (DR) of CO⁺ ion. The dominant source of the nonthermal escape of hot carbon from Mars is found to be photodissociation of CO, which is sensitive to solar activity and occurs mostly deep in the dayside thermosphere of Mars. The escape flux of hot carbon from dissociative recombination of CO⁺ has also been estimated using the latest available branching ratio and appropriate choice of rate coefficient. In this study, the calculated total global escapes of hot carbon from all dominant photochemical processes at different solar activities and Martian seasons are presented. To describe self-consistently the exosphere and the upper thermosphere, a combination of our 3D Direct Simulation Monte Carlo (DSMC) model [Valeille, A., Combi, M., Bougher, S., Tenishev, V., Nagy, A., 2009. J. Geophys. Res. 114, E11006. doi:10.1029/2009JE003389] and the 3D Mars Thermosphere General Circulation Model (MTGCM) [Bougher, S.W., Bell, J.M., Murphy, J.R., Lopez-Valverde, M.A., Withers, P.G., 2006. Geophys. Res. Lett. 32, doi: 10.1029/2005GL024059. L02203] is used. Profiles of density and temperature, atmospheric loss rates and return fluxes are studied using the model for the cases considered. Comparisons of DSMC model outputs will be made with those from other recent exosphere model studies.

The escape of water from Mars is understood to happen through escape of atomic Hydrogen and atomic Oxygen from the upper thermosphere. Escape of oxygen, which we examined in this work, was expected to occur mainly through non-thermal escape of a supra-thermal population of atomic Oxygen. Data measuring the population of atomic Oxygen in the exosphere has been sparse. Mariner and Viking measurements were the basis for constraining models of the upper atmosphere and ionosphere for decades. Few measurements were taken between 1976 and the arrival of Mars Express (MEX) in 2003, followed by a Rosetta fly-by in 2007. Feldman et al.’s 2011 analysis of the Rosetta flyby data was inconsistent with “recent models.” We here present analysis of two spectra taken by the (Hubble) Space Telescope Imaging Spectrograph using the first-order G140L low-resolution grating, with spatially resolved data along the disk and above the limb. One exposure was integrated for 700.199 seconds using a 52"x2" aperture, the other was integrated for 1680.191 seconds using a 52"x0.5" aperture. Both observations were taken on August 7, 2003, near opposition and the Martian perihelion, in the middle of the solar declining phase with an f10.7 indicative of moderate solar activity. We modeled the Oxygen density and fit limb
profiles using a similar method to Chaufray et al.'s 2009 analysis of MEX airglow data. Both the 1304 Å triplet and the 1356 Å forbidden doublet profiles were used to obtain the Oxygen populations. We compared our resulting fitted profiles to accepted models.

214.04 Observations of Ionospheric Currents at Mars

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How the solar wind interacts with a planetary object depends upon the object's properties, such as the presence of a magnetic field or an atmosphere. An unmagnetized object cannot stand-off the solar wind unless it possess a substantial atmosphere. Currents can be induced in the ionosphere which act to cancel out the external solar wind magnetic field preventing it from reaching the surface. Here we present observations of such induced currents in the ionosphere of Mars. During aerobraking maneuvers, Mars Global Surveyor made several passes through the ionosphere in the unmagnetized northern hemisphere. From the observed changes in the local magnetic field, we calculate vertical profiles of (predominantly) horizontal ionospheric currents. Given an atmospheric model, we also calculate the ionospheric conductivity and the ionospheric electric fields associated with these currents. These results can give us insights into how external magnetic fields are effectively screened out by induced currents and how induced magnetospheres form around unmagnetized objects. This work is supported in part by NASA's Mars Fundamental Research and Mars Data Analysis Programs.

214.05 Response of the M1 Layer of the Mars Ionosphere to Solar Variability

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We investigate the response of the two main plasma layers of the ionosphere of Mars to changes in incident ionizing solar flux, with a focus on the highly variable secondary layer. We determine the altitude, number density, and vertical width of both layers in 5600 Mars Global Surveyor (MGS) electron density profiles, and analyze the variation in these parameters with the solar zenith angle. We also compare these parameters to changes in the incident EUV and soft X-ray solar flux as represented by the Solar Irradiance Platform (SIP) model. We find that the low-altitude, secondary layer, (M1), responds to changes in the solar flux and solar zenith angle in a manner similar to that of the primary layer of the ionosphere, (M2). One significant difference is the vertical width of the M1 layer, which increases with increasing peak electron density, whereas the width of M2 layer does not appear strongly correlated with the density of the layer. We also use a one-dimensional photochemical model to simulate the Mars ionosphere each day during a six month stretch of MGS observations, with daily SIP irradiances as input. Both layers of the simulated electron density profiles exhibit many of the same responses to solar zenith angle and incident solar flux as seen in the MGS data. However, the simulations do not show an increase in the vertical width of the M1 layer as the peak number density increases.

214.06 An Observational Study Of The Response Of The Thermosphere Of Mars To Lower Atmospheric Dust Storms

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The effects of dust storms on densities, temperatures, and winds in the lower atmosphere of Mars are substantial. Here we use thermospheric observations to investigate how dust storms affect the upper atmosphere of Mars. These effects illuminate the vertical extent of atmospheric circulation patterns and associated diabatic heating during extreme dust loading, timescales for the onset and decay of the thermospheric response, and highlight potential dangers to spacecraft operations. We examined in situ measurements of thermospheric density (120-160 km) from aerobraking accelerometer instruments on Mars Global Surveyor, Mars Odyssey, and Mars Reconnaissance Orbiter; remote measurements of thermospheric density and pressure (60-120 km) obtained from stellar occultation observations by the SPICAM ultraviolet spectrometer on Mars Express; and ionospheric peak altitudes (~140 km) measured by radio occultation instruments on Mariner 9 and Mars Global Surveyor.
Ionospheric peak altitudes are a useful diagnostic as they indicate the height of a particular thermospheric pressure level. We find that: (1) Thermospheric conditions can be perturbed by dust storms outside the classical "dust storm season" of Ls=180 deg-360 deg. (2) The thermospheric regions affected by even a small dust event can include nearly all latitudes. (3) Atmospheric temperatures can be affected by dust storms at altitudes as high as 100 km. (4) The onset of the thermospheric response to a distant dust event can be a few days or less. (5) The characteristic timescale for the decay of the thermospheric response to a dust event can be tens to one hundred days, and it may differ from the corresponding timescale for the lower atmosphere. (6) Average thermospheric densities can change by factors of a few during mere regional dust storms and an order of magnitude change is possible for the largest storms.

214.07 GoogleMars, A Visualization Of Mariner 9 UVS Data
- Karen E. Simmons¹, K. D. Mankoff², C. A. Barth¹
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A new Mariner 9 UV Reflectance data set has been created using Mars data from the Mariner 9 Ultraviolet Spectrometer (UVS) [¹] instrument and solar irradiance data from the SORCE mission [²]. Each 2107 to 3497A Reflectance spectrum was then coded into a KML file, called GoogleMars, for visualization with the Google Earth Mars layer using a new library of kdm-idl code [³]. This code produces a file that displays each Reflectance spectrum as a color-coded rectangular field-of-view footprint on the Mars image so that direct comparison with image features can be seen. At these wavelengths the pressure of the atmosphere, the presence of dust, ozone, ice crystals and the ground albedo influences the intensity. Besides displaying all of the Reflectance spectrum footprints from the loaded orbits, this KML code also allows the user to display additional detail for individual footprints in several ways: a) by zooming in on a portion of an orbit a set of balloons appear containing each Reflectance spectrum plotted between 2100 and 3500A for each footprint or b) by selecting a specific footprint, a more detailed balloon containing the Reflectance plotted between 2100 and 3500A plus the viewing geometry, date and spacecraft clock (DAS) time, along with the orbit number and the 3049A Reflectance value is displayed. For a detailed description and to further explore the Mariner 9 UVS GoogleMars KML data set go to http://lasp.colorado.edu/home/mariner9/GoogleMars. This Mariner 9 UVS instrument web site contains complete instructions to use the GoogleMars tool, a detailed description of the reanalysis process and access to the new Mariner 9 UVS Reflectance data sets. This work was supported from ROSES grant NNX09AM04GS04. References [¹] Hord C. W., Barth C. A., Pearce J.B., Icarus, 12, 63-77 (1970). [²] http://lasp.colorado.edu/sorce/data [³] https://code.google.com/p/kdm-idl/

214.08 Latitudinal And Seasonal Variations Of O2 And D/H On Mars Using Herschel/hifi
- Therese Encrenaz¹, R. Moreno¹, E. Lellouch¹, T. Fouchet¹, P. Hartogh², C. Jarchow², F. Lefèvre³, T. Cavalié⁴
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As a non-condensible species, molecular oxygen on Mars is expected to show spatial and temporal variations, but these measurements have not been performed yet. In addition, mapping the D/H ratio and recording its seasonal variations is a key diagnostic for understanding the past history of water on Mars, as well as surface/atmosphere exchange in the water cycle (Montmessin et al. JGR 110, E3, CiteID E03006, 2005). We have been using HIFI aboard Herschel to study the latitudinal variations of O2 and D/H on Mars for two different seasons, Ls = 47° (Dec. 23, 2011) and Ls = 108-115° (May 09-25, 2012). Three sets of transitions have been recorded: H218O and HDO around 1630 GHz, O2 and HDO around 1815 GHz, and 13CO and CO18 around 1870 GHz. The diameter of Mars was 8.3 arcsec on Dec. 23, 2011, and 8-9 arcsec in May 2012. The Herschel field of view is 11.3 arcsec at 1870 GHz and 9.8 arcsec at 1630 GHz. For each period, three observations were successively recorded, centered along the central meridian, at the south limb, the center and the north limb. The total observing time, over the two periods, was 26 hours. A preliminary reduction indicates a mean O2 abundance in agreement with previous measurements (1400 ppm, Hartogh et al. AA 521, id.L49, 2010). No significant variation is observed in O2 and CO between North and South for Ls = 47°, as expected in the vicinity of equinox (Forget et al. LPI-1494, 2009). An analysis of the two data sets will be presented.

214.09 Heterogeneous Ice Processes Important for Odd Hydrogen and Ozone on Mars
Odd-hydrogen chemistry plays an important role in the ozone budget and the stabilization of carbon dioxide in the Martian atmosphere. In the lower atmosphere, heterogeneous processes influence the fate of odd-hydrogen species. The quantitative details of these heterogeneous physicochemical processes are poorly understood, leading to discrepancies between models and observations of the Martian atmosphere. Atmospheric models consistently underestimate the ozone abundances and overestimate the hydrogen peroxide densities. Heterogeneous loss of odd-hydrogen species has been suggested as a possible explanation. Relevant laboratory results are scarce in the literature, especially at the temperature range appropriate for the Martian atmosphere. We are conducting laboratory experiments to determine the uptake of various odd-hydrogen species by water ice and other substrates. We use a Knudsen cell apparatus, which is a low-pressure stirred-flow reactor in a configuration that allows heterogeneous uptake effects to be quantified by the change in the concentration of a gas phase species mixture flowing over a condensed matter substrate. We will present our recent results and discuss their relevance to the Martian odd-hydrogen and ozone chemistry. This material is based upon work supported by the National Aeronautics and Space Administration under Grant NNX10AM85G issued through the Mars Fundamental Research Program.

214.10 Isotopic Differences in CO Air Broadening and Shift Parameters


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Line shape parameters were measured in the 2−0 bands at 2.3 μm for the three most abundant isotopologues of carbon monoxide at temperatures between 150 K and 298 K and total pressures up to 0.9 atm. These parameters include the Lorentz half-width coefficients with their temperature dependence exponents; pressure-induced line shift coefficients with their temperature dependences, speed dependence parameters, and off-diagonal relaxation matrix elements. For this, we recorded more than 50 high resolution (0.005 cm⁻¹) spectra of CO and two of its isotopologues (¹³CO and C¹⁸O) using a coolable absorption cell [1] in the sample compartment of the Bruker IFS 125HR Fourier transform spectrometer at Jet Propulsion Laboratory. Line parameters were retrieved by broadband constrained multispectrum least-squares fitting [2] of 16 or more spectra simultaneously. The individual line positions and intensities were constrained to their theoretical relationships in order to obtain the rovibrational (G, B, D, and H) and band intensity parameters, including Herman-Wallis coefficients, as has been done for CO₂ previously [3]. Differences between the air-broadening results for the ¹²C¹⁶O band [4] and the ¹³C¹⁶O and ¹²C¹⁸O 2-0 bands [5] are examined. This research is supported by NASA’s Earth Science Atmospheric Composition Laboratory Research Program. Part of the research at the Jet Propulsion Laboratory, California Institute of Technology, the College of William and Mary, and Connecticut College was performed under contracts and grants with the National Aeronautics and Space Administration. 1. K. Sung et al., J. Mol. pectrosc. 262 (2010) 122. 2. D. C. Benner et al., J. Quant. Spectrosc. Radiat. Transfer 53 (1995) 705. 3. V. Malathy Devi et al., J. Mol. Spectrosc. 242 (2007) 90. 4. V. Malathy Devi et al., J. Quant. Spectrosc. Radiat. Transfer 113 (2012) 1013. 5. V. Malathy Devi et al., J. Mol. Spectrosc. 276-277 (2012) 33.

214.11 Addition Of Atmospheric Volatiles At Mars Via Impact

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The Martian atmosphere has changed over time. The magnitude and timing of this change is debated, but it is clear that Mars was once capable of supporting liquid water at the surface for time periods sufficiently long to carve river channels. Further, isotopic evidence indicates that a substantial fraction of the atmosphere has escaped to space over time. One way to significantly change climate is to alter the amount and composition of atmospheric gases; the changing climate of Mars can be studied by examining and quantifying the various sources and sinks that have been active over its history. Impacts by asteroids and comets are unique in that they can provide both a source and sink of atmospheric gases, depending upon the circumstances of each impact. Here we present
calculations of the role of impacts in changing atmospheric abundance at Mars. Our previous work has considered the amount of atmosphere that can be removed by large impacts since the onset of the geologic record. Here we extend this method to examine the addition of atmosphere via impacts of all sizes. Our approach is to use the observed crater densities on Martian surfaces of different ages to infer the global impact rate at different epochs as a function of impactor size. This impact rate can be converted in a straightforward manner to the amount of gas added or removed from the atmosphere. Our result will constrain the total supply of atmospheric volatiles available from impacts over Martian history. Together with estimates of removal of volatiles via impacts we can being to construct models of the role that impacts have played in altering Martian climate. This research is supported by NASA's Planetary Atmospheres Program.

214.12 Upper Boundary Extension of the NASA Ames Mars General Circulation Model
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The NASA Ames Mars General Circulation Model (MGCM) upper boundary is being extended from ~90 km to ~120 km. Extending the MGCM upper boundary will expand our understanding of the connection between the lower and upper atmosphere of Mars through the middle atmosphere, and will provide support for future missions (i.e. the 2013 MAVEN mission). The extension of the MGCM upper boundary mainly requires the incorporation of Non-Local Thermodynamic Equilibrium (NLTE) heating (visible) and cooling (infrared). The NLTE solar heating rates correction is from Table 1 in López-Valverde et al. (1998) and the CO2 15 μm cooling parameterization is adapted from Bougher et al. (2006). Currently, extensive testing has been done with the 1D radiation code and the incorporation into the 3D MGCM has begun. Progress on this research will be presented.

214.13 Radio Occultation Measurements with the Mars Reconnaissance Orbiter
- David P. Hinson1, S. Asmar2, D. Kahan2, V. Akopian2, S. Maalouf2
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The Mars Reconnaissance Orbiter (MRO) circles Mars in a low-altitude, sun-synchronous, polar orbit, crossing the equator at local times of about 3 and 15 h. There are frequent opportunities for radio occultation (RO) sounding of the martian atmosphere, which has been conducted routinely since January 2008. Observations are limited to one orbit per day, so as to minimize the impact on transmission of data collected by the primary scientific instruments. We are retrieving atmospheric profiles from the MRO RO data, and we are delivering the results to the NASA Planetary Data System (PDS) for archiving and public distribution. The value of these RO profiles derives from their combination of accurate absolute calibration, excellent vertical resolution (about 500 m), and accurate registration in radius. The first attribute qualifies the RO profiles as a reliable standard for cross-instrument calibration, and comparisons are underway with atmospheric observations by the MRO Mars Climate Sounder (MCS). The second attribute yields unique insight into the structure and dynamics of the lower atmosphere (0-10 km) and its interaction with surface reservoirs of dust and volatiles. The third attribute allows precise measurements of geopotential height and surface pressure, which constrain the mass distribution of the atmosphere and its seasonal variations. These attributes also enable long-term monitoring of interannual variability and climatic trends. We will characterize the spatial and seasonal coverage of the observations to date, and we will illustrate the atmospheric phenomena captured by the MRO RO profiles. This research is funded in part by Grant NNX12AL48G of the Mars Data Analysis Program.

214.14 Temperature Profile and Surface Pressure Retrieval of Mars' Atmosphere Using Infrared Heterodyne Spectroscopy
- Ramsey L. Smith1, T. Hewagama2, T. A. Livengood3, K. E. Fast1, T. Kostiuk1
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Infrared heterodyne spectroscopy of CO2 transitions in the Martian atmosphere was obtained using the Goddard Space Flight Center's Heterodyne Instrument for Planetary Winds and Composition, HIPWAC, on the NASA Infrared Telescope Facility 3-m telescope, with resolving power of 2.5107. The measured spectra are not fully consistent with temperature profiles for this location and season derived from the Mars Global Surveyor mission (MGS),
particularly constraining the pressure and temperature in the deepest part of the troposphere with unambiguous differences between the MGS temperature profile and that required to satisfy the measured emergent spectrum. The temperature information is useful for studying seasonal and global variability, for comparison of results from flight mission results, as well as better profiles for interpreting flight obtained measurements. We will report data collected from our analysis of our high-resolution measurement of $^{16}$O$^{12}$C$^{16}$O used to develop a temperature profile and surface pressure. CO$_2$ is uniformly mixed in the Martian atmosphere, which makes it an ideal candidate for temperature determination. We are able to collect spectra of the isotopologues of CO$_2$ in the same spectra, which eliminates a source of error for molecular species identification and atmosphere temperature determination. The aforementioned parameters are critical for Martian atmospheric-surface investigations such as isotopologue determination and isotope ratio calculations. For example, an average over measurements acquired at the subsolar point and in the early afternoon at the subsolar latitude yields the terrestrial VSMOW standard, with a minimal difference of $^{18}$O = +9±14 ‰. This precision is sufficient to enable a remote investigation of seasonal variations, i.e. due to mass-dependent fractionation in the polar ice cap freeze-sublimate cycle.

214.15 Interannual Variability of Gravity Waves in MCS & MGS RS Data

- Robert Edmonds$^1$, J. Murphy$^1$

Heavens’ et al. (2010) observed within Mars Climate Sounder (MCS) vertical temperature profiles increased instances of ‘significant instabilities’ at high northern latitudes occurring within ~ 80 degrees of Solar Longitude prior to the Mars Year (MY) 28 dust storm. Heaven’s et al. (2010) defined significant instabilities to be instances where convective available potential energy (CAPE) values for an individual vertical temperature profile exceeded 300 J/kg. The instabilities are thought to be the result of gravity (buoyancy) wave saturation. These high latitude instabilities temporally coincided with cooling at 0.1 Pa in low northern latitudes, and this cooling may be the result of gravity waves’ effect on the mean meridional circulation due to increased horizontal momentum deposition. With more data from MY 30 available we expand upon their analysis. We also explore whether the increased instances of significant instabilities can be explained by increased wave activity or changes in the background wind and thermal environment limiting the vertical propagation of gravity waves. An analysis of gravity wave activity is explored by investigating interannual variability of gravity wave energies using techniques similar to Creasey et al.’s (2006) analysis of Mars Global Surveyor (MGS) Radio Science (RS) vertical temperature data. We further explore the effect of the background wind and thermal environment on the vertical propagation of gravity waves by investigating the Scorer parameter. Vertical changes in the Scorer parameter have an ability to affect the vertical propagation of terrain generated gravity waves. This analysis may show that changes in the background wind and thermal environment may have allowed vertical propagation of gravity waves to produce the observed instabilities prior to the MY 28 dust storm. Similar analysis of the MGS RS vertical temperature data is conducted searching for further variability in gravity wave activity before the MY 25 dust storm.

214.16 The Mars Dust Cycle: Investigating the Effects of Radiatively Active Water Ice Clouds on Surface Stresses and Dust Lifting Potential with the NASA Ames Mars General Circulation Model

- Melinda A. Kahre$^1$, J. L. Hollingsworth$^1$, R. M. Haberle$^1$, F. Montmessin$^2$

The dust cycle is a critically important component of Mars’ current climate system. Dust is present in the atmosphere of Mars year-round but the dust loading varies with season in a generally repeatable manner. Dust has a significant influence on the thermal structure of the atmosphere and thus greatly affects atmospheric circulation. The dust cycle is the most difficult of the three climate cycles (CO$_2$, water, and dust) to model realistically with general circulation models. Until recently, numerical modeling investigations of the dust cycle have typically not included the effects of couplings to the water cycle through cloud formation. In the Martian atmosphere, dust particles likely provide the seed nuclei for heterogeneous nucleation of water ice clouds. As ice coats atmospheric dust grains, the newly formed cloud particles exhibit different physical and radiative characteristics. Thus, the coupling between the dust and water cycles likely affects the distributions of dust, water vapor and water ice, and thus atmospheric heating and cooling and the resulting circulations. We use the NASA Ames Mars GCM to investigate the effects of radiatively active water ice clouds on surface stress and the potential
for dust lifting. The model includes a state-of-the-art water ice cloud microphysics package and a radiative transfer scheme that accounts for the radiative effects of CO2 gas, dust, and water ice clouds. We focus on simulations that are radiatively forced by a prescribed dust map, and we compare simulations that do and do not include radiatively active clouds. Preliminary results suggest that the magnitude and spatial patterns of surface stress (and thus dust lifting potential) are substantially influenced by the radiative effects of water ice clouds.

214.17 Sensitive Ground-based Search for Sulfuretted Species on Mars
- Alain Khayat¹, G. L. Villanueva², M. J. Mumma³, T. E. Riesen⁴, A. T. Tokunaga¹
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  ⁴NASA Astrobiology Institute / Institute for Astronomy.

We searched for active release of gases on Mars during mid Northern Spring and early Northern Summer seasons, between Ls= 34° and Ls= 110°. The targeted volcanic areas, Tharsis and Syrtis Major, were observed during the interval 23 Nov. 2011 to 13 May 2012, using the high resolution infrared spectrometer (CSHELL) on NASA’s Infrared Telescope Facility (NASA/IRTF) and the ultra-high resolution heterodyne receiver (Barney) at the Caltech Submillimeter Observatory (CSO). The two main reservoirs of atmospheric sulfur on Mars are expected to be SO2 and H2S. Because these two species have relatively short photochemical lifetimes, 160 and 9 days respectively (Wong et al. 2004), they stand as powerful indicators of recent activity. Carbonyl sulfide (OCS) is the expected end-product of the reactions between sulfuretted species and other molecules in the Martian atmosphere. Our multi-band survey targeted SO2, SO and H2S at their rotational transitions at 346.523 GHz, 304.078 GHz and 300.505 GHz respectively, and OCS in its combination band (ν1+ν3) at 3.42 μm and its fundamental band (ν3) centered at 4.85 μm. The radiative transfer model used to derive abundance ratios for these species was validated by performing line-inversion retrievals on the carbon monoxide (CO) strong rotational (3-2) line at sub-mm wavelengths (rest frequency 345.796 GHz). Preliminary results and abundance ratios for SO2, H2S, SO, OCS and CO will be presented.

We gratefully acknowledge support from the NASA Planetary Astronomy Program (AK, ATT, MJM), NASA Astrobiology Institute (MJM), NASA Planetary Atmospheres Program (GLV), and NSF grant number AST-0838261 to support graduate students at the CSO (AK). References: Wong, A.S., Atreya, S. K., Formisano, V., Encrenaz, T., Ignatiev, N.I., "Atmospheric photochemistry above possible martian hot spots", Advances in Space Research, 33 (2004) 2236-2239.

214.18 GCM Investigation of Martian Methane Observations
- Malynda Chizek¹, J. R. Murphy¹, M. A. Kahre²
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Recent observations have indicated spatially and temporally variable abundances of methane (or another gas in the same spectral range) in the Martian atmosphere (1, 2, 3, 4, 5, 6), although the validity of these reports is debated (7) and the inferred methane lifetimes (<1 year) are much shorter than expected (~600 years; 1, 8). These observations cover several methane bands over several years, and suggest different source locations and production rates, as well as different seasonal peaks in abundance. GCMs have been used to interpret the martian methane observations of 4 (8, 9), but there are no published GCM analyses of the observations of 2, 3, 5, 6. We use the NASA Ames GCM version 1.7.3 (10) to analyze the suggested sources required for each of these observations in order to search for characteristics in common for all of the martian methane observations, and to attempt to rectify the differences. In addition, we will present the abundances expected to be measured at Gale Crater for each of these observations. Krasnopolsky, Icarus (2004) Formisano et al., Science (2004) Geminale et al., P&SS (2008) Mumma et al., Science (2009) Fonti & Marzo, A&A (2010) Geminale et al., P&SS (2011) Zahnle et al., Icarus (2011) Lefevre & Forget, Nature (2009) Mischna et al., P&SS (2011) Kahre et al., JGR (2006)

- Julie Dequaire¹, M. A. Kahre², R. M. Haberle², J. L. Hollingsworth²
  ¹USRA / NASA Ames Research Center, ²NASA Ames Research Center.
One of the most intriguing and least understood climate phenomena on Mars is the existence of a perennial south polar CO₂ ice cap that is offset from the pole in the western hemisphere. Colaprete et al. (2005) hypothesize that since the process by which CO₂ surface frost accumulates (i.e., precipitation or direct vapor deposition) affects the albedo of the ice, the atmosphere can play a role in the stability and asymmetry of the cap. They show that the stationary wave pattern set up by the Argyre and Hellas basins results in a colder western hemisphere in which atmospheric CO₂ condensation and precipitation is favored. Because precipitated CO₂ is brighter than directly deposited CO₂, they suggest that the topographically forced atmospheric circulation maintains the asymmetry of the residual cap. However, Colaprete et al (2005) do not explicitly model the albedo of the south cap to demonstrate the viability of their hypothesis. We build on their study with a version of the NASA Ames GCM that includes a newly incorporated CO₂ cloud microphysics scheme. Simulated results compare well to observed temperatures, pressures, cap recession rates and cloud occurrence. Precipitation and direct vapor deposition are predicted in the model, which will allow us to design schemes to model the cap albedo based on known physical quantities such as precipitated particle size and dust content. The goal of this work is to develop a more complete understanding of the asymmetry of the south residual CO₂ cap and of the Martian CO₂ cycle.

214.20 Surface Spectral Endmember Recovery of CRISM Mapping Data for Radiative Transfer Modeling
- David R. Klassen¹

¹Rowan Univ.

My goal is to measure the cloud optical depth, and thus water/ice abundance, in Martian clouds at VIS-NIR wavelengths. This task is complicated by the fact that radiative transfer modeling requires an a priori knowledge of the surface spectral reflectance, but all spectral data are a mixture of surface, atmosphere, and aerosol (dust and ice) spectra. So there is a need for a technique to isolate surface components. Principal Components Analysis (PCA) and Target Transformation (TT) [1] are proving to be useful in this endeavor [2-7]. PCA has been shown to recover 3-4 eigenvector spectra that show good consistency over diurnal, seasonal, and inter-annual time (the higher dimensions are more variable and/or noise) [2-7] which account for over 95% of the spectral variance. They show high correlations to surface albedo features, implying a surface component with little or no aerosol component. This smaller set of spectral dimensions are then run through TT to recover a set of "pure" surface-only spectral endmembers. I will present the results of the endmember recovery from CRISM multispectral mode data. I will show the limits over which these endmembers can be considered constant enough (as seen in previous ground-based work) to use as the a priori surface reflectance for use in a production-mode radiative transfer modeling ice cloud recovery program. References: [1] Bandfield, J. L., et al. (2000) JGR, 105, 9573. [2] Klassen, D. R. and Bell III, J. F. (2001) BAAS 33, 1069. [3] Klassen, D. R. and Bell III, J. F. (2003) BAAS, 35, 936. [4] Klassen, D. R., Wark, T. J., Cugliotta, C. G. (2005) BAAS, 37, 693. [5] Klassen, D. R. (2009) Icarus, 204, 32. [6] Klassen, D. R. (2011) EPSC-DPS Joint Meeting 2011, 1554. [7] Klassen, D. K., in preparation.

214.21 Comparison Of TES FFSM Eddies And MOC Storms MY 24-26
- John Noble¹, R. M. Haberle², A. F. C. Bridger³, R. J. Wilson³, J. R. Barnes⁴, J. L. Hollingsworth², B. A. Cantor⁵

¹NASA Ames Research Center/San Jose State University, ²NASA Ames Research Center, ³Geophysical Fluid Dynamics Laboratory, NOAA, ⁴Oregon State University, ⁵Malin Space Science Systems.

Mars Global Surveyor (MGS) orbiter observed a planet-encircling dust storm (PDS) in Mars year (MY) 25 from Ls=176.2-263.4°. Although PDSs occur on an irregular basis, all well-documented storms have begun within ± 75° of Ls from perihelion (Ls=251°) when insolation is greatest near the SH summer solstice (Ls=270°) and the south polar cap is receding. PDS seasonal occurrence suggests the presence of climatic/environmental precursors and components, yet interannual variability suggests that initiation and expansion mechanisms are not solely seasonal in character. We have integrated and examined all available MGS data in order to better understand and characterize the dynamical processes responsible for MY 25 PDS initiation and expansion. Here we present an examination of Mars Orbiter Camera (MOC) dust storms and transient baroclinic eddies identified from Fast Fourier Synoptic Mapping (FFSM) of Thermal Emission Spectrometer (TES) temperatures for the first two phases of the storm: precursor, Ls=176.2-184.7°, and expansion, Ls=184.7-193°. FFSM analysis of TES 3.7 hPa thermal data shows the presence of eastward-traveling waves at 60° S with a period of about three sols. We hypothesize that these waves are transient baroclinic eddies that contributed to the initiation of precursor storms near Hellas. An
examination of the spatial and temporal relationship of FFSM eddies and MOC storms suggests an interesting association between eastward eddy propagation and eastward storm evolution. Determining the factors responsible for PDS genesis in MY 25 and not 24 and 26 is difficult. The most notable difference is the amplitude of E1-E7 eddies in Hellas, with all seven MY 25 eddies colder than ~ -3.5 K, compared with three in MY 24 and two in MY 26. It is possible that the sustained series of high-amplitude eddies in MY 25 was a factor in PDS interannual variability.

215 Future Missions and Instruments
Tuesday, 3:30 PM – 6:00 PM, Exhibit Hall

215.01 The Rosetta Mission - Exploring Solar System Formation
- Rita Schulz, L. O’Rourke, N. Altobelli, B. Gieger, M. Kueppers
  1ESA/ESTEC, Netherlands, 2ESA/ESAC, Spain.

The International Rosetta Mission, ESA’s first Planetary Cornerstone, is a rendezvous mission with a comet nucleus combining an Orbiter with a Lander. Rosetta is on its way to meet Jupiter-family comet 67P/Churyumov-Gerasimenko in 2014. It will go in orbit around the comet nucleus when it is still far away from the Sun, and escort it for more than a year along its pre- and post-perihelion orbit. With the 12 scientific instruments on board the Orbiter, Rosetta will investigate the nucleus and the inner coma as well as their evolution as a function of increasing and decreasing solar flux input. Moreover, the Lander Philae will get down onto the surface of the nucleus at a time when it is still at a low state of activity, and analyse comet nucleus material in-situ with the 10 instruments on board. Launched in 2004 Rosetta has already completed all four gravity assists (3 at Earth, 1 at Mars) that were necessary to acquire the orbital energy needed to rendezvous and go in orbit around the comet nucleus. After the second and third Earth gravity assist Rosetta performed close fly-bys at the main-belt asteroids (2867) Steins and (21) Lutetia. Both have turned out to be extraordinary, hence a very good choice for close inspection. The spacecraft is now in hibernation while moving further into the outer solar system. It will wake up on 20 January 2014, at 4.5 AU heliocentric distance to proceed to its rendezvous. Rosetta will reach the comet in May 2014 and go into close orbit in September 2014. The landing of Philae is planned for 11 November 2014 at a heliocentric distance of 3 AU. After a five-day prime Lander mission, both the Orbiter and the Lander will enter the routine scientific phase, escorting the comet to perihelion and beyond.

215.02 The European Sample Return Mission MarcoPolo-R: Understanding The Nature Of Extraterrestrial Primitive Materials And Tracing The Origins
  1INAF-Oss. Astro. di Roma, Italy, 2LESIA-Observatoire de Paris, France, 3Univ. Nice, CNRS, OCA, France, 4MPS, Katlenburg-Lindau, Germany, 5INAF-Oss. Astro. di Arcetri, Italy, 6Univ. of Leiden, Netherlands, 7Open Univ., Milton Keynes, United Kingdom, 8IAA-CSIC, Granada, Spain, 9CRPG, France, 10ESA-ESTEC, Netherlands, 11ESA-ESAC, Spain.

MarcoPolo-R is a European sample return mission to a primitive Near-Earth Asteroid (NEA) selected in February 2011 for the Assessment Study Phase of ESA’s Cosmic Vision M3-class (Medium) program with 3 other mission candidates. The study will last until September 2013, for a selection of one mission at the end of 2013 and a launch in 2022-2024. MarcoPolo-R will rendezvous with a unique kind of target, the primitive binary NEA (175706) 1996 FG3. It will scientifically characterize the NEA binary system at multiple scales, and return a unique pristine sample to Earth unaltered by the atmospheric entry process or terrestrial weathering. The binary target provides enhanced science return: precise measurements of the mutual orbit and rotation state of both components can be used to probe higher-level harmonics of the gravitational potential, and therefore the internal structure. A unique opportunity is offered to study the dynamical evolution driven by the YORP/Yarkovsky thermal effects. Possible migration of regolith on the primary from poles to equator allows the increasing maturity of asteroidal regolith with time to be expressed as a latitude dependent trend, with the most weathered material at the equator matching what is seen in the secondary. The main goal of MarcoPolo-R is to return unaltered NEA material for
detailed analysis in ground-based laboratories. It will allow scientists to study the most primitive materials available to investigate early solar system formation processes. Laboratory measurements are vital for revealing the evidence of stellar, interstellar medium, pre-solar nebula and parent body processes that are retained in primitive asteroidal material unaltered by atmospheric entry or terrestrial contamination. It is no surprise therefore that sample return missions are considered a priority and are developed by a number of the leading space agencies.

215.03 AIDA: Asteroid Impact & Deflection Assessment

- Andrew F. Cheng\textsuperscript{1}, A. Rivkin\textsuperscript{1}, A. Galvez\textsuperscript{2}, I. Carnelli\textsuperscript{2}, P. Michel\textsuperscript{1}, C. Reed\textsuperscript{1}
  \textsuperscript{1}Johns Hopkins, APL, \textsuperscript{2}ESA HQ, France, \textsuperscript{1}University of Nice-Sophia Antipolis, France.

Near Earth objects are small bodies orbiting the Sun near Earth’s orbit, some of which impact the Earth. The impact of an object as large as 30 m in diameter occurs every few centuries. The impact of such an object would already release an energy of at least a megaton of TNT, and the impact of a larger object, which would occur less often, would be even more hazardous. To protect the Earth from a potential asteroid impact, various mitigation methods have been proposed, including deflection of the asteroid by a spacecraft impact. The Double Asteroid Redirection Test (DART) is such an asteroid mitigation mission concept. This mission would be a valuable precursor to human spaceflight to an asteroid, as it would return unique information on an asteroid’s strength and internal structure and would be particularly relevant to a human mission for asteroid mitigation. We report initial results of the AIDA joint mission concept study undertaken by the Johns Hopkins Applied Physics Laboratory and ESA with support from NASA centers including Goddard, Johnson and Jet Propulsion Laboratory. For AIDA, the DART study is coordinated with an ESA study of an Asteroid Impact Monitoring (AIM) mission, which would rendezvous with the same target. AIDA follows the previous Don Quijote mission study performed by ESA in 2005-2007, with the objective of demonstrating the ability to modify the trajectory of an asteroid and measure the trajectory change. Don Quijote involved an orbiter and an impactor spacecraft, with the orbiter arriving first and measuring the deflection, and with the orbiter making additional characterization measurements. Unlike Don Quijote, DART envisions an impactor spacecraft to intercept the secondary member of a binary near-Earth asteroid, with ground-based observations to measure the deflection as well as additional spacecraft observations from AIM. Low cost mission approaches will be presented.

215.04 A Swarm Of Micro-satellites For In Situ NEO Characterization

- Martin Elvis\textsuperscript{1}, D. Landau\textsuperscript{2}, J. Kasper\textsuperscript{1}, G. Lantoine\textsuperscript{2}, C. Marrrese-Reading\textsuperscript{2}, J. Mueller\textsuperscript{2}, R. P. Russell\textsuperscript{3}, N. Strange\textsuperscript{2}, J. K. Ziemer\textsuperscript{2}, A. Nash\textsuperscript{7}, D. Yeomans\textsuperscript{2}
  \textsuperscript{1}Harvard-Smithsonian CfA, \textsuperscript{2}JPL, \textsuperscript{3}University of Texas, Austin.

Crewed missions to near-Earth objects (NEOs), as well as reconnaissance for hazard reduction, for science, and for resource exploitation, require in situ robotic precursor missions. Because potential crewed mission targets have multiple requirements, even quite high probabilities for each single requirement lead to a need for multiple targets to be investigated. To ensure mission robustness, multiple good targets with well-spaced launch windows will be needed. Numerous robotic precursors, or order tens to hundreds, will thus be essential. These will have to be micro-satellites in order to be affordable. We describe a concept to place a few hundred Small Wandering Autonomous Reconnaissance Modules (SWARM) in a Solar orbit slightly interior to the Earth. These SWARM micro-satellites would first survey for NEOs, and then visit numerous NEOs as they come into energetically favorable locations.

215.05 The Europa Clipper and Orbiter Mission Concepts: Innovative Approaches for Exploring Europa’s Habitability

- David A. Senske\textsuperscript{1}, L. Prockter\textsuperscript{2}, R. Pappalardo\textsuperscript{1}, W. Patterson\textsuperscript{2}, S. Vance\textsuperscript{1}, Europa Science Definition, Technical Teams
  \textsuperscript{1}JPL, \textsuperscript{2}APL.

Europa is unique among the large icy satellites because it probably has a long-lived saltwater ocean beneath an ice shell that is geodynamically active. The combination of irradiation of its surface and tidal heating of its interior
could make Europa a rich source of chemical energy for life. Direct contact of the ocean with a rocky mantle and potential hydrothermal activity could provide energy and nutrients to support biological activity. NASA has enlisted a study team to consider Europa mission options feasible over the next decade, compatible with NASA’s projected planetary science budget and addressing Planetary Decadal Survey priorities. Two Europa mission concepts (Orbiter and multiple flyby, call the “Clipper”) are undergoing continued study with the goal to “Explore Europa to investigate its habitability.” The Orbiter and Clipper architectures lend themselves to specific types of scientific measurements. The Orbiter concept is tailored to geophysical science that requires being in orbit at Europa. This would include confirming the existence of and characterizing the ocean along with mapping of the global morphology and topography. This architecture provides for radiation-shielded instruments with low mass, power, and data rate. The Clipper concept focuses on remote sensing science that could be accomplished through multiple close flybys of Europa. This would include exploring the ice shell for evidence of liquid water within or beneath it along with exploring the composition of the surface and atmosphere. Morphologic and topographic mapping would also be done. This architecture can provide for radiation-shielded instruments with higher mass, power, and data rate. NASA has directed the Europa team to evaluate, within a cost constrained budget, the ability of the Orbiter concept to characterize the ice shell and surface composition, and for the Clipper concept to address investigations to characterize the ocean. The status of these updated concepts will be reported.

215.06 Photometric Observations of Interstellar Hydrogen by HDAC: In-flight Calibration and First Results

- Horst Uwe Keller¹, Y. Skorov¹, O. Katushkina², V. Izmodenov², R. Reulke³, K. Glaßmeier¹

A. Geophysics and extraterrestrial Physic, Universität Braunschweig, Germany, ²Lomonosov Moscow State University, Russian Federation, ³Institut für Informatik Computer Vision, Humboldt Universität, Germany.

HDAC is part of the ultraviolet imaging spectrometer (UVIS) onboard the Cassini spacecraft. The instrument scans the Lyman-α emission lines of hydrogen and deuterium atoms. In the photometer mode only the CEM detector is used to register the signals within a 3 degree field of view. HDAC has been switched on in photometer mode most of the time producing a unique continuous data set for more than a decade. An analysis of the Lyman-α background data serves two purposes: determination of the parameters of the interstellar/interplanetary hydrogen and determination of the properties of the solar wind. The exhaustive pre-flight laboratory calibrations included evaluation of the absolute sensitivity of the instrument; evaluation of the instrument spectral sensitivity; evaluation of the off-axis response. During the mission these characteristics may change over time due to continuous time degradation of electronics and/or abrupt events. For example, three dramatic sensitivity breakdowns were observed in 2001. Thus the only chance to determine the current sensitivity of HDAC is to make in-flight comprehensive evaluation, e.g. measuring known fluxes from stars or other bodies. We systematically analyzed photometric observations of the star SPICA in order to perform in-flight calibrations. All three aspects listed above were explored. We found that the instrument is still in good condition. The current sensitivity of 12 count/s/Rayleigh is still sufficient to provide good signal to noise data. Off-axis responsivity is non-uniform and visibly differs from pre-flight determinations. At the same time the shape of the spatial sensitivity response is constant and can be used for all observations. The calibrated data are compared with sophisticated theoretical models describing the spatial distribution of interstellar/interplanetary hydrogen. First results will be reported.

215.07 Performance Results from In-Flight Commissioning of the Juno Ultraviolet Spectrograph (Juno-UVS)

- Thomas K. Greathouse¹, G. R. Gladstone¹, M. W. Davis¹, D. C. Slater¹, M. H. Versteeg¹, K. B. Persson¹, G. S. Winters¹, S. C. Persyn¹, J. S. Eterno¹

¹Southwest Research Institute.

We present a description of the Juno ultraviolet spectrograph (Juno-UVS), results from the successful in-flight commissioning performed between December 5th and 13th 2011, and some predictions of future Jupiter observations. Juno-UVS is a modest power (9.0 W) ultraviolet spectrograph based on the Alice instruments now in flight aboard the European Space Agency’s Rosetta spacecraft, NASA’s New Horizons spacecraft, and the LAMP instrument aboard NASA’s Lunar Reconnaissance Orbiter. However, unlike the other Alice spectrographs, Juno-UVS sits aboard a rotationally stabilized spacecraft. The planned 2 rpm rotation rate for the primary mission results in integration times per spatial resolution element per spin of only ~17 ms. Thus, data was retrieved from many spins
and then remapped and co-added to build up integration times on bright stars to measure the effective area, spatial resolution, map out scan mirror pointing positions, etc. The Juno-UVS scan mirror allows for pointing of the slit approximately ±30° from the spacecraft spin plane. This ability gives Juno-UVS access to half the sky at any given spacecraft orientation. We will describe our process for solving for the pointing of the scan mirror relative to the Juno spacecraft and present our initial half sky survey of UV bright stars complete with constellation overlays. The primary job of Juno-UVS will be to characterize Jupiter’s UV auroral emissions and relate them to in situ particle measurements. The ability to point the slit will facilitate these measurements, allowing Juno-UVS to observe the surface positions of magnetic field lines Juno is flying through giving a direct connection between the particle measurements on the spacecraft to the observed reaction of Jupiter’s atmosphere to those particles. Finally, we will describe planned observations to be made during Earth flyby in October 2013 that will complete the in-flight characterization.

215.08 MAVEN’s Imaging UV Spectrograph: Studying Atmospheric Structure and Escape at Mars

- Nicholas M. Schneider, W. E. McClintock, IUVS Science Team
- LASP, Univ. of Colorado.

MAVEN (Mars Volatile and Atmosphere EvolutioN) is a Mars Scout mission slated for launch in November 2013. The key hardware and management partners are University of Colorado, Goddard Space Flight Center, University of California at Berkeley, Lockhead Martin, and the Jet Propulsion Laboratory. MAVEN carries a powerful suite of fields and particles instruments and a sophisticated Imaging UltraViolet Spectrograph (IUVS). In this presentation we will describe IUVS’ science goals, instrument design, operational approach and data analysis strategy. IUVS supports the top-level MAVEN science goals: measure the present state of the atmosphere, observe its response to varying solar stimuli, and use the information to estimate loss from Mars' atmosphere over time. The instrument operates at low spectral resolution spanning the FUV and MUV ranges in separate channels, and at high resolution around the hydrogen Lyman alpha line to measure the D/H ratio in the upper atmosphere. MAVEN carries the instrument on an Articulated Payload Platform which orients the instrument for optimal observations during four segments of its 4.5 hr elliptical orbit. During periapse passage, IUVS uses a scan mirror to obtain vertical profiles of emissions from the atmosphere and ionosphere. Around apoapse, the instrument builds up low-resolution images of the atmosphere at multiple wavelengths. In between, the instrument measures emissions from oxygen, hydrogen and deuterium in the corona. IUVS also undertakes day-long stellar occultation campaigns at 2 month intervals, to measure the state of the atmosphere at altitudes below the airglow layer and in situ sampling. All data will be pipeline-processed from line brightnesses to column abundances, local densities and global 3-D maps and provided to the PDS Atmospheres Node. The combined results from all instruments on ion and neutral escape will bear on the central question of the history of Mars’ atmosphere and climate change.

215.09 Hirims: A High Resolution IR Spectrometer Proposed For Juice

- Thierry Fouchet, HIRIMS Team
- Obs. de Paris, France.

HIRIMS is a high spectral resolution spectrometer proposed for the ESA-led JUICE mission. Its spectral range covers the 2.6- to 4.75-micron window at a sampled spectral resolution power of 10,000. It can operate both in nadir, limb and solar occultation modes. Its scientific objectives comply with the scientific objectives of the JUICE mission: 1. Study the dynamics and the chemistry of Jupiter’s atmosphere with an emphasis on the upper and middle atmosphere, its relations with the Jupiter environment; 2. Study the exospheres of the icy Galilean satellites: their sources and sinks, and their relations with the jovian environment; 3. Study the evolution of icy satellites surfaces in a high radiation environment and link the surface composition with interior processes; 4. Monitor Io’s activity and atmosphere. The presentation will highlight the unique measurements a high resolution IR spectrometer can perform to address JUICE scientific objectives and investigations.

215.10 X-ray Imaging Spectroscopy for Planetary Science


X-ray Imaging Spectroscopy for Planetary Science is a technique that utilizes X-ray imaging and spectroscopy to study the atmospheres and surfaces of planets. It is particularly useful for detecting and analyzing light elements in planetary atmospheres, which can provide insights into the chemical composition and dynamics of these worlds. The availability of X-ray imaging spectroscopy has revolutionized our understanding of planetary environments, allowing for detailed observations of planetary surfaces and atmospheres. This technique has been instrumental in advancing our knowledge of the physical and chemical processes that govern the evolution of planetary systems. X-ray Imaging Spectroscopy is a powerful tool for studying the atmosphere and surface conditions of planets, providing critical insights into their geophysical and chemical characteristics.
We are developing monolithic backside illuminated CMOS detectors as soft X-ray imaging spectrometers for high energy astrophysics missions. These devices represent a significant advance over CCD technology and have unique properties that would make them ideal sensors for various planetary mission concepts. The benefits of CMOS include higher levels of integration which provide maximum pixel gain and therefore very low noise, very fast parallel output signal chains for high frame rates. CMOS imaging detectors have zero or one charge transfer so that they can withstand many orders of magnitude more radiation than conventional CCDs before degradation. The capability of high read rates provides dynamic range and temporal resolution. Additionally, the rapid read rates minimize shot noise from thermal dark current and optical light. CMOS detectors can therefore run at warmer temperatures and with ultra-thin optical blocking filters. Thin OBFs provide near unity quantum efficiency below 1 keV, thus maximizing response at the C and O lines. Possible mission concepts for these sensors include X-ray fluorescence studies of rocky bodies, and investigation of the magnetospheres of the gas giants and their moons. In this presentation, we discuss the current state of our technology development and outline its scientific potential for planetary physics with particular emphasis on studies of the Jovian magnetosphere. We contrast the capabilities of our instrument with that which has been achieved by the current generation of Earth-orbiting X-ray observatories.

215.11 Earth-orbiting Extreme Ultraviolet Spectroscopic Mission SPRINT-A/EXCEED
- Fuminori Tsuchiya¹, I. Yoshikawa², A. Yamazaki³, K. Yoshioka³, K. Uemizu³, G. Murakami³, T. Kimura³, M. Kagitani¹, N. Terada¹, Y. Kasaba¹, T. Sakanoi¹
  ¹Tohoku University, Japan, ²The University of Tokyo, Japan, ³ISAS/JAXA, Japan.

The EXCEED (Extreme Ultraviolet Spectroscope for Exospheric Dynamics) mission is an Earth-orbiting extreme ultraviolet (EUV) spectroscopic mission and the first in the SPRINT series of ISAS/JAXA. It will be launched in the summer of 2013. EUV spectroscopy is suitable for observing tenuous gases and plasmas around planets in the solar system. One of the primary targets is an inner magnetosphere of Jupiter, whose plasma dynamics is dominated by planetary rotation. In the EUV range, a number of emission lines originate from plasmas distributed in Jupiter’s inner magnetosphere. The spectrograph is designed to have a wavelength range of 55-145 nm with minimum spectral resolution of 0.4 nm, enabling the electron temperature and ion composition in the inner magnetosphere to be determined. Another objective is to investigate an unresolved problem concerning the escape of the atmosphere to space. EXCEED plans to make imaging observations of plasmas around Venus and Mars to determine the amounts of escaping atmosphere. The optics of the instrument consists of a primary mirror with a diameter of 20cm, a laminar type grating, and a 5-stage micro-channel plate assembly with a resistive anode encoder. The spectrograph slits have a FOV of 400 x 140 arc-seconds (maximum). To achieve high efficiencies, the surfaces of the primary mirror and the grating are coated with CVD-SiC. A feasibility study shows that EXCEED can determine plasma parameters in the Io plasma torus using an exposure time of 50 minutes. EXCEED also has another instruments, a target guide camera. It will be used to capture the target and guide the observation area to the slit with an accuracy of ±5 arc-seconds. With the help of the target guide camera, we will take spectral images with a long exposure time of 50 minutes and good spatial resolution of 20 arc-seconds.

215.12 Science-Driven NanoSpacecraft: High Science, High Risk, Low Cost
- Andrew Klesh³, J. Castillo-Rogez²
  ²Jet Propulsion Laboratory.

The concept of NanoSats (derived from present-day CubeSats) as secondary spacecraft on Discovery (and possibly New Frontiers) missions opens the door to new exploration. At its core, we are considering these NanoSats as smart instruments - instruments that can fly by, recognize, and/or land on planetary surface areas of high scientific significance. Trading a medium-sized instrument for several potentially very low-cost NanoSats (for redundancy), one could access the surface and obtain fine chemistry measurements (like isotopic and elemental ratios of selected elements), measure soil mechanical properties, or do regional reconnaissance (like e.g., gravity and topography mapping of potential landing sites on Mars’ moons) without compromising the main spacecraft. Still,
NanoSats are small enough such that the mothership can still carry a more classical payload. Using NanoSats as scouts, for reconnaissance, or for performing key science, without involving the entirety of the expensive mothership could relax the risk imposed upon the whole mission - it in effect shares the primary science between the mothership and the daughterships. CubeSat capability has advanced significantly in the last decade, but it has been primarily technology driven with a “here’s a vehicle, what can you do with it” approach. We present science application results derived from “thinking small” and informed by nanospacecraft capability, but flex the boundaries of the class to identify appropriate families of applications that might fit in a given small size. Based on input from CubeSat experts and experienced engineers, and driven by science measurements, we highlight areas of development that may assist in the adoption of these small vehicles to achieve science objectives that are otherwise unlikely for the primary vehicle, such as direct plume passages, or surface reconnaissance. This work has been developed at the Jet Propulsion Laboratory, California Institute of Technology, under contract to NASA. Government sponsorship acknowledged.

215.13 Assessing The Potential Of Stratospheric Balloons For Planetary Science
- Tibor Kremic
  \(^1\)NASA Glenn Research Center.

Recent developments in high altitude balloon platform capabilities, specifically long duration flights in excess of 50 days at over 100,000 ft and precision pointing with performance at the arc sec level or better have raised the question whether this platform can be utilized for high-value planetary science observations. In January of 2012 a workshop was held at NASA Glenn Research Center in Cleveland, Oh to explore what planetary science can be achieved utilizing such a platform. Over 40 science concepts were identified by the scientists and engineers attending the workshop. Those ideas were captured and then posted to a public website for all interested planetary scientists to review and comment on. The results of the workshop, and subsequent community review, have demonstrated that this platform appears to have potential for high-value science at very competitive costs. Given these positive results, the assessment process was extended to include 1) examining, in more detail, the requirements for the gondola platform and the mission scenarios 2) identifying technical challenges and 3) developing one or more platform concepts in enough fidelity to enable accurate estimating of development and mission costs. Upon completion, assessment results will be provided to NASA’s planetary science division to help them determine whether to embark on science efforts utilizing this platform. The poster will provide the current status of the assessment efforts.

215.14 NASA’s Stratospheric Observatory for Infrared Astronomy (SOFIA): Capabilities for Planetary and Exoplanetary Science
- Dana E. Backman\(^1\), W. T. Reach\(^1\), E. W. Dunham\(^3\), J. Wolf\(^4\), J. Rho\(^1\), SOFIA Science Team
  \(^1\)SOFIA / SETI Institute, \(^2\)SOFIA / USRA, \(^3\)Lowell Observatory, \(^4\)SOFIA / DSI.

The Stratospheric Observatory for Infrared Astronomy (SOFIA) enables high angular and spectral resolution observations with its seven first-generation instruments: 3 cameras, 3 spectrometers, and a high-speed photometer. These capabilities make SOFIA a powerful facility for advancing understanding of planetary and exoplanetary atmospheres, star and planet formation processes, and chemistry of the protosolar nebula and protoplanetary disks. SOFIA’s Early Science program, using the FORCAST mid-IR camera (PI Terry Herter, Cornell), the GREAT far-IR spectrometer (PI Rolf Guesten, MPIfR), and the HIPO occultation photometer (PI Ted Dunham, Lowell Observatory), is now complete. Some Early Science results were published in special issues of Ap.J.Letters (v.749) and Astronomy & Astrophysics (v.542). Regarding solar system targets, SOFIA obtained mid-IR images of Jupiter and of Comet 103P/Hartley 2 (the latter observations were part of Earth-based support for the EPOXI mission). On 23 June 2011, SOFIA intercepted the center of Pluto’s shadow that crossed the Pacific at nearly 30 km/sec. The occultation light curve was observed from SOFIA simultaneously by the HIPO photometer and the Fast Diagnostic Camera (FDC; PI Juergen Wolf, DSI). HIPO is specifically intended for planetary science, including stellar occultations by solar system bodies and extrasolar planet transits. HIPO can be co-mounted with the near-IR camera FLITECAM (PI Ian McLean, UCLA) to provide simultaneous photometric coverage in two bands (0.3-1 and 1-5 microns); this was first demonstrated in October 2011. At longer wavelengths SOFIA will make unique contributions to the characterization of astrochemical processes and molecular contents of planets, exoplanets,
and protoplanetary disks with a mid-IR spectrometer, a far-IR imaging spectrometer, and a far-IR camera with grism that are soon to be commissioned.

215.15 The NASA Infrared Telescope Facility (IRTF) - The Next 5 Years

- Alan T. Tokunaga\textsuperscript{1}, S. J. Bus\textsuperscript{1}, M. S. Connelley\textsuperscript{1}, J. T. Rayner\textsuperscript{1}

\textsuperscript{1}Institute for Astronomy, Univ. of Hawaii.

The funding for IRTF operations will be renewed in Feb. 2013 for another 5 years. We discuss upgrades and new capabilities of the IRTF during this period. Current instruments include: (1) SpeX, a 1-5 μm moderate-resolution spectrograph and camera, (2) MORIS, a high-speed CCD imager attached to SpeX for simultaneous visible and near-IR observations, (3) CSHELL, a 1-5 μm high-resolution spectrograph, and (4) NSFCAM, a 1-5 micron camera. MIRSI, an 8-25 μm camera, will be available after an upgrade to the array control electronics. Information on these instruments and also visitor instruments are given at: http://irtfweb.ifa.hawaii.edu/Facility/. Detector upgrades are planned for NSFCAM and SpeX during semester 2012B to 2013B. We are also designing and constructing a new echelle spectrograph for 1-5 μm. This instrument will be commissioned starting in 2015. The IRTF supports remote observing from any site. This eliminates the need for travel to the observatory, and therefore short observing time slots can be supported. We also welcome on-site visiting astronomers. In terms of future capabilities, we would like input for planetary science cases needing diffraction-limited imaging at 1-5 μm. For further information see: http://irtfweb.ifa.hawaii.edu/. We gratefully acknowledge the support of Cooperative Agreement no. NNX-08AE38A with the NASA Science Mission Directorate, Planetary Astronomy Program.

215.16 The LCOGT Network for Solar System Science

- Tim Lister\textsuperscript{1}

\textsuperscript{1}Las Cumbres Observatory.

Las Cumbres Observatory Global Telescope (LCOGT) network is a planned homogeneous network of over 35 telescopes at 6 locations in the northern and southern hemispheres. This network is versatile and designed to respond rapidly to target of opportunity events and also to do long term monitoring of slowly changing astronomical phenomena. The global coverage of the network and the apertures of telescope available make LCOGT ideal for follow-up and characterization of Solar System objects (e.g. asteroids, Kuiper Belt Objects, comets, Near-Earth Objects (NEOs)) and ultimately for the discovery of new objects. Currently LCOGT is operating the two 2m Faulkes Telescopes at Haleakala, Maui and Siding Spring Observatory, Australia and in March 2012 completed the install of the first member of the new 1m telescope network at McDonald Observatory, Texas. Further deployments of six to eight 1m telescopes to CTIO in Chile, SAAO in South Africa and Siding Spring Observatory are expected in late 2012-early 2013. I am using the growing LCOGT network to confirm newly detected NEO candidates produced by PanSTARRS (PS1) and other sky surveys and to obtain follow-up astrometry and photometry for radar-targeted objects. I have developed an automated system to retrieve new PS1 NEOs, compute orbits, plan observations and automatically schedule them for follow-up on the robotic telescopes of the LCOGT Network. In the future, LCOGT has proposed to develop a Minor Planet Investigation Project (MPIP) that will address the existing lack of resources for minor planet follow-up, takes advantage of ever-increasing new datasets, and develops a platform for broad public participation in relevant scientific exploration. We plan to produce a cloud-based Solar System investigation environment, a citizen science project (AgentNEO), and a cyberlearning environment, all under the umbrella of MPIP.

215.17 Exploring the Sutherland High-speed Optical Cameras (SHOC).

- Rocco Coppejans\textsuperscript{1}, A. A. S. Gulbis\textsuperscript{2}, P. Fourie\textsuperscript{2}, M. Rust\textsuperscript{2}, C. Sass\textsuperscript{2}, J. Stoffels\textsuperscript{2}, H. Whittal\textsuperscript{2}, J. Cloete\textsuperscript{2}

\textsuperscript{1}University of Cape Town and South African Astronomical Observatory, South Africa, \textsuperscript{2}South African Astronomical Observatory, South Africa.

Based on two existing instruments POETS (Souza et al., 2006, PASP, 118, 1550) and MORIS (Gulbis et al. 2011, PASP, 123, 461), two new instruments, SHOC (the Sutherland High-speed Optical Cameras), have been developed for use on the South African Astronomical Observatorie’s (SAAO) 1.9m, 1.0m and 0.75m telescopes at Sutherland, South Africa. Each SHOC system consists of a camera, GPS, control computer and
peripherals. The primary components are two, off-the-shelf Andor iXon X3 888 UVB cameras, each of which utilizes a 1024x1024, frame transfer, thermoelectrically-cooled, back-illuminated CCD. SHOC's most important feature is that it can achieve frame rates of between one and twenty frames per second during normal operation (dependent on binning and subframing) with nanosecond timing accuracy on each frame (achieved using frame-by-frame GPS triggering). Frame rates can be increased further and fainter targets observed by making use of the electron multiplying (EM) modes. SHOC is therefore ideally suited to observing transiting exoplanets and stellar occultations of Kuiper Belt objects. For occultations, this advantage is further increased by Sutherland being one of a few observatories on the African continent operating 1m class optical telescopes. Here, we will present the instrument, measured characteristics (including signal-to-noise ratios (SNR) for conventional and EM modes as a function of stellar magnitudes and exposure times), and SHOC's applications to planetary science. Attention will specifically be given to recently completed characterization work in which the SNR parameter space was explored and a comparison made between the SNR obtained in the EM and conventional modes. This will not only enable observers to optimize the instrument settings for their observations but also clearly demonstrates the advantages and potential pitfalls of the EM modes.

215.18 Planetcam: A Visible And Near Infrared Lucky-imaging Camera To Study Planetary Atmospheres And Solar System Objects
- Agustin Sanchez-Lavega1, J. Rojas1, R. Hueso1, S. Perez-Hoyos1, L. de Bilbao2, G. Murga2, J. Ariño3, I. Mendikoa1
1E.T.S. Ingenieros, UPV/EHU, Spain, 2IDOM-Ada, Spain.

PlanetCam is a two-channel fast-acquisition and low-noise camera designed for a multispectral study of the atmospheres of the planets (Venus, Mars, Jupiter, Saturn, Uranus and Neptune) and the satellite Titan at high temporal and spatial resolutions simultaneously invisible (0.4-1 μm) and NIR (1-2.5 μm) channels. This is accomplished by means of a dichroic beam splitter that separates both beams directing them into two different detectors. Each detector has filter wheels corresponding to the characteristic absorption bands of each planetary atmosphere. Images are acquired and processed using the “lucky imaging” technique in which several thousand images of the same object are obtained in a short time interval, coregistered and ordered in terms of image quality to reconstruct a high-resolution ideally diffraction limited image of the object. Those images will be also calibrated in terms of intensity and absolute reflectivity. The camera will be tested at the 50.2 cm telescope of the Aula EspaZio Gela (Bilbao) and then commissioned at the 1.05 m at Pic-duMidi Observatory (Franca) and at the 1.23 m telescope at Calar Alto Observatory in Spain. Among the initially planned research targets are: (1) The vertical structure of the clouds and hazes in the planets and their scales of variability; (2) The meteorology, dynamics and global winds and their scales of variability in the planets. PlanetCam is also expected to perform studies of other Solar System and astrophysical objects. Acknowledgments: This work was supported by the Spanish MICIIN project AYA2009-10701 with FEDER funds, by Grupos Gobierno Vasco IT-464-07 and by Universidad Pais Vasco UPV/EHU through program UFI11/55.

215.19 Advances in Starlight Suppression Technology for Exoplanet Imaging
- Peter R. Lawson1
1Jet Propulsion Laboratory, Caltech.

A central theme in NASA’s vision for future space missions is the search for life and habitable worlds beyond our Solar System. Here we review progress in the development of starlight suppression technology for exoplanet detection. At optical wavelengths, Earth-like planets are about 10 billion times fainter than their host stars. Starlight suppression is therefore essential to enable measurements of biosignatures in the atmospheres of faint Earth-like planets. Quantitative milestones to measure technology progress are presented and recent results are discussed.

215.20 Tunable Spatial Heterodyne Spectroscopy (shs) For Visible And Uv Interferometry Of Extended Targets
- Sona Hosseini1, W. Harris1, J. Corliss1
1University of California, Davis.
In the study of faint, extended sources at high resolving power in visible and UV ranges, a Spatial Heterodyne Spectrometer (SHS) offers significant etendue advantages relative to conventional dispersive grating spectrometers and other interferometric techniques. A SHS is a compact two-beam interferometer that produces 2-D Fizeau fringe pattern from which the input spectrum can be obtained via a Fourier transform. Because of the unique concept in the basic SHS design, it can provide a resolving power \( R \sim 10^5 \) over a \( \sim 0.5^\circ \) field of view (FOV) at visible and UV wavelengths. The primary limitation comes from its narrow resolvable bandpass that is defined by the highest spatial frequency that can be sampled by the detector (typically \( \sim 50\AA \)). This limitation has made these instruments useful primarily for studies of single emission line features or molecular bands. However we are working on a Tunable Spatial Heterodyne Spectrometer (TSHS) design that enables slewing the acceptance band over a much broader spectral range. We describe here continuing progress toward development of an all-reflective TSHS at a fixed focal plane shared by the 0.6m Coude auxiliary telescope and the 3m Shane telescope on Mt. Hamilton. Our present effort involves a full description of building and setting up the first field version of TSHS in Mt. Hamilton in which we address technical design and alignment, instrument characteristics and setup, data reduction pipeline and preliminary observations.

215.21 A Miniature Spectrometer for the Detection of Organics and Identification of their Mineral Context
- Nancy J. Chanover\(^1\), K. Uckert\(^1\), D. Glenar\(^1\), D. Voelz\(^1\), X. Xiao\(^1\), R. Tawalbeh\(^1\), P. Boston\(^2\), S. Getty\(^3\), W. Brinckerhoff\(^4\), P. Mahaffy\(^3\)
\(^1\)New Mexico State Univ., \(^2\)New Mexico Institute of Mining and Technology, \(^3\)NASA Goddard Space Flight Center.

On future landed missions to Mars and small solar system bodies, efficient sample pre-screening will be necessary to select interesting targets for further analysis by analytical instruments with very limited time and power resources. Near infrared spectroscopy is well suited for rapid and non-invasive identification of mineral classes, and the possible presence of organic molecules. A small spectrometer on the surface also enables ground-truth for orbiting reflectance spectrometers operating at overlapping wavelengths. Here we describe a miniature acousto-optic tunable filter (AOTF) point spectrometer that is tunable from 1.6-3.6 microns. It identifies minerals associated with aqueous environments at sample scales of \( \sim 1 \) mm, as well as organic molecules and volatiles, where they are present. Our low-power AOTF point spectrometer can be combined with other diagnostic instruments as part of a landed instrument package. It was recently integrated with a laser desorption time-of-flight (LDTOF) mass spectrometer developed at GSFC. The integration of the two instruments allows for coincident spectral measurements of a geologic sample. The LDTOF mass spectrometer shares an optical axis with the AOTF; follow-up measurements from the LDTOF are taken from an identical region on a sample of interest, allowing for a direct comparison between the two complementary data sets. The AOTF point spectrometer could be deployed in a variety of configurations, either as a stand-alone instrument or paired with the LDTOF, depending on the nature of the mission. The addition of AOTF technology to an \textit{in situ} instrumentation suite could enable significant near-IR spectroscopic diagnostic capability without exceeding the resources of a small surface laboratory. This work was supported by NASA’s ASTID and EPSCoR programs through grant numbers NNX08AY44G and NNX08AV85A, respectively.

215.22 Technologies for the Discovery and Characterization of Subsurface Habitable Environments on Mars
- Lauren Fletcher\(^1\), N. Bowles\(^1\)
\(^1\)Atmospheric, Oceanic and Planetary Physics; University of Oxford, United Kingdom.

One of the most important steps in the search for life (extinct or extant) on Mars is to determine if a specific location it is “habitable” or that it provides the conditions and requirements to support life as we know it. These requirements include water, an energy source, and materials necessary for cellular growth, while all under appropriate environmental conditions. Constructing an understanding of the past and current habitability of Mars will require new compact sensors for future drilling missions. A miniature IR Thermal Radiometer under development as part of this project will rely on the unique thermal and optical properties of more than 20 samples that were collected from around the Earth as analogs to materials already identified on Mars. This spectral information can be used to determine the temperature, the presence of water ice, and the discrimination of minerals which could provide a source of energy and enable cellular growth, thus determining the habitability of
the sampled location. The device under development will be suitable for drilling applications with less than 25 mm
diameter boreholes and limited available power (<30watts). This paper reviews the technical requirements,
development, laboratory testing, and performance of early prototyping of this IR Thermal Radiometer.

215.23 Capacitive Ultrasonic Transducer Development for Acoustic Anemometry on Mars
- Eurion Leonard-Pugh, C. Wilson, S. Calcutt, L. Davis
  *University of Oxford, United Kingdom, *University of Warwick, United Kingdom.

Previous Mars missions have used either mechanical or thermal anemometry techniques. The moving parts of
mechanical anemometers are prone to damage during launch and landing and their inertia makes them unsuited
for turbulence studies. Thermal anemometers have been used successfully on Mars but are difficult to calibrate
and susceptible to varying ambient temperatures. In ultrasonic anemometry, wind speed and sound speed are
calculated from two-way time-of-flight measurements between pairs of transducers; three pairs of transducers are
used to return a 3-D wind vector. These high-frequency measurements are highly reliable and immune from drift.
Piezo-electric ultrasonic anemometers are widely used on Earth due to their full-range accuracy and high
measurement frequency. However these transducers have high acoustic impedances and would not work on Mars.
We are developing low-mass capacitive ultrasonic transducers for Mars missions which have significantly lower
acoustic impedances and would therefore have a much stronger coupling to the Martian atmosphere. These
transducers consist of a metallised polymer film pulled taught against a machined metal backplane. The film is
drawn towards the backplane by a DC bias voltage. A varying signal is used on top of the DC bias to oscillate the
film; generating acoustic waves. This poster will look at the operation of such sensors and the developments
necessary to operate the devices under Martian conditions. Transducer performance is determined primarily by
two elements; the front film and the backplane. The sensitivity of the transducer is affected by the thickness of the
front film; as well as the diameter, curvature and roughness of the metal backplane. We present data on the
performance of the sensors and instrument design considerations including signal shapes and transducer
arrangements.

- Simon Tardivel, P. Michel, D. Scheeres
  *The University of Colorado at Boulder, *Observatoire de la Côte d’Azur, France.

The European Space Agency is currently performing an assessment study of the MarcoPolo-R space mission, in the
framework of the M3 class competition of its Cosmic Vision Program. MarcoPolo-R is a sample return mission to a
primitive asteroid, whose baseline target is the binary asteroid 1996FG3. The baseline mission, including the
sample, is focused on the primary of the binary system. To date, little has yet been considered for the investigation
of the secondary, apart from remote observations from the spacecraft. However, MarcoPolo-R may carry an
optional lander, and if such a lander could be accommodated it may be relevant to use it for a more detailed
investigation of the secondary. This poster presents a strategy for deploying a lander using an unpowered
trajectory towards the secondary. This ballistic deployment allows for the design of a light lander with minimum
platform overhead and maximum payload. The deployment operations are shown to be very simple and require
minimum preparation. The main spacecraft is set on an orbit that reaches a specific point near the binary system
L2 Lagrange Point facing the far side of the secondary, about 220 meters from the secondary surface, with a
relative speed of about 10cm/s. The lander is then jettisoned using a spring-release mechanism that sets it on an
impact trajectory that robustly intersects with the secondary surface. On impact, the lander only needs to dissipate
a small amount of kinetic energy in order to ensure that it is energetically and dynamically trapped on the surface.
Considering errors on spacecraft GNC and on the spring-release mechanism, and very large uncertainties on the
gravity field of the asteroids, the strategy presented here yields a successful landing in more than 99.9% of cases,
while ensuring the absolute safety of the spacecraft before, during and after deployment operations.

215.25 Trojan Tour Enabled by Solar Electric Based Mission Architecture
- Kurt K. Klaus, M. Elsperman, D. B. Smith, J. Behrens, G. Bingaman, J. Horsewood
A Trojan Tour and Rendezvous mission was recommended by the most recent Planetary Science Decadal Survey. We utilize this concept as a basis for re-examining the feasibility of a Solar Electric Propulsion (SEP) mission using a Boeing bus and Advanced Modular Power System (AMPS) for solar power generation. The concept study for the Decadal survey concluded that a SEP mission is not viable because of low solar intensity levels. With the new AMPS Technology that involves a Solar Concentrator array, SEP missions to the outer planets become viable. The mission objective is 1143 Odysseus, a Trojan within the Trojan cloud, consistent with the Decadal Survey REP (Radioisotope Electric Propulsion) mission objective. The REP mission concept flight time was 8 years. Our cruise time is 6 years. The Trojan asteroid exploration spacecraft is based around our flight proven 702HP bus. The bus has been slightly modified for this mission. Two 30 kW FAST solar wings replace the 9 kW 6 panel solar wings. The AMPS array has a 12.5:1 concentration ratio. At Jupiter (5.2 AU), the AMPS array solar cells still see .46 suns, which is high enough that LILT effects are negligible. The science payload instruments, data rates, mass and power requirements are identical to the Trojan Decadal study. The AMPS Technology benefits from over $30M in development investment by DARPA and the AFRL. The investments focused on lightweight structures, advanced deployment systems, linear concentrator arrays, high voltage power systems, and high efficiency solar cells. Additional investment in a flight demonstration mission is needed to reach TRL 7. Utilizing the AMPS technology with the concentrator array, SEP becomes a viable alternative. SEP with the AMPS concentrator also provides efficient on-station maneuvering for science at the Trojan. We seek support for Technology Demonstration Mission through the NASA OCT.

215.26 Laboratory Astrophysics Division Of The AAS (LAD)
  1NASA Ames Research Center, 2University of Michigan, 3University of Toledo, 4University of California, 5Columbia University.

The purpose of the Laboratory Astrophysics Division (LAD) is to advance our understanding of the Universe through the promotion of fundamental theoretical and experimental research into the underlying processes that drive the Cosmos. LAD represents all areas of astrophysics and planetary sciences. The first new AAS Division in more than 30 years, the LAD traces its history back to the recommendation from the scientific community via the White Paper from the 2006 NASA-sponsored Laboratory Astrophysics Workshop. This recommendation was endorsed by the Astronomy and Astrophysics Advisory Committee (AAAC), which advises the National Science Foundation (NSF), the National Aeronautics and Space Administration (NASA), and the U.S. Department of Energy (DOE) on selected issues within the fields of astronomy and astrophysics that are of mutual interest and concern to the agencies. In January 2007, at the 209th AAS meeting, the AAS Council set up a Steering Committee to formulate Bylaws for a Working Group on Laboratory Astrophysics (WGLA). The AAS Council formally established the WGLA with a five-year mandate in May 2007, at the 210th AAS meeting. From 2008 through 2012, the WGLA annually sponsored Meetings in-a-Meeting at the AAS Summer Meetings. In May 2011, at the 218th AAS meeting, the AAS Council voted to convert the WGLA, at the end of its mandate, into a Division of the AAS and requested draft Bylaws from the Steering Committee. In January 2012, at the 219th AAS Meeting, the AAS Council formally approved the Bylaws and the creation of the LAD. The inaugural gathering and the first business meeting of the LAD were held at the 220th AAS Meeting in Anchorage in June 2012. You can learn more about LAD by visiting its website at http://lad.aas.org/ and by subscribing to its mailing list.

Wednesday, 17 October, 2012

300 Titan Atmosphere 1
Wednesday, 8:30 AM - 10:00 AM, Tahoe Room

300.01 Atmospheric Chemical And Thermal Structure Evolution After One Titan Year
  3LESIA - Observatoire de Paris, CNRS, UPMC Univ. Paris 06, Univ. Paris-Diderot, France, 2National and Kapodistrian Univ. of Athens, Physics, Greece, 3Univ. Maryland, USA, 4GSMA, Univ. Reims, France,
We analyze Cassini Composite Infrared Spectrometer (CIRS) data taken during Titan flybys from 2004-2010 and compare them to the 1980 Voyager 1 flyby values inferred from the re-analysis of the Infrared Radiometer Spectrometer (IRIS) spectra [1], as well as to the intervening ground- and space- based observations (such as with ISO, [2]), providing us with a good view of the stratospheric evolution over a Titanian year (V1 encounter Ls = 9° was reached in mid-2010). Our radiative transfer code (ARTT, [3]) was applied to CIRS nadir and limb spectra [3, 4]. We look at variations in temperature and composition at mid-latitudes and find [5, 6] that a return to the 1980 abundance values is achieved for most molecules over the globe, indicative of the solar radiation being the dominating energy source at 10 AU, as for the Earth. However, some unexpected exceptions to this behaviour are found among the most abundant species or the most complex hydrocarbons in the North. In addition, we monitor and quantify the compositional northern hemisphere enhancement, and find indication for a maximum at the time of the Titan northern spring equinox (mid-2009), followed by a sharp decrease within the next two Earth years, caused by a reversal in the atmospheric circulation, leading to a moderate enrichment as observed by Voyager. Finally, we demonstrate that the maximum and minimum in atmospheric chemical composition at mid-latitudes occurs at the northern spring equinox (near 1980 and 2009) and the fall one (near 1997) respectively. References: [1] Coustenis, A., Bézard, B., Icarus 115, 126, 1995. [2] Coustenis, A., et al., Icarus 161, 383, 2003. [3] Coustenis, A., et al., Icarus 207, 461, 2010. [4] Vinatier, S., et al., Icarus, 205, 559, 2010. [5] Bampasidis et al., submitted, 2012. [6] Coustenis, A., et al., submitted, 2012.

300.02 Seasonal Variations In Titan’s Stratosphere Observed With Cassini/CIRS: Temperature, Trace Molecular Gas And Aerosol Mixing Ratio Profiles

- Sandrine Vinatier1, B. Bézard1, C. Anderson2, N. Teanby3, R. de Kok4, R. Atherberg2, A. Coustenis1, CIRS Team
1LESIA, Obs. de Paris-Meudon, France, 2NASA/Goddard Space Flight Center, 3School of Earth Sciences, University of Bristol, United Kingdom, 4SRON Netherlands Institute for Space Research, Netherlands.

Titan’s northern spring equinox occurred in August 2009. General Circulation Models predict strong modifications of the global circulation in this period, with formation of two circulation cells instead of the pole-to-pole cell that occurred during northern winter. This winter single cell, which had its descending branch at the north pole, was at the origin of the enrichment of molecular abundances and high stratopause temperatures observed by Cassini/CIRS at high northern latitudes. The predicted dynamical seasonal variations after the equinox have strong impact on the spatial distributions of trace gas, temperature and aerosol abundances. We will present here an analysis of CIRS limb-geometry datasets acquired in 2010, 2011 and 2012 that we used to monitor the seasonal evolution of the vertical profiles of temperature, molecular (C2H2, C2H6, HCN, ...) and aerosol abundances.

300.03 Investigating the Seasonal Evolution of Titan’s Circulation and Superrotation Mechanisms using the Ashima Research Titan General Circulation Models

- Claire E. Newman1, Y. Lian1, M. I. Richardson1
1Ashima Research.

We will present simulations of the atmospheric circulation predicted by Titan general circulation models (GCMs) developed at Ashima Research. We first compare these results with observations to assess the realism of the GCMs, focusing on the maintenance of superrotation and the seasonal evolution of the stratosphere. We then present detailed analyses of instabilities, waves and wave-mean flow interactions to investigate the mechanisms by which superrotation is produced and maintained in our GCMs. Titan’s atmosphere, even more so than that of Mars or Earth, appears highly sensitive to aspects of the modeling environment such as grid structure, numerical solver, etc., resulting in a wide dispersal between results from different Titan GCMs worldwide. We will therefore compare the results of a suite of superrotating GCMs in order to demonstrate the sensitivity of our results (and hence the robustness of our conclusions) to these factors, focusing on: (1) the TitanWRF GCM, using a finite-difference solver and a traditional latitude-longitude grid; (2) the Ashima/MIT Titan GCM, using a finite-volume...
solver and a traditional latitude-longitude grid; and (3) the Ashima/MIT Titan GCM, using a finite-volume solver and a cubed-sphere grid.

300.04 Cassini ISS Observations Of The Early Stages Of The Formation Of Titan's South Polar Hood And Vortex In 2012
- Robert A. West1, A. Del Genio2, J. Perry3, A. P. Ingersoll4, E. P. Turtle5, C. Porco6, A. Ovanessian1
1Jet Propulsion Lab, California Institute of Technology, 2Goddard Institute for Space Studies, 3University of Arizona, 4California Institute of Technology, 5Johns Hopkins University/ Applied Physics Lab, 6Space Science Institute.

Northern spring equinox on Titan occurred on August 11, 2009. In March of 2012 the Imaging Science Subsystem (ISS) on the Cassini spacecraft saw the first evidence for the formation of a polar hood in the atmosphere above Titan’s south pole. Views of the limb showed an optical thickening primarily at about 360 km altitude across a few degrees of latitude centered on the pole. Images of Titan in front of Saturn provide a nearly direct measure of the line-of-sight optical depth as a function of latitude and altitude from about 250 km and higher. Two or more distinct layers are seen, both near the pole and at other latitudes. The highest of these, near 360 km altitude, hosts the embryonic polar hood. On June 27, 2012 ISS observed the pole from high latitude. These images show a distinct and unusual cloudy patch, elongated and not centered on the pole and with an elevated perimeter. The morphology and color indicate an unfamiliar (for Titan) composition and dynamical regime. The interior of the feature consists of concentrations of cloud/haze organized on spatial scales of tens of kilometers. Its morphology is reminiscent of the open cellular convection sometimes seen in the atmospheric boundary layer over Earth’s oceans under conditions of large-scale subsidence. Unlike Earth, where such convection is forced by large surface heat fluxes or the onset of drizzle, convection at 360 km on Titan is more likely to be driven from above by radiative cooling. During the 9 hours we observed Titan, this feature completed a little over one rotation around the pole, providing direct evidence for a polar vortex rotating at a rate roughly consistent with angular-momentum-conserving flow for air displaced from the equator. Part of this work was performed by the Jet Propulsion Laboratory, California Institute of Technology.

300.05 Re-analysis of the 2003-Nov-14 Stellar Occultation by Titan with New Haze and Methane Optical Constants: Implications for Vertical Structure and Zonal Winds
- Eliot F. Young1, A. Zalucha2
1Southwest Research Inst., 2A. M. Zalucha Consulting.

Zalucha et al. (2007) looked at the 2003-Nov-14 stellar occultation by Titan using lightcurves obtained with the ULTRACAM instrument (Dhillon et a. 2007). Previous occultations, beginning with the 28 Sgr occultation in 1989 (Hubbard et al. 1993; Sicardy et al. 1990), measured central flashes that served as extremely sensitive constraints on Titan's atmospheric figure. The ULTRACAM lightcurves were obtained at 30 Hz in three simultaneous passbands (u', g' and i', with effective centers at 358, 487 and 758 nm). The i' and g' bands show a central flash event. In the i' band, the central flash shows three clear large peaks and two small peaks. The 30-Hz cadence of the ULTRACAM observations corresponds to a sampling rate of 375 m on the sky (given the event velocity of 11.25 km/sec), actually smaller than the Fresnel scale of around 600 m and the estimated stellar diameter of about 730 m at Titan. Using Titan haze optical parameters from Huygens/DISR instrument (Tomasko et al. 2008), we retrieve temperature and haze opacity profiles between altitudes of roughly 200 to 600 km with a vertical resolution better than 5 km. Unlike Zalucha et al. (2007), we use a forward model to iteratively generate and compare model lightcurves to the u', g' and i' observations. The forward modeling approach lets us investigate lightcurves from atmospheres with arbitrary haze distributions, temperature fluctuations and wind distortions. We discuss solutions that are consistent with the ULTRACAM observations and compare results to ISS vertical haze profiles. Hubbard et al. 1993, A&A 269, 541. Sicardy et al. 1990, Nature 343, 350. Tomasko et al. 2008, P&SS 56, 669. Zalucha et al. 2007, Icarus 192, 503.

300.06 Revisiting the Photochemical Processes on Titan: Insight from Cassini Observations
- Cheng Li1, X. Zhang1, J. A. Kammer1, M. C. Liang2, Y. L. Yung1
1Caltech, 2Research Center for Environmental Changes, Academia Sinica, Taiwan.
The recent measurements from the nadir-view and limb-view soundings of Cassini/CIRS (Vinatier et al., 2010) and the stellar occultations from Cassini/UVIS (Kammer et al., 2010, Koskinen et al., 2011) revealed the complete vertical profiles of minor species (mainly C2H2 and C2H4) from 100 to 1000 km in the atmosphere of Titan. In this study, we introduce a new eddy diffusivity profile and revise the rate coefficients for the chemistry of hydrocarbons, especially for C2H4. Our new results are in better agreement with the new Cassini measurements than the previous 1D chemistry-diffusion models (e.g., Yung et al., 1984; Lavvas et al., 2008 a, b; Krasnopolsky, 2010). An inversion technique is developed to retrieve the vertical profile of eddy diffusivity. We use the abundance of C2H2 as a proxy to retrieve the eddy diffusivity profile and verify it through the chemistry-diffusion modeling of other tracers. We found that the new eddy profile features a turnover near the altitude of detached haze layer (~550 km), which might lead to the formation of the detached haze layer through a potential positive feedback process. Secondly, the same retrieval method is applied to the chemistry of C2H4. The result suggests a revision of rate coefficients for the three body reactions of C2H4 so as to keep the simulated profile close to the observation. The revised rate coefficients will also be used and tested for the hydrocarbon chemistry on giant planets.

300.07 Upper Atmospheric Density Retrievals from UVIS Dayglow Observations of Titan
  1NRL, 2Computational Physics, Inc., 3NASA/JPL, 4University of Central Florida, 5George Mason University, 6Applied Physics Laboratory, 7University of Texas at San Antonio.

The Cassini Ultraviolet Imaging Spectrograph (UVIS) observed Titan’s dayside limb on multiple occasions between 2007-2012. The airglow observations reveal the same variety of EUV (600-1150 Å) and FUV (1150-1900 Å) emissions arising from photoelectron impact and photofragmentation of molecular nitrogen (N₂) on Earth. Through spectral analysis we extract radiance profiles for each set of UVIS limb emissions in the EUV and FUV, which are attenuated by methane (CH₄). Using a terrestrial airglow model adapted to Titan, we derive the N₂ and CH₄ density profiles using the prescribed solar irradiance for the relevant Cassini orbit and compare the calculated radiance profiles directly with observations. We find that the Titan airglow can be explained by solar driven processes to within the uncertainties of the UVIS observations. Fluctuations in the observed airglow between flybys suggest compositional changes in the background atmosphere. The source of these compositional changes is not yet known, although the interaction of Titan with Saturn’s magnetosphere has been implicated as an important contributing factor. Here we use unique UVIS airglow observations over Titan’s disk to quantify compositional fluctuations with latitude and local time. We furthermore compare N₂ and CH₄ densities retrieved from the UVIS airglow to in situ observations by the Cassini Ion and Neutral Mass Spectrometer (INMS) and discuss how the UVIS and INMS variations may be related to Titan’s varying plasma environment.

300.08 Titan’s Higher Atmosphere Composition from EUV Solar Occultation Measurements
- Fernando J. Capalbo, Y. Benilan, T. Koskinen, R. Yelle
  1LISA, Laboratoire Interuniversitaire des Systemes Atmospheriques, France, 2LPL, Lunar and Planetary Laboratory, University of Arizona.

Solar and stellar occultations observed by the Ultraviolet Imaging Spectrograph (UVIS) onboard the Cassini spacecraft allow studying the composition and temperature profiles in Titan’s upper atmosphere at altitudes between 400 - 1400 km. In particular, solar occultations recorded by the EUV channel probe the highest part of this altitude range in Titan’s thermosphere. Solar occultations benefit from higher signal-to-noise ratio than stellar occultations, and, contrary to the latter, provide a unique opportunity to study the absorption of radiation at EUV wavelengths shorter than 90 nm. This permits to determine the density of N₂, which does not absorb significantly in the FUV, longward of 110 nm. The quality of the retrieval depends strongly on the resolution of the measured transmission spectra and the accuracy of available absorption cross section data of the absorbers (Vervack et al. 2004). We have combined data from a solar occultation observed by UVIS during flyby T53 on April 20 2009, and laboratory measurements of absorption cross sections to study the upper atmosphere of Titan. We note that the T53 occultation was very stable and slow, resulting in a nominal altitude resolution of a few km. After performing instrument corrections, including a wavelength calibration and scattered light elimination, we calculated the
transmission through Titan’s atmosphere for wavelengths corresponding to solar emission lines at 584.3 and 629.7 angstroms. Using the continuum region of the N2 absorption cross section (Gurtler et al. 1977), local number densities for this species were determined in the range 1160 - 1420 km using a regularized inversion algorithm. The derived N2 scale height is 70 +/- 10 km and the inferred temperature 135 +/- 15 K. Our results were compared with previous studies in this altitude range. The values derived can be used to constrain photochemical models in the upper atmosphere.

**300.09 Nitrogen Chemistry in Titan’s Upper Atmosphere**

- Joshua Kammer¹, D. E. Shemansky², X. Zhang¹, Y. L. Yung¹

¹California Institute of Technology, ²Space Environment Technologies.

Titan’s atmosphere has evolved over time into its current state through a complex suite of photochemical processes involving nitrogen (N2), the dominant molecular species in the atmosphere, as well as methane (CH4). Since 2004, observations by the Cassini spacecraft have greatly improved our knowledge of the current composition of Titan’s atmosphere, and measurements made using the Ultraviolet Imaging Spectrograph (UVIS) in particular are able to probe the region of interest from roughly 400 km to 1500 km in altitude where much of the photochemistry on Titan occurs. This photochemistry is responsible for converting nitrogen from stable N2 molecules into other detectable nitrile compounds such as HCN, HC3N, and heavier species that are further processed into tholins. Therefore an analysis of nitrogen and nitrile abundances on Titan is of particular interest, and we examine UVIS solar and stellar occultation observations in both the EUV and FUV regions of the spectrum in order to directly retrieve the vertical profiles of N2 in addition to its related hydrocarbon derivatives. Furthermore, global analysis of these density profiles strongly indicates possible spatial and seasonal variability both for composition and temperature of the upper atmosphere.

**301 Io**

Wednesday, 8:30 AM - 10:00 AM, Carson 1/2

**301.01 The Role of Volatiles in Volcanism at Loki and other Hotspots on Io**

- Robert R. Howell¹, D. R. Allen¹, C. E. Landis¹, R. M. C. Lopes²

¹Univ. of Wyoming, ²Jet Propulsion Laboratory.

To determine the role of volatiles in volcanic processes on Io we are analyzing Voyager, Galileo, and New Horizons images to obtain colors and high resolution maps near hotspots, in particular Loki. We are also producing numerical transport models for volatiles such as sulfur. As a part of this effort we have also developed Python-based software tools for updating the Voyager and Galileo NAIF pointing kernels, and for analyzing the observations themselves. At Loki, despite their relatively low abundance, volatiles clearly play a significant role. Color photometry of the small bright spots colloquially known as "sulfur bergs", which we suspect are fumarole deposits, show their reflectance is consistent with sulfur but not sulfur dioxide. Mapping of their location shows they avoid the patera margins, and may show other spatial patterns. Preliminary transport models suggest their sizes are consistent with that expected for sulfur fumarole deposits over cooled lava crust. We are currently comparing the high resolution Voyager images with the best available Galileo and New Horizons images to measure changes in the volatile locations over time, and also measure changing locations of nearby silicate flows. We are also beginning stress modeling to understand the structural features seen in island patera such as Loki and are also beginning an analysis of other hotspots such as Tupan.

**301.02 Copious Volcanism on a Compression-dominated Planet? Insights into Magma Ascent and Mountain Building on Io from Numerical Modeling**

- Patrick J. McGovern¹, M. R. Kirchoff²

¹Lunar and Planetary Institute, ²Southwest Research Institute.

Jupiter’s moon Io is the most volcanically active body in the solar system. However, the largest mountains on Io are not massive shield volcanoes, but rather tabular features with a characteristic tilted-block morphology created by
compressional faulting. A global bias towards compression may be produced by a vertical “conveyor belt” of repeated burial and subsidence of volcanic units, but this hypothesis begs the question of how the magma ascends to the surface in apparent violation of the long-standing principle that compression inhibits eruption. Here we explore the twin paradoxes of “copious volcanism on a compression-dominated planet” and “dominance of compression-built mountains on a volcanic planet” via quantitative modeling of the evolution of stresses in and deformation of Io’s lithosphere. Consideration of the pressure balance on a vertical magma conduit (dike) reveals that the vertical stress gradient associated with the conveyor belt stress state (compression decreasing upward) actually provides a driving force for magma ascent. Unfortunately, the components of the conveyor belt stress state (thermal, Poisson, and subsidence stresses) add together to produce horizontal compression in the lower lithosphere. This is inconsistent with vertical conduits, instead favoring horizontal ones (sills). However, the combined flexural (bending) and membrane (stretching) responses to loading produce stress changes beneath and surrounding large loads that can alter the principal stress orientations, re-enabling magma ascent. The particle-based Distinct Element Method (DEM) provides another way to model the response of Io’s lithosphere to the conveyor belt stress state. We model the lithosphere as a gravitationally loaded and bonded assemblage of particles, subject to horizontal displacements that increase with depth. The resulting deformation produces intact triangular blocks with tilted margins that resemble Ionian mountains. This work is sponsored by the NASA Outer Planets Research Program.

301.03 Post-eclipse Behavior Of Io’S Atmosphere
- Cesare Grava¹, N. Schneider², J. Morgenthaler³, F. Leblanc⁴, V. Mangano⁵, C. Barbieri⁶, K. Retherford⁷
  ¹SWRI, ²LASP - University of Colorado, ³Planetary Science Institute, ⁴CNRS/IPSL, France, ⁵IAPS, Italy, ⁶University of Padua, Italy.

We report ground-based spectroscopic observations of Io’s sodium cloud before and after eclipse by Jupiter shadow, in a search for possible effects of the eclipse on the total sodium content in the atmosphere. These observations aim to test the importance of sunlight in maintaining the supply of atoms from the thicker atmosphere, which lies close to the surface, to the more extended sodium cloud. If sunlight is important, there should be observable consequences in the total content of atmospheric species. We performed ground-based observations in the region of the sodium doublet (visible) with an echelle high-resolution spectrograph mounted on the Italian telescope Galileo on La Palma Island. The challenge of these observations lies in disentangling true variations in sodium content from the changing strength of resonant scattering due Io’s changing Doppler shift in the solar sodium absorption line. We will present results that point towards a response of the atmosphere to the changing solar flux, with the total sodium content immediately after eclipse being below the values of pre-eclipse observations, and reaching these values hours after the reappearance. This is consistent with an atmosphere supported mainly by sublimation, given its dependence on the total incident solar flux. Alternatively, our results may be also explained with a collapse of the ionosphere immediately after the ingress, when the photochemistry is turned off and this results in lack of ions, which create neutral sodium via ion sputtering. We will also compare our spatial profiles with previous observations and will provide new insights on the velocity structure of the extended sodium cloud, which appears to depend on the orbital position of Io. This work has been supported by NSF’s Planetary Astronomy Program, INAF/TNG and the Astronomy Department and Cisas institute of University of Padua, through a contract by the Italian Space Agency ASI.

301.04 New Horizons-LEISA Observations Of Io’s Hotspots During The 2007 Encounter
- Constantine Tsang¹, J. A. Rathbun², J. R. Spencer³
  ¹Southwest Research Institute, ²University of Redlands.

The New Horizons spacecraft flew past Jupiter and its satellites in February 2007. The flyby provided one of the most exquisite sets of observations of Io’s active plumes and hotspots yet taken, including many observations of a large 350 km high eruption plume at Tvashtar. Among the suite of instruments active during the flyby was the Linear Etalon Infrared Spectral Array (LEISA), a near-infrared imaging spectrometer. It covers the wavelength region between 1.25 and 2.5 μm, at a resolving power of 240, with a higher resolving power segment (R=540), covering 2.1 to 2.25 μm. Both segments share the same detector array to give on a 256 x 256 pixel spectral image at 62 μrad per pixel field-of-view. LEISA identified more than 30 individual hotspots on Io, over the seven spectral
cubes taken during the flyby. We can measure the thermal emission from these volcanoes, and arrive at eruption temperatures by fitting blackbody curves to hotspot spectra. The temperatures of Tvashtar, Pele and East Girru were all derived in the Spencer et al., (2007) study. These volcanoes were consistent with basaltic volcanism with temperatures between 1287 and 1335 K. Here, we present blackbody fits of the other volcanic hotspots identified in the spectral images to complete the study of hotspot locations, eruption temperatures, emitting area and temporal variability where possible.

301.05 Io’S Active Volcanoes During The New Horizons Era: Insights From LORRI And MVIC
- Julie A. Rathbun¹, R. Lopes², J. R. Spencer³
  ¹Univ. of Redlands, ²Jet Propulsion Laboratory, ³Southwest Research Institute.

Io was a major target of New Horizons as it flew by the Jupiter system in February 2007. The Long-Range Reconnaissance Imager (LORRI), a high resolution panchromatic camera, obtained 190 images of Io at wavelengths from 400-900 nm. The Multicolor Visible Imaging Camera (MVIC), a near-infrared imager, obtained 17 color nighttime and eclipse images of Io. We have examined these data and determined which volcanoes were active, their exact location and activity level. Both instruments observed Tvashtar and E. Girru, so we fit blackbody curves to determine the temperatures of these hotspots. We have tracked the location of several hotspots as a function of time and will discuss the implications for eruption mechanism. We also compare the level volcanic activity during the New Horizon era with the Galileo era.

301.06 Spatially Resolved Observations of Io’s Dayside Equatorial Atmosphere
- Kandis-Lea Jessup¹, J. Spencer³
  ¹South West Research Inst..

The revival of the Hubble Space Telescope Imaging Spectrograph (HST/STIS) has made spatially resolved observations of Io in the UV possible again. Consequently, we have obtained HST/STIS long 0.1” slit limb-to-limb observations of Io’s equatorial region (±25° latitude) on 10 different occasions, 5 centered at Central Meridian Longitude (CML) 200 W and 5 centered CML 250W longitude. Each observation was obtained using the G230L grating, thus each spectrum extends from 170-310 nm, and we have high S/N spectra in the 200-310 nm region. For each observation, the slit was oriented 23° from parallel to Io’s equator, and centered at 5N, 235W. Binning the limb-to-limb spectra into five 25° spatial bins per CML, we were able to observe the same longitude regions, at 2 distinct times of day, with a maximum of 6° variation in latitude for each spatial bin. We then fit the observed spectra using the Malkmus band transmission model and report our initial analysis of the variation of the SO2 gas temperature and density, as well as the magnitude of the SO2 continuum emission observed in the equatorial region from the morning to the evening terminators.

301.07 Io Volcanic Activity Since 2003 As Seen By 8-10-m-class Telescopes Equipped With Adaptive Optics (ao)
- Franck Marchis¹, A. Davies²
  ¹SETI Institute, ²Jet Propulsion Laboratory.

Io, most volcanic place in the our Solar System, has been monitored since 2003 on a semi-irregular basis using the Keck II and the Gemini North Adaptive Optics (AO) systems equipped with a near infrared (NIR) camera sensitive to 5 um. We present a global view of Io volcanic activity, identifying permanent hot spots, sporadic outbursts, and possible surface changes from these observations. AO observations were also obtained at the time of the New Horizons flyby in early 2007, from these data we can constrain the style of volcanism at specific volcanic centers. Finally, we discuss the relatively quiescent state of Io volcanism observed over the past 2 years. The monitoring of Io’s volcanic activity will continue through 2016, which includes the arrival of the Juno spacecraft in July of that year, and beyond. An ever-increasing timeline of volcanic activity and thermal emission variability continues to be constructed and which will be further complimented by data obtained by other missions to the Jupiter system (such as JUICE, or a dedicated Europa or Io mission). Until these missions, however, the task of monitoring Io’s volcanic activity will be from large, AO-enabled ground-based telescopes. The support of the NASA Planetary Outer Planets Research Program is acknowledged.
301.08 DSMC Simulations of Io’s Pele Plume
- William McDoniel¹, D. Goldstein¹, P. Varghese¹, L. Trafton¹
  ¹The University of Texas at Austin.

Io’s Pele plume rises over 300km in altitude and leaves a deposition ring 1200km across on the surface of the moon. Material emerges from an irregularly-shaped vent, and this geometry gives rise to complex 3D flow features. The Direct Simulation Monte Carlo method is used to model the gas flow in the rarefied plume, demonstrating how the geometry of the source region is responsible for the asymmetric structure of the deposition ring and illustrating the importance of very small-scale vent geometry in explaining large observed features of interest. Simulations of small particles in the plume and comparisons to the black “butterfly wings” seen at Pele are used to constrain particle sizes and entrainment mechanisms. Preliminary results for the effects of plasma energy and momentum transfer to the plume will also be presented.

301.09 Opportunities for Monitoring Io’s Volcanic Activity in the Visible and Infrared From JUICE - It’s All About (Eruption) Style
- Ashley Davies¹, D. Matson¹, A. S. McEwen², L. Keszthelyi³
  ¹JPL, ²University of Arizona, ³USGS Astrogeology Science Center.

The ESA Jupiter Icy Moons Explorer (JUICE) provides many opportunities for long-range monitoring of Io’s extraordinary silicate volcanic activity [1, 2]. A considerable amount of valuable work can be performed even with relatively low-spatial-resolution observations [2]. Techniques developed from the study of Galileo NIMS data and observations of terrestrial silicate volcanism allow the identification of likely eruption style [2] at many locations where the entire eruption is sub-pixel. Good temporal coverage, especially for episodic eruptions (including high-energy “outburst” eruptions), is important for modelling purposes. With opportunities to observe Io on a regular basis (hours-days) during cruise/orbital reduction phases, a visible-to-near-infrared mapping spectrometer (covering ~0.4-5.5 μm) is the best instrument to chart the magnitude and variability of Io’s volcanic activity, allowing comparison with an existing and constantly expanding set of Io observations [e.g. 1, 3]. The eruption temperature of Io’s dominant silicate lava, a constraint on interior composition and conditions, is a major unanswered question in the wake of the Galileo mission [1]. A careful approach to instrument design is needed to ensure that observations by both imager and IR spectrometer on JUICE are capable of determining lava eruption temperature [e.g., 4] in low spatial resolution data. With an ideal thermal target (e.g., outburst eruption; the proposed lava lake at Pele) the imager should obtain multi-spectral data in a rapid sequence to allow stability of the thermal source to be quantified. Observations by imager and spectrometer have to be contemporaneous and unsaturated. References: [1] Davies, A. (2007) “Volcanism on Io”, Cam. Univ. Press. [2] Davies et al. (2010) JVGR, 194, 75-99. [3] Veeder et al. (2012) Icarus, 219, 701-722. [4] Davies et al. (2011) GRL, 38, L21308. This work was performed at the Jet Propulsion Laboratory-California Institute of Technology, under NASA contract. AGD thanks the NASA OPR program for support.

302 Asteroids 4: MBCs, Comet Remnants, and Asteroids
Wednesday, 8:30 AM - 10:00 AM, Reno Ballroom

302.01 Hst Measurements Of Main Belt Comet 300163
- David Jewitt¹, H. Weaver², J. Agarwal³, M. Mutchler⁴, S. Larson⁵
  ¹UCLA, ²Johns Hopkins University/APL, ³University of Potsdam, Germany, ⁴Space Telescope Science Institute, ⁵University of Arizona.

Asteroid 300163 (semimajor axis 3.05 AU, eccentricity 0.20, inclination 3 deg., Tisserand parameter 3.20) is a source of dust, giving it the dual cometary designation P/2006 VW139. It satisfies the definition of a main-belt comet (MBC) by having the orbital character of a main-belt asteroid but the diffuse appearance of a comet. We obtained Hubble Space Telescope observations of this object in December 2011 in order to study the morphology of the ejected dust at the highest angular resolution and to determine the cause of the mass loss from the nucleus. One of the two HST observing epochs was carefully timed to coincide with the Earth’s crossing of the orbital plane.
(out of plane angle 0.01 deg.) to obtain a measure of the vertical velocity dispersion free from the effects of projection. We find an extraordinarily thin dust sheet and infer a sub-meter per second dust ejection velocity. Observations at the second epoch show a change in the near-nucleus dust morphology that indicates continuing ejection (i.e. the dust emission is not impulsive). We use the low velocity ejection, coupled with the absence of an observable coma, to help constrain the possible source mechanisms for the dust.

302.02 A Coma Search in Jovian Trojans
- Sarah Nymeyer
- D. Jewitt

The Jovian Trojans orbit far beyond the snow line and are widely believed to contain water ice. However, they have resisted all spectroscopic efforts to identify water ice, which must therefore be rare on their surfaces. Simple models show that water ice is thermodynamically unstable when exposed, but could survive indefinitely beneath a thin, refractory surface mantle. Water ice might be exposed on some objects by impact or by other processes capable of puncturing or disturbing the surface mantle. We will present wide field survey data taken using Subaru Telescope's Suprime-Cam in order to search for evidence of outgassing from Jovian Trojans.

302.03 ExploreNEOs: A Search for Near-Earth Objects of Cometary Origin
- Michael Mommert
- A. W. Harris
- D. E. Trilling
- M. Mueller
- J. L. Hora
- M. Delbo
- W. F. Bottke
- J. P. Emery
- G. Fazio
- A. R. Hagen
- A. Morbidelli
- H. A. Smith
- C. A. Thomas

The short dynamical lifetime of near-Earth objects (NEOs) compared to the age of the Solar System implies the existence of sources of replenishment in order to maintain the observed population of NEOs. Main belt asteroids and Jupiter family comets (JFCs), which can end up in typical NEO orbits via planetary perturbations and non-gravitational forces, are the most important sources of replenishment of NEOs. JFCs that become NEOs suffer accelerated loss of their near-surface volatiles, evolving into inactive “dormant” or “extinct” comets that are observationally indistinguishable from low albedo asteroids. Dynamically, however, they retain “comet-like” orbital characteristics. Knowledge of the fraction of extinct comets in the NEO population is important for assessing the amount of cometary material that has been transported to Earth. Furthermore, identifying inactive comet candidates facilitates detailed investigations of the final phase of comet evolution. We present an independent analysis of the fraction of former comet objects in the NEO population. Due to the large number of NEOs we use a statistical approach to identify dormant or extinct comets based on dynamical and physical properties. We utilize (1) the Tisserand parameter with respect to Jupiter, (2) the minimum orbit intersection distance with respect to Jupiter and (3) albedo measurements. Our albedos are determined from thermal-IR observations made by the Warm Spitzer Space Telescope Exploration Science project "ExploreNEOs", using thermal modeling. The main goal of this work is to estimate the fraction of dormant or extinct comets in the NEO population. We will further provide a list of former comet candidate objects and assess their accessibility with spacecraft via the delta-V parameter. We enhance our investigation by adding data from the literature to our sample and compare our results to earlier published works based on independent analyses. MM acknowledges support by the DFG SPP 1385.

302.04 The Canadian Meteor Orbit Radar II: A new Facility for Measurement of the Dust Environment in near-Earth space
- Peter G. Brown
- R. J. Weryk
- D. K. Wong
- M. D. Campbell-Brown

The Canadian Meteor Orbit Radar (CMOR) is a backscatter, multi-station meteor radar operating at 29.85 MHz. CMOR has been in operation as a three station system since 2001, but a major upgrade in 2009 has expanded the system to six stations and doubled the transmit power to 15 kW; the new facility is termed CMOR II. CMOR II measures ~5000 individual orbits per day of meteoroids with masses ~10^{-8} kg. These large number statistics permit
near real-time identification of as many as a dozen significant daily meteor showers, through application of a 3D wavelet transform. As individual meteor echoes are detected at up to six stations, CMOR II is able to measure electron line density profiles and decelerations for select events. This permits estimation of meteoroid bulk density through comparison with entry models for particles as small 100 μm. For events with more than four station detections, errors in radiant and speed are comparable to similar measurements made with video systems. Making use of multiple, independent techniques for speed measurements, including time-of-flight, Fresnel amplitude and Fresnel phase fitting, it is possible to estimate speed accuracy for individual events. Monte Carlo modeling of individual echoes allows a separate estimate for uncertainty in both speed and radiant measurement. Here we present initial results from CMOR II measurements of major meteor showers including the 2012 Daytime Arietids and South Delta Aquariid streams. Detections of several unusual meteor shower outbursts with CMOR II and verification of previously reported weak showers will also be shown. We will demonstrate the capacity of CMOR II for individual meteoroid physical characterization by using measured trajectory, speed, deceleration and electron line density measurements combined with entry model fits to estimate meteoroid parameters. Funding from the NASA Meteoroid Environment Office through cooperative agreement NNX11AB76A is gratefully acknowledged.

302.05 Radar Imaging Of 11066 Sigurd, 2000 YF29, And 2004 XL14 And The Obliquity Distribution Of Contact Binary Near-Earth Asteroids

1NRAO, 2JPL, 3University of Maine, 4University of Colorado, 5Arecibo Observatory, 7Bloomsburg University.

At least 10% of near-Earth asteroids larger than ~200 m in diameter observed by radar are contact binaries, which we define as objects composed of two lobes in contact with each other that may once have been in mutual orbit. We will present new shape models and pole directions for three contact binaries imaged by radar: 11066 Sigurd, 2000 YF29, and 2004 XL14. The maximum dimensions for each object are ~4.2 km for Sigurd, ~0.4 km for 2000 YF29, and ~0.3 km for 2004 XL14. Sigurd's lobes are elongated, roughly ellipsoidal, and are joined on their long axis; 2000 YF29's larger lobe is oblate; and 2004 XL14 has lobes that are distinctly angular. Sigurd and 2000 YF29 have obliquities between 50º-130º and 2004 XL14 has an ambiguous obliquity that is close to either 0º or 180º. Of the contact binaries imaged by Arecibo and/or Goldstone, data from eleven are suitable for estimating pole directions. Eight of the eleven objects (73 ± 16%) have high obliquities between 50º and 130º, compared to 40 ± 13% of non-contact-binary single NEAs (10 of 25 objects) and 33 ± 19% of binary NEA systems (3 of 9 objects). Although this is only a marginally-significant detection (95% confidence), estimation of spin vectors from radar observations hints that contact binaries have systematically higher obliquities than other objects in the near-Earth population.

302.06 Radar Observations and Shape Modeling of Near-Earth Asteroid (162421) 2000 ET70
- Shantanu Naidu1, J. L. Margot1, P. A. Taylor2, M. C. Nolan3, M. Brozovic5, L. A. M. Benner1, J. D. Giorgini3, E. S. Howell2, M. W. Busch4, C. Magri3

1UCLA, 2Arecibo Observatory, 3Jet Propulsion Laboratory, California Institute of Technology, 4NRAO, 5University of Maine.

Asteroid 2000 ET70 was discovered by the LINEAR program on Mar 8th, 2000. During its close approach to the Earth in Feb 2012 (~0.045 A.U.), we acquired ~350 range-Doppler images over 6 days with range resolutions as fine as 15 meters using the Arecibo Planetary Radar (2380 MHz, 13 cm). We also obtained ~800 range-Doppler images over 9 days with range resolutions as fine as 75 meters using the Goldstone Solar System Radar (8560 MHz, 3.5 cm). The single-run Arecibo images have sufficient signal to use as is whereas the Goldstone images were summed in groups of 10 for our analysis. This extensive radar data set allowed us to model the shape of the asteroid and to fit for its spin period and spin axis orientation. The regularity of the rotation evidenced in the entire sequence of images suggests that the asteroid is a principal axis rotator. The best-fit shape model indicates a sidereal spin period of 8.96 ± 0.04 hours. The current vertex shape model has an effective resolution of ~150 meters and an equivalent diameter of ~2 km. The asteroid has an elongated oblate shape with a polar extent of 1.9 km and
equatorial extents of 2.0 km and 2.2 km (with 10 % uncertainties) and it exhibits multiple kilometer scale ridges. We expect to achieve resolutions finer than ~50 meters for the shape model with additional processing.

302.07 The Shape and Spin Distributions of Near-Earth Asteroids Observed with the Arecibo Radar System

- Patrick A. Taylor¹, E. S. Howell¹, M. C. Nolan¹, A. A. Thane²
  ¹Arecibo Observatory, ²The University of Montana.

Radar observations of near-Earth asteroids have revealed a heterogeneous population with diameters spanning meter to kilometer scales, diverse shapes ranging from simple spheroids to extremely irregular bodies, and rotation periods stretching from minutes to weeks. Since 1998, when the Arecibo Observatory S-band radar system was upgraded to transmit up to 1 MW, over 260 near-Earth asteroids have been detected. We find the radar-observed near-Earth asteroid population with absolute magnitude H < 21 is not dominated by a single category of basic shape: spheroids, multiple-asteroid systems, double-lobed contact binaries, elongated bodies, or irregularly shaped asteroids. A radar-observed binary fraction of 17% (N = 32) among near-Earth asteroids with H < 21 is in agreement with optical observations, while contact binaries account for another 14% (N = 27). At smaller sizes, binaries and contact binaries are much rarer (one of each with H < 21). The spin distribution of near-Earth asteroids estimated from radar matches very well with the spin distribution determined from optical lightcurves, including the curious lack of small, slowly rotating bodies despite the different biases in these observational techniques. The shape and spin distributions of near-Earth asteroids observed with radar both show a distinct change in the population around H of 21 or 22 (100- to 200-m diameters), possibly indicating fundamental structural changes at this scale. Future observations will focus on the H > 21 size range to explore this possibility.

302.08 Asteroid Sizes Determined by Combining Shape Models and Keck Adaptive Optics Images

- Josef Hanus¹, F. Marchis², J. Durech¹
  ¹Astronomical Institute of Charles University, Prague, Czech Republic, ²SETI Institute, Carl Sagan Center, 189 Bernado Avenue, Mountain View CA 94043, USA.

We selected 67 main-belt asteroids (D ~ 20 - 400 km) for which we have (i) shape models derived by the lightcurve inversion method (LI) and (ii) observations collected with the Keck II Adaptive Optics (AO) system by the NIRC-2 camera in H, FeII or Kc filters. In order to determine the true size of the asteroid model, we minimized the difference between the contour directly obtained from the AIDA-deconvolved AO image and the projected silhouette calculated from the shape model at the time of the AO observation. As preliminary analysis, we computed the volume for 37 scaled shape models and derived their equivalent diameters. For 10 asteroids, we removed the ambiguity of the pole orientation typical for shape models derived by LI. We computed the average relative differences between our equivalent diameters and effective diameters derived by IRAS, WISE and AKARI: 10 %, 12 % and 11 %, respectively, without any systematic trends. This work has been supported by the grant GA UK 134710 of the Grant agency of the Charles University, the grant GACR P209/10/0537 of the Czech Science Foundation, the project SVV 261301 of the Charles University, the Research Program MSM0021620860 of the Ministry of Education and the NASA grant NNX11AD62G.

302.09 The Triaxial Ellipsoid Diameters and Rotational Pole of Asteroid (9) Metis from AO at Gemini and Keck

- Jack D. Drummond¹, W. J. Merline², A. Conrad³, C. Dumas⁴, P. Tamblyn⁵, J. Christou⁶, B. Carry⁶, C. Chapman⁷
  ¹Starfire Optical Range, ²Southwest Research Institute, ³Max-Planck-Institut fur Astronomie, Germany, ⁴European Southern Observatory, Chile, ⁵Gemini Observatory, ⁶European Space Astronomy Centre, Spain.

From Adaptive Optics (AO) images of (9) Metis at 14 epochs over 2008 December 8 and 9 at Gemini North, triaxial ellipsoid diameters of 218x175x112 km are derived with fitting uncertainties of 3x3x47 km. However, by including just two more AO images from Keck-II in June and August of 2003 in a global fit, the fitting uncertainty of the small axis drops by more than a third because of the lower sub-Earth latitude afforded in 2003 (-28°) compared to 2008 (+47°), and the triaxial ellipsoid diameters become 218x175x129 km with fitting uncertainties of 3x3x14 km. We have estimated the systematic uncertainty of our method to be 4.1, 2.7, and 3.8%, respectively, for the three
diameters. These values were recently derived (Drummond et al., in prep) from a comparison of KOALA (Carry et al, Planetary and Space Science 66, 200-212) and our triaxial ellipsoid analysis of four asteroids. Quadratically adding this systematic error with the fitting error, the total uncertainty for Metis becomes 9x5x15 km.

Concurrently, we find an EqJ2000 rotational pole at [RA; Dec]=[185°; +19°] or in ecliptic coordinates, [λ ; β ]=[176°; +20°] (ECJ2000).

303 Titan Atmosphere 2

Wednesday, 10:30 AM - 12:00 PM, Tahoe Room

303.01 Sensitivity Study of the Cassini INMS Flyby-specific Measurements of the Nitrogen Isotope Ratios and Ar Mixing Ratios to Evaluate the Eddy Diffusion Coefficient In Titan’s Atmosphere

- Kathleen Mandt, A. Nagy, J. Waite, Jr., J. Bell, S. Bougher, B. Magee

1Southwest Research Institute, 2University of Michigan.

We have conducted a sensitivity study of the Ar measurements made by the Cassini Ion Neutral Mass Spectrometer (INMS) in Titan’s upper atmosphere over more than 30 Titan flybys. We determine the possible range of values for the Ar mixing ratio based on the mass 40 signal and determine the range of possible values for the eddy diffusion coefficient based on limits set by these measurements. We then compare these results with the suggested altitude profile for the nitrogen isotope ratios measured by Cassini INMS. The eddy diffusion coefficient determines the homopause altitude in Titan’s atmosphere and plays a key role in calculating the escape rate of methane.

303.02 Why Is a Titan-generated Nitrogen Torus Not Observed In Saturn’s Magnetosphere?


1Johns Hopkins Applied Physics Lab, 2University of Virginia, 3Mullard Space Science Laboratory, UCL, United Kingdom, 4Southwest Research Institute.

Prior to Cassini’s arrival at Saturn, Titan-generated nitrogen ions were thought to dominate heavy plasma in Saturn’s magnetosphere. Therefore, the presence of a Titan nitrogen torus was anticipated. However, it is now known water-group ions dominate Saturn’s heavy ion magnetospheric plasma. While nitrogen ions have been detected beyond the orbit of Rhea, these ions appear to be primarily originating from the Enceladus plumes with little nitrogen plasma detected in the magnetosphere near Titan’s orbit. In fact, pick-up oxygen ions from Enceladus are much more abundant than nitrogen in Titan’s orbit. These results appear inconsistent with the expectation that Titan’s dense relatively unprotected atmosphere should provide a significant source of heavy particles to Saturn’s magnetosphere. This inconsistency suggests that the plasma environment at Titan’s orbit is much more complex than originally anticipated. In this talk, we expand on our previous research that categorizes the plasma environments near Titan to include all locations along Titan’s orbit. Using these categories, we develop characteristic plasma spectra of each type of environment, update ionization lifetimes for each region and apply these results in a 3D Monte Carlo model to more accurately examine the fate of nitrogen and methane escaping Titan’s atmosphere to support the possible presence of a Titan torus despite the lack of observations. We also present preliminary Cassini data analysis that is focused on regions where such a torus could be detected. This work is supported by the NASA Cassini Data Analysis Program and NASA JPL contract 1243218 for Cassini MIMI and CAPS investigation.

303.03 A Global Model of the Precipitation of Magnetically-mirroring Magnetospheric Electrons in Titan’s Ionosphere

- Darci Snowden, R. Yelle, M. Galand, A. Coates, G. Jones, A. Wellbrock, P. Lavvas

1Lunar and Planetary Laboratory, University of Arizona, 2Imperial College, United Kingdom, 3Mullard Space Science Laboratory, University College London, United Kingdom, 4University of Reims, France.

The global precipitation of electrons into Titan’s ionosphere is still poorly understood because it depends on Titan’s complex and variable interaction with Saturn’s magnetosphere. We address this issue by coupling a 3D
model of Titan’s plasma interaction to a 1D electron precipitation model. A three-dimensional multi-fluid model of Titan’s plasma interaction is used to determine the trajectory of magnetic flux tubes drifting through Titan’s upper atmosphere. These results are coupled to a two-stream electron transport model to calculate energy deposition rates, ionization rates, and electron energy spectra. CAPS-ELS data show that the electron flux along field lines connected to Titan’s atmosphere is depleted, producing features known as electron bite-outs. The bite-outs indicate that the electron flux impacting Titan’s atmosphere is reduced on time scales comparable to the electron bounce time in Saturn’s magnetosphere. We account for the decrease in electron flux in our two-stream model with time-dependent boundary conditions. We also calculate electron bounce times in Saturn’s magnetosphere near Titan for several plasma disk configurations. We show that the reduction of incident flux results in less energy being deposited at altitudes below ~1300 km compared to models that do not account for the depletion of magnetospheric electrons by the Titan interaction. We also produce global energy deposition and ionization profiles for two cases: when Titan’s dayside ionosphere is aligned with the ram direction and when Titan’s dayside ionosphere is aligned with the sub-ram direction.

**303.04 The Composition of Titan’s Ionospheric Outflow: Mass Resolved INMS Observations of Exospheric Ions From the T40 Flyby**

- Joseph H. Westlake\(^1\), C. P. Paranicas\(^2\), T. E. Cravens\(^2\), J. G. Luhrmann\(^3\), K. E. Mandt\(^4\), H. T. Smith\(^5\), D. G. Mitchell\(^6\), A. M. Rymer\(^1\), M. E. Perry\(^1\), J. H. Waite\(^7\), J. Wahlund\(^8\)

\(^1\)John Hopkins Applied Physics Lab, \(^2\)Department of Physics and Astronomy, University of Kansas, \(^3\)Space Physics Research Group, University of California, Berkeley, \(^4\)Southwest Research Institute, \(^5\)Swedish Institute of Space Physics, Sweden.

We report on Cassini Ion and Neutral Mass Spectrometer (INMS) observations above Titan’s exobase at altitudes of 2225 km to 3034 km. During the January 2008 T40 Cassini flyby of Titan the Ion and Neutral Mass Spectrometer (INMS) serendipitously observed non-thermal, exospheric ions. This is the first mass-resolved observation of Titan’s exospheric ions. We observe significant densities of CH\(_5^+\), HCNH\(^+\) and C\(_2\)H\(_5^+\) that require ion-molecule reactions to be produced in the quantities observed. During the observation the Cassini spacecraft was executing a roll causing the INMS to observe several locations in velocity space. Ions are observed with velocities of about 1 km/s. The measured composition and ion velocity suggest that the observed ions must have been created deep inside Titan’s ionosphere (below the exobase) and then transported to the detection altitude. Plasma motion from below Titan’s exobase to large distances can be driven by a combination of thermal pressure and magnetic forces. The observed outward flows may link the main ionosphere with the more distant wake and provide a source of hydrocarbon ions in the Saturnian system.

**303.05 Photochemical Modeling Of Water In Titan’s Atmosphere Constrained By Herschel Space Observatory**

- Luisa-Maria Lara\(^1\), E. Lellouch\(^1\), R. Moreno\(^1\), H. Feuchtgruber\(^4\), M. Rengel\(^5\), P. Hartogh\(^5\), R. Courtin\(^5\)

\(^1\)Inst. de Astrofisica de Andalucia-CSIC, Spain, \(^2\)Obs. Paris - Meudon, France, \(^3\)Obs. Paris-Meudon, France, \(^4\)Max-Planck Institute for Extraterrestrial Physics, Germany, \(^5\)Max-Planck Institute for Solar System Research, Germany.

Disk-averaged observations of water vapour in Titan’s atmosphere acquired with the Herschel Space Observatory indicate that in the range 100-450 km there is no variation of the H\(_2\)O abundance between the leading and trailing sides, nor variation over a 1 year interval. Both the narrow widths of the HIFI-observed lines, and the relative contrasts of the five H\(_2\)O lines indicate that the H\(_2\)O mole fraction strongly increases with altitude. Comparing the previous proposed water vertical profiles on the basis of 1-D photochemical models with the best profile fitting the observations, we conclude that previous photochemical models produce too much water, and none of them have the adequate slope. Thus, photochemical models of oxygen species in Titan’s atmosphere are reconsidered, updating the Lara et al. (1996) model for oxygen chemistry, and adjusting the eddy diffusion coefficient in order to match both our H\(_2\)O observations and the C\(_2\)H\(_6\) and C\(_3\)H\(_4\) vertical profiles determined from Cassini/CIRS. We find that the H\(_2\)O profile can be reproduced by invoking a OH/ H\(_2\)O influx of (2.7-3.4)x10\(^{10}\) mol cm\(^{-2}\) s\(^{-1}\), referred to the surface. This is essentially one order of magnitude lower than invoked by previous modellers, and also a factor of ~10 less than required to match the observed CO\(_2\) mole fraction. Therefore, we conclude that this reflects a temporal change in the oxygen influx into Titan, that could be currently much smaller than averaged over the past
centuries. Both interplanetary dust particles and Enceladus’ activity appear to provide sufficient supply for the current Titan H$_2$O. We tentatively favour the latter source as potentially more prone to time variability.

303.06 Chemical Nature Of Titan’s Organic Aerosols Constrained from Spectroscopic and Mass Spectrometric Observations

- Hiroshi Imanaka$^1$, D. P. Cruikshank$^2$
- $^1$University of Arizona, $^2$NASA Ames Research Center.


303.07 The Titan Haze Simulation Experiment: Probing the Different Steps of Titan’s Atmospheric Chemistry at Low Temperature

- Ella Sciamma-O’Brien$^1$, C. S. Contreras$^1$, C. L. Ricketts$^1$, F. Salama$^1$
- $^1$NASA Ames Research Center.

In Titan’s atmosphere, a complex chemistry between its two main constituents, N$_2$ and CH$_4$, leads to the production of heavy molecules and subsequently to solid aerosols. The Titan Haze Simulation (THS) experiment has been developed on the Ames simulation chamber, COSmIC, to study the chemical pathways that link the simple molecules resulting from the first steps of the N$_2$-CH$_4$ chemistry (C$_2$H$_2$, C$_2$H$_4$, HCN $\cdots$) to benzene, and to polycyclic aromatic hydrocarbons (PAHs) and nitrogen-containing PAHs (PANHs) as precursors to the production of solid aerosols. In the THS experiment, Titan’s atmospheric chemistry is simulated by plasma in the stream of a supersonic expansion. With this unique design, the gas mixture is cooled to Titan-like temperature (~150K) before inducing the chemistry by plasma discharge. Different gas mixtures containing N$_2$, CH$_4$, and the first products of Titan’s chemistry but also much heavier molecules like PAHs or PANHs can be injected to study specific chemical reactions. The products of the chemistry are detected and studied using two complementary techniques: Cavity Ring Down Spectroscopy and Time-Of-Flight Mass Spectrometry. Thin tholin deposits are also produced in the THS experiment and can be analyzed by Gas Chromatography-Mass Spectrometry (GC-MS) and Scanning Electron Microscopy (SEM). Here we present the results of a systematic mass spectrometry study using different gas mixtures of N$_2$ with hydrocarbon precursors, and similar mixtures with N$_2$:CH$_4$ (90:10) instead of pure N$_2$, to study specific pathways associated with the presence of these trace elements in Titan’s atmosphere. These results show the uniqueness of the THS experiment to help understand the first steps of Titan’s atmospheric chemistry as well as intermediate steps of the chemistry and specific chemical pathways leading to Titan’s haze formation. We will also present preliminary results of the tholin ex situ analysis and discuss the implications for our understanding of Titan’s haze formation.

303.08 Laboratory Studies Of Titan Haze: Simultaneous In Situ Detection Of Gas And Particle Species
Analyses of data obtained by multiple instruments carried by Cassini and Huygens have increased our knowledge of the composition of Titan’s atmosphere. While a wealth of new information about the aerosols in Titan’s atmosphere was obtained, their composition is still not well constrained. Laboratory experiments will therefore play a key role in furthering our understanding of the chemical processes resulting in the formation of haze in Titan’s atmosphere and its possible composition. We have obtained simultaneous in situ measurements of the gas- and particle-phase compositions produced by our Titan atmosphere simulation experiments (see e.g. [1]). The gas phase composition was measured using a Proton-Transfer Ion-Trap Mass Spectrometer (PIT-MS) and the aerosol composition was measured using a High-Resolution Time-of-Flight Aerosol Mass Spectrometer (HR-ToF-AMS). This complementary set of measurements will allow us to address the partitioning of gas- and aerosol-phase species. Knowledge of the gas phase composition in which the particles in our experiments form allows both for better comparison to the chemistry that is occurring in Titan's atmosphere and for enabling more accurate determination of the possible pathways involved in the transition from gas phase to aerosol. We will compare the results from experiments that used two different initial gas mixtures (98% N2/2% CH4 and 98%N2/2%CH4/50 ppm CO) and two different energy sources to initiate the chemical reactions that result in particle formation (spark discharge using a Tesla coil or FUV irradiation from a deuterium lamp (115-400 nm)). [1] Trainer, M.G., et al. (2012) Astrobiology, 12, 315-326. SMH is supported by NSF Astronomy and Astrophysics Postdoctoral Fellowship AST-1102827.

303.09 Far-IR Absorption Features of Titan Aerosol Analogs Produced from Aromatic Precursors
- Joshua Sebree1, M. G. Trainer1, C. M. Anderson1, M. J. Loeffler1
  1Goddard Space Flight Center.

The arrival of the Cassini spacecraft in orbit around Saturn has led to the discovery of benzene (C6H6) at ppm levels, as well as large positive ions in Titan’s atmosphere, tentatively identified as polycyclic aromatic hydrocarbons (PAHs).[1] The presence of aromatic molecules, which are photolytically active in the ultraviolet, may be an important part of the formation of aerosol particles in Titan’s haze layers, even at these low concentrations. To date, there have been no laboratory experiments in the literature exploring this area of study. The analysis of data from the Composite Infrared Spectrometer (CIRS) on-board Cassini has recently uncovered a broad emission feature centered at ~140 cm-1 in the far-IR that is unique to the aerosol layers of Titan’s atmosphere.[2] Current optical constants from laboratory-generated aerosol analogs have been unable to reproduce this feature.[3,4] From the broadness of this feature, we speculate that the emission is a blended composite of low-energy vibrations of large molecules such as PAHs and their nitrogen containing counterparts, polycyclic aromatic nitrogen heterocycles (PANHs). We hypothesize that the inclusion of trace amounts of aromatic precursors will aid in the production of these large structures in the laboratory-generated aerosols. In this study, we perform UV irradiation of several aromatic precursors, both with and without nitrogen heteroatoms, to understand their influence on the observable characteristics of the aerosol. Measured optical and chemical properties will be compared to those formed from CH4/N2 mixtures [5,6] as well as to those from Cassini observations. [1] Waite, J. H., et al. (2007) Science 316 870-875. [2] Anderson, C.M, et al. (2011) Icarus 212 762-778. [3] Khare, B.N., et al. (1984) Icarus 60 127-137. [4] Imanaka, H., et al. (2012) Icarus 218 247-261. [5] Trainer, M.G., et al. (2006) PNAS 103 18035-18042. [6] Trainer, M.G., et al. (2012) Astrobiology 12 315-326.

304 Pluto and its Entourage

Wednesday, 10:30 AM - 12:00 PM, Reno Ballroom

304.01 Charon’s Size And Orbit From Double Stellar Occultations
Stellar occultations of a same star by both Pluto and Charon (double events) yield instantaneous relative positions of the two bodies projected in the plane of the sky, at ~10km-level accuracy. Assuming a given pole orientation for Charon’s orbit, double events provide the satellite plutocentric distance \( r \) at a given orbital longitude \( L \) (counted from the ascending node on J2000 mean equator), and finally, constraints on its orbit. A double event observed on 22 June 2008 provides \( r=19,564\pm14 \) km at \( L=153.483\pm0.071 \) deg. (Sicardy et al. 2011), while another double event observed on 4 June 2011 yields: \( r=19,586\pm15 \) km at \( L = 343.211\pm0.072 \) deg. (all error bars at 1-sigma level). These two positions are consistent with a circular orbit for Charon, with a semi-major axis of \( a=19,575\pm10 \) km. This can be compared to the circular orbit found by Buie et al. (2012), based on Hubble Space Telescope data, with \( a=19,573\pm2 \) km. The 4 June 2011 stellar occultation provides 3 chords across Charon, from which a radius of \( Rc= 602.4\pm1.6 \) km is derived. This value can be compared to that obtained from the 11 July 2005 occultation: \( Rc= 606.0\pm1.5 \) km (Person et al. 2006) and \( Rc= 603.6\pm1.4 \) km (Sicardy et al. 2006). A third double event, observed on 23 June 2011 is under ongoing analysis, and will be presented. Buie et al. (2012), AJ 144, 15-34 (2012) Person et al, AJ 132, 1575-1580 (2006) Sicardy et al., Nature 439, 52-54 (2006) Sicardy et al., AJ 141, 67-83 (2011) B.S. thanks ANR “Beyond Neptune II”. L.A.Y. acknowledges support by NASA, New Horizons and National Geographic grants. We thank B. Barnard, M.J. Brucker, J. Daily, C. Erikson, W. Fukunaga, C. Harlinton, C. Livermore, C. Nance, J.R. Regester, L. Salas, P. Tamblyn, R. Westhoff for help in the observations.

304.02 Pluto’s Atmosphere from the 23 June 2011 Stellar Occultation: Airborne and Ground Observations


\(^1\) MIT, \(^2\) Lowell Observatory, \(^3\) South African Astronomical Observatory, South Africa, \(^4\) Williams College, \(^5\) Institute for Astronomy, \(^6\) Deutsche SOFIA Institut, Germany, \(^7\) NASA Ames Research, \(^8\) Leeward Community College, \(^9\) Winward Community College, \(^10\) Hawaii Geophysics and Planetology, \(^11\) JPL, \(^12\) University of Tennessee, \(^13\) Mt. Stromlo Observatory, Australia, \(^14\) EOS Space Systems, Australia.

The double stellar occultation by Pluto and Charon of 2011 June 23 was observed from numerous ground stations as well as the Stratospheric Observatory for Infrared Astronomy (SOFIA). This first airborne occultation observation since 1995 resulted in the best occultation chords recorded for the event, in three optical wavelength bands. The data obtained from SOFIA were combined with chords obtained from the ground at the IRTF (including a full spectral light curve), the USNO–Flagstaff Station, and Leeward Community College to give a detailed profile of Pluto’s atmosphere. The data show a return to the distinct upper and lower atmospheric regions with a knee, or kink in the light curves separating them as was observed in 1988 (Millis et al. 1993), rather than the smoothly transitioning bowl-shaped light curves of recent years (Elliot et al. 2007). We analyze the upper atmosphere by fitting a model to all of the light curves obtained, resulting in a half-light radius of 1288 ± 1 km. We analyze the lower atmosphere with two different methods to provide results under the separate assumptions of particulate haze and a strong thermal gradient. Results indicate that the lower atmosphere evolves on short seasonal timescales, changing between 1988 and 2006, and then returning to approximately the 1988 state in 2011, though at significantly higher pressures. Throughout these changes, the upper atmosphere remains remarkably stable in structure, again excepting the overall pressure changes. No evidence of the onset of atmospheric collapse predicted by frost migration models is yet seen, and the atmosphere appears to be remaining at a stable pressure level. This work was supported in part by NASA Planetary Astronomy grants to MIT (NNX10AB27G) and Williams College (NNX08AO50G, NNH11ZDA001N), as well as grants from USRA (#8500-98-003) and Ames Research (#NAS2-97-001) to Lowell Observatory.
304.03 Probing Pluto’s Upper Atmosphere: a 2011 Occultation Graze in Visible Images and Infrared Spectra

Amanda A. S. Gulbis1, J. P. Emery2, M. J. Person3, A. S. Bosh4, C. A. Zuluaga5, J. M. Pasachoff4, B. A. Babcock5

1SALT/MIT, South Africa, 2University of Knoxville, 3MIT, 4Williams College and Caltech, 5Williams College.

On 2011 June 23, a 14.43 UCAC2 magnitude star was occulted by Pluto as observed from multiple sites. Observations made at NASA’s 3-m Infrared Telescope Facility (IRTF) on Mauna Kea, Hawaii, detected a full occultation of the star by Charon followed by an atmospheric graze by Pluto. Data were taken simultaneously with MORIS (the MIT Optical Rapid Imaging System; Gulbis et al. 2011, PASP, 123, 461) and SpeX (Rayner et al. 2003, PASP, 115, 362). MORIS recorded visible images of a 1 arcmin by 1 arcmin field of view, with an effective central wavelength of 0.74 microns, at a cadence of 0.3 seconds and negligible deadtime. Low-resolution spectral IR data of the occultation star and a comparison were taken with SpeX, using the 1.6 arcsec slit, over the range of 0.9-2.5 microns, at a cadence of 1.5 seconds including approximately 0.75 seconds deadtime. Pluto’s lower atmosphere has been evolving since the first definitive detection in 1988 (e.g., Elliot et al. 2007, AJ, 134, 1; Young et al. 2008, AJ, 136, 1757). Possibilities for explaining the lower atmospheric structure include a steep thermal gradient and/or extinction, the latter of which can be characterized as a dependence between occultation flux and wavelength. This graze reached a minimum normalized flux level of roughly 0.35, serving primarily as a probe of Pluto’s upper atmosphere. However, there appears to be a slight dependence of flux with wavelength in the minimum portion of the graze. We will present the IRTF lightcurves and an analysis of the wavelength-resolved data. Funding for this work was provided in part by the South African National Research Foundation and NASA grants NNX08AO50G & NNH11ZDA001N (Williams), NNX10AB27G (MIT), and NNX10AB23G (UT).

304.04 Mapping Pluto’s Temperature Distribution Through Twenty Years of Stellar Occultations

Amanda Zangari1, R. P. Binzel1, M. J. Person1

1MIT.


304.05 Hybrid Model Of Molecular Escape From Pluto’s Highly Extended Atmosphere

Justin Erwin1, R. Johnson1, D. Strobel2, X. Zhu3, O. J. Tucker4

1University of Virginia, 2The Johns Hopkins University, 3Applied Physics Lab, The Johns Hopkins University, 4University of Michigan.

We connect a fluid model with a molecular-kinetic model of escape to simulate the atmosphere of Pluto and to obtain an accurate description of its escaping atmosphere. The atmosphere extends out to several Pluto radii, with adiabatic cooling being the dominant process in the upper atmosphere. The escape rates found are consistent with previous fluid models, but the structure of the upper atmospheric is significantly affected by our description of the
escape process. Direct-Simulated Monte-Carlo (DSMC) is used to model the transition from the fluid to rarified flow. Jeans escape can also be used to approximate the upper boundary conditions for the fluid model, but does not yield the same description of the upper atmosphere as the DSMC. We include a detailed radiative heating model down to the surface, including both IR and UV sources, arriving at a description of the full atmosphere. With Pluto’s extended atmosphere, the effect of Charon on the escape process must be considered. After finding a consistent solution between heating, gravity and the escape process, we then estimate the influence of solar wind on the extended atmosphere.

304.06 Pluto’s Volatile Transport  
- Leslie Young

Pluto’s varying subsolar latitude and heliocentric distance leads to large variations in the surface volatile distribution and surface pressure. I present results of new volatile transport models (Young 2012a, b). The models include insolation, thermal emission, subsurface conduction, heating of a volatile slab, internal heat flux, latent heat of sublimation, and strict global mass balance. Numeric advances include initial conditions that allow for rapid convergence, efficient computation with matrix arithmetic, and stable Crank-Nicholson timesteps for both bare and volatile-covered areas. Runs of the model show six distinct seasons on Pluto. (1) As Pluto approaches perihelion, the volatiles on the old winter pole (the Rotational North Pole, RNP) becomes more directly illuminated, and the pressure and albedo rise rapidly. (2) When a new ice cap forms on the Rotational South Pole, RSP, volatiles are exchanged between poles. The pressure and albedo change more slowly. (3) When all volatiles have sublimed from the RNP, the albedo and pressure drop rapidly. (4-6) A similar pattern is repeated near aphelion with a reversal of the roles and the poles. I will compare results with earlier Pluto models of Hansen and Paige (1996), show the dependence on parameters such as substrate inertia, and make predictions for the New Horizons flyby of Pluto in 2015. This work was supported, in part, by funding from NASA Planetary Atmospheres Grant NNG06GF32G and the Spitzer project (JPL research support Agreement 1368573). Hansen, C. J. and D. A. Paige 1996. Seasonal Nitrogen Cycles on Pluto. Icarus 120, 247-265. Young, L. A. 2012a. Volatile transport on inhomogeneous surfaces: I - Analytic expressions, with application to Pluto’s day. Icarus, in press. Young, L. A. 2012b. Volatile transport on inhomogeneous surfaces: II. Numerical calculations, with application to Pluto’s season. In preparation.

304.07 Pluto’s P4 and P5: Latest Results for Pluto’s Tiniest Moons  

We report on the discovery and subsequent analyses of "P4" and "P5", Pluto’s fourth and fifth known moons (officially designated S/2011 (134340) 1 and S/2012 (134340) 1). P4 was discovered in Hubble Space Telescope images from June-July 2011. Numerous pre-discovery detections have now been identified in the Hubble archive, spanning 2005-2011. These detections provide a long time baseline for determining the body's orbital elements. Based on a preliminary analysis, P4 has an orbital period $P = 32.17 \pm 0.01$ days, placing it at a semimajor axis $a \approx 59,500$ km, between the orbits of Nix and Hydra. It appears to fit the general trend of orbital elements in the Pluto system, with Nix near the 1:4 mean motion resonance with Charon, P4 near the 1:5, and Hydra near the 1:6. The size of P4 depends on the assumed geometric albedo: diameter $d = 14$ km if its albedo is $0.35$, comparable to that of Charon, or $40$ km if it has a much darker albedo $d \approx 0.04$, which would be more typical of other Trans-Neptunian Objects. P5 was discovered in Hubble images from June-July 2012 and is roughly half as bright as P4. It orbits interior to Nix with $P = 20.2 \pm 0.1$ days or a $\sim 42,000$ km, raising the possibility of an association with Charon’s 1:3 resonance. This configuration of five moons in co-planar, near-circular, near-resonant orbits suggests that the bodies formed in place and/or have undergone significant orbital evolution. We will also report on the search for faint rings and additional moons.

304.08 Searching for Satellites in the Pluto System Interior to Charon’s Orbit
In 2012, we received HST time for an aggressive program to search for additional satellites and debris in the Pluto system. This presentation will cover the objective designed to perform the most sensitive survey to date of the region interior to Charon. There are clearly stable regions for objects (satellites down to dust) but there is limited understanding of how material can get there. However, if a satellite were found to exist in this region it would naturally follow that there could be dust throughout the area. This potential population of dust could pose a serious threat to the New Horizons mission, particularly because the currently planned spacecraft trajectory passes interior to Charon’s orbit. The range of stable orbits includes some with motions at or near the 1:2 mean-motion resonance interior to Charon. These orbits are no more or less probable than non-resonant orbits but lead to non-trivial timing constraints on the imaging cadence to ensure complete coverage of this type of orbit. The HST observations were designed to provide complete coverage of this type of orbit while also constraining the existence of any non-resonant objects. We will report on the details of this search and present results from the survey of the inner region of the Pluto System.

304.09 A Keck Search for Faint Satellites of Pluto in Support of New Horizons
- William J. Merline1, H. A. Weaver2, P. M. Tamblyn3, C. Neyman3, S. A. Stern1, B. Carry3, J. R. Spencer1, A. R. Conrad3, M. A. Showalter6, C. B. Olkin1, A. J. Steffl1, S. S. Sheppard7, M. W. Buie1, B. L. Enke1
1Southwest Research Inst., 2JHU/APL, 3W.M. Keck Observatory, 4ESA, Spain, 5Max Planck Institute for Astronomy, Germany, 6SETI, 7Carnegie Institution of Washington.

We report on our efforts to search for faint satellites of Pluto using Keck 2 adaptive optics (AO). Last year, using HST, Showalter et al. 2011 (IAUC 9221) discovered a new, faint satellite (“P4”) around Pluto, demonstrating that Pluto is even richer with orbiting material than was thought previously. That discovery led to speculations that these small satellites could be a source of debris (from random impacts) that could pose a hazard to the New Horizons (NH) spacecraft during its 2015 Pluto flyby. The ejecta would form a cloud around Pluto. The NH project began an aggressive program of HST- and ground-based studies to identify additional as-yet-unseen satellites or debris rings in the system. Only several days into their campaign, a 5th satellite “P5” was discovered with HST (Showalter et al. 2012, IAUC 9253). The output of these studies will be used to plan a contingency (“safe-haven”) trajectory through the system. The Keck observations support and complement the new HST observations. Real objects in the HST images may be hidden by bad pixels or diffraction spikes, and Keck may have advantages in some regions of parameter space, such as interior to Charon. r Observing in a near-IR band, the Keck imaging provides additional constraints on the objects, but this makes the observations particularly challenging because of the sky brightness. We have made an effort to optimize the Keck AO observations. Near-IR imaging requires tradeoffs between sky brightness and post-correction Strehl. Expectations and our early results favor H-band in typical conditions. Contrary to prior experience with V~14 targets, we find Laser-Guide-Star AO correction to be far more effective than using Pluto as the wavefront source (NGS). We have achieved imaging that could detect satellites smaller than Nix at good S/N, even in a relatively short (15 min) span.

305 Asteroids 5: Near-Earth Object Potpourri
Wednesday, 10:30 AM - 12:00 PM, Carson 1/2

305.01 The Near-Earth Encounter of Asteroid 308635 (2005 YU55): Thermal IR Observations
- Lucy F. Lim1, J. P. Emery2, N. A. Moskovitz3, M. W. Busch1, B. Yang5, M. Granvik6
1NASA / GSFC, 2U. Tennessee Knoxville, 3Carnegie DTM and MIT, 4UCLA, 5U. Hawaii IfA, 6U. Helsinki, Finland.

The near-Earth approach (0.00217 AU, or 0.845 lunar distances) of the C-type asteroid 308635 (2005 YU55) in November 2011 presented a rare opportunity for detailed observations of a low-albedo NEA in this size range. As part of a multi-telescope campaign to measure visible and infrared spectra and photometry, we obtained mid-
infrared (~8 to 22 micron) photometry and spectroscopy of 2005 YU55 using Michelle [1] on the Gemini North
established the rotation state of YU55. In addition, the radar imaging resulted in a shape model for the asteroid,
detection of numerous boulders on its surface, and a preliminary estimate of its equatorial diameter at 380 +/- 20
m. In a preliminary analysis, applying the radar and lightcurve-derived parameters to a rough-surface
thermophysical model fit to the Gemini/Michelle thermal emission photometry results in a thermal inertia range of
approximately 500 to 1500 J m^{-2} s^{-1/2} K^{-1}, with the low-thermal-inertia solution corresponding to the small end of
the radar size range and vice versa. Updates to these results will be presented and modeling of the thermal
correction to the measured near-infrared spectra from Palomar/Triplespec and IRTF/SpeX will also be discussed.
The authors gratefully acknowledge the assistance of observatory staff and the support of the NASA NEOO
program (LFL and JPE), the Carnegie fellowship (NAM), and NASA AES, NSF, and the NRAO Jansky Fellowship

305.02 Near Earth Asteroids with Measurable Yarkovsky Effect
  1JPL, 2University of Pisa, Italy, 3Charles University, Czech Republic, 4SpaceDyS, Italy, 5IAPS-INAF, Italy.

High precision orbit estimation and trajectory propagation for small solar system objects are more and more
important, e.g., for linking old observations and assessing the risk of an impact. At high precision levels
nongravitational perturbations cannot be neglected. The Yarkovsky effect is the most important nongravitational
perturbation as it produces a secular drift in semimajor axis, thus we searched for Near Earth Asteroids (NEAs) with
measurable Yarkovsky signal. We modeled the related recoil force as a transverse acceleration depending on the
heliocentric distance. To consistently detect the Yarkovsky effect we accounted for accelerations down to the
same order of magnitude, including perturber asteroids and planetary relativistic terms. Moreover, as star catalog
biases may lead to inaccurate results, we applied debiasing and weighting from Chesley et al., Icarus, 2010. We
found a few tens of objects with measurable Yarkovsky effect (significant signal to noise ratio). The inclusion of the
Yarkovsky perturbation allowed the recovery of observations otherwise considered as outliers. The best Yarkovsky
determination allows the recovery of one radar apparition for asteroid (101955) 1999RQ36 and results in an orbit
improvement by two orders of magnitude. Other remarkable cases are (1862) Apollo, with a robust Yarkovsky
detection allowing the recovery of three radar observations, and (2100) Ra-Shalom. The sign of the semimajor axis
drift can be related to the asteroid spin orientation and thus connected with the delivery mechanism from the
most NEA feeding resonances. All three examples above are retrograde rotators. The consequences of the
Yarkovsky effect on impact predictions in the next century are relevant, as in the well studied case of (101955). In
the current century most possible impacts are low probability events and therefore are typically weakly affected
by nongravitational perturbations, but there can be exceptions.

305.03 Source Regions for Near-Earth Objects
  Tsiganis
  1Univ. of Helsinki, Finland, 2OCA, France, 3SwRI, 4IfA, Univ. of Hawaii, 5Charles University, Czech Republic,
  6Aristotle University of Thessaloniki, Greece.

We integrate the orbits of about 80,000 known main-belt objects as well as Hungaria, Cybele and Hilda asteroids
(hereafter collectively called MBOs) for 100 Myr in order to locate source regions for near-Earth objects (NEOs).
The selected sample of MBOs with perihelion distance q > 1.3 AU and semimajor axis a < 4.2 AU is essentially
complete with an absolute-magnitude limit ranging from H_v < 15.9 in the inner belt (a < 2.5 AU) to H_v < 14.4 in the
outer belt (2.5 AU < a < 4.2 AU). We model the semimajor-axis drift caused by the Yarkovsky force and assign four
different sizes (diameters 0.1, 0.3, 1.0, and 3.0 km) and random spin obliquities (either +90° or -90°) for each test
particle. We find more than ten obvious source regions for NEOs and most of these coincide with low-order mean-
motion resonances with Jupiter. The locations of the source regions are independent of the semimajor-axis drift
rate and thus also the asteroid diameter. The locations of the source regions are unaffected when we add a simple
model for the YORP cycles coupled with secular evolution of the rotation pole due to the solar gravitational torque.
At the end states of the YORP evolution we assume collisional re-initialization of the rotation state and/or mass shedding. This brings a random element in the obliquity evolution making the semimajor axis random-walk over a long-enough timescale. We find that the model-dependent net semimajor-axis drift rate for 0.1-km-diameter objects is approximately equal to the instantaneous drift rate for 10-km-diameter objects. The Yarkovsky+YORP model is able to provide a nearly constant flux of NEOs for tens of Myr starting from the initial distribution of test particles. These results are utilized for constructing a new debiased NEO model that we plan on finishing in mid-2013.

305.04 New Findings on Primitive Asteroid Families in the Inner Asteroid Belt: An Important Source of Primitive NEOs

- Kevin J. Walsh¹, M. Delbo², W. F. Bottke³

  ¹Southwest Research Institute, ²Observatoire de la Cote d'Azur, France.

The inner main asteroid belt (2.15 AU < a < 2.5 AU) is the dominant source region of near-Earth objects (NEOs). Most asteroids from this region become NEOs after being delivered via the ν6 secular resonance at 2.15 AU. In particular, this pathway is the most likely delivery source for NEOs on low delta-velocity orbits such as the proposed space mission targets 1996 RQ36 and 1999 JU3. These missions are specifically targeting primitive asteroids, those asteroids of C- or B-type that are thought to be related to Carbonaceous Chondrite meteorites. The largest collections of primitive bodies in the inner main asteroid belt are found among the Nysa-Polina complex and the diffuse background of low-albedo bodies. Data from the NASA WISE mission have allowed a closer analysis of all low-albedo, primitive, asteroids in this region which is valuable for determining the location and size of asteroid families and the background population. We have found that the low-albedo component of the Nysa-Polina complex is centered very close to the 3:1 mean motion resonance with Jupiter, with (495) Eulalia as the likely parent. The previously assumed parent, (142) Polana, does not appear to be a member of the family. Also, the diffuse background of primitive bodies appears to be an asteroid family as well, potentially one of the oldest and most extended primitive asteroid family in this region of the asteroid belt.

305.05 High-inclination Atens ARE Rare

- Sarah Greenstreet¹, B. Gladman³

  ¹University of British Columbia, Canada.

Recent results reported by the NEOWISE team (Mainzer et al. 2012) show an inclination distribution for the Aten-class NEA population that is more strongly confined to the ecliptic than predicted by the Bottke et al. (2002), and thus S3M (Grav et al. 2011), orbital models. Are low-inclination Atens missing? Or is there a process which pumps low semimajor axis NEAs to large orbital inclinations? Our recent improvement of the NEA orbital model (Greenstreet et al. 2012, Icarus, 217, 355) was specifically designed to increase the accuracy and resolution in the a<1.0 AU NEO region. This model includes integrations which better resolve Venus and Earth close encounters for low-a NEAs by implementing a smaller integration time step than previously used. The smaller time step does not significantly alter the fraction of Atens (for example) in the NEA population, but the details of the orbital element distribution for Atens and Atiras (Q<0.983 AU NEAs) should better match reality. The larger integration time step used by Bottke et al. (2002) may have resulted in poorly-resolved high-speed planetary close encounters incorrectly pumping NEAs to orbits with higher e and higher i than they should have. At the time, we could not test this hypothesis. A comparison of the NEOWISE detections provides a first opportunity to measure and observationally verify the predicted a<1.0 AU NEO orbital distribution. Applying the NEOWISE biases to the Greenstreet et al. (2012) model predicts a smaller fraction of the NEOWISE Aten discoveries to be at large inclinations, and provides a better match to the true NEOWISE detections. No hypotheses related to NEA orbital distribution may thus be required as the Atens appear to be distributed as expected. This research was supported by the Canadian Space Agency and NSERC.

305.06 The Detectability of Earth’s Temporarily Captured Orbiters

- Bryce T. Bolin¹, R. Jedicke¹, M. Granvik¹, J. Vaubaillon¹, R. Wainscoat¹, P. Brown¹, P. Jenniskens⁵, E. Howell¹, M. Nolan⁶, M. Chyba⁷, G. Picot⁷, G. Patterson⁷

  ¹Institute for Astronomy, University of Hawaii, ²Department of Physics, University of Helsinki, Finland,
Natural Earth Satellites (NES) are Temporarily Captured Orbiters (TCO) from the Near Earth Object (NEO) population. Only one, 2006 RH120 has been identified. Granvik et al. (2012) showed that at least one object of 1-meter diameter is in orbit around Earth at any time. The average lifetime of the TCOs is 286+/-18 days. We present the detectability of TCOs in the size range of 0.1 to 1 meters diameter with optical, infrared, radar surveys. Future surveys like the Asteroid Terrestrial-impact Last Alert System that can see objects to V~20 will see TCOs every ~120 days and the Large Synoptic Survey Telescope (V<24.7) will see ~1 TCO at any given time. TCOs can be detected in targeted optical surveys. Hyper Suprime-Cam on the Subaru telescope can detect ~0.4 TCOs when surveying about 400 sq. deg. to V~25. Targeted radar surveys at Arecibo are unlikely to detect TCOs. The spin rate distribution in the TCO size range makes them essentially undetectable by radar. One percent of all TCOs impact the Earth at near-escape speed. Meteor surveys such as Cameras for All-sky Meteor Surveillance (CAMS) have the capability of detecting them as meteors to V~5.4. We predict that CAMS should detect 0.22+/-0.02 TCO meteors / day. CAMS detects ~10x fewer TCO meteors than we predict. The discrepancy may be due to the meteor detection efficiency for the faint and slow TCOs.

305.07 The Pan-STARRS1 Search for Near Earth Objects: Recent Progress and Future Plans
- Richard J. Wainscoat, L. Denneau, P. Veres, R. Jedicke, B. Bolin
  Univ. of Hawaii.

The Pan-STARRS1 telescope (PS1) is a 1.8-meter telescope located on Haleakala in Maui, Hawaii. PS1 has a large camera with a 7 square degree field of view. PS1 is conducting a diverse survey that includes a search for Near Earth Objects. The NEO survey is improving in efficiency, and the survey strategy has been altered to optimize discovery of NEOs. Recent developments include production of a static sky in the w-band that helps us to detect fainter NEOs, and fitting of asteroid trails to improve photometry and to improve detection efficiency for faster moving NEOs. Using the static sky images, existing data can be reprocessed and archival detections of sources approximately 0.4 mag fainter is possible. Future plans will be described. These include a larger fraction of observing time dedicated to the NEO search, and a second Pan-STARRS telescope.

305.08 The Value Of Enhanced Neo Surveys
- Alan W. Harris
  MoreData!

NEO surveys have now achieved, more or less, the “Spaceguard Goal” of cataloging 90% of NEAs larger than 1 km in diameter, and thereby have reduced the short-term hazard from cosmic impacts by about an order of magnitude, from an actuarial estimate of ~1,000 deaths per year (actually about a billion every million years, with very little in between), to about 100 deaths per year, with a shift toward smaller but more frequent events accounting for the remaining risk. It is fair to ask, then, what is the value of a next-generation accelerated survey to “retire” much of the remaining risk. The curve of completion of survey versus size of NEA is remarkably similar for any survey, ground or space based, visible light or thermal IR, so it is possible to integrate risk over all sizes, with a time variable curve of completion to evaluate the actuarial value of speeding up survey completion. I will present my latest estimate of NEA population and completion of surveys. From those I will estimate the “value” of accelerated surveys such as Pan-STARRS, LSST, or space-based surveys, versus continuing with current surveys. My tentative conclusion is that we may have already reached the point in terms of cost-benefit where accelerated surveys are not cost-effective in terms of reducing impact risk. If not yet, we soon will. On the other hand, the surveys, which find and catalog main-belt and other classes of small bodies as well as NEOs, have provided a gold mine of good science. The scientific value of continued or accelerated surveys needs to be emphasized as the impact risk is increasingly “retired.”

305.09 Impact Hazard Assessment for 2011 AG5
2011 AG5 is a Potentially Hazardous Asteroid roughly 140 m in diameter. The current orbit determination, based on 213 optical measurements from 2010-Nov-08.6 to 2011-Sep-21.4, allows for the possibility of an Earth impact on 2040-Feb-05.2 with probability 0.2%. The 2040 potential impact is a 17:10 resonant return from a 2023 Earth encounter, where if the asteroid passes through a 365 km keyhole, it will go on to impact in 2040. We discuss the critical points on the decision tree for averting this potential impact. The decision to proceed with a deflection mission should not be made prematurely, when there is still a chance for eliminating the impact hazard through observations rather than intervention, and yet the decision must not be delayed past the point where it is no longer feasible to achieve a deflection. Thus the decision tree is informed by the evolution of the asteroid’s orbital uncertainty and by the available mission scenarios. We approach the orbital prediction problem by assessing the expected future evolution of the orbital uncertainty at the 2040 encounter based on various observational scenarios. We find that observations made at the next favorable apparition in 2013 are 95% likely to eliminate the possibility of a 2040 impact altogether. With the addition of 2015-16 observations, this likelihood increases to about 99%. Conversely, if the asteroid turns out to really be on an Earth impacting trajectory, the 2013 observations could raise the chance of impact to 10-15%, and observations in 2015-2016 could raise the chance of impact to ~70%. On the deflection side, we describe a range of viable kinetic deflection mission scenarios. Mission timelines allow detailed planning to be delayed until after the 2013 observations and spacecraft fabrication to be delayed until after the 2015-16 observations. The full report is available at http://neo.jpl.nasa.gov/news/news175.html.

307 Exploring the Planet Mercury: 1.5 Years of MESSENGER Orbital Observations
Wednesday, 2:05 PM - 2:40 PM, Reno Ballroom

307.00C1 Chair
- Faith Vilas
  1Planetary Science Institute.

307.00C2 Chair
- Jeffrey M. Moore
  1NASA Ames Research Center.

307.01 Exploring the Planet Mercury: 1.5 Years of MESSENGER Orbital Observations
- Sean C. Solomon
  1Lamont-Doherty Earth Observatory, 2Carnegie Institution of Washington, 3Johns Hopkins University Applied Physics Laboratory.

Launched in 2004, MESSENGER flew by Mercury three times in 2008-2009 en route to becoming the first spacecraft to orbit the solar system’s innermost planet in March 2011. MESSENGER’s chemical remote sensing measurements of Mercury’s surface indicate that the planet’s bulk silicate fraction, low in Fe and high in Mg, differs from those of the other inner planets. Moreover, surface materials are richer in the moderately volatile constituents S and K than predicted by most current models for inner planet formation. Global image mosaics and targeted high-resolution images reveal that Mercury experienced globally extensive volcanism, with large expanses of plains emplaced as flood lavas and widespread examples of pyroclastic deposits likely emplaced during explosive eruptions of volatile-bearing magmas. Bright deposits within impact craters host fresh-appearing, rimless depressions or hollows, often with high-reflectance interiors and halos and likely formed through processes involving the geologically recent loss of volatiles. The large-scale deformational history of Mercury, although dominated by near-global contractional deformation as first seen by Mariner 10, is more complex than first appreciated, with numerous examples of extensional deformation that accompanied impact crater and basin
modification. Mercury’s magnetic field is dominantly dipolar, but the field is axially symmetric and equatorially asymmetric, a geometry that poses challenges to dynamo models for field generation. The interaction between the solar wind and Mercury’s magnetosphere, among the most dynamic in the solar system, serves both to replenish the exosphere and space weather the planet’s surface. Plasma ions of planetary origin are seen throughout the sampled volume of Mercury’s magnetosphere, with maxima in heavy-ion fluxes in the planet’s magnetic-cusp regions. Bursts of energetic electrons, seen at most local times, point to an efficient acceleration mechanism operating within Mercury’s magnetosphere on a regular basis that produces electrons with energies up to hundreds of keV on timescales of seconds.

308 Mars Science Laboratory: Mission, Landing Site, and Initial Results
Wednesday, 2:40 PM - 3:15 PM, Reno Ballroom

308.01 Mars Science Laboratory: Mission, Landing Site, and Initial Results
- John Grotzinger¹, D. Blake², J. Crisp³, K. Edgett⁴, R. Gellert⁵, J. Gomez-Elvira⁶, D. Hassler⁷, P. Mahaffy⁸, M. Malin⁹, M. Meyer⁹, I. Mitrofanov¹⁰, A. Vasavada³, R. Wiens¹¹
  ¹Caltech, ²NASA AMES, ³Jet Propulsion Laboratory, ⁴Malin Space Science Systems, ⁵University of Guelph, Canada, ⁶Centro de Astrobiología, Spain, ⁷Southwest Research Institute, ⁸Goddard Space Flight Center, ⁹NASA Headquarters, ¹⁰Space research Institute, Russian Federation, ¹¹Los Alamos National Laboratory.

Scheduled to land on August 5, 2012, the Mars Science Laboratory rover, Curiosity, will conduct an investigation of modern and ancient environments. Recent mission results will be discussed. Curiosity has a lifetime of at least one Mars year (~23 months), and drive capability of at least 20 km. The MSL science payload was specifically assembled to assess habitability and includes a gas chromatograph-mass spectrometer and gas analyzer that will search for organic carbon in rocks, regolith fines, and the atmosphere; an x-ray diffractometer that will determine mineralogical diversity; focusable cameras that can image landscapes and rock/regolith textures in natural color; an alpha-particle x-ray spectrometer for in situ determination of rock and soil chemistry; a laser-induced breakdown spectrometer to remotely sense the chemical composition of rocks and minerals; an active neutron spectrometer designed to search for water in rocks/regolith; a weather station to measure modern-day environmental variables; and a sensor designed for continuous monitoring of background solar and cosmic radiation. The 155-km diameter Gale Crater was chosen as Curiosity’s field site based on several attributes: an interior mound of ancient flat-lying strata extending almost 5 km above the elevation of the landing site; the lower few hundred meters of the mound show a progression with relative age from clay-bearing to sulfate-bearing strata, separated by an unconformity from overlying likely anhydrous strata; the landing ellipse is characterized by a mixture of alluvial fan and high thermal inertia/high albedo stratified deposits; and a number of stratigraphically/geomorphically distinct fluvial features. Gale’s regional context and strong evidence for a progression through multiple potentially habitable environments, represented by a stratigraphic record of extraordinary extent, insure preservation of a rich record of the environmental history of early Mars.

309 InSight: NASA’s Discovery Mission to Explore Terrestrial Planet Interiors
Wednesday, 3:15 PM - 3:30 PM, Reno Ballroom

309.01 Invited Speaker
- W. Bruce Banerdt¹
  ¹Jet Propulsion Laboratory, California Institute of Technology.

The InSight mission, recently selected by NASA’s Discovery Program, will perform the first comprehensive surface-based geophysical investigation of Mars using a seismometer, a heat flow probe, and precise measurements of rotational variations. It will illuminate the fundamental processes of terrestrial planet formation and evolution, providing unique and critical information about the initial accretion of the planet, the formation and differentiation of the core and crust, and the subsequent evolution of the interior. The specific scientific goals of InSight are to understand the formation and evolution of terrestrial planets through investigation of the interior structure and
processes of Mars and to determine its present level of tectonic activity and impact flux. A straightforward set of scientific objectives address these goals: 1) Determine the size, composition and physical state of the core; 2) Determine the thickness and structure of the crust; 3) Determine the composition and structure of the mantle; 4) Determine the thermal state of the interior; 5) Measure the rate and distribution of internal seismic activity; and 6) Measure the rate of impacts on the surface.

310 Centaurs and Trans-Neptunian Objects
Wednesday, 3:30 PM - 6:00 PM, Exhibit Hall

310.01 Modeling Central-Flash Stellar Occultations using Ray Tracing
- Catherine B. Olkin1, E. Young1, L. Young2
1, E. Young1, L. Young1
1, E. Young1
2, L. Young1
2, SWRI.

A central flash was observed in July 2007 as Pluto passed in front of a V=13.2 magnitude star (Olkin et al. 2012). Using a forward modeling algorithm of ray tracing code (Young 2012), we explore model atmospheres that could produce the distinct multi-peaked central flash feature observed in 2007. One advantage of the forward modeling approach is that it can accommodate arbitrary atmospheric density and opacity distributions. We show the sensitivity of the central flash to small changes in Pluto's atmospheric figure. We will examine the effects of non-spherical atmospheres on the central-flash region. We will discuss possible sources of non-sphericity such as zonal winds, tidal bulges and subsolar hot spots that would be consistent with the observed central flash.

310.02 A Peculiar Stable Region Around Pluto
- Silvia M. Giuliaatti-Winter1, O. Winter1, E. Vieira Neto1, R. Sfair1
1, O. Winter1, E. Vieira Neto1, R. Sfair1
1, UNESP, Brazil.

In a previous paper Giuliaatti Winter et al. (2010) found several stable regions for a sample of particles located between the orbits of Pluto and Charon. Some of these particles are in orbits around Pluto and some of them are in orbits around Charon. One peculiar stable region (hereafter region 1), located at a=[0.5d, 0.65d], where d is the Pluto-Charon distance, presents large values of the particle's eccentricity e=[0.2, 0.9]. This region is associated to a family of periodic orbits derived from the circular restricted three body problem (Pluto-Charon-particle). The evolution of the periodic and quasi periodic orbits associated to each value of the Jacobi constant is presented in this work. We also analyse the evolution of the region 1 for a set of initial conditions, the nominal values of the argument of pericentre (ω) and the inclination (I), of the particles. We concluded that region 1 is present in all values of the inclination of the particles, I= [0, 90°], and for two intervals of ω, ω = [-10°, 10°] and ω = [170°, 190°].

310.03 Analysis Of The Origin And Evolution Of The Small Satellites Of Pluto
- Priscilla Maria Pires Dos Santos1, A. Morbidelli2, D. Nesvorny3, S. M. Giuliaatti Winter1
1, A. Morbidelli2, D. Nesvorny3, S. M. Giuliaatti Winter1
1, A. Morbidelli2, D. Nesvorny3, S. M. Giuliaatti Winter1
1, Unesp, Brazil, 2Université de Nice - Sophia Antipolis, Observatoire de la Côte d'Azur, France, 3Department of Space Studies, Southwest Research Institute.

At this time the origin of the small satellites of Pluto remains elusive. In this work we envisioned an alternative scenario. Pluto-Charon was already formed and embedded into a massive planetesimal disk, then planetesimals got captured by Pluto-Charon binary from the heliocentric disk. For a dynamically "cold" disk, temporary capture in the Pluto-Charon system can occur with non-negligible probability. We conjecture that if the captured planetesimals got disrupted during their Pluto-bound phase by a collision with other planetesimals of the disk, then these events could have generated a debris disk. This disk damped under internal collisional evolution, until turning itself into an accretional disk that could form small satellites on circular orbits, co-planar with Charon. Objects large enough to carry a sufficient amount of mass to generate the small satellites of Pluto have collisional lifetimes orders of magnitude longer than the typical capture time (~100 years). Thus, this scenario, although add new arguments to an unsolved problem, cannot also explain the origin of the small satellites of Pluto, which remains elusive. Additionality, we will also present some preliminary results on the analysis of the evolution of the Pluto system in the framework of the “new” Nice model (see, e.g. Levison et al, 2008). Their results explain very
well the distribution of Plutinos, bodies trapped in 2:3 mean motion resonance with Neptune. By assuming that
the bodies observed today in the Pluto system were put together before the Late Heavy Bombardment period
(Gomes et al, 2005), through encounter histories of Pluto and its members during the dynamical evolution of the
 giants planets, we analyse if this multiple system is destroyed by such interactions. In fact, understanding the
evolution of the plutinos provides hints to the understanding of the history of the outer Solar system.

310.04 Photometry Of Pluto At Low Galactic Latitudes
- Erin George1, M. Buie2, F. Bagenal1
  1University of Colorado at Boulder, 2Southwest Research Institute.

Our research is part of an ongoing project to continue the long-term photometric monitoring of Pluto in hopes to
constrain volatile migration on the surface. As Pluto passes near the center of the galaxy, the fields are too
crowded with stars for normal aperture photometry. We approached this problem by using Optimal Image
Subtraction (OIS). We took images, both containing and not containing Pluto, using the 0.8m robotic telescope at
Lowell Observatory, the 1m robotic telescope at New Mexico State University, and the Faulkes 2m robotic
telecope at Siding Spring, part of Las Cumbres Observatory. We are presently gathering data, but our main focus
was the data from 2010. We began by taking images of the star fields at the galactic center without Pluto to build
catalogs of standard stars. These catalogs were applied to the Pluto images in order to make interpolated images
and to cross check our results. We extracted the photometry of Pluto from differenced images where the
background stars were subtracted, and we then applied the transformation equation to solve for Pluto’s standard
magnitude. We will present the details of our data processing methodology, as well as the 2010 Pluto B, V, and B-V
light curves in comparison to those from previous years. This work was supported by NASA Planetary Astronomy
Grant NNX09AB43G.

310.05 Exploration Of The Trans-Neptunian Population With Miosotys And Stellar Occultations
- Alain Doressoundiram1, F. Roques1, I. Shih1, C. Liu1, F. Dauny1, A. Fernandez1, Miosotys team
  1Observatoire de Paris, France.

Miosotys is a muti-fiber instrument coupled with a fast CCD camera (20Hz). It is mounted on the 193-cm of
Observatoire de Haute-Provence, France. The aim is the detection of serendipitous trans-Neptunian occultations,
revealing 0.1 to 1km-sized objects during unpredicted events. This will in turn allow to characterise the number
density distribution and the radial extension of the Kuiper Belt. After 3 years of operations and fine-tuning of the
instrument, we have obtained 3782 star-hours. We analysed this dataset using a statistical method to search for
significant dips in the lightcurve of target-stars. We present and discuss the results obtained so far.
Wednesday, October 17, 2012

310.06 Studying the Outer Solar System - Technology Development for the Whipple Mission Concept
- Charles Alcock1, R. Kraft1, A. Kenter2, S. Murray2, T. Gauron1, M. Loose1, M. Werner3
  1Harvard-Smithsonian, CfA, 2Johns Hopkins University, 3Markury Scientific, 4JPL.

The Whipple mission, "Reaching into the Outer Solar System", was proposed to NASA’s 2010 Discovery program
and was awarded funding for technology development. Whipple will conduct the first direct, systematic study of
the outer Solar system, the Kuiper belt, the Sedna region, and the Oort cloud, using a blind stellar occultation
survey. The instrument will monitor photometrically 10,000 stars at a cadence of 40 Hz (or 20,000 at 20 Hz, ...) to
search for stellar occultations by outer solar system objects to characterize the size and spatial distribution of
these objects. The occultations typically last less than a second, so the photometer must be able to continuously
monitor the light curves of a large number of stars at video rates. The focal plane will be composed of 32 Teledyne
H1RG sensors, each with a dedicated SIDECAR ASIC and an FPGA to process the light curve data and identify
candidate occultation events. The H1RG sensor will be operated in a windowing mode with between 700 and 3000
windows per sensor at rates up to 40 Hz. We are currently developing an end-to-end system at SAO to evaluate
the focal plane concept. This system includes a stellar occultation simulator that stimulates the sensor with
simulated light curves, a Teledyne sensor with custom readout software to operate the sensor and SIDECAR ASIC in
this windowed mode, and an FPGA that will process the light curves and identify candidate events. In this
presentation we will outline the scientific capabilities of the Whipple mission and discuss the current status of our laboratory efforts.

310.07 Searching for Kuiper Belt Object Flyby Targets for the New Horizons Spacecraft.


¹National Research Council, Canada, ²Southwest Research Institute, ³Carnegie Institute of Washington, ⁴Massachusetts Institute of Technology, ⁵University of Victoria, Canada, ⁶Northern Arizona University, ⁷Southern Illinois University, ⁸Harvard-Smithsonian Center for Astrophysics, ⁹Carnegie Observatories, Chile, ¹⁰University of Hawaii, ¹¹Lowell Observatory.

The New Horizons spacecraft will fly past Pluto in July 2015 and then continue deeper into the Kuiper Belt, providing an opportunity to encounter one or more small (~50 km) KBOs. This first flyby of a typical KBO would revolutionize our understanding of these bodies, providing information that can be extrapolated to hundreds of thousands of similar objects in the Kuiper Belt. Statistically, we expect several KBOs with ground based V magnitude less than 26.0 to be accessible with the delta-V available onboard New Horizons. At this point, however, no known KBOs are reachable by the spacecraft. We have therefore begun a dedicated search for suitable targets, using the Subaru, Magellan, and CFHT telescopes. The search is complicated by the fact that targetable objects are currently in the Milky Way, so search depth is limited by confusion with background stars unless seeing is exceptional. As of mid-2012, we have discovered 24 KBOs near the spacecraft trajectory, none of which are accessible to the spacecraft. Several of the targets could be reached with less than twice the available delta-V, and much of the accessible volume has not yet been searched to sufficient depth. Several objects already discovered will be observable at long range from New Horizons, providing opportunities for (for example) searches for binarity with much higher spatial resolution than is possible from Earth. The search has already yielded the second known trailing Neptune Trojan (Parker et al., this conference).

310.08 Mutual Events and Photometry of Transneptunian Binary (79360) Sila-Nunam

- Anne J. Verbiscer¹, W. M. Grundy², D. L. Rabinowitz³, S. D. Benecchi⁴, M. J. Brucker⁵, S. W. Tourtellotte⁶, L. H. Wasserman⁷

¹University of Virginia, ²Lowell Observatory, ³Yale University, ⁴Carnegie Institution of Washington, Dept. of Terrestrial Magnetism, ⁵University of Nebraska-Lincoln.

The transneptunian binary (79360) Sila-Nunam (provisionally designated 1997 CS29) is currently undergoing mutual events in which the two nearly-equal brightness components alternate in eclipsing and occulting each other as seen from Earth [1]. The low eccentricity of the orbit, determined from Hubble Space Telescope observations of the resolved components [1], and the coincidence of the system’s photometric lightcurve and orbital period are consistent with a system that is tidally locked and synchronized like that of Pluto-Charon. Mutual events provide a rich opportunity to learn about sizes, colors, shapes, and albedo patterns on the system components; our current knowledge of albedo patterns on Pluto-Charon derives from observations of their mutual events between 1985 and 1990. The duration of the mutual event season depends on the size and separation of the bodies. Using sizes determined from thermal observations, the mutual event season for Sila-Nunam should last about a decade; however, the deepest, most central events should be observable in the 2013 apparition [1], with progressively shallower events observable thereafter for the next 4-5 years. We present observations of two mutual events in the 2012 apparition, additional photometric observations of Sila-Nunam’s rotational and solar phase curves in broadband V, R, and I filters and the Sloan r’ filter, and review opportunities to observe upcoming mutual events. A. Verbiscer acknowledges support from NASA's Planetary Astronomy Program. W. Grundy acknowledges support from NSF Planetary Astronomy and the Hubble Space Telescope. [1] Grundy et al. 2012 Icarus 220, 74-83.

310.09 Infrared Spectra and Optical Constants of Acetylene and Ethane Ices

- Marla H. Moore¹, R. E. Ferrante², R. L. Hudson³, W. J. Moore⁴

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Hydrocarbon-containing ices have characteristic absorption bands in both the mid- and near-infrared spectral regions, yet accurate optical constants are not available for most of these molecules. Ices with a hydrocarbon component have been identified on several TNOs (1) and the presence of volatiles, such as hydrocarbons, is inferred for intermediate or large TNOs based on sublimation models (2, 3). In our laboratory we recently have undertaken low-temperature spectroscopic studies of C2 hydrocarbons. We report IR spectra for acetylene (C2H2) and ethane (C2H6) ice in both the amorphous and crystalline phases at multiple temperatures. We include measurements of the refractive index at 670 nm for both the amorphous and crystalline phases of each ice. The optical constants, the real (n) and imaginary (k) components of the complex index of refraction, were determined from ~ 7000 - 400 cm-1 (1.4 - 25 microns) at multiple temperatures using a Kramers-Kronig analysis. A goal of the present work is to provide a data base of optical constants of C2 molecules similar to that of Hudgins et al. (4) and Moore et al. (5). These values, as well as our calculated individual band strengths, will have great practical importance for the ongoing analysis of TNO spectra. (1) Brown, M.E. et al., Astron J., 133, 284, 2007. (2) Delsanti, A. et al., A&A, 52, A40, 2010. (3) Schaller, E. L. & Brown, M. E., ApJ, 659, L61, 2007. (4) Hudgins, D. M. et al., ApJS, 86, 713, 1993. (5) Moore, M. H. et al., ApJS, 191, 96, 2010. This work is supported by NASA’s Planetary Atmospheres, Outer Planets, and Cassini Data Analysis programs, and The Goddard Center for Astrobiology.

310.10 Laboratory Measurements Of Pure And Diluted Methanol In Water Ice In The Nir And Mir Wavelength Ranges.

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Observations performed in the mid infrared (MIR) show evidence of large amount of ices in the Galaxy. Water ice is the most abundant but other chemical compounds, such as carbon monoxide and methanol, can be present and be enriched in molecular clouds or protostellar disks (Garrod & Pauly 2011). Methanol forms mainly on ice-covered dust grain surfaces primarily through hydrogenation of CO or from an electron-irradiated H2O-CH4 icy mixture (see Moore & Hudson 1998 or Dartois et al. 1999). These compounds appear to be pristine in the minor bodies of the solar system (Merlin et al. 2012) and were found in comets (Bockelée-Morvan et al. 2004) and on the surface of Trans-Neptunian Objects and Centaurs (Barucci et al. 2012 for instance for methanol). Laboratory measurements are needed to constrain information on the physical and chemical properties of these objects and give constraint on the formation and evolution of the solar system. In the aim to give constraints on the physical properties of H2O and CH3OH from their spectral behavior, we performed laboratory measurements in the observable wavelength ranges accessible from the space and ground based observatories (in the MIR and in the near IR, respectively). We present new laboratory measurements depending on the ratio of each component and the ambient temperature (from 18 to 145K) for the amorphous and the crystalline phases. We focus our analyses on the effects of the dilution level of CH3OH in H2O and the phase changes, especially on the absorption bands located at 2,3 and 3,45 microns (associated to CH asymmetric stretch) and the possible formation of the mono hydrate CH3OH:H2O based on the 3,12 micron band (associated to the OH stretch).

310.11 Near Infrared Reflectances and Compositions of Kuiper Belt Objects

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The compositions of outer Solar System objects are important clues to the history of our Solar System. We are carrying out a large Spitzer program to constrain surface compositions of Kuiper Belt Objects (KBOs) by measuring their reflectances at 3.6 and 4.5 microns. Complete interpretation of the Spitzer data requires K-band (2.2 microns) photometry as well. Here we present new broadband infrared photometry for 14 KBOs obtained with the Gemini North Telescope. This combined Gemini and Spitzer photometry will allow us to find the surface compositions (organics, H2O, CO2, CH4, and/or hydrated silicates) for these 14 objects. Some additional compositional constraints are available from the broadband near infrared (YJHK) spectra. This compositional information will help us understand the original environment in the outer Solar System as well as identifying objects that are compositionally anomalous.
Identification Of Volatiles On Outer Solar System Surfaces From Very Low Signal Spectra

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The icy surfaces of Kuiper Belt Objects (KBOs) represent the best probe of the cosmochemical origin and evolution of the outer Solar System. Spectroscopic investigations of faint KBOs are expensive. Here we present a novel, fast technique to identify the dominant volatile ices on KBO surfaces even with very low signal-to-noise input spectra (intrinsic SNR &lt;10). We obtained spectra of a dozen outer Solar System objects using NASA's Infrared Telescope Facility and SpeX, with the addition of using MORIS in guide camera mode. In post-processing we substantially bin the spectra into six medium band pseudo-filters that are defined to discriminate among methane rich, water ice rich, and neutral surfaces through color-color analysis. Here we present our first results from this survey. We confirm previously published results for several objects and identify a number of neutral objects, and at least one object with a hint of a water signature. While detailed spectroscopic studies are not possible with our data, we broadly characterize the surface volatile ice components of all observed objects. The speed of our technique will allow us to make a large-scale compositional map of the outer Solar System with a reasonable amount of telescope time (perhaps 10 nights per year). This technique will be particularly important when PS1-discovered KBOs are released, as the effective limiting magnitudes are well matched, allowing quick identification of interesting objects and creation of a large database suitable for taxonomy and large-scale compositional studies.

TNO Diameters And Albedos: The Final MIPS Dataset

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The bulk of our knowledge about sizes and albedos of TNOs and Centaurs is derived from observations of their thermal-emission continuum combined with thermal modeling. Spitzer and Herschel provided and are providing an unsurpassed wealth of photometric data for this purpose. We here report the results of a coherent re-analysis of all photometric Spitzer-MIPS observations of TNOs and Centaurs, 402 observations (AORs) of a total of 106 objects. Most objects are observed at 24 and 70 micron. This dataset is a super-set of that described in previous MIPS TNO publications (e.g., Stansberry et al., 2008, 2012; Brucker et al., 2009). We use the latest knowledge about MIPS data reduction and flux calibration. Where possible, the sky background is subtracted from multiple observations of the same target, leading to substantial improvements in SNR. Particular attention is paid to a coherent treatment of faint and non-detections, largely ignored in previous work, using the latest ephemerides. We use the NEATM (Harris, 1998) to determine sizes and albedos from the MIPS data. Correlations between albedo, size, and other physical or dynamical properties are discussed. Where possible, we also determine the beaming factor eta, a measure of the apparent color temperature and a proxy for thermal inertia. MIPS was a unique tool to measure TNO temperatures due to its spectral coverage (24 and 70 micron) straddling the thermal emission peak. Current and upcoming facilities lack similar "short-wavelength" capabilities. MIPS data therefore form a lasting legacy for the analysis of TNO data from far-IR facilities including Herschel and ALMA.

Physical And Thermal Properties Of The Centaurs 2060 Chiron And 10199 Chariklo: Results From Far-infrared Observations With The Herschel Space Observatory

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Centaurs are trans-Neptunian Objects (TNOs) on unstable orbits between Jupiter and Neptune. Centaurs may show activity and some of them are classified also as comets. In order to better investigate the albedo, size
distribution and thermal properties of TNOs and Centaurs an Open Time Key Program entitled "TNOs are Cool: A survey of the Transneptunian Region" was submitted to the Herschel Space telescope (Muller et al. 2009, EM&P, 105, 209). This proposal was awarded 372.7 hours to perform radiometric measurements of a large sample of 140 TNOs/Centaurs. Eighteen Centaurs were observed within this program with the PACS instrument in 3 bands (70, 100, and 160 micron), and two of them (Chiron and Chariklo), were observed also at longer wavelengths (250, 350, and 500 micron) with the SPIRE instrument. In this work we present the results of the combined SPIRE and PACS instruments observations of 2060 Chiron and 10199 Chariklo. The Herschel data, coupled with those obtained by Spitzer-MIPS at 24 and 70 micron, have been modeled with both NEATM (Harris 1998, Icarus 131) and thermophysical models in order to derive their albedo, diameter and thermal properties, including thermal inertia and emissivity. Particular care was taken in estimating the absolute magnitude from new and literature data of the two Centaurs during the Herschel observations, as both bodies show brightness variation with the heliocentric distance caused by their cometary activity. Chiron and Chariklo have very similar sizes, and both show a decrease of their emissivity with wavelength, decrease which is particularly strong on Chiron. No coma was detected in the far-infrared images for these two Centaurs. We will present the derived physical and thermal properties for both targets and discuss the possible cause for the emissivity drop at submm-wavelengths.

310.15 Search For Coma In Centaurs (2060) Chiron, (5145) Pholus And (10199) Chariklo
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Polarimetric measurements of Centaurs (5145) Pholus, (10199) Chariklo, and (2060) Chiron were obtained in 2007 and 2008 with the FORS instrument of the 8m ESO Very Large Telescope. Each observing series consisted of one or two acquisition images, and from 8 to 16 images obtained with polarimetric optics in, setting the retarder plate at different position angles. Polarimetric curves (i.e., the observed polarization versus phase-angle) were presented by Belskaya et al. (2010, Icarus, 210, 472). In this work we analyze deep imaging of these Centaurs. By stacking all polarimetric images of each individual observing series, we have obtained ultra-high signal-to-noise ratio intensity maps. We have used these maps to search for and characterize possible coma activity, using a method devised by Tozzi et al. (2007, A&A, 476, 979) for the study of active comets, and later applied also by Boehnhardt et al. (2008, A&A, 489, 1337) and by Bagnulo et al. (2010, A&A, 514, A99) to the polarimetric images of comet nuclei. To characterize the instrumental scattered light, that can be interpreted as a faint coma, we have also analyzed background stars. Unfortunately, the number of such reference objects is strongly limited by the fact that half of the observed field of view is vignetted by the Wollaston mask, and that, due to the telescope differential tracking, most of the background stars are not visible throughout each observing series. In spite of this shortcoming, for (2060) Chiron we were able to confirm the presence of a coma, while in (5145) Pholus and (10199) Chariklo the coma activity is not clear.

310.16 Polarimetry of Transneptunian Objects Interpreted Using a Radiative-Transfer Coherent-Backscattering Model
- Karri Muinonen\textsuperscript{1}, G. Videen\textsuperscript{2}, S. Bagnulo\textsuperscript{3}, M. A. Barucci\textsuperscript{4}, I. N. Belskaya\textsuperscript{5}, H. Boehnhardt\textsuperscript{6}, S. Fornasier\textsuperscript{4}, G. P. Tozzi\textsuperscript{7}, A. Stinson\textsuperscript{3}, O. Wilkman\textsuperscript{8}
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We interpret the polarimetric observations of transneptunian objects (TNOs) using a radiative-transfer coherent-backscattering model that utilizes a so-called phenomenological fundamental single scatterer (Muinonen and Videen, JQSRT, in press, 2012). The new modeling allows us to constrain the single-scattering albedo, phase function, and polarization characteristics as well as the mean free path length between successive fundamental scatterings. We concentrate on the explanation of the two main types of polarimetric behaviors observed for
TNOs, that is, the shallow polarization signatures observed for large TNOs and the pronounced signatures observed for small TNOs (Bagnulo et al., Astron. Astrophys. 491, L33, 2008). The new modeling allows for a systematic analysis of polarimetric observations of atmosphereless Solar System objects at large. Research supported, in part, by the Academy of Finland (contract 127461) and by the NASA Outer Planets Research Program (contract NNX10AP93G).

310.17 Plutinos and Trojans as Probes of Planet Building
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Previous work has shown steep power-law distributions in the TNO region for diameters > 100 km. Recent results claim a dramatic roll-over in the size distribution of Neptune Trojans and other KBO populations, with a strong deficit of intermediate-size planetesimals with D<100 km. One interpretation is that planetesimals were born big, skipping the intermediate sizes. Regardless of interpretation, exploration of the TNO size distribution requires more precisely calibrated detections in order to improve statistics on these results (there are, for example, only seven known Neptune Trojans). In 2011 we used MegaCam on the Canada-France-Hawaii Telescope to begin surveying 40 square degrees in the Neptune L4 region, where Trojans reside and many Plutinos & other TNOs come to perihelion. We acquired 42 hours of r-band imaging. In the better-quality half of the observations (20 sq. deg.) we have discovered 70 TNOs with a search limit of m_r~24.5 (m_g~25.0). Most of the discovered TNOs have successfully been tracked over several months of arc, giving us high-quality orbits, with the goal of tracking every TNO brighter than some a limit (roughly 24.5) to a high quality orbit so that they can be precisely modelled. In August to December 2012 we will obtain another ~42 hours of follow-up observations to complete this project. Here we present some preliminary results of the survey, concentrating on the Plutino population coupled with the CFEPS L7 Plutino model (Gladman et al., 2012, AJ, 144, 23) in order to study the Plutino size distribution. This research was supported by the Canadian National Sciences and Engineering Research Council.

310.18 Dynamical Origin Of Detached Objects Near The 2:5 And 1:3 Mmr With Neptune
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Currently the trans Neptunian population is divided into at least four regions: "Cold Kuiper Belt, "Hot Kuiper Belt", "Scattered Disk" and "Extended Scattered Disk" (ESD), whose objects are also known as detached objects. 2004XR190 - also known as Buffy is a very peculiar detached object with e = 0.106 and i = 46°.6, close but outside the 3:8 mean motion resonance. Gomes (2011, Icarus 215, 661) presents a scenario in which Buffy is formed through the interaction between the 3:8 mean motion resonance and the Kozai resonance. 2004XR190 would have escaped both resonances when it was in a state of low eccentricity and high inclination orbit (hibernating mode) while Neptune was in its final migration phase. A natural question is: in the region close to other mean motion resonances with Neptune, such as the 2:5 and the 1:3, would the same mechanisms act to form objects with characteristics similar to Buffy? We did numerical integrations of the equations of motion including the giant planets and particles near the 2:5 and 1:3 regions with and without a residual migration of Neptune. We conclude that the same mechanisms that must have acted on Buffy are also effective for objects in those resonances. There are escapes from resonances with high (q > 40 AU) and moderate (35 < q < 40 AU) mean perihelion distances while Neptune migrates. Objects that escape with low eccentricity exhibit dynamical characteristics like Buffy. A preliminary estimate of the escape ratio between particles with high and moderate mean perihelion distances is approximately 3/1. The authors thank Research Foundation of São Paulo for financial support (proc. FAPESP n° 2011/08540-9)

310.19 2012 DR30, The Most Distant Solar System Object
- Csaba Kiss¹, G. Szabó¹, A. Pál¹, L. Kiss¹, K. Sárneczky¹, T. Müller², E. Vilenius³, P. Santos-Sanz³, E. Lellouch³, B. Conn⁴, J. Ortiz⁵, R. Duffard⁵, N. Morales⁵, J. Horner⁶, M. Bannister⁷, J. Stansberry⁸
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2012 DR30, the most distant TNO in the Solar System (a=1103 AU) has recently been observed with the Herschel Space Observatory. Radiometric model results using the far-infrared fluxes and visual range data show a dark and cratered surface (p_V =~6%) and provide a diameter of ~200km. If considered as a Centaur, this is the fifth largest object known in this dynamical class. Recent visual range measurements indicate the presence of methane ice on the surface, a feature that has been seen previously for objects with diameters of >=1000km only (like Eris, Makemake and Pluto). The presence of methane ice can be explained assuming that the object spent most of its lifetime in a very cold environment and has been recently placed to its present orbit. This scenario is in agreement with the results of a dynamical study of the object’s orbit, also suggesting an Oort-cloud origin. This research has been supported by the following grants: (1) The PECS program of the European Space Agency (ESA) and the Hungarian Space Office, PECS-98073; (2) C.K. and A.P. acknowledges the support of the Bolyai Research Fellowship of the Hungarian Academy of Sciences.

310.20 The Transneptunian Automated Occultation Survey (TAOS II)

- Matthew Thomas Lehner1, S. Wang1, C. A. Alcock1, K. H. Cook1, G. Furesz2, J. C. Geary1, P. T. Ho1, T. Horton2, M. Reyes-Ruiz3, A. Szentgyorgyi1, W. Yen1, Z. Zhang1

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The Transneptunian Automated Occultation Survey (TAOS II) will aim to detect occultations of stars by small (~1 km diameter) objects in the Solar System and beyond. Such events are very rare (<0.001 events per star per year) and short in duration (~200 ms), so many stars must be monitored at a high readout cadence. TAOS II will operate three 1.3 meter telescopes at the Observatorio Astronómico Nacional at San Pedro Mártir in Baja California, México. With a 2.3 square degree field of view and a high speed camera comprising CMOS imagers, the survey will monitor 10,000 stars simultaneously with all three telescopes at a readout cadence of 20 Hz.

310.21 Color in the Kuiper Belt: Size vs Class

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Color measurement observations introduce non-intuitive biases in size-color relationships that cannot be disentangled without a well characterized sample population and a systematic color measurement of those objects. Peixinho (2012) report that KBO color bimodality is a property of object size regardless of object class. Where as, Tegler (2003) find that KBO color is a property of object class. We construct a synthetic model of the observed Kuiper belt and assign colors based on two color distribution scenarios. One model with B-R color distribution dependent on H magnitude (the H-Model) and another model with B-R color distribution based on object classification (the Class-Model). These synthetic B-R color distributions were modified to account for observational flux biases, creating a ‘color-biased’ synthetic sample. For both the original synthetic color distributions and the color-biased versions, the synthetic B-R distributions of ‘Hot’ and ‘Cold’ KBOs were compared with two observed B-R distributions of ‘Hot’ and ‘Cold’ KBOs: a sample of CFEPS objects, and a sample drawn from the Meudon Multicolor Survey (2MS, Doressoundiram 2007). All synthetic models were consistent with the CFEPS ‘Hot’ objects. The color distribution of the ‘Cold’ CFEPS was consistent with both the H-Model and the Class-model prior to application of the color-bias. The addition of color-bias resulted in the H-Model being excluded and increased the goodness of fit to the Class-Model. The 2MS sample excludes the H-Model for the ‘Hot’ objects, but with the additional color-bias the ‘Hot’ H-model was acceptable. The ‘Cold’ 2MS sample rejects the H-Model when the color-bias is applied. The match with the Class-Model increases significantly for both object types with the addition of the color measurement bias.

310.22 On the use of Video Camera Systems in the Detection of Kuiper Belt Objects by Stellar Occultations
Due to the distance between us and the Kuiper Belt, direct detection of Kuiper Belt Objects (KBOs) is not currently possible for objects less than 10 km in diameter. Indirect methods such as stellar occultations must be employed to remotely probe these bodies. The size, shape, as well as atmospheric properties and ring system information of a body (if any), can be collected through observations of stellar occultations. This method has been previously used with some success - Roques et al. (2006) detected 3 Trans-Neptunian objects; Schlichting et al. (2009) detected a single object in archival data. However, previous assessments of KBO occultation detection rates have been calculated only for telescopes - we extend this method to video camera systems. Building on Roques & Moncuquet (2000), we present a derivation that can be applied to any video camera system, taking into account camera specifications and diffraction effects. This allows for a determination of the number of observable KBO occultations per night. Example calculations are presented for some of the automated meteor camera systems currently in use at the University of Western Ontario. The results of this project will allow us to refine and improve our own camera system, as well as allow others to enhance their systems for KBO detection.

gravity change, through degree 2 potential Love number, $k_2$, which could constrain the state of the core (solid or liquid) and viscosity of the lower mantle of the Moon. Dissipations of lunar librations also depend on core and lower mantle states. Liquid metallic core would be caused by significant amount of sulfur to lower core melting temperature, whereas low-viscosity lower mantle would suggest the presence of water. In effect, the pressure level of lunar lower mantle is compatible with that of terrestrial asthenosphere, where water in silicate decreases viscosity significantly. Existence of volatiles in lunar deeper interior would modify lunar evolution scenario of hot origin: from the giant impact through the magma ocean. The $k_2$ is sensitive to the state of deep interior. When the core radius is 350 km, $k_2$ value changes by about 5% between liquid and solid cores. SELENE-2 is a planned lunar lander-orbiter mission by JAXA after successful mission KAGUYA (SELENE). We propose VLBI radio (V1RAD) sources both in SELENE-2 lander and orbiter. Using same-beam (or two-beam) multi-frequency VLBI, we will determine orbits of the orbiter precisely, measure low-order gravity changes, and estimate $k_2$ with uncertainty below 1%. If the core size is constrained by SELENE-2 seismometer, contributions of lower mantle and core on $k_2$ would separated. We also propose a Lunar Laser Ranging (LLR) reflector on SELENE-2 lander. With pre-existing reflectors, latitudinal component of lunar libration and its dissipation will be measured. Among LLR parameters, $k_2$ and core oblateness are coupled. Once $k_2$ is fixed, we can determine core oblateness, which would also constrain core and lower mantle states.

311.03 Lunar Far-UV Dayside Albedo Maps: LRO/LAMP Investigations of Surface Hydration and Space Weathering

  
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The Lyman Alpha Mapping Project (LAMP) is an ultraviolet (UV) spectrograph on the Lunar Reconnaissance Orbiter (LRO) that is currently mapping the lunar albedo at far-UV wavelengths. LAMP primarily measures faint interplanetary HI Lyman-alpha sky-glow and far-UV starlight reflected from the nightside lunar surface to pioneer an innovative technique for studying the permanently shadowed regions (PSRs) near the poles. Far-UV reflectance measurements of the bright lunar dayside are also frequently obtained. LAMP dayside measurements utilize a "pinhole" aperture with a factor of 736 less throughput to obtain a comparable dynamic range of detector count rates as for the nightside measurements. Initial spectral analysis of broad (~10 deg latitude) regions within the dayside dataset indicate evidence for latitudinal and diurnal trends that are diagnostic of surface hydration and space weathering, as reported by Hendrix et al. 2012. We report initial results from follow on analyses of high spatial resolution maps produced using the LAMP dayside reflectance dataset.

311.04 The Ultraviolet Reflectance of the Moon: Hydrated Species and Weathering Effects

  
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The Lyman Alpha Mapping Project (LAMP) aboard the Lunar Reconnaissance Orbiter (LRO) is finding evidence of water frost in the permanently shadowed regions (PSRs) at the lunar poles, measuring the lunar nightside surface using interplanetary Lyman alpha as an illumination source, and studying the lunar atmosphere. LAMP has also been making measurements of the lunar dayside, and here we report on the results from our analyses of the far-ultraviolet reflectance spectra of the Moon. We find variations in spectral shape with terrain type, latitude and time of day, with implications for space weathering effects and diurnally varying composition -- consistent with the presence of water and hydrated species. We study the effects of space weathering across the surface, and measure the varying levels of hydration with time of day and latitude to understand the surface processes currently in action at the Moon.

311.05 Compilation of a Global GIS Crater Database for the Moon
We are using primarily Lunar Reconnaissance Orbiter (LRO) information to compile a new global database of lunar impact craters 5 km in diameter and larger. Each crater’s information includes coordinates of the crater center (ULCN 2005), crater diameter (major and minor diameters if crater is elliptical), azimuthal angle of orientation if crater is elliptical, ejecta and interior morphologies if present, crater preservation state, geologic unit, floor depth, average rim height, central peak height and basal diameter if present, and elevation and elemental/mineralogy data of surroundings. LROC WAC images are used in ArcGIS to obtain crater diameters and central coordinates and LROC WAC and NAC images are used to classify interior and ejecta morphologies. Gridded and individual spot data from LOLA are used to obtain crater depths, rim heights, and central peak height and basal diameter. Crater preservational state is based on crater freshness as determined by the presence/absence of specific interior and ejecta morphologies and elevated crater rim together with the ratio of current crater depth to depth expected for fresh crater of identical size. The crater database currently contains data on over 15,000 craters covering ~80% of the nearside and ~15% of the farside. We also include information allowing cross-correlation of craters in our database with those in existing crater catalogs, including the ground-based “System of Lunar Craters” by Arthur et al. (1963-1966), the Lunar Orbiter/Apollo-based crater catalog compiled by Andersson and Whitaker (1982), and the Apollo-based morphometric crater database by Pike (1980). We find significant differences in crater diameter and classification between these earlier crater catalogs and our new compilation. Utilizing the capability of GIS to overlay different datasets, we will report on how specific crater features such as central peaks, wall terraces, and impact melt deposits correlate with parameters such as elevation, geologic unit, and crater diameter.

**311.06 Lunar Mare Photometry from SMART-1/AMIE Data**

- Olli Wilkman, K. Muinonen, H. Parviainen, J. Näränen, G. Videen, J. Josset, S. Beauvivre, SMART-1 AMIE Team

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The SMART-1 spacecraft pioneered European lunar exploration with its orbiting mission in 2004-2006. Among its instruments was the optical/near-infrared camera AMIE which mapped the lunar surface with a resolution between 40 to 200 metres per pixel. We have taken a sample of over eight hundred AMIE frames, representing most of the mare regions of the near side. We extracted multi-angular photometry from the images by sampling the brightness of the surface and estimating the local observational geometry (the directions to the camera and the Sun compared to the surface normal). We assume that the photometric properties of mare surfaces are similar in all the regions studied and consider the entire data set as representing "average" mare properties. Mare surfaces were chosen because they are smooth, making the estimation of the observational geometry simple, and also because they are dark, justifying the use of the Lommel-Seeliger scattering law. Using a numerical ray-tracing code with a simulated regolith medium we compute the effect of mutual shadowing of surface particles. This simulation considers the full observational geometry and includes azimuthal shadowings effects. The contribution of shadowing can then be removed from the data, resulting in a phase function for the lunar mare surfaces. In all cases, the reduced phase function shows a significant opposition effect, indicating that the lunar opposition effect is not explainable through shadowing effects only. Physical properties of the surface such as porosity and surface roughness affect the shadowing function. By varying these properties in the ray-tracing simulation, some information of the corresponding properties of the lunar surface may be gained. Research supported, in part, by the Academy of Finland (contract 127461) and by the NASA Lunar Advanced Science and Exploration Research Program (contract NNX11AB25G).

**311.07 Growth and Destruction from Low-Velocity Dust Aggregate Collisions**

- Adrienne Dove, J. Colwell, C. Vamos

  4University of Central Florida.
By exploring a variety of impactor densities and velocities, we can observe the ranges over which growth, compaction, or erosion occur for cm-sized aggregates. Evolution of proto-planetary and planetary ring systems is driven by collisions between objects that are likely to themselves be formed from aggregates of smaller particles. In these collisional systems, impacts between objects may occur at very low velocities, much less than 1 m/s. Low-velocity impacts may play a critical role in the growth of larger aggregates. In planetary ring systems and circumplanetary disks, collisions between aggregates or dust-covered objects release dust that is a more visible tracer of the underlying parent population of massive objects. We have designed and built an apparatus to simulate these low-velocity collisions in a laboratory vacuum environment. In our experiment, one aggregate is launched upward by a spring launching mechanism, while another is dropped from directly above the launcher to create the impact. Impact velocities are controlled by initial spring launch velocity, masses of the particles, and timing of the collisions. Initially, we use JSC-1 lunar regolith simulant to create the aggregates; the simulant can be packed to different densities to control the mass and porosity of the impactors. A high-speed digital video camera is used to record the impacts to observe the behavior of both impactors and the resulting ejecta material. By exploring a variety of impactor densities and velocities, we can observe the ranges over which grow, compaction, or erosion occur for cm-sized aggregates.

311.08 Low-Energy Impacts onto Lunar Regolith Simulant
- Laura M. Seward1, J. Colwell1, M. Mellon2, B. Stemm1
- 1University of Central Florida, 2Southwest Research Institute.

Low-Energy Impacts onto Lunar Regolith Simulant Laura M. Seward1, Joshua E. Colwell1, Michael T. Mellon2, and Bradley A. Stemm1, 1Department of Physics, University of Central Florida, Orlando, Florida, 2Southwest Research Institute, Boulder, Colorado. Impacts and cratering in space play important roles in the formation and evolution of planetary bodies. Low-velocity impacts and disturbances to planetary regolith are also a consequence of manned and robotic exploration of planetary bodies such as the Moon, Mars, and asteroids. We are conducting a program of laboratory experiments to study low-velocity impacts of 1 to 5 m/s into JSC-1 lunar regolith simulant, JSC-Mars-1 Martian regolith simulant, and silica targets under 1 g. We use direct measurement of ejecta mass and high-resolution video tracking of ejecta particle trajectories to derive ejecta mass velocity distributions. Additionally, we conduct similar experiments under microgravity conditions in a laboratory drop tower and on parabolic aircraft with velocities as low as 10 cm/s. We wish to characterize and understand the collision parameters that control the outcome of low-velocity impacts into regolith, including impact velocity, impactor mass, target shape and size distribution, regolith depth, target relative density, and crater depth, and to experimentally determine the functional dependencies of the outcomes of low-velocity collisions (ejecta mass and ejecta velocities) on the controlling parameters of the collision. We present results from our ongoing study showing the positive correlation between impact energy and ejecta mass. The total ejecta mass is also dependent on the packing density (porosity) of the regolith. We find that ejecta mass velocity fits a power-law or broken power-law distribution. Our goal is to understand the physics of ejecta production and regolith compaction in low-energy impacts and experimentally validate predictive models for dust flow and deposition. We will present our results from one-g and microgravity impact experiments.

312 Titan
Wednesday, 3:30 PM - 6:00 PM, Exhibit Hall

312.01 Solubility and Thermal Stability Investigation of Titan Tholins: New Insight from NMR Analysis
- Chao He1, M. A. Smith1
- 1Department of Chemistry, University of Houston.

We investigated the solubility and thermal stability of Titan’s aerosol analogs (tholins) to understand the basic property of organics on Titan and the potential for chemical modification upon in situ sampling. The tholin generated by AC discharge in CH4/N2 (5/95) mixture preferentially dissolves in polar solvent to non-polar solvent, totally soluble in DMSO (>21.5 mg/mL), 60% in mass soluble in methanol, 25% in acetone, 27% in acetonitrile and 30% in water while only 1% in benzene and chloroform. The 1H solution-state NMR spectra of respective
deuterated solutions exhibit the structural information of the soluble fraction in each solvent, confirming the large percentage of polar species in tholins. The solubility study not only helps us understand the solubility of Titan’s aerosols in possible liquid phase in Titan’s surface/atmosphere, but also provides the basis for the solvent selection and methods development of liquid separation and/or solution based analysis in future Titan missions. These include methods such as NMR and LC/MS, which can be non-destructive providing objective information regarding nascent chemical identification. Thermal stability studies demonstrate the thermal lability of tholins and indicate significant structural changes of when heated beyond 150 oC for even short time periods in inert atmospheres. Dynamic studies at 200 oC demonstrate that several predominant chemical reactions fit first-order reaction kinetics with half-lives between 5 to 141 minutes. This study is critical to ongoing discussion regarding the development of in situ analysis methods and instruments for Titan mission and other outer planet exploration.

312.02 Modeling The Vertical Profile Of Tholin Particles In The Atmosphere Of Titan
- Mao-Chang Liang¹, C. Li², X. Zhang², Y. Yung²
  ¹Academia Sinica, Taiwan, ²Caltech.

Detailed vertical profiles of minor species from 100 to 1000 km and of tholins above ~300 km have recently been deduced from Cassini observations. To match the observed profiles of three major C2-hydrocarbons (C2H2, C2H4, and C2H6), modifications to the existing kinetics and vertical transport are needed. The latter plays a crucial role. Incorporating these modifications and a parameterized aerosol formation pathway into a chemistry-diffusion model, we could explain the observed tholin profile made by the Cassini/UVIS instrument. Processes that affect the profile are (1) aerosol production, (2) aerosol coagulation, and (3) dynamical transport. Sensitivity of the resulting tholin profile to the processes is examined and discussed.

312.03 Synergism of Saturn, Enceladus and Titan and Formation of HCNO Exobiological Molecules
- Edward C. Sittler¹, J. F. Cooper¹
  ¹NASA’S GSFC.

Saturn as a system has two very exotic moons Titan and Enceladus. Titan with energy input from Saturn’s magnetosphere, solar UV irradiation, and galactic cosmic rays (GCRs) can make HCN based molecules. Space radiation effects at both moons, and as coupled by the Saturn magnetosphere, could lead to the evolution of biological models at Titan composed of HCN with oxygen as the new ingredient. The “Old Faithful” model by Cooper et al. (2009) suggests that Enceladus, highly irradiated by Saturn magnetospheric electrons, has episodic ejections of water vapor into Saturn’s magnetosphere. At Titan Cassini discovered keV oxygen ions, evidently from Enceladus, bombarding Titan’s upper atmosphere (Hartle et al., 2006a,b) and abundant heavy positive and negative ions within Titan’s upper atmosphere (Coates et al., 2007). Heavy ion formation in Titan’s upper atmosphere can be due polymerization of aromatics such as Benzenes to make polycyclic aromatic hydrocarbons (PAH) (Waite et al., 2007) and/or the polymerization of carbon chains from acetylene to make fullerenes (Sittler et al., 2009). Fullerenes, which are hollow carbon shells, can trap the keV oxygen ions. Clustering of fullerenes, PAHs and PAHNs can form larger aerosols enriched in trapped oxygen which can then precipitate down to Titan’s surface. GCRs will chemically process aerosol materials at the surface and provide sufficient energy for processing them into more complex organic forms such as amino acids. We have developed an advanced model of GCR interaction with Titan’s atmosphere, surface and sub-surface. This allows one to estimate dose rates at the surface and below and then using laboratory results by Hudson et al. (2008) to estimate abundances of the amino acid such glycine to ~ 100 ppb over time periods relatively short compared to solar system timescales. Therefore, the Saturn system can provide pathways for the accumulation of prebiotic chemicals on Titan’s surface.

312.04 Influence of Haze on Molecular Lines Formed in the Atmosphere of Titan
- Sang J. Kim¹
  ¹Kyunghee Univ., Korea, Republic of.

Radiative transfer calculations for the ro-vibrational lines of CH4, C2H2, C2H6, and HCN in atmosphere of Titan have been carried out without consideration of haze opacities (e.g., Yelle and Griffith, 2003), or only for very high (z > 500 km) atmospheric layers where haze influence is assumed to be negligible (e.g., Adriani et al. 2011; and

312.05 Exploring Titan’s Aerosols with a Three Dimensional GCM
- Erik J. Larson1, O. B. Toon1, A. J. Friedson2, R. A. West4
1University of Colorado, 4Jet Propulsion Lab.

In this work, we try to understand the origin and nature of Titan’s aerosols using a three dimensional global circulation model with aerosol microphysics. We explore how the aerosol properties including shape, size, production height and charge affect the spatial and temporal distribution and radiative properties of the aerosols. Specifically, we compare the wavelength dependence of the aerosol optical depth, the seasonal changes in Titan’s albedo, heating and cooling rates and their contribution to the driving of the zonal jets to relevant data sets in order to constrain these parameters. The aerosols are produced high in the atmosphere and have coagulated to roughly 0.7 μm aggregates by the time they fall to our model top near 320 km. We find that the atmospheric dynamics can accurately reproduce the N/S albedo asymmetry and seasonal evolution with a slight phase lag due to a slightly low altitude of the “optical depth =1” contour. The wavelength dependence of the optical depth can be accurately modeled with particles having fractal dimensions of 2.4 and 2.8 at altitudes between 80-30 km and below 30 km respectively. This model extends previous one-dimensional attempts at exploring aerosols microphysics and previous three-dimensional models that parameterize the aerosols. In this work, we also explore numerical parameters such as horizontal resolution and vertical height to see their effect on the model. These comparisons are very useful for other numerical modelers and applicable beyond Titan and this particular dynamical core. Understanding numerical effects in the code is crucial to interpreting model results and comparing with Titan’s atmosphere.

312.06 Mapping Methane Escape from Titan with the Cassini Plasma Spectrometer
- Adam Woodson1, R. E. Johnson1
1University of Virginia.

A primary goal of the Cassini mission has been to measure atmospheric loss from Saturn’s largest moon Titan. Methane, the second most abundant molecule in Titan’s atmosphere (2-3%) after nitrogen (95%), is believed critical for the atmosphere’s maintenance. Its photochemistry generates a haze of complex hydrocarbons that heat the atmosphere through absorption of solar IR and UV radiation. This heating determines structure, drives dynamics, and prevents condensation and collapse of the atmosphere’s nitrogen. Titan is particularly interesting because unlike bodies of comparable size and mass in similar environments such as Io, Europa, and Ganymede, it has managed to retain an atmospheric column density nearly ten times that of Earth and an atmosphere-to-solid mass-ratio comparable to that of Venus. Prior to Cassini the methane escape rate was thought to be small, but atmospheric density data since acquired by the spacecraft has been used to suggest an escape rate orders of magnitude larger than pre-Cassini estimates. Recent molecular kinetic simulations carried out near Titan’s exobase fail to confirm this, however, and additional data analysis is needed to constrain the methane loss rate. In this regard, the Cassini Plasma Spectrometer (CAPS) data has been studied for only a handful of Titan encounters and so far implies a dearth of heavy ions originating from Titan. The purpose of this study is to survey the CAPS data for all 80+ Titan encounters since October, 2004 and map methane ion densities and velocities above the exobase as a function of latitude, longitude, and altitude out to ~20 Titan radii. These values can then be used to directly estimate loss due to pickup and indirectly to estimate thermal escape in order to constrain the global methane loss rate.

312.07 FT-IR Measurements of Cross Sections of Cold C3H8 in the 7 - 15 μm for Titan
- Keeyoon Sung1, L. R. Brown1, G. C. Toon1, A. W. Mantz2, M. A. H. Smith3
1Jet Propulsion Laboratory, 2Connecticut College, 3NASA Langley Research Center.
To support atmospheric remote sensing of Titan, the absorption cross sections of N2-broadened C3H8 were obtained at temperatures between 145 and 296 K. For this, 17 spectra of pure- and N2-broadened propane were recorded in the 690 to 1550 cm⁻¹ region using a Fourier transform spectrometer (Bruker IFS-125HR) at the Jet Propulsion Laboratory configured with a 20.38 cm long temperature-stabilized cryogenic absorption cell. The coolable cell was developed at Connecticut College and described previously [1]. We report the absorption cross sections at the various cold temperatures for nine strong propane bands (v26, v8, v21, v20, v7, v19, v18, v4, v24). In addition, we present results from ‘pseudo-line generation’, which includes positions, intensities, and effective lower state energies’ determined from high-resolution laboratory spectra, (see http://mark4sun.jpl.nasa.gov/data/spec/Pseudo/Readme). The resulting compilation will be compared to earlier work, including the C3H8+N2 spectra recorded at PNNL [2] and available line-by-line predictions [3,4]. Research described in this paper was performed at the Jet Propulsion Laboratory, and California Institute of Technology, Connecticut College, NASA Langley Research Center, under contracts and cooperative agreements with the National Aeronautics and Space Administration. References [1] K. Sung, A. W. Mantz, M. A. H. Smith, et al., J Mol Spectrosc 262, 122, 2010. [2] S. W. Sharpe, et al., Appl Spectrosc 58, 1452, 2004. [3] J. M. Flaud et al., Mol Phys 108, 699, 2010. [4] J. M. Flaud et al., J Chem Phys 114, 9361, 2001.

312.08 Water Vapor in Titan’s Stratosphere from Cassini CIRS Far-infrared Spectra


We will report the measurement of water vapor in Titan’s stratosphere (Cottini et al. 2012), using the Cassini Composite Infrared Spectrometer (CIRS, Flasar et al. 2004). CIRS senses water emissions in the far infrared spectral region near 50 microns, which we have modeled using a radiative transfer code (NEMESIS, Irwin et al. 2008). From the analysis of nadir spectra we have derived a mixing ratio of 0.14 ± 0.05 ppb at an altitude of 97 km, which corresponds to an integrated (from 0 to 600 km) surface normalized column abundance of 3.7±1.3 × 10^{14} molecules/cm². In the latitude range 80°S to 30°N we see no evidence for latitudinal variations in these abundances within the error bars. Using limb observations, we obtained mixing ratios of 0.13 ± 0.04 ppb at an altitude of 115 km and 0.45 ± 0.15 ppb at an altitude of 230 km, confirming that the water abundance has a positive vertical gradient as predicted by previous photochemical models. We have also fitted our data using scaling factors of ~0.1-0.6 to these photochemical model profiles, indicating that the models over-predict the water abundance in Titan’s lower stratosphere. Valeria Cottini is supported by the NASA Postdoctoral Program.


312.09 Compositional Effects In Titan’s Thermospheric Gravity Waves

- Jun Cui, Y. Lian, I. Mueller-Wodarg, R. Yelle


In Titan’s upper atmosphere, the density profiles of several constituents (N2, CH4, H2 and 29N) as measured by the Cassini Ion Neutral Mass Spectrometer (INMS) show periodical structures which we interpret as internal gravity waves. Compositional effects are frequently seen in the data: (1) The CH4 and H2 wave amplitudes are smaller than the N2 wave amplitude, but the 29N2 wave amplitude tends to be larger; (2) The wave structures in different constituents are roughly in phase, and the 29N2-N2 phase difference is smaller than the CH4-N2 and H2-N2 phase differences. We use a simple linearized wave perturbation theory to explain the observations. The model
illustrates the importance of wave-induced diffusion, especially for H2. Taking T39 as an example, the data-model comparison suggests typical wavelength of ~320 km and typical wave period of ~64 min (to be compared with the Brunt-Vaisala period of ~60 min). The wave propagation is preferentially horizontal, with a small upward component inclined by ~75 deg from vertical.

312.10 Ice condensation layers in Titan’s Stratosphere
- Erika L. Barth1
  1Southwest Research Institute.

Photochemical destruction of methane along with the destruction of nitrogen molecules from energetic electrons in Titan’s upper atmosphere result in the production of a number of hydrocarbon and nitrile compounds which may be capable of condensing at the colder temperatures of Titan’s lower stratosphere. Stratospheric ices can contribute to the opacity of Titan’s atmosphere as well as affect the chemistry of the more optically thick clouds seen in the troposphere, should they survive long enough to serve as condensation nuclei. Recently, Anderson & Samuelson (2011, Icarus, v. 212, p. 762) examined data from the Cassini Composite Infrared Spectrometer (CIRS) and found evidence for emission features centered around 90 km which are consistent with nitrile ices, notably HCN and HC3N. These compounds along with other possible contributors have been added to the Titan-CARMA column microphysics model (Barth & Toon, 2006, Icarus, v. 182, p. 230) to explore the altitudes for condensation as well as expected particle sizes in these stratospheric ice layers. Simulations show an ice layer of combined HCN and HC3N forming near 90 km, with particle sizes of microns. C2H6 and C2H2 condense out as ices in separate layers between 50 and 60 km with slightly larger particles.

312.11 Six Years of Keck OSIRIS Observations of Titan: Quantifying the Transport of Aerosol Haze
- Mate Adamkovics1, I. de Pater1
  1University of California, Berkeley.

We present spatially-resolved observations of Titan in the near-infrared obtained with the field integral spectrograph, OSIRIS, at the W. M. Keck Observatory. Datacubes were acquired in H (1.5 μm) and K (2 μm) bands from April 2006 to January 2012. Broadband spectra reveal the aerosol vertical structure from the surface through the stratosphere. We describe the temporal and spatial variation in aerosol distribution as constrained by our radiative transfer models, which include updates to methane opacity and aerosol scattering. This work is supported by NSF planetary astronomy grant AST-1008788.

312.12 A Serendipitous Line Survey of Titan in the 1.3mm Band
- Mark A. Gurwell1, B. J. Butler2, A. Moullet2
  1Harvard-Smithsonian Center For Astrophysics, 2National Radio Astronomy Observatory.

The millimeter and submillimeter bands are rich in rotational transitions from many molecular species detected and/or expected in the atmosphere of Titan. The lines are typically well-separated, and their line shapes, governed by both pressure broadening in the low- to mid-stratosphere and thermal broadening at higher altitudes, can be used to determine vertical abundance profiles given sufficient spectral resolution. This quantity of spectral lines have made Titan a popular target for millimeter and submillimeter radiotelescopes, which have reported detections of many nitriles along with CO (e.g. Muhleman et al 1984; Marten et al 1988; Tanguy et al 1990; Hidayat et al 1995; Gurwell & Muhleman 1995; Hidayat et al 1997; Marten et al 2002; Gurwell 2004; etc). The submillimeter bands are also covered by instruments on Cassini (CIRS) and Herschel (HIFI, SPIRE). The Submillimeter Array has been in operation for nearly 9 years, and during that time has observed Titan several times as a science target. In addition, Titan is utilized at the SMA as a primary standard for flux calibration in the 1.3mm, 1.1mm and 870 micron transmission windows. While each observation used for flux calibration is typically only 10-20 minutes in length, there have been many such observations during the SMA’s operation. Thus, while in many small chunks, this SMA calibration data represents a sizable investment of telescope time, and presents an opportunity for use in a serendipitous line survey. This presentation will describe some initial results from an archival project to locate, calibrate, and combine data from multiple SMA observations of Titan, starting in the 1.3mm band. This will include, to our knowledge, the first reported detections in the millimeter bands of
vibrationally excited HC3N (v7=1 and v7=2) and also CH3C2H as well as ongoing searches for HC5N and C2H3CN,
and isotopic ratios in HC3N and CH3CN.

312.13 C2H2 On Titan As Seen By Herschel/PACS

- Miriam Rengel1, H. Sagawa2, P. Hartogh1, E. Lellouch3, H. Feuchtwangler4, R. Moreno5, C. Jarchow1, L. Lara5,
  R. Courtin3, J. Cernicharo6
1Max Planck Institute for Solar System Research, Germany, 2National Institute of Information and Communications
  Technology, Japan, 3LESIA, Observatoire de Paris, France, 4Max-Planck-Institut für extraterrestrische Physik,
  Germany, 5Instituto de Astrofísica de Andalucía (CSIC), Spain, 6Instituto de Estructura de la Materia, Spain.

Acetylene (C2H2) is a very important molecule in planetary sciences. It is one of the most abundant minor
components in Titan and has been previously traced in the upper atmosphere of Titan in the mid-infrared (with
ISO/SWS and Cassini/CIRS). Existing vertical distributions for C2H2 have inferred information on the abundance,
however, results have revealed C2H2 variations with latitude, and also a higher constant distribution at all
latitudes. A spectroscopy study of the C2H2 on Titan in the far-infrared has not been previously available. In the
framework of the key program “Water and related chemistry in the Solar System”, we have analysed Titan
observations performed in July 2012 by Herschel/PACS around the ~69 microns window with a higher signal-to-
noise ratio than previous related PACS observations (which revealed an ambiguous C2H2 detection). We report
here the new spectra obtained and the preliminary C2H2 abundance retrieved from these observations. This study
helps to give constraints on atmospheric models, and better understand the atmosphere of Titan.

312.14 Properties of the Scattered FUV Solar Spectrum at Titan

- D. E. Shemansky1, X. Zhang2, M. Liang3, Y. L. Yung2
1SET/PSSD, California, USA ; 2 CIT California, USA ; 3 Res. Ctr. Env. Change, Taipei, Taiwan

D. E. Shemansky1, X. Zhang2, M-C. Liang3, and Y. L. Yung2 1 SET/PSSD, California, USA ; 2 CIT California, USA ; 3 Res.
Ctr. Env. Change, Taipei, Taiwan The strong solar reflection spectrum in the FUV in Cassini UVIS observations with
line of sight below the solid limb allow the examination of spectral properties of the scattering medium. At
wavelengths longward of 1525 Å the spectrum is characterized mainly by solar emission structure. Absorption
features in acetylene , the main known absorber in this region, are weak. The spectrum therefore shows the
properties of a Rayleigh scattering continuum in a wavelength range of 1920. - 1525.1 Å, below which the solar
continuum and line emissions are cut-off by absorption in the medium. The observed emission is evidently multiply
scattered. At a line of sight altitude of 1040 km, analysis assuming Mie scattering gives an estimated particle radius
of 76 Å. The evident strong absorber at lower altitude giving the sharp extinction of the emission spectrum below
1525 Å needs investigation. The PAH naphthalene, with an ionization potential of 1526.9 Å is the nearest candidate
identified to date. The spectral properties of the scattering medium in the 1920. - 1525.1 Å region will be
described.

312.15 Dielectric Property Measurements to Support Interpretation of Cassini Radar Data

- Corey Jamieson1, M. Barmatz2
1SETI Institute, 2Jet Propulsion Laboratory.

Radar observations are useful for constraining surface and near-surface compositions and illuminating geologic
processes on Solar System bodies. The interpretation of Cassini radiometric and radar data at 13.78 GHz (2.2 cm)
of Titan and other Saturnian icy satellites is aided by laboratory measurements of the dielectric properties of
relevant materials. However, existing dielectric measurements of candidate surface materials at microwave
frequencies and low temperatures is sparse. We have set up a microwave cavity and cryogenic system to measure
the complex dielectric properties of liquid hydrocarbons relevant to Titan, specifically methane, ethane and their
mixtures to support the interpretation of spacecraft instrument and telescope radar observations. To perform
these measurements, we excite and detect the TM020 mode in a custom-built cavity with small metal loop
antennas powered by a Vector Network Analyzer. The hydrocarbon samples are condensed into a cylindrical
quartz tube that is axially oriented in the cavity. Frequency sweeps through a resonance are performed with an empty cavity, an empty quartz tube inserted into the cavity, and with a sample-filled quartz tube in the cavity. These sweeps are fit by a Lorentzian line shape, from which we obtain the resonant frequency, $f$, and quality factor, $Q$, for each experimental arrangement. We then derive dielectric constants and loss tangents for our samples near 13.78 GHz using a new technique ideally suited for measuring liquid samples. We will present temperature-dependent, dielectric property measurements for liquid methane and ethane. The full interpretation of the radar and radiometry observations of Saturn’s icy satellites depends critically on understanding the dielectric properties of potential surface materials. By investigating relevant liquids and solids we will improve constrains on lake depths, volumes and compositions, which are important to understand Titan’s carbon/organic cycle and inevitably the evolution of its environment.

312.16 Photometric Roughness of Titan’s Surface Observed by the DISR Cameras on Huygens
- Erich Karkoschka$^1$, C. See$^1$

$^1$Univ. of Arizona.

During the descent of the Huygens probe through Titan's atmosphere, the Descent Imager/Spectral Radiometer (DISR) took more than 200 images of Titan's surface. The photometric analysis of areas taken from different viewing angles can yield information about the surface roughness on scales smaller than the resolution limit. The resolution varied from 1 km to less than 1 m. The variation of photometric properties with surface roughness has been studied for the case of a point source as illumination, which is appropriate for all satellites except Titan. At the effective wavelength of the DISR imagers (about 770 nm), less than 1 percent of the illumination is direct sunlight, the rest is light scattered by aerosols in Titan’s atmosphere. On Titan, unlike other satellites, photometric variations with viewing direction occur mostly with emission angle but less so with phase angle. I measured the photometric variation of the imaged terrain with emission angle considering the scattering of light in Titan’s atmosphere according to the DISR haze model. This created a map of the surface roughness. I compared it with a Cassini RADAR image, which probes surface roughness at the scale of the radar wavelength (2 cm). While several features correlate well, some significant differences may reveal how the surface roughness varies with the scale. After landing, DISR imaged an area of relatively flat soil partially covered by pebbles. The photometric variations with emission angle of the soil and pebbles are similar to those in the descent mosaic for implied smooth and rough terrains, respectively. Thus, the post-landing image with sub-centimeter resolution helps the interpretation of the photometric roughness determined from descent images. This research was supported by NASA grant NNX10AF09G.

312.17 Preliminary Results Of Titan’s Tropical Surface Albedo Using Cassini Vims Measurements
- Jake Turner$^1$, C. A. Griffith$^1$, P. Penteado$^1$

$^1$University of Arizona, $^2$University of Sao Paulo, Brazil.

Titan is shrouded by a thick atmosphere, which limits studies of its surface composition. Cassini’s Visual and Infrared Mapping Spectrometer (VIMS) offers an opportunity to investigate Titan’s surface at 8 near-IR wavelengths where the atmosphere is relatively transparent and a portion of the reflected sunlight comes from Titan’s surface. The challenge is to characterize the scattering and absorption of Titan’s atmosphere well enough to determine the surface albedo. To this effect, we designed a discrete ordinates radiative transfer model of its atmosphere, the scattering characteristics of the tropical atmosphere so that it accurately reproduces in situ measurements by Huygens' Descent Imager-Spectral Radiometer (DISR). We limited our study to the tropical region of Titan that is characterized by the same haze and methane conditions measured by Huygens. We determine the surface albedo at 0.93, 1.08, 1.28, 1.58, 2.00, 2.78, and 5.0 microns, between the methane vibrational bands. We present here preliminary results of several tropical regions on Titan where the surface albedo has been accurately determined.

312.18 Vertical Distribution of Gases and Aerosols in Titan’s Atmosphere Observed by VIMS/Cassini Solar Occultations
We present the vertical distribution of gaseous species and aerosols in Titan's atmosphere through the analysis of VIMS solar occultations. We employ the infrared channel of VIMS, which covers the 1 - 5 μm wavelength range. VIMS occultations can provide good vertical resolution (~10 km) and an extended altitude range (from 70 to 700 km), complementing well the information from other Cassini instruments. VIMS has retrieved 8 solar occultations up to now. They are distributed through the whole Cassini mission and they probe different latitudes in both hemispheres. Two main gases can be observed by VIMS occultations: methane, through its bands at 1.2, 1.4, 1.7, 2.3 and 3.3 μm, and CO, at 4.7 μm. We can extract methane's abundance between 70 and 700 km and CO’s between 70 and 180 km. Regarding aerosols, the VIMS altitude range allows to get information on the properties of both the main haze and the detached layer. Aerosols also affect the transmittance through their spectral signatures. In particular, a spectral signature at 3.4 μm that was attributed to aerosols was recently discovered by the analysis of the first VIMS occultation. We will monitor the latitudinal and temporal variations of the 3.4 μm feature through various occultations. A change in the global circulation regime of Titan sets in with the approaching to the vernal equinox, and a strong decrease of the altitude of the detached layer between the winter solstice and the equinox has indeed been observed. The temporal coverage of VIMS occultations allows the study the effect of these variations in the vertical distribution of aerosol optical and spectral properties.

**312.19 Seasonal Changes in the Composition of Titan's Southern Stratosphere**

- NASA GSFC, University of Maryland, Catholic University, University of Bristol, United Kingdom, LESIA/Observatoire de Paris/CNRS, France, University of Oxford, United Kingdom.

In August 2009 Titan passed through northern spring equinox, and the southern hemisphere passed into fall. Since then, the moon's atmosphere has been closely watched for evidence of the expected seasonal reversal of stratospheric circulation, with increased northern insolation leading to upwelling, and consequent downwelling at southern high latitudes. If the southern winter mirrors the northern winter, this circulation will be traced by increases in short-lived gas species advected downwards from the upper atmosphere to the stratosphere. The Cassini spacecraft in orbit around Saturn carries on board the Composite Infrared Spectrometer (CIRS), which has been actively monitoring the trace gas populations through measurement of the intensity of their infrared emission bands (7-1000 μm). In this presentation we will show fresh evidence from recent CIRS measurements in June 2012, that the shortest-lived and least abundant minor species (C₃H₄, C₄H₂, C₆H₆, HC₃N) are indeed increasing dramatically southwards of 50°S in the lower stratosphere. Intriguingly, the more stable gases (C₂H₂, HCN, CO₂) have yet to show this trend, and continue to exhibit their 'summer' abundances, decreasing towards the south pole. Possible chemical and dynamical explanations of these results will be discussed, along with the potential of future CIRS measurements to monitor and elucidate these seasonal changes. The US-based authors thank the Cassini Mission and the NASA NPP program for their support of this research.

**312.20 Impact-induced climate change on Titan**
- Kevin Zahnle, D. Korycansky

- NASA Ames Research Center, University of California, Santa Cruz.

Titan's thick atmosphere and volatile surface cause it to respond to big impacts -- like the one that produced the prominent Menrva impact basin -- in a somewhat Earth-like manner. As a first iteration, we construct a globally-averaged model that tracks the energy released by big comet impacts on a simple Titan with a 1.4 bar N₂ atmosphere over a water ice crust, with methane in the atmosphere, in lakes, and saturating the upper (porous) crust. Menrva was big enough to raise the surface temperature by ~80 K. If methane in the regolith is generally as abundant as it was at the Huygens landing site, Menrva would have doubled the amount of methane in the atmosphere. The extra methane would have drizzled out of the atmosphere over hundreds of years. Bigger impacts can create shallow liquid water oceans at the surface. If Titan's crust is made of water ice, the putative
Hotei impact (a possible 800-1200 km diameter basin, Soderblom et al 2009) would have raised the average surface temperature to 350-400 K. Water rain would have fallen and global meltwaters would have averaged 50 m to as much as 500 m deep. It is appreciated that ice and most hydrocarbons will float on the meltwaters. If water freezes at depths greater than 140 m, methane clathrate is stable and it is likely that methane clathrate forms. Global meltwaters may not have lasted more than a few decades or centuries at most, but are interesting to consider given Titan’s organic wealth. Impacts also create local crater lakes set in warm ice but these quickly sink below the warm ice; whether the cryptic waters quickly freeze by mixing with the ice crust or whether they long endure under the ice remains a open question.

313 Comets 1: Hartley 2 and Garradd

Wednesday, 3:30 PM - 6:00 PM, Exhibit Hall

313.01 Jet Morphology and Coma Analysis of 103P/Hartley 2

Charles Vaughan, D. Pierce, G. Dorman, A. Cochran
Mississippi State University, University of Texas, McDonald Observatory.

We have observed comet 103P/Hartley 2 using the George and Cynthia Mitchell Spectrograph (formerly VIRUS-P) on the 2.7 m telescope at McDonald Observatory (Hill et al. 2008). Data for CN, C2, C3, and NH2 were collected over six nights from 2010 July 15 to November 10. The data were processed to form images of the coma for each of the observed species. We have performed azimuthal average division on each of the coma images to examine jet morphology and have investigated the nature of the production of the radical species using our modified vectorial model (Ihalawela et al. 2011). This work enhances the ongoing investigation of the chemistry and outgassing behavior of Hartley 2 as studied by the EPOXI flyby mission.

313.02 High-Dispersion Optical Spectra in the Inner Coma of Comet 103P/Hartley 2 at the Close Approach to the Earth

Yoshiharu Shinnaka, H. Kawakita, H. Kobayashi, M. Hashimoto
Kyoto Sangyo University, Japan, Saga Space Science Museum, Japan.

Comet 103P/Hartley 2 is a Jupiter-family comets with an orbital period of ~6.5 years. This comet was a target of EPOXI mission (NASA), in which the comet was observed in situ from the Deep Impact spacecraft on UT 2010 November 4. Many observations not only from the ground-based observatory but also from the space observations were conducted in various wavelength regimes before and after the EPOXI flyby. We performed the high-dispersion optical spectroscopic observations of comet 103P/Hartley 2 with the high dispersion spectrograph (HDS) mounted on the Subaru telescope atop of Mauna Kea, Hawaii on UT 2010 October 18. Here we present (1) ortho-to-para abundance ratios (OPRs) of water and ammonia inferred from the high-dispersion spectra of H2O+ and NH3, and (2) spatial distributions of radicals (C2, NH2, and H2O+) and dust continuum in the inner coma. We will discuss about the chemical reaction in cometary coma and the origin of icy materials of comet 103P/Hartley 2. This work is supported by the MEXT - Supported Program for the Strategic Research Foundation at Private Universities (2008-2012).

313.03 Evidence for Two Modes of Water Release in Comet 103P/Hartley 2: Distributions of Column Density, Rotational Temperature, and Ortho-Para Ratio

Goddard Center for Astrobiology-NAI/Catholic University of America, Goddard Center for Astrobiology-NAI/NASA Postdoctoral Fellow, Goddard Center for Astrobiology-NAI/NASA-GSFC, Goddard Center for Astrobiology-NAI/University of Missouri – St. Louis, University of Hawaii – National Astrobiology Institute, University of Michigan.

We acquired high-resolution near-infrared spectra of H2O emission from comet 103P/Hartley-2 using NIRSPEC at Keck 2. Long-slit spectroscopy can directly probe the inner comae of comets via spectrally and spatially resolved
measurements. This capability strengthens the quantitative view of conditions within the closest ~200 km from the cometary nucleus, thereby providing direct constraints for models of density and temperature distributions in this collisionally dominated region of the coma. The near-Earth approach of comet 103P/Hartley 2 in 2010 presented an especially interesting opportunity to investigate the near-nucleus region of an active comet with substantial extended (vs. nuclear) release of water. We present spatially resolved measurements of rotational temperature and column density and discuss insights into the nature of volatile release. We also present spatially resolved measurements of the H2O ortho-para ratio (OPR). We compare these measurements with OPRs retrieved by various techniques during the 1998 and 2010 apparitions. We gratefully acknowledge support by the NSF Astronomy and Astrophysics Research Grants Program (PI/co-PI Bonev/Gibb), by the NASA Astrobiology Institute (PI: Meech, PI: Mumma), by the NASA Postdoctoral Program (Fellow: Paganini), and by NASA’s Planetary Astronomy (PI: DiSanti; PI: Mumma; PI: Villanueva), Planetary Atmospheres (PI: Combi; PI: DiSanti; PI: Villanueva), and Discovery (PI: Meech) Programs. NOAO (through the Telescope System Instrumentation Program funded by NSF) and the University of Hawaii granted Keck-2 telescope time for this investigation.

313.04 The Coma Of A Comet With Areas Of Diverse Compositions: Comet 103P/Hartley 2
- Nicolas Fougere1, M. R. Combi1, M. Rubin1, V. Tenishev1
1University of Michigan.

The spectacular images of comet 103P/Hartley 2 (A’Hearn et al. 2011) recorded by the Extrasolar Planet Observation and Deep Impact Extended Investigation (EPOXI) spacecraft revealed that its bi-lobed very active nucleus outgasses volatiles heterogeneously. Indeed, at the time of the flyby CO2 was the primary driver of activity by dragging out chunks of pure ice from the small sub-solar lobe which appear to be the major source of water in Hartley 2’s coma by sublimating slowly as they go away from the nucleus. However, water vapor is released by direct sublimation from the nucleus at the narrow waist between the two end lobes without a significant amount of either CO2 or icy grains. The coma structure for a comet with such areas of diverse composition differs from the usual models where gases are produced in a homogeneous way from the surface. We use the fully kinetic Direct Simulation Monte Carlo model of Tenishev et al. (2008 & 2011) applied to comet 103P/Hartley 2 to reproduce the observations made by EPOXI at close approach. A bi-lobed nucleus with axial symmetry and a succession of active areas with different compositions was included in the model with gas and icy grains emissions to match the EPOXI data which enables us to explore the physical state of the coma of Hartley 2. The gas dynamics is different from the classical direct nucleus sublimation model such that the water vapor remains warmer but its bulk velocity is decreased within ~100 km from the nucleus, which is the maximum distance where icy grains are still adding water vapor to the coma before completely sublimating. Acknowledgements: This work was supported by grant NNX09AB59G from the NASA Planetary Atmospheres program. References: A’Hearn et al. 2011, Science 332:1396 Tenishev et al. 2008, ApJ 685:659, & 2011, ApJ 732:104

313.05 The Water Production Rate of Comet 2009 P1 (Garradd) throughout the 2011-2012 Apparition
- Michael R. Combi1, J. T. T. Mäkinen2, J. Bertaux3, E. Quémerais3, S. Ferron4
1Univ. of Michigan, 2Finnish Meteorological Institute, Finland, 3LATMOS/IPSI, Université de Versailles Saint-Quentin, France, 4ACRI-st, France.

The all-sky hydrogen Lyman-alpha camera, SWAN (Solar Wind Anisotropies), on the SOlar and Heliospheric Observatory (SOHO) satellite made observations of the hydrogen coma of comet 2009 P1 (Garradd) throughout its apparition from August 15, 2011 through April 6, 2012. SOHO has been operating in a halo orbit around the Earth-Sun L1 Lagrange point since its launch in late 1995. Most water vapor produced by the comet is ultimately photodissociated into two H atoms and one O atom producing a huge atomic hydrogen coma that is routinely observed in the daily full-sky SWAN images in comets of sufficient brightness. Water production rates were calculated from 117 images over 8 months of the apparition using our time-resolved model (Mäkinen & Combi, 2005, Icarus 177, 217), yielding about 1 observation every 2 days on the average. The activity during much of the pre-perihelion leg was dominated by likely seasonal variability rather than a consistent increasing trend with decreasing heliocentric distance and varied between 1 and 3 x 10^29 s^-1. A single peak value for the water production rate (4 x 10^29 s^-1) was found on November 3, 2011, 50 days before perihelion. On the other hand during the post-perihelion leg the production rate decreased rather consistently from 2 x 10^29 s^-1 at perihelion,
approximately as $r^{-4.6}$, where $r$ is the heliocentric distance. The overall shape of the variation with time over the apparition shows many of the same general features as the visual light curve of Yoshida (http://www.aerith.net/comet/catalog/index-T-earth.html). SOHO is an international cooperative mission between ESA and NASA. Support from grant NNX11AH50G from the NASA Planetary Astronomy Program is also acknowledged.

313.06 Post-perihelion Spectroscopic Monitoring Of Comet C/2009 P1 (garradd) In L-band By Keck II / Nirspec
- Chiharu Naka1, M. Kyoudou1, H. Kawakita1, N. Dello Russo2, R. Vervack, Jr2, H. Kobayashi1
  1Koyama Astronomical Observatory, Japan, 2The Johns Hopkins University Applied Physics Laboratory.

We conducted near-infrared spectroscopic observations of comet C/2009 P1 (Garradd) on multiple dates (UT 2012 January 9 and 10, February 1, and April 4) after its perihelion passage by using NIRSPEC at KECK II telescope atop of Mauna Kea, Hawaii. We observed 8 parent molecules: H2O, HCN, C2H2, NH3, H2CO, CH3OH, CH4 and C2H6. The mixing ratios of these parent molecules relative to H2O were derived based on fluorescence excitation models. We compare our results with the observations performed before the perihelion passage and discuss the temporal change of chemistry for this comet. We also compare our results with other comets observed so far.

313.07 Pre-Perihelion Radio Observations of Comet C/2009 P1 Garradd
- Amy J. Lovell1, E. S. Howell2
  1Agnes Scott College, 2Arecibo Observatory.

We report results from radio observations of 18cm OH spectra in comet C/2009 P1 Garradd leading up to its perihelion. Spectra were obtained between July, 2011 and March, 2012, using both the Arecibo Observatory 305m radiotelescope and the National Radio Astronomy Observatory Green Bank Telescope (GBT). At 1667 MHz, the Arecibo beam resolution on the sky is 3 arcminutes, while that of the GBT is 8 arcminutes. Sampling in a hexagonal mapping pattern around the nucleus yields 7 positions on the coma spanning across 12 or 24 arcminutes, respectively. We followed the comet, regularly sampling spectra to constrain gas production, outflow velocity, and collisional quenching, over nearly a 1 AU range in heliocentric distance pre-perihelion. Coma outflow velocities, as would be expected at larger heliocentric distances, remain consistently low, and will be compared to estimates from other comets observed at heliocentric distances outside 1 AU. We also present OH production rates, considering collisional quenching as needed, in context with observations of other long-period comets.

313.08 A Study of C/2009 P1 Garradd's Dominant Volatiles as Observed by the Deep Impact HRI-IR Spectrometer
- Lori M. Feaga1, M. A'Hearn1, T. Farnham1, A. Gersch1, D. Bodewits1, K. Klaasen1
  1Univ. of Maryland, 2JPL.

In 2012, the Deep Impact (DI) spacecraft observed comet C/2009 P1 Garradd during its post-perihelion passage through the inner Solar System. The HRI-IR observations of Garradd (1.05-4.85 microns) were made on March 26 and April 2 when Garradd was at a heliocentric distance of 2 AU. All three dominant cometary volatiles, H2O, CO2, and CO, were detected simultaneously in the data and preliminary analysis shows that Garradd has high CO2 and CO to water ratios as compared to other comets. Further analysis and comparison to theoretical molecular emission spectra will allow for more accurate production rates and absolute abundances to be calculated. Derived values will be presented. Correlations with rotation period will also be studied. Final results will be compared to the DI narrow-band analysis and other pre- and post-perihelion data of Garradd’s 2011 apparition.

314 Comets 2
Wednesday, 3:30 PM - 6:00 PM, Exhibit Hall

314.01 Modeling Regolith to Test Point Designs for Microgravity Landers
- Naor Movshovitz1, E. Asphaug1, D. Korycansky1, T. Gabriel2
  1UC Santa Cruz, 2U. Central Florida.
A number of comet and asteroid rendezvous missions have flown in recent years, or are flying, and the pace of missions to microgravity bodies will accelerate to meet NASA’s goals of NEO characterization. We evaluate low cost, low risk, lander designs by considering ‘pods’ that have no moving parts, no guidance or thrust, that are designed to be thrown to the surface from the orbiting spacecraft. The design goal is to encourage the pods to land upright regardless of surface properties. With no need for guidance or articulation, these pods can be made and deployed to the surface at low cost and low risk. We consider three point designs: (1) a weighted ellipsoidal shape, the bottom five times as dense as the top, analogous to the children’s toy; (2) a pod with one side elastic and the other side inelastic; and (3) a combination. We have used a discrete element model based on NVIDIA’s PhysX library to design a simulation software suitable for modeling astrophysical rubble (Movshovitz, Asphaug and Korycansky, submitted). We then deploy different pod designs onto a numerical regolith testbed. Initial studies are very promising, although to date we have not included forces such as cohesion, and the effect of much smaller grain sizes than can be resolved in our simulations. We study the effect of bulk density, the velocity of deployment, and the effects of a tumbling or spinning deployment to the comet or asteroid surface. We are able to model the utility of internal actuators (vibrators, thumpers) that can rearrange or pods on the surface, or serve to embed them into a bed of loose soil. The size of the pods we are studying is ~30 cm average diameter. The key variables are shape, density distribution, and elastic properties, modeled by a coefficient of restitution.

314.02 Discrete Dipole Approximation Models of Crystalline Forsterite: Applications to Cometary Crystalline Silicates

Sean Lindsay1, D. H. Wooden2, C. E. Woodward3, D. E. Harker4, M. S. Kelley5, J. R. Murphy6
1University of Tennessee, 2Space Science Division, NASA Ames Research Center, 3Minnesota Institute of Astrophysics, University of Minnesota, 4Center for Astrophysics and Space Science, University of California San Diego, 5Department of Astronomy, University of Maryland, 6New Mexico State University.

In cometary comae, the crystalline silicate forsterite (Mg2SiO4) is the dominant crystalline component. Within the 8 - 40 micron spectral range, the crystal shape has been demonstrated to have a measurable effect on the crystalline features’ shape and peak wavelength locations. We present discrete dipole approximation (DDA) absorption efficiencies for a variety of forsterite grain shapes to demonstrate: a) that the 10, 11, 19, 23, and 33.5 micron resonances are sensitive to grain shape; b) spectral trends are associated with variations in crystallographic axial ratios; and c) that groups of similar grain shapes (shape classes) have distinct spectral features. These computations are performed using DDSCAT v7.0 run on the NASA Advanced Supercomputing (NAS) facility Pleiades. We generate synthetic spectral energy distribution (SED) fits to the Infrared Space Observatory (ISO) SWS spectra for the coma of comet C/1995 O1 (Hale-Bopp) at a heliocentric distance of 2.8 AU. Hale-Bopp is best fit by equant grain shapes whereas rounded grain shapes fit significantly poorer than crystals with sharp edges with well-defined faces. Moreover, crystals that are not significantly elongated along a crystallographic axis fit better. By comparison with Kobatake et al. (2008) condensation experiments and Takigawa et al. (2009) evaporation experiments, our analyses suggest that the forsterite crystals in the coma of Hale-Bopp predominantly are high temperature condensates. The laboratory experiments show that grain shape and grain formation temperature, and hence disk environment, are causally linked. Specifically, the Kobatake et al. (2008) condensation experiment reveals three shape classes associated with temperature: 1) ‘Bulky’ grains (1300 K < T < 1700 K), 2) ‘Platy’ grains (1000 K < T < 1300 K), and 3) columnar/needle grains (T < 1000 K). We construct DDA grain shape analogs to these shape classes to connect grain shapes to distinguishable spectral signatures and crystal formation environments.

314.03 Cometary Porous Aggregates Grains with Forsterite Crystal Inclusions: DDSCAT Modeling of Qabs for fitting IR SEDs

Diane H. Wooden1, S. S. Lindsay2, D. E. Harker3, M. S. Kelley4, C. E. Woodward5
1NASA Ames Research Center, 2University of Tennessee, 3UCSD/CASS, 4University of Maryland, 5University of Minnesota.

We present computations of absorption efficiencies (Qabs) of porous aggregate grains with forsterite crystal inclusions for modeling cometary IR spectral energy distributions (SEDs). We employ the DDA method using the DDSCAT code. DDSCAT computations of porous aggregates composed of monomers of amorphous pyroxene and forsterite (Mg2SiO4), with crystal mass fractions of 10-50%, yield interesting trends, namely: 1) in contrast to CDA
computational methods (Min et al. 2008), aggregates with spherical crystal monomers and crystalline mass fractions of ≥25%-50% still yield reasonably shaped features; 2) the crystal spectral features appear as if the aggregates have slightly higher crystal mass fractions than actually present, assessed by fitting aggregate’s Qabs by a linear mix of Qabs from discrete monomer grains; 3) an aggregate with 0.1μm sized crystal spherical monomers produces the 11μm peak that is broader and at longer wavelengths, mimicking a discrete ∼1μm crystal sphere; 4) the 23.5 μm feature complex, which is highly sensitive to crystal shape (Lindsay et al. 2012), traces the asymmetries of the 23.5 μm feature from a discrete crystal sphere but amplifies the longest wavelength shoulder; and 5) crystal features have higher contrast when incorporated into more highly porous aggregates. So, crystal mass fractions need to be assessed together with the aggregate grain porosity. The shapes of the crystal monomers, however, likely are not spherical but instead are prismatic shapes including tetrahedra and rectangular prisms, as shown by comparison to Nearly Isotropic comet Hale-Bopp’s SED at 2.8 AU. For Ecliptic comet comae that may be dominated by larger aggregate grains, crystal spectral features may be accounted for by crystal inclusions within their aggregate grains. Cometary silicate crystal mass fractions are benchmarks for disk radial transport models and aggregate porosities probe grain agglomeration and compaction processes in the protoplanetary disk prior to their incorporation into comet nuclei.

314.04 Formation Of Cometary Hydrocarbons By Hydrogen Addition Reactions On Cold Grains
- Hitomi Kobayashi1, N. Watanabe2, H. Kawakita1, T. Fukushima1
1Koyama Astronomical Observatory, Kyoto Sangyo University, Japan, 2Institute of Low Temperature Science, Hokkaido University, Japan.

Hydrogen addition reactions on cold grains are considered to play an important role to form many kinds of volatiles in low temperature conditions like molecular clouds or early solar nebula. We can investigate the physical conditions (e.g., temperature, gas density, and etc.) of the early solar nebula via chemical properties of the pristine bodies like comets. The hydrocarbons like C2H2 and C2H6 have been studied so far and C2H6 might be a product of successive hydrogen addition of C2H2 on the cold grain. To evaluate the efficiency of hydrogen addition reactions from C2H2 to C2H6 quantitatively, we conducted laboratory measurements of those reactions under multiple conditions of the samples (on H2O ice) at different temperatures (10, 20, 30 K) with the LASSIE apparatus at Hokkaido University. Our results provide more detailed information about those reactions than previous quantitative studies. We discuss about the reaction rates with different samples and conditions.

314.05 Light Scattering by Agglomerates with Varying Density
- Evgenij Zubko1, K. Muinonen1, Y. Shkuratov2, G. Videen3
1University of Helsinki, Finland, 2Kharkov National University, Ukraine, 3Space Science Institute.

We study light scattering by irregularly shaped agglomerate particles with packing densities of ρ=0.169, 0.236, and 0.336. At material densities of cometary refractory materials (i.e., 2-3 g/cm3), the bulk density of target particles is in the range 0.34-1 g/cm3, which is consistent with the Stardust samples [Hörz et al. 2006: Science 314, 1716]. We consider five different refractive indices m=1.313+0i, 1.5+0.1i, 1.855+0.45i, 2.43+0.59i, and 1.6+0.0005i, which represent water ice, organic materials, amorphous carbon, and Mg-rich silicates, i.e., the most abundant cometary species. At a wavelength of 0.684 μm, the radius of particles is varied from 0.1 μm to 3.9 μm (icy particles), 3.5 μm (carbonaceous particles), and 2.8 μm (silicate particles). Light-scattering properties are averaged over a minimum 500 particle shapes, and we also average light-scattering properties over particle size using the power-law size distribution r-a, and consider index a to range from 1 to 4. Our computations reveal quite weak impact of particle morphology on the light-scattering response. For instance, the phase dependence of the degree of linear polarization, geometric albedo, efficiencies for extinction and radiation pressure are nearly coincide for all three types of agglomerates having the same m and a. Varying refractive index or power index does alter the light-scattering properties considerably as compared to the morphology of agglomerates. Thus, one can attribute the spatial inhomogeneity of polarization in various comets [Hadamcik & Levasseur-Regourd 2003: J. Quant. Spectr. Rad. Tr., 79-80, 661] to variations in either chemical composition or size distribution of cometary dust, rather than to its morphology. Acknowledgments: This work was supported by the Academy of Finland (contract 127461), NASA programs for Outer Planets Research (grant NNX10AP93G) and Lunar Advanced Science and Exploration Research (grant NNX11AB25G).
314.06 Numerical Simulations of Lightcurves of Non-principal Axis Rotators

- Beatrice E. A. Mueller\textsuperscript{1}, N. H. Samarasinha\textsuperscript{1}
  \textsuperscript{1}Planetary Science Institute.

Theory predicts that most short-period comets should be in non-principal axis (NPA) rotational states (Jewitt 1997) due to torques caused by outgassing from the nuclei. However the fraction that is currently observed to be in such a state is small (less than 15%; Samarasinha et al 2004, and references therein). This suggests that NPA states naturally occurring as a consequence of cometary jetting are more rapidly damped because comets are structurally far weaker than has been assumed. However, there is a serious question whether this discrepancy is real or an artifact of interpreting lightcurve observations. We will present initial results of our numerical simulation of the observational manifestation of lightcurves over the range of possible NPA rotation states and determine the effects of observing geometry, signal-to-noise, and sampling. References: Jewitt, D. 1997. Cometary Rotation: An Overview. Earth, Moon, and Planets 79, 35-53. Samarasinha, N.H., B.E.A. Mueller, M.J.S. Belton, L. Jorda 2004. Rotation of Cometary Nuclei. In Comets II, pp. 281-299.

314.07 Comet Bursting Through Relaxation

- Seth A. Jacobson\textsuperscript{1}, D. J. Scheeres\textsuperscript{1}
  \textsuperscript{1}University of Colorado at Boulder.

Comets may be excited and occupy non-principal axis (complex) rotation states for a large fraction of their lifetimes. Many comet nuclei have been identified or are suspected to occupy non-principal axis (complex) rotation [Belton 2005, etc.] as well as have evolving rotation rates [Belton 2011, etc.]. Comet orbits drive these rotation states through cycles of excitation due to surface jets and relaxation due to time variable internal stresses that dissipate energy in the anelastic comet interior. Furthermore, relaxation from complex rotation can increase the loads along the symmetry axis of prolate comets. These loads stretch the body along the symmetry axis and may be the cause of the characteristic “bowling pin” shape and eventually may lead to failure. This is an alternative model for comet bursting. Each cycle deposits only a small amount of energy and stress along the axis, but this process is repeated every orbit during which jets are activated. Our model for the evolution of comet nuclei includes torques due to a number of discrete jets located on the surface based on Neishtadt et al. [2002]. The model also includes internal dissipation using an approach developed by Sharma et al. [2005] and Vokrouhlicky et al. [2009]. These equations are averaged over the instantaneous spin state and the heliocentric orbit so the long-term evolution of the comet can be determined. We determine that even after the inclusion of internal dissipation there still exist non-principal axis equilibrium states for certain jet geometries. For ranges of dissipation factors and jet geometries, prolate comets are found to occupy states that have time variable internal loads over long time periods. These periodic loadings along the symmetry axis may lead to “necking” as the body extends along the axis to release the stress and eventually disruption.

314.08 Radar Exploration of Cometary Nuclei

- Yonggyu Gim\textsuperscript{1}, E. Heggy\textsuperscript{1}, M. Belton\textsuperscript{2}, P. Weissman\textsuperscript{1}, E. Asphaug\textsuperscript{3}
  \textsuperscript{1}Jet Propulsion Laboratory, California Institute of Technology, \textsuperscript{2}Belton Space Exploration Initiatives LLC, \textsuperscript{3}Department of Earth and Planetary Sciences, University of California, Santa Cruz.

We have developed a mission formulation, based on the use of previously flown planetary radar sounding techniques, to image the 3D internal structure of the nucleus of a Jupiter-family comet (JFC). Believed to originate in the outer solar system and to be delivered recently to the inner solar system from the Kuiper Belt, JFCs are among the most primitive bodies accessible by spacecraft, and are indicated in the 2010 Decadal Survey as primary targets for primitive bodies sample return. We consider a sounder design operating at dual frequencies, 5 and 15 MHz center frequencies with 1 and 10 MHz bandwidths, respectively. Operating from close orbit about the nucleus of a spinning comet nucleus, CORE obtains a dense network of echoes that are used to image its interior structure to ~10 m and to map the dielectric properties inside the nucleus to better than 200 m throughout. Clear images of internal structure and dielectric composition will reveal how the nucleus was formed and how it has evolved. Radiometric tracking of the spacecraft orbit will provide an interior mass distribution that constrains the radar-
based models of interior composition. High-resolution visible and infrared color images provide surface and exterior boundary conditions for interior models and hypotheses. They present the geology and morphology of the nucleus surface at meter-scales, and the time-evolving activity, structure, and composition of the inner coma. By making global yet detailed connections from interior to exterior, the data from CORE will provide answers to fundamental questions about the earliest stages of planetesimal evolution and planet formation, will be an important complement to the Rosetta mission science, and will lay the foundation for comet nucleus sample return.

314.09 Compositional Taxonomy and Physical Properties of Comets from 35 Years of Narrowband Photometry
- Allison Bair¹, D. G. Schleicher²
  ¹Lowell Observatory.

Remnants from the epoch of early solar system formation, comet nuclei are less processed than any other class of objects currently available for detailed study. Consequently, differences in the chemical composition among comets can indicate either differences in protoplanetary material and primordial conditions in our solar system or subsequent evolutionary effects. By gathering chemical and physical data on as wide a sample of comets as possible, and correlating these with dynamical properties, we can perform statistical analyses to determine the actual cause of a specific difference in properties. We have recently completed a new uniform reduction and set of analyses of the Lowell comet database, which includes 35 years of narrowband photometry of 167 comets. To minimize uncertainties due to too few data points or other systematics, a restricted subset of the database was created for compositional studies, and mean abundance ratios were computed for each of these 102 comets. Between 5 and 7 compositional groupings are revealed through cluster analyses, including sub-groups of the original carbon-chain depleted class as defined by A'Hearn et al. (1995; Icarus 118, 223). All evidence continues to indicate that carbon-chain depletion reflects the primordial composition at the time and location of cometary accretion and is not associated with evolution. There is additionally a new grouping of several comets identified as being depleted in ammonia but not depleted in carbon-chain molecules. Other, non-compositional analyses were also performed, including active areas, active fractions, and the behavior of the dust-to-gas ratio. These investigations were not confined to our restricted subset, and instead used subsets of the entire database that were appropriate for each individual analysis. Details of these and other results will be presented. Support was provided by NASA Planetary Atmospheres grant NNX08AG19G.

314.10 New Techniques for Investigating the Morphology and Rotation of Component C of the Periodic Comet 73P/Schwassmann-Wachmann 3
- Melissa J. Dykhuis¹, N. H. Samarasinha², B. E. A. Mueller², S. P. Storm³
  ¹University of Arizona, ²Planetary Science Institute, ³University of Maryland.

Observations of temporal variations in the dust and gas morphology of comet nuclei can be used to infer the rotation states of the nuclei. The rotation of component C of Comet 73P/Schwassmann-Wachmann 3 is of particular interest, as it could place constraints on the damping timescale for non-principal axis rotation following the comet’s breakup event of 1995 (Crovisier et al. 1995, IAU Circ., 6227). We obtained narrowband H-B and broadband R images of component C from May 3-10, 2006 UT, near the comet’s perigee passage, using the 4-meter Mayall telescope on Kitt Peak. We identified the morphological features in the images using the enhancement method of division by azimuthal average. In addition, we binned the data to alleviate issues related to poor guiding and to increase the signal-to-noise. A new method for quantifying measurements of the features allowed for the development of a more robust statistic to evaluate the results, which yielded different period constraints than those found previously in Storm et al. (2007). Analysis of the dust morphology suggests a minimum periodicity of repeatability of the features of about 15 hours. This value is consistent with the lower limit of 10 hours determined from radar data (Nolan et al. 2006, BAAS 38, 504); however, it does not agree with the values around 3-4 hours determined using HST lightcurves and HCN morphology (Toth et al. 2006, BAAS 38, 489; Drahus et al. 2010, A&A 510, respectively). MJD’s work was supported by a National Science Foundation Graduate Research Fellowship. NHS and BEAM were supported by the NASA Planetary Atmospheres Program.

314.11 Gas Activity in Comets at Large Heliocentric Distances
Observations of comets and associated cometary activity as a function of heliocentric distance are a useful constraint on the various outgassing mechanisms. For heliocentric distances < 3 AU, the assumed primary driver of cometary activity is H2O sublimation. Activity at heliocentric distances > 3 AU has been observed for a number of comets, and debates continue as to if the activity is driven by an amorphous to crystalline H2O ice transition, or sublimation of other highly volatile species such as CO. As part of a narrowband imaging program utilizing the Hale-Bopp cometary filters and a spectroscopy program at the 2.3-m Bok Telescope, we present results on the gas and dust production of 7 comets with comae at heliocentric distances ranging from 3.34 to 6.72 AU. From this sample of objects at distances > 3 AU, we also present CN, C2, and C3 gas production values for 3 comets discovered in 2012 in order to classify them as either carbon "normal" or carbon-depleted.

314.12 A Numerical Study of Comet Mcnaught over a Wide Range of Heliocentric Distances
- Yinsi Shou¹, M. R. Combi¹, M. Rubin¹, G. Toth¹
  ¹Univ. of Michigan.

A numerical study of Comet McNaught combining two models is conducted. First, a single species magnetohydrodynamics (MHD) [Gombosi et al. (1996, JGR 101, 15233)] simulation is performed using a set of 'observed' comet parameters as input. Then a chemistry model [Häberli et al. (1997, Icarus 130, 373)] extracts the streamlines from the MHD model and calculates the densities of different species accounting for photo-dissociation, photo-ionization, electron recombination, ion-molecule and charge-exchange reactions. The MHD results are able to give the diamagnetic cavity sizes and shock distances at various heliocentric distances while the chemistry model better resolves the distribution of the major chemical species in the cometary plasma environment. The combination of the two models allows us to obtain detailed information on the chemical composition of a much wider range of atoms and molecules compared to multi-species or multi-fluid MHD models and at much lower computational expense. Some preliminary results are presented and discussed. This work has been partially supported by grant AST-0707283 from the NSF Planetary Astronomy program and NASA Planetary Atmospheres program grant NNX09AB59G.

314.13 A Sensitive Survey of Ammonia (NH₃) in Comets
- Karen P. Magee-Sauer⁴, G. L. Villanueva⁵, B. P. Bonev⁵, L. Paganini⁶, M. A. DiSanti⁶, M. J. Mumma⁴

Being the fully reduced form of nitrogen, ammonia (NH₃) is a key molecule for understanding the nitrogen chemistry in comets and to properly characterize the primordial conditions under which these icy bodies formed. Yet, its abundance has not been well characterized, even though NH₃ is a major reservoir of volatile nitrogen in comets. To date the abundance has been directly measured in only ~10 comets, all at radio and infrared wavelengths. This small sample is largely due to the difficulty in measuring emission from NH₃ since its emission is normally weak, can be affected by terrestrial extinction, and (without sufficient spectral resolution) is not resolved from other volatile cometary emissions. In this paper, we present a search for NH₃ in seven comets using archival data acquired by our Team using the NIRSPEC instrument at the Keck-2 telescope and the CSHELL instrument at the NASA Infrared Telescope Facility, both atop Mauna Kea, HI. Using an updated fluorescence model that is based on millions of ammonia spectral lines (Villanueva et al., in prep.), we present relative abundances of NH₃ with respect to H₂O. We find the relative abundance of NH₃/H₂O varies from ~0.3% to ~1.6% in these seven comets, and
we compare this indicator with other properties measured for these comets (isotopic fractionation and mixing ratios of selected primary volatiles). We gratefully acknowledge support from NASA's Postdoctoral Program (LP), the NASA Astrobiology Institute (PI MJM), NASA's Planetary Astronomy (PI GLV; PI MJM; PI DiSanti) and Planetary Atmospheres (PI DiSanti, PI Villanueva) programs, and from NSF Planetary Astronomy program (PI BPB).

314.14 A Search For 15NH2 Lines In Comet C/2002 T7 (LINEAR)
- Philippe Rousselot1, O. Pirali2, E. Jehin3, M. Vervloet2, D. Hutsemékers3, J. Manfroid4, M. Martin-Drumel2, S. Gruet2, M. Lobanova1
1Obs. de Besançon, UTINAM UMR 6213 CNRS, France, 2Synchrotron SOLEIL, ligne AILES, UMR 8214 CNRS, France, 3Centre d’Astrophysique et de Géophysique, Belgium.

The determination of isotopic ratios in comets is of primary importance for a good understanding of their origin and the formation of solar system. The $^{14}\text{N}/^{15}\text{N}$ ratio is an interesting tracer, because of its variability among various solar system bodies. So far it has only been measured in bright comets through optical observations of the CN radical (Arpigny et al., 2003; Manfroid et al., 2009) and millimeter observations of HCN (Bockelée-Morvan et al., 2005, 2008). The measurements give for both species the same non-terrestrial isotopic composition ($^{14}\text{N}/^{15}\text{N}=150$ in comets versus $272$ in the Earth atmosphere), but HCN and CN are minor species. In order to get a determination of this ratio in another molecule we have searched for $^{15}\text{NH}_2$ lines in a high-resolution and high signal-to-noise ratio spectrum of comet C/2002 T7 (LINEAR) obtained with the UVES spectrometer at the VLT ESO 8-m telescope (Hutsemékers et al., 2008). This work is based on a new laboratory experiment conducted with the AILES beamline spectrometer at synchrotron SOLEIL to determine the $^{15}\text{NH}_2$ wavelengths by Fourier transform spectroscopy. We will present the first results obtained from these data, which have allowed to search for the first time $^{15}\text{NH}_2$ emission lines in a comet. References: Arpigny et al., 2003, Science, 301, 1522 Bockelée-Morvan et al., 2005, in Comets II, ed. M. C. Festou, H. U. Keller, & H. A. Weaver (Tucson: Univ. Arizona Press), 391 Bockelée-Morvan et al., 2008, ApJ, 679, L49 Hutsemékers et al., 2008, A&A 490, L31 Manfroid et al., 2009, A&A 503, 613

314.15 A Study Of CH A-X And B-X Emission Lines In Comets
- Mi-Rim Sohn1, S. Kim1
1Kyung Hee University, Korea, Republic of.


314.16 Composition and Cosmogonic Parameters of the Chemically Distinct Comet C/2007 N3 (Lulin)
- Erika L. Gibb1, G. L. Villanueva2, B. P. Bonev2, M. A. DiSanti2, M. J. Mumma2, Y. L. Radeva2
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Comets are remnants from the early solar system that retain the volatiles (ices) from the cold outer protoplanetary disk (beyond 5 AU) where they formed. Comet nuclei were among the first objects to accrete in the early solar nebula and many of them were subsequently incorporated into the growing giant planets. Gravitational scattering redistributed the remaining comet population by either sending them to the inner solar system, where they may have enriched the early biosphere, or scattering them into their present-day dynamical reservoirs. Since this early time, comets have been orbiting the Sun relatively untouched by processing mechanisms, until their orbits are perturbed towards the inner solar system. As such, they are believed to be among the most primitive objects in the solar system and may be representative of the material from which the solar system formed. Of particular interest is their icy volatile composition since other solar system objects have either lost or have had significant modifications to their volatile compositions since their formation. Many of the volatiles observed in
comets are also important prebiotic species. For example, H2CO is a chemical precursor to sugars and HCN and NH3 are precursors of amino acids. Studying comets is therefore a vital link to understanding the origin and evolution of our planetary system and life on Earth. We obtained high-resolution, near-infrared spectroscopic observations of Comet C/2007 N3 (Lulin) on 30 January - 1 February 2009 with NIRSPECT on Keck II. Lulin is an Oort Cloud comet with a very large aphelion distance, suggesting that it may have been dynamically new. We report production rates of H2O, C2H6, HCN, C2H2, CH4, NH3, H2CO, CH3OH, and CO. We also report two cosmogonic parameters: D/H ratio in H2O and CH4, and isomeric spin temperatures. The implications for comet formations scenarios are discussed.

314.17 Outgassing Of Parent Molecules In Comet C/2010 G2 (Hill) During Its Outburst At RH=2.5 AU


1Kyoto Sangyo University, Japan, 2The Johns Hopkins University Applied Physics Laboratory, 3University of California-Davis, 4McDonald Observatory, 5LEISA, Observatoire de Paris, France.

We performed high-dispersion near-infrared spectroscopic observations of Comet C/2010 G2 (Hill) at 2.5 AU from the Sun using NIRSPECT (R ~ 2.5x10^4) at the Keck II telescope on UT 2012 Jan 9 and 10. The comet had been in outburst since the end of Dec 2011. Over the two nights of our observations, prominent CH4 and C2H6 lines were detected. However, no obvious emissions were detected for H2O, HCN and CH3OH despite deep searches for those molecules. The change in relative strength of two emission lines of CH4 (R0 and R1) indicates that the rotational temperature was decreasing from Jan 9 to 10, indicating that the comet was likely near the tail end of its outburst. This work was supported by the NASA Planetary Astronomy and Planetary Atmospheres Programs and by the MEXT - Supported Program for the Strategic Research Foundation at Private Universities (2008-2012).

314.18 The Volatile Composition of 81P/Wild 2 and a Chemical Comparison to Other Jupiter-Family Comets


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The volatile abundances in Jupiter-family comet 81P/Wild 2 were measured on four dates in (UT 2010 Feb 22, 23 and Mar 28, 29) using high-dispersion (spectral resolving power ~ 25,000) infrared spectroscopy with NIRSPECT at the W. M. Keck Observatory. H2O was detected on all dates while CH3OH, C2H6 and HCN were detected on three dates. Tentative detections or upper-limits are also reported for C2H2, H2CO and NH3. Total gas production was about 50 - 100% higher in late February than in late March. Rotational temperatures were determined for H2O on UT February 22 and 23 and found to be about 30 K. HCN and NH3 abundances relative to H2O are in the typical range, while CH3OH, C2H6 and C2H2 are slightly depleted in 81P compared to other comets. We compare the overall parent volatile composition of 81P with other Jupiter-family comets, and while the parent volatile composition of 81P is formally consistent with its optical classification of carbon-chain depleted, it is more similar in parent volatile chemistry to carbon-chain normal 9P/Tempel 1 and 103P/Hartley 2 than to carbon-chain depleted 73P/Schwassmann-Wachmann 3. This work is supported by the NASA Planetary Astronomy and Planetary Atmospheres Programs.

314.19 Properties of the Nucleus, Dust Coma, and Gas Coma of Comet 29P/Schwassmann-Wachmann 1 As Observed By WISE/NEOWISE


1Univ. of Central Florida, 2Jet Propulsion Lab./Caltech and Infrared Processing and Analysis Ctr./Caltech, 3Applied Physics Lab./JHU, 4Planetary Science Inst., 5Jet Propulsion Lab./Caltech, 6Monterey Inst. for Research in Astronomy, 7Inst. for Astronomy/Univ. of Hawaii.

We present our analysis of mid-infrared imaging of comet 29P/Schwassmann-Wachmann 1 by the Wide-field Infrared Survey Explorer (WISE) [1,2]. The comet was observed on May 3-4, 2010 - not in strong outburst - with
imaging at 3.4, 4.6, 12, and 22 microns (a.k.a. bands W1, W2, W3, and W4). W1 and W2 were sensitive to the reflected-sunlight continuum and W3 and W4 to thermal emission. The comet’s coma was seen in all bands, with a point-source clearly embedded in W1, W3, and W4 imaging. A coma-fitting technique [3,4] let us photometrically extract this point-source from the images, thereby letting us measure the nucleus’s size, W1-band geometric albedo, and infrared beaming. The dust coma was most clearly seen at bands W1, W3, and W4, letting us estimate the dust production rate, extract spatially-resolved information about the dust albedo and color temperature, and constrain the grain composition and size distribution. W2 imaging shows a coma whose radial surface-brightness profile and photometry suggest we are seeing a gas component, specifically emission from CO and/or CO2, i.e. high-abundance species with emission lines within the bandpass. This lets us estimate 29P’s gas production rate and dust-to-gas ratio independently from earlier methods. We present a comparison of our dust, gas, and nucleus results to those from earlier studies of this comet. References: [1] E. L. Wright et al. 2010, AJ, 140, 1868. [2] A. K. Mainzer et al. 2011, ApJ, 731, 53. [3] C. M. Lisse et al. 1999, Icarus, 140, 189. [4] P. L. Lamy et al. 2004, in Comets II, pp. 223-264. Acknowledgements: This publication makes use of data products from (1) WISE, which is a joint project of UCLA and JPL/Caltech, funded by NASA; and (2) NEOWISE, which is a project of JPL/Caltech, funded by the Planetary Science Division of NASA.

314.20 Highly Depleted Ethane and Slightly Depleted Methanol in Comet 21P/Giacobini-Zinner: Application of Empirical g-factors for CH3OH near 50 K
- Michael A. DiSanti1, B. P. Bonev2, G. L. Villanueva1, M. J. Mumma1
  1Goddard Center for Astrobiology-NAI/NASA-GSFC, 2Goddard Center for Astrobiology-NAI/Catholic University of America.

We report results from high resolution (λ/Δλ ~ 24,000) infrared spectra of Comet 21P/Giacobini-Zinner (21P/GZ) using NIRSPEC at Keck II on UT 2005 June 03, approximately one month before perihelion. We simultaneously sampled emissions from the ν2 band of C2H6, the ν2 and ν3 bands of CH3OH, and several hot bands of H2O, permitting a direct measure of parent volatile abundances in 21P/GZ. Our production rate for H2O was consistent with that measured from previous apparitions as retrieved from optical, infrared, and mm-wavelength observations. Our analysis of C2H6 confirmed its previously reported strong depletion from IR observations during the 1998 apparition [1,2], similar to the depletion of C2 in 21P/GZ known from optical studies [3]. For CH3OH, we applied our recently published quantum model for ν3 [4], obtaining T_{r, rot} consistent with that for H2O (~ 50 K) and a high abundance ratio CH3OH/C2H6 (~ 9). We observed similar T_{r, rot} and CH3OH/C2H6 in Comet 8P/Tuttle [5,6], and used these to produce effective (empirical) ν2 g-factors for 157 lines [7]. Application of our empirical ν2 model to 21P/GZ provided a production rate consistent with that from ν3, and an abundance ratio CH3OH/H2O in agreement with that measured previously [1,8]. We present a summary of our results for 21P/GZ and compare with abundances obtained for other Jupiter family comets. Our study provides the first measure of primary volatile production rates for any JFC over multiple apparitions using high resolution ground-based IR spectroscopy. We acknowledge support from the NASA Planetary Atmospheres, Planetary Astronomy, and Astrobiology Programs and from the NSF Astronomy and Astrophysics Research Grants Program. References [1] Weaver et al. 1999 Icarus 142:482 [2] Mumma et al. 2000 ApJ 531:L155 [3] A’Hearn et al. 1995 Icarus 118:223 [4] Villanueva et al. 2012 ApJ 747:37 [5] Bonev et al. 2008 ApJ 680:L61 [6] Boehnhardt et al. 2008 ApJ 683:L71 [7] DiSanti et al. 2012 ApJ (in press) [8] Biver et al. 2002 EMP 90:323

314.21 WISE Observations of Rendezvous Mission Candidate Comets
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In 1992, Osip et al. wrote: "Several comet flyby and/or rendezvous missions are currently being planned, for which supporting groundbased data from previous apparitions should prove useful. Here, we discuss groundbased narrowband photometry obtained over the last 15 years for nine candidate comets, five of which have been observed on multiple apparitions--we derive limits on the size of each cometary nucleus. In order to facilitate spacecraft mission planning, we also present molecular abundance ratios, note variations in cometary activity as a function of orbital position and between apparitions, and note the overall degree of dustiness. A detailed analysis
of the characteristics of these nine viable mission candidates will provide necessary information for prioritizing targets for any future missions." In this work, we update Osip et al.’s 1992 work using recent photometric infrared observations of the best candidate comet spacecraft targets observed by WISE and other (IRAS, MSX, ISO, Spitzer) infrared space telescopes. The comets studied include 2P/Encke, 9P/Tempe1 1, 10P Tempe1 2, 19P/Borrelly, 22P/Kopff, 67P/Churyumov-Gerasimenko, 81P/Wild, 103P/Hartley 2, 107P/Wilson-Harrington. We present imagery, photometry, and temporal trend data, and derived estimates of the dust mass, spatial distribution, albedo/emissivity, and PSD for each comet.

314.22 Orbit Determination for Comet C/2011 W3 (Lovejoy) Using a New Technique
- Paul Chodas\(^1\), Z. Sekanina\(^2\)
\(^1\)Jet Propulsion Laboratory.

On Nov. 27, 2011, a bright, new member of the Kreutz system of sungrazing comets was discovered, designated C/2011 W3 (Lovejoy). During the 18 days remaining before perihelion, 116 ground-based astrometric observations were made, along with a several dozen from spacecraft observing the Sun. Unfortunately, pre-perihelion data alone was not sufficient for an accurate determination of the orbital period, and the spaceborne astrometric observations were not sufficiently accurate to help. Surprisingly, the comet survived perihelion, but it clearly underwent major changes: the nuclear condensation completely disappeared within days, and a narrow spine tail formed. Post-perihelion ground-based astrometry from Rob McNaught was referenced to the sunward tip of the spine tail, but it could not be used successfully in orbit solutions. We show that the spine tail was a synchronic feature which originated from the terminal disintegration of the nucleus, on Dec. 17.6 ± 0.2 UT (Sekanina & Chodas, submitted). In a new technique, we derive astrometric positions of the missing nucleus via two constraints: first, that it would lie on the extrapolated spine tail, and second, that it would lie on a line of orbital-period variation, obtained by forcing a range or orbital periods to sets of elements based on pre-perihelion astrometry. The resulting osculating orbital period is 698 ± 2 years, which shows that C/2011 W3 cannot be a fragment of any sungrazer observed since the 17th century, and must be a member of the expected new 21st-century cluster of bright Kreutz-system sungrazers, predicted by Sekanina & Chodas (2007).

314.23 Modeling and Retrieval of Cometary Gas Spectral Lines for Rosetta-MIRO Observations Of Comet 67p
- Seungwon Lee\(^1\), P. von Allmen\(^1\), S. Gulkis\(^1\), M. Hofstadter\(^1\), L. Kamp\(^1\)
\(^1\)Jet Propulsion Laboratory.

The Microwave Instrument for the Rosetta Orbiter (MIRO), on board the ESA Rosetta spacecraft, will observe spectral lines of water, carbon monoxide, ammonia, and methanol at submillimeter wavelengths from the coma of Comet 67P Churyumov-Gerasimenko. Realistic modeling of observations of the cometary gas spectral lines is critical in preparation and interpretation of the MIRO observations. In addition, a reliable and efficient inverse method to retrieve cometary parameters from the observed lines is needed to interpret the observation results and to refine the future observation planning. This paper reports the forward models and retrieval methods developed for the Rosetta-MIRO observations. The forward models start from a nucleus and coma surface condition to a coma profile, to a molecular level distribution, to MIRO spectral lines. A Direct-Simulation Monte Carlo (DSMC) technique is applied to model the gas kinetics in the cometary coma. The population distribution of the molecular levels is calculated using the accelerated Monte Carlo method. The retrieval problem that we faces with MIRO observation is (1) to retrieve coma profiles from the MIRO spectral lines and (2) to retrieve nucleus and coma surface conditions (jets, outgassing rate, outgassing velocity distribution) from the MIRO retrieved coma profile. The optimal estimation theory is applied for the MIRO retrieval problem. By using the forward models in combination, we studied the effect of the physical conditions of the comet nucleus and coma on the observations by MIRO at various observational conditions such as different heliocentric distances, local solar phases, observation distances to the comet nucleus, and viewing angles (e.g. nadir or limb). We also studied the behavior and performance of the retrieval method for various observational data and a priori knowledge. The study results are used to prepare the MIRO observations and refine the forward model and the retrieval scheme.

314.24 Rotational Properties of Comet 22P/Kopff
Timm-Emanuel Riesen¹, K. J. Meech¹, A. Zenn², M. Nassir²
¹Institute for Astronomy / NASA Astrobiology Institute, ²Institute for Astronomy.

Comet 22P/Kopff was discovered in 1906 (recovered 1916) and it was found that the orbit of the comet could not be explained fully by gravitational forces only. Several attempts to model these effects were carried out in the past. Jets on the surface of the nucleus are believed to cause the observed Nongravitational forces but all models suffer from a large number of assumptions on nucleus properties that are required to perform the theoretical calculations. The rotational period is particularly important as it is used to derive other characteristics as thermal properties, oblateness, and albedo. Lowry & Weissman (2003) reported a period of 12.30 +/- 0.08h. An extensive set of observations of comet 22P/Kopff has been obtained in an observational program of K. Meech that aimed to study the activity of comets as a function of heliocentric distance. >24 sets of observations have been performed between 1988 and 2012. Most data were taken with the UH 2.2m telescope, followed by Cerro Tololo Inter-American Observatory and Kitt Peak National Observatory. More than 400 frames on target have been obtained. Not all datasets are suitable for rotational analysis and cover enough time baseline to be used individually for period determination. Since most heliocentric distances are covered, there are data sets with no or little rotational information due to activity. The current work aims to analyze all available data in order to obtain the best rotational period possible. Preliminary results will be presented at the conference. This material is partly based upon work supported by the National Aeronautics and Space Administration through the NASA Astrobiology Institute under Cooperative Agreement No. NNA08DA77A issued through the Office of Space Science. References: Lowry, S. C., and Weissman, P. R.: CCD observations of distant comets from Palomar and Steward observatories, Icarus, Vol. 164, pp. 492-503, 2003.

314.25 Optical Properties Of Metal-silicate Dust Grain Analogs In The Infrared As A Function Of Wavelength, Temperature, And Composition
- Christina Richey¹, R. Kinzer¹, G. Cataldo², D. Benford³, J. Nuth³, R. Silverberg³, E. Wollack³, S. Rinehart³
¹Goddard Space Flight Center (ORAU), ²Goddard Space Flight Center (USRA), ³Goddard Space Flight Center.

Introduction: Interstellar dust grains are found in virtually every astrophysical environment. While the composition of interstellar dust remains a point of contention, there is little doubt that silicate material contributes a substantial fraction of the total mass of interstellar dust, illustrated by the strong absorption features at 9.7 and 18 μm due to silicates. The main objectives of this proposed research are to answer two questions: 1. What are the optical properties of silicate dust grains? 2. How do these properties vary as a function of wavelength, temperature, and composition? Experiment: Samples are produced at GSFC at the dust analog production facility. Due to the frequency dependence of the optical constants, different sample preparation methods must be used. The OPASI-T program utilizes multiple instruments (including novel techniques) to provide spectral data over a wide range of temperature and wavelengths. Methods include: 1. Transmission measurements via a Fourier Transform Spectrometer. 2. Waveguide measurements for extinction data at microwave wavelengths. 3. Reflection/Scattering measurements via a custom-built integration sphere. Analysis: From the transmission data we can determine the optical constants, n and k. The analysis of the laboratory transmittance data for each sample type is based upon different mathematical models, which are applied to each data set according to their degree of coherence. Mathematical models were implemented in MATLAB through a least-squares nonlinear fit of the transmission equations to the laboratory data. Results: Presented here are results from iron silicate and magnesium silicate dust grain analogs, in several sample types and at temperatures ranging from ~5 K to 300 K, across the infrared portion of the spectrum (from ~2-1,000 μm or ~5,000-10 [1/cm]). Fits of the models to the experimental data are relatively good. Water contamination played a role in our analysis for the KBr samples, and was accounted for.

Thursday, 18 October, 2012

400 Titan's Methane Cycle
Thursday, 8:30 AM - 10:00 AM, Tahoe Room
400.01 Specular Reflections From Titan: Implications For Titan’s Lakes And Atmosphere
- Jason M. Soderblom¹, C. Sotin², J. W. Barnes³, R. H. Brown⁴, K. J. Lawrence⁵, S. Le Mouelic⁶, L. A. Soderblom⁶, K. H. Baines⁷, B. J. Buratti⁷, R. N. Clark⁷, P. D. Nicholson⁷, VIMS team
  ¹Massachusetts Institute of Technology, ²Jet Propulsion Laboratory, ³University of Idaho, ⁴University of Arizona, ⁵Université de Nantes, France, ⁶U.S. Geological Survey, ⁷Cornell University.

Observations of near-infrared sunlight specularly reflected from Titan’s lakes provide valuable information regarding the composition and nature of the satellite’s surface and atmosphere (e.g., Barnes et al., 2010; Soderblom et al., 2012). Here we report on such observations acquired by the Cassini Visual and Infrared Mapping Spectrometer (VIMS) during the recent Cassini flybys T83 and T84 (May & June 2012). These are the first VIMS observations specifically designed to observe the specular reflection of the Sun from Titan’s lakes, following from fortuitous observations in July 2009 (Stephan et al., 2010). VIMS successfully observed several specular reflections during each of these flybys. These observations were acquired at higher incidence angles (order 80°) and (some) at lower altitudes (order 50,000km) than the 2009 data. Initial analyses show the observed intensity is consistent with the models published by Soderblom et al. (2012). Further analysis will provide tighter constrain on the atmospheric opacity at the time of the observations (data acquired at higher incidence angle are more sensitive to atmospheric attenuation). In the closest observation acquired during the T83 flyby, an increased signal is observed in the four pixels surrounding the specular point, creating a cross-like pattern of five pixels (the Sun is unresolved in these observations). Interpretations of these observations will be discussed.

400.02 Oases on Titan?
- Caitlin Ann Griffith¹, J. M. Lora¹, J. D. Turner¹, P. F. Penteado², R. H. Brown¹, M. G. Tomasko¹, L. Doose¹, C. See¹
  ¹University of Arizona, ²Universidade de Sao Paulo, Brazil.

Titan has clouds, rain and lakes, like Earth, but composed of methane rather than water. Unlike Earth, most of the condensible, the equivalent of 5m of methane globally averaged, lies in the atmosphere. That detected on the surface (~2m) appears black in Cassini Radar images. These lakes reside only poleward of the 50 latitude circles, where their presence is expected, because Titan’s circulation efficiently transports methane to the poles, thereby desiccating the tropics. Here we present an investigation of Titan’s tropical surface, using VIMS data recorded within 20S and 20N latitude (Nature, 486, 327, 2012). With a radiative transfer calculation that reproduces the in situ measurements by the Huygens Probe, we can derive the surface albedos to within 2% at 5 of the 7 window wavelength regions that probe Titan’s surface. Our analysis detects the presence of a 2,400 km² region where the surface is uniformly black at the 7 near-IR windows. These measurements indicate the presence of a ≥1m deep tropical lake, which is long lasting, having existed since 2004. Also indicated is the existence of several shallow ponds with ankle level depths. Because liquid methane is unstable on Titan’s tropical surface, this unexpected detection indicates a recent supply of methane from the subsurface. Our study poses the question of whether subsurface reservoirs supply Titan’s atmospheric methane. Such a source would explain the methane and the abounding organic material in Titan’s atmosphere, which is produced by the irreversible photolysis of methane. Unless resupplied, the current atmospheric methane inventory will be exhausted in 20 million years.

400.03 Have Titan’s North-Polar Lakes Changed?
- Stephen D. Wall¹, A. Hayes², C. Elachi³, E. Stefan³, P. Paillou⁴, T. Formico³, K. Mitchell¹, D. Casarano⁵, C. Notarnicola⁶
  ¹Jet Propulsion Laboratory, California Institute of Technology, ²University of California at Berkeley, ³Proxemy Research, ⁴Observatoire Aquitain des Sciences del’Univers, France, ⁵CNR-IRPI, Italy, ⁶EURAC-Institute of Applied Remote Sensing, Italy.

Cassini’s RADAR instrument acquired a SAR swath over Titan’s north polar lakes on May 22, 2012, providing repeat images of a number of the smaller lakes. Previous coverage of these lakes was obtained on various passes in 2006 and 2007. Among the principal objectives of the Cassini mission is to monitor the liquid in the lakes with the approach of northern summer. Evidence of change in the lakes’ levels might consist of shoreline changes, changes
in radar backscatter (e.g. as penetration increases or dry spots appear), or combinations of these. We have chosen ten lakes and lake complexes for study, ranging from ~4 to ~100 km largest dimension. Visual comparison of repeat images is complicated by the dissimilar imaging geometry and (in some cases) resolution, and by SAR speckle. There are ambiguous cases that require further study, but at this writing we cannot identify certain changes. Ambiguous cases will be analyzed by using electromagnetic models, which can also take into account different acquisition geometry. Further analysis will be carried out exploiting electromagnetic scattering models and inversion approaches (e.g., Bayesian) to provide estimate of the lake parameters and any related changes. Parts of the research described in this paper were carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

400.04 Is the Evaporation Rate of Methane from Titan's Lakes Greatly Overestimated?
- Scot C.R. Rafkin* 1
  1SWRI.

The only certain and known source of methane for the atmosphere of Titan on short timescales is the volatile organic lake reservoirs. In general, there will be a turbulent exchange of methane and sensible heat between the atmosphere and the surface of these lakes. The turbulent fluxes of methane and heat are controlled by a variety of factors that includes: the temperature of the lake and atmosphere, the molar fraction of methane in the lake, the methane vapor pressure of the air, the wind speed, the atmospheric stability, and the solar and infrared heat available to drive the system. In addition, the dynamics of both the lake and the atmosphere influence how the turbulent fluxes evolve over time. We present results from numerical simulations that explicitly calculate the turbulent fluxes of methane and energy at a lake surface under a variety of conditions. Results show that evaporative cooling of the lakes results in the production of a low level atmospheric inversion that drastically diminishes the magnitude of the fluxes by suppressing turbulent winds and lowering the bulk exchange coefficient. These results suggest that the rate at which lakes can supply methane to the atmosphere has been greatly overestimated. This work was supported by the NASA Planetary Atmospheres Program under Grant NNX10AB97G.

400.05 A Change Of Seasons On Titan Observed By Cassini
- Nicholas Teanby 1, P. Irwin 2, C. Nixon 3, R. de Kok 4, S. Vinatier 5, A. Coustenis 5, E. Sefton-Nash 1, S. Calcutt 2, M. Flasar 6
  1University of Bristol, United Kingdom, 2University of Oxford, United Kingdom, 3University of Maryland, 4SRON, Netherlands, 5Observatoire de Paris, France, 6Goddard Space Flight Center.

Cassini's tour of the Saturn system now spans over eight years, equivalent to more than a quarter of a Titan year. This provides us with an excellent opportunity to study atmospheric seasonal behaviour. Here we use infrared spectra measured by Cassini's CIRS instrument to determine variations in temperature and composition throughout the mission - covering northern fall to northern spring - and use these quantities as tracers to probe changes in atmospheric circulation. Our results focus on the middle atmosphere (stratosphere-mesosphere at 100-500km altitude), where the majority of atmospheric super-rotation occurs and where high altitude photochemical production is linked to the lower atmosphere and surface. Our observations show significant changes in the distribution of trace chemical species with season - indicating changes in large-scale circulation patterns around the 2009 equinox. The timing and behaviour of the transition between different seasonal regimes will be discussed, in addition to implications for atmospheric general circulation models. Cassini has allowed us to study these phenomena for the first time and is providing fresh insight into planetary atmospheric processes.

400.06 Low-Latitude Ethane Rain on Titan
- Paul Dalba 1, B. J. Buratti 1, R. H. Brown 2, J. W. Barnes 3, K. H. Baines 1, C. Sotin 1, R. N. Clark 4, K. J. Lawrence 1, P. D. Nicholson 5
  1Jet Propulsion Laboratory, California Institute of Technology, 2Lunar and Planetary Laboratory, University of Arizona, 3Department of Physics, University of Idaho, 4United States Geological Survey, 5Department of Astronomy, Cornell University.
Cassini ISS observed multiple widespread changes in surface brightness in Titan's equatorial regions over the past three years (Barnes, J. W. et al. 2012, Icarus, submitted). These brightness variations are attributed to rainfall from cloud systems that appear to form seasonally (Turtle, E. P. et al. 2011, Science, 331, 1414-1417). Determining the composition of this rainfall is an important step in understanding the “methanollogial” cycle that dominates Titan’s surface and atmosphere. In this study, we use data from Cassini VIMS to complete a thorough spectroscopic investigation of rain-wetted areas near Yalaing Terra, Hetpet Regio and central Adiri on Titan. We compute “before-and-after” spectral ratios of any areas that show either deposition or evaporation of rain at any point in the time span of August 2009 to January 2012. By comparing these spectral ratios to a model of liquid ethane that was calculated to match the resolution and sampling interval of VIMS (Brown, R. H. et al. 2008, Nature, 454, 607-610), we find that the rain is most likely composed of liquid ethane. The spectrum of liquid ethane contains multiple absorption features that fortunately fall within the 2-micron and 5-micron spectral windows in Titan’s atmosphere. We show that these features are visible in the spectra taken of Titan’s surface and that they are characteristically different than those in the spectrum of liquid methane. Furthermore, just as ISS saw the surface brightness reverting to its original state after a period of time, we show that VIMS observations of later flybys show the surface composition in different stages of returning to its initial form as well. This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology under contract to the National Aeronautics and Space Administration. Copyright 2012. All rights reserved.

400.07 Dark and Bright Albedo Changes in the Wake of a Titan Rainstorm

¹University of Idaho, ²JPL, ³JHU/APL, ⁴JPL/UCBerkeley, ⁵University of Arizona, ⁶Laboratoire AIM, France, ⁷University of Nantes, France, ⁸University of Wisconsin, ⁹Bear Fight Institute, ¹⁰USGS, ¹¹DLR, Germany, ¹²Caltech, ¹³Cornell, ¹⁴MIT.

Turtle et al. (2011) previously announced large-scale surface changes in Titan's tropics following a 2010 September cloudburst event. Those changes were areas that had darkened, and the darkening was attributed to surface wetting by rain. Here we will discuss the results of continued monitoring of the darkened areas by Cassini VIMS and ISS. These new observations show that instead of reverting to their previous state, the rain-darkened areas instead brightened beyond their original albedos starting a few months after the cloudburst event. The brightening was unexpected, and spectra show that it occurs in each of Titan’s atmospheric wavelength windows. The brightened spectra show some similarity to the heretofore unique signature of Xanadu. The areas slowly revert to their original spectra over a period of a year. The two hypotheses that we have not eliminated involve (1) volatile frosts resulting from evaporative cooling of rain-derived surface methane that later sublime, (2) deposition of a thin surface layer of very-fine-grained particles (similar to terrestrial playa lakes) that degrade due to aeolian erosion. Future calculations and observations will serve to constrain the mechanism that drives the brightening.

400.08 Titan’s Tropopause Temperatures from CIRS: Implications for Stratospheric Methane Cloud Formation
- Carrie Anderson¹, R. Samuelson², R. Achterberg², J. Barnes³, F. Flasar¹

¹NASA GSFC, ²University of Maryland, ³University of Idaho.

Analysis of Cassini Composite Infrared Spectrometer (CIRS) far-IR spectra enable the construction of Titan’s temperature profile in the altitude region containing the tropopause. Whereas the methane ν4 band at 1306 cm⁻¹ (7.7 μm) is the primary opacity source for deducing thermal structure between 100 km and 500 km, N₂–N₂ collision-induced absorption between 70 and 140 cm⁻¹ (143 μm and 71 μm) is utilized to determine temperatures at Titan’s tropopause. Additional opacity due to aerosol and nitrile ices must also be taken into account in this part of the far-IR spectral region. The spectral characteristics of these particulate opacities have been deduced from CIRS limb data at 58°S, 15°S, 15°N, and 85°N. Empirically, the spectral shapes of these opacities appear to be independent of both latitude and altitude below 300 km (Anderson and Samuelson, 2011, Icarus 212, 762–778), justifying the extension of these spectral properties to all latitudes. We find that Titan’s tropopause temperature is cooler than the HASI value of 70.5K by ~6K. This leads to the possibility that subsidence at high northern latitudes...
can cause methane condensation in the winter polar stratosphere. A search for methane clouds in this region is in progress.

400.09 The Strength Of Titan's Transport-driven Methane Cycle
- Jonathan L. Mitchell

The strength of Titan's methane cycle, as measured by precipitation and evaporation, is key to interpreting fluvial erosion and other indicators of the surface-atmosphere exchange of liquids. But the mechanisms behind the occurrence of large cloud outbursts and precipitation on Titan have been disputed. A global- and annual-mean estimate of surface fluxes indicated only 1% of the insolation, or \( \sim 0.04 \, \text{W/m}^2 \), is exchanged as sensible and/or latent fluxes. Since these fluxes are responsible for driving atmospheric convection, it has been argued that moist convection should be quite rare and precipitation even rarer, even if evaporation globally dominates the surface-atmosphere energy exchange. In contrast, climate simulations that allow atmospheric motion indicate substantial cloud formation and/or precipitation. We argue the top-of-atmosphere radiative imbalance -- a readily observable quantity -- is diagnostic of horizontal heat transport by Titan's atmosphere, and thus constrains the strength of the methane cycle. Simple calculations show the top-of-atmosphere radiative imbalance is \( \sim 0.5-1 \, \text{W/m}^2 \) in Titan's equatorial region, which implies 2-3 MW of latitudinal heat transport by the atmosphere. Our simulation of Titan's climate suggests this transport may occur primarily as latent heat, with \( \sim 7 \, \text{cm/year} \) net evaporation at the equator and net accumulation at higher latitudes. Thus the methane cycle could be 10-20 times previous estimates. Opposing seasonal transport at solstices, compensation by sensible heat transport, and focusing of precipitation by large-scale dynamics could further enhance the local, instantaneous strength of Titan's methane cycle by a factor of several.

401 Mercury and the Moon: Above, Middle, and Below
Thursday, 8:30 AM - 10:10 AM, Carson 1/2

401.01 Mercury’s Na Exosphere from MESSENGER data

MESSENGER entered orbit about Mercury on March 18, 2011. Since then, the Ultraviolet and Visible Spectrometer (UVVS) channel of MESSENGER’s Mercury Atmospheric and Surface Composition Spectrometer (MASCS) has been observing Mercury's exosphere nearly continuously. Daily measurements of Na brightness were fitted with non-uniform exospheric models. With Monte Carlo sampling we traced the trajectories of a representative number of test particles, generally one million per run per source process, until photoionization, escape from the gravitational well, or permanent sticking at the surface removed the atom from the simulation. Atoms were assumed to partially thermally accommodate on each encounter with the surface with accommodation coefficient 0.25. Runs for different assumed source processes are run separately, scaled and co-added. Once these model results were saved onto a 3D grid, we ran lines of sight from the MESSENGER spacecraft to infinity using the SPICE kernels and we computed brightness integrals. Note that only particles that contribute to the measurement can be constrained with our method. Atoms and molecules produced on the nightside must escape the shadow in order to scatter light if the excitation process is resonant-light scattering, as assumed here. The aggregate distribution of Na atoms fits a 1200 K gas, with a PSD distribution, along with a hotter component. Our models constrain the hot component, assumed to be impact vaporization, to be emitted with a 2500 K Maxwellian. Most orbits show a dawnside enhancement in the hot component broadly spread over the leading hemisphere. However, on some dates there is no dawn/dusk asymmetry. The hot portion of the source appears to be highly variable. The authors
acknowledge support from NASA through the MESSENGER Participating Scientist Program and Planetary Atmospheres research grants.

401.02 Seasonal Variability in Mercury’s Calcium Exosphere
- Matthew H. Burger¹, R. M. Killen², W. E. McClintock³, R. J. Vervack, Jr.⁴, A. W. Merkel³, A. L. Sprague⁵, M. Sarantos⁶, T. A. Cassidy³
  ¹Morgan State University & NASA GSFC, ²NASA GSFC, ³University of Colorado/LASP, ⁴John Hopkins University Applied Physics Laboratory, ⁵University of Arizona/LPL, ⁶University of Maryland Baltimore County.

Since MESSENGER orbital observations of Mercury began on 29 March 2011, the Ultraviolet and Visible Spectrometer (UVVS) channel of the Mercury Atmospheric and Surface Composition Spectrometer (MASCS) has made near-daily observations of calcium emissions in Mercury’s exosphere. These data, along with data obtained during the three MESSENGER flybys of Mercury in 2008 and 2009, have shown that the principal source of atomic calcium in the exosphere is located in the dawn equatorial region. Calcium is seen originating from a small region at a high temperature (>20,000 K), possibly as a product of the dissociation of calcium-bearing molecules ejected from the surface. However, the mechanism by which either atomic or molecular calcium is ejected from the surface is not currently known. During the one-year MESSENGER primary mission, UVVS measurements conducted over four Mercury years allow us to search for seasonal trends in the exospheric calcium abundance and the size and strength of the dawn calcium emission region.

401.03 Cometary Delivery of Lunar Water: Transient Atmosphere Dynamics and Deposition Patterns
- Parvathy Prem¹, N. A. Artemieva², E. Pierazzo², B. D. Stewart¹, D. B. Goldstein¹, P. L. Varghese¹, L. M. Trafton¹
  ¹The University of Texas at Austin, ²Planetary Science Institute.

Several missions have yielded observations that could indicate the presence of water ice in lunar polar regions. Our work aims to investigate cometary impacts as a mechanism for the delivery of water to permanently shadowed craters (‘cold traps’) at the lunar poles. Of particular interest is the influence of parameters such as impact angle, velocity and location on the long-term retention of cometary water. Our 3D, unsteady simulations use the SOVA hydrocode to model the impact and vaporization of a cometary nucleus composed of pure water ice, 2km in diameter, impacting at 30 km/s. Subsequently, a Direct Simulation Monte Carlo code, designed to handle rarefied planetary flows, is used to simulate the transient water vapor atmosphere that develops. Molecules in this atmosphere collide and migrate across the lunar surface, driven by diurnal variations in surface temperature, and may land in permanently shadowed craters, cold enough to trap water over geological time scales. Here, we discuss the dynamic development of the transient atmosphere and compare initial deposition patterns as gravitationally bound water vapor begins to fall back to the lunar surface, for two different impact angles: 45° and 60° from the horizontal. A greater fraction of water remains gravitationally bound to the Moon in the 60° case, and a less pronounced downrange focusing of the vapor results in a more symmetric initial deposition pattern. On the cold night-side of the Moon, water simply sticks to the surface. However, on the warm day-side, where residence times are much shorter, we observe the development of a relatively dense, low-speed, surface-hugging flow. A particularly interesting depositional feature is the concentration of mass at a point almost antipodal to the point of impact, where a convergence of streamlines results in a shock that channels water to the surface.

401.04 Understanding The Apparent Lack Of Cometary Impactors During The Late Heavy Bombardment On The Moon
- David A. Minton¹, J. Richardson¹
  ¹Purdue University.

The most widely adopted models for the cause of the LHB predict that comets, small bodies originating in the Kuiper Belt beyond Neptune, should have dominated this bombardment. However, observations of the size-frequency distribution of LHB-era impact craters are well matched by objects originating in the Main Asteroid Belt, not the Kuiper Belt. Some mechanisms have been proposed to explain this discrepancy, but none have been tested.
due to the lack of a well-constrained size distribution for comets originating in the Kuiper Belt. With a unique new numerical code called the Cratered Terrain Evolution model, we test hypotheses for the absence of a comet signature in the lunar cratering record, as well as set model-independent constraints on the amount of cometary bombardment allowed by the crater record.

**401.05 Ground-based Detection and Analysis of the LCROSS Impact Plume**

- **Paul D. Strycker**¹, N. J. Chanover², C. Miller², R. T. Hamilton³, B. Hermaly³, R. M. Suggs⁴

  ¹University of Wisconsin-Platteville, ²New Mexico State University, ³University of Hawaii / NASA Astrobiology Institute, ⁴NASA/John H. Glenn Research Center.

We observed the Lunar Crater Observation and Sensing Satellite (LCROSS) lunar impact on 9 October 2009 using the Agile camera with a V filter on the Astrophysical Research Consortium 3.5 m telescope at Apache Point Observatory. We employed a principal component analysis (PCA) to filter out large-scale seeing effects and imperfections in image registration from a series of 0.5-second images spanning eight minutes centered on the Centaur upper stage impact time. After applying the PCA filter, we detected an evolving plume from approximately 5-35 seconds after impact. We validated our detection method by comparing the time-varying plume brightness profiles from the LCROSS plume to those extracted from a synthetic image sequence that included a simulated plume. We performed 3-D ballistic simulations of trial plumes, extracted images with the correct viewing geometry from these simulations at 0.5-second intervals, superimposed these onto a computer-generated lunar landscape, and added actual seeing conditions and noise sources. We then extracted synthetic plume brightness profiles with the identical PCA filtering algorithm used to extract the LCROSS plume and compared them to the LCROSS plume brightness profiles. This comparison confirmed that the maximum surface brightness of the LCROSS plume was below the reported 3-σ detection limit for unfiltered data of 9.5 magnitudes arcsec⁻² at 4 km above the impact point (Chanover et al. 2011, JGR, 116, 8003). We generated two-part synthetic plumes consisting of a high-angle and low-angle component and compared brightness profiles of our synthetic plumes to our observed LCROSS plume to constrain the relative particle densities and initial velocities of the two components. The temporal evolution of the plume that we extracted from our ground-based observations of the LCROSS impact, combined with our ballistic modeling, provides insight into the plume dynamics. This has important implications for future lunar impact studies and future lunar missions.

**401.06 Consequences of Viscous Core-Mantle Coupling for Mercury's Spin Orientation**

- **Stanton J. Peale**¹, J. L. Margot², S. A. Hauck, II², S. C. Solomon³

  ¹UC, Santa Barbara, ²UC Los Angeles, ³Case Western Reserve University, ⁴Carnegie Institution of Washington.

Mercury has at least a partially liquid core, and it is rotating sufficiently slowly that the hydrostatic core-mantle boundary is nearly spherical. Viscous coupling between the core and mantle leads to a torque on the mantle proportional to the difference in the vector angular velocities. The constant of proportionality is related to the kinematic viscosity of the core material through the Greenspan and Howard spinup time for a fluid differentially rotating in its rotating spherical container. The torque on the core is the negative of the torque on the mantle. Differential rotation of the core and mantle leads to dissipation that drives the mantle and core to equilibrium states where the spin axes of the core and mantle are fixed in the frame of reference precessing with the orbit. These states involve significant offsets of the vector spins of mantle and core from each other and displacement of the mantle spin from the expected Cassini state position, which displacement increases as kinematic viscosity decreases. The core-mantle coupling has to be relatively strong with kinematic viscosity greater than 10 cm²/s in order that the mantle spin be within one standard deviation of its observed position.

**401.07 Mercury’s Tides As a Window to its Interior**

- **Sebastiano Padovan**¹, J. L. Margot², S. A. Hauck, II², S. C. Solomon³

  ¹UCLA, Department of Earth and Space Sciences, ²Case Western University, Department of Geological Sciences, ³Carnegie Institution of Washington, Department of Terrestrial Magnetism.
Measurements of the obliquity and forced librations of Mercury, along with the precise determination of the static component of the gravitational field obtained by MESSENGER, provide estimates of the polar moment of inertia of the planet and of the planet’s outer solid shell. Although these data greatly improve our knowledge of the planet’s interior, the process of inverting geodetic observations to infer the interior structure is highly non-unique, and a wide range of models are compatible with the available observations. The recent determination of the tidal component of the gravitational field, particularly the Love number $k_2$, can provide additional constraints on the interior structure of Mercury. The orbital timescale that characterizes the tidal action of the Sun is sufficiently short that the response of materials inside Mercury is dictated both by their elastic properties and by their physical state (e.g., solid or liquid). The presence of a liquid layer below the mantle should then manifest itself in the tidal component of the gravity field. Furthermore, it has recently been suggested that a dense solid metallic layer might surround the fluid core and form the bottom of the planet’s outer solid shell. If present, this layer, depending on its thickness and material properties, may influence the tidal response of Mercury. Calculations of the tidal response for a variety of interior models for Mercury provide a basis for comparison with observations.

401.08 The Effect of Nonhydrostatic Features on the Interpretation of Mercury’s Mantle Density from MESSENGER Results

- Peter Gao$^1$, D. J. Stevenson$^1$
- $^1$California Institute of Technology.

Recent Mercury gravity data obtained from MESSENGER, as reported by Smith et al., (Science, 336, 214-217, 2012) and Earth-based radar measurements of Mercury’s libration by Margot et al. (Science, 316, 710-714, 2007) have given an estimated value of Mercury’s mantle density of $3.650 \pm 0.225 \text{ g cm}^{-3}$. However, this value is too large when compared to surface composition results, and thus have led to the hypothesis that a solid layer of FeS exists below the silicate mantle. In this work, we offer an alternate explanation by invoking the effects of a non-spherical core caused by a degree 2, order 2 nonhydrostatic feature in the mantle on Mercury’s Cm/C value (mantle moment of inertia divided by total moment of inertia). Pioneered by Peale (Nature, 262, 265-276, 1976), the method used to calculate Cm/C requires that only the planet’s mantle contributes to the difference between the non-polar moments of inertia, $B-A$; thus, if there is a core contribution, then this method breaks down. We resolve this issue by calculating the value of a coefficient that represents the core-contribution to $B-A$ that would multiply the reported Cm/C value to give the correct one, assuming the core-mantle boundary is an equipotential. As this calculation is linear in the absence of other nonhydrostatic features, the value of the coefficient is independent of the magnitude of the nonhydrostatic effect. Thus, this effect must exist for any nonhydrostatic degree 2, order 2 feature, as opposed to the effects of other nonhydrostatic contributions, such as mantle convection. Resulting coefficient values lie between 0.58-0.81 for reasonable core densities, which correspond to mantle densities between 3 and 3.4 g cm$^{-3}$, matching that of typical silicate compounds. The value of the coefficient varies by less than 1% for variations in mantle and core densities over reasonable ranges.

401.09 Lunar Atmospheric Helium Detections By the LAMP UV Spectrograph On the NASA Lunar Reconnaissance Orbiter

- S. Alan Stern$^1$, K. Retherford$^1$, J. Cook$^1$, C. Tsang$^1$, P. Feldman$^2$, W. Pryor$^3$, R. Gladstone$^1$
- $^1$SwRI, $^2$Johns Hopkins University, $^3$Central Arizona College.

The LAMP far ultraviolet spectrograph aboard the NASA Lunar Reconnaissance Orbiter (LRO) was used in 2011 to search for the lightest noble gas, helium, in the tenuous lunar atmosphere. Based on that search, we report here the first detection of lunar atmospheric He by remote sensing, and point to future observations that can address questions about its source. We also report the discovery of lunar He atmospheric abundance variations detected by LAMP, including what appear to be several short-lived, extreme abundance increase events. If these are confirmed, the logical next question will be to determine whether they are of indigenous or exogenous origin. If they are of indigenous origin, they may offer a way to measure some kinds of lunar internal activity or seismicity from orbit.

401.10 Temporal Variability of Lunar Exospheric Helium During January 2012 from LRO/LAMP
We report observations of the lunar helium exosphere made between December 29, 2011, and January 26, 2012, with the Lyman Alpha Mapping Project (LAMP) ultraviolet spectrograph on NASA's Lunar Reconnaissance Orbiter Mission. The observations were made of resonantly scattered He I emission at 584 Å from illuminated atmosphere against the dark lunar surface on the dawn side of the terminator. We find no or little variation of the derived surface He density with latitude but day-to-day variations that likely reflect variations in the solar wind alpha flux. The 5-day passage of the Moon through the Earth’s magnetotail results in a factor of two decrease in surface density, which is well explained by model simulations.

402 Trans-Neptunian Objects 1: Dwarfs and Size
Thursday, 8:30 AM - 10:00 AM, Reno Ballroom

402.01 Stellar Occultations By Large TNOs On 2012: The February 3rd By (208996) 2003 AZ84, And The February 17th By (50000) Quaoar

1Observatoire de Paris-Meudon / LESIA, France, 2Instituto de Astrofísica de Andalucía, CSIC, Spain, 3Observatório Nacional / MCTI, Brazil, 4Observatoire de Paris-Meudon / IMCCE, France, 5Observatoire de la Côte d’Azur, France, 6Gnosca Observatory, Switzerland, 7Wise Observatory, Tel Aviv University, Israel, 8Weizmann Institute of Science, Israel, 9Physical Research Laboratory, India, 10IUCAA Girawali Observatory, India, 11Nikaya Observatory, India, 12Observatorio de Busot, Spain, 13Université de Toulouse, UPS-OMP, IRAP, France, 14EURASTER, Ibis cours Jovin Bouchard, 42000, France, 15Institut d’Astrophysique de l’Université de Liège, Belgium, 16Observatório do Valongo / UFRJ, Brazil, 17Observatoire de Genève, Switzerland, 18Observatorium Bosscha, Institut Teknologi Bandung, Indonesia, 19Oukaimeden Observatory, LPHEA, Cadi Ayyad University, Morocco, 20Moroccan Oukaimeden Sky Survey, Morocco.

On February 2012, two stellar occultation’s by large Trans-neptunian Objects (TNO’s) were observed by our group. On the 3rd, an event by (208996) 2003 AZ84 was recorded from Mont Abu Observatory and IUCAA Girawali Observatory in India and from Weizmann Observatory in Israel. On the 17th, a stellar occultation by (50000) Quaoar was observed from south France and Switzerland. Both occultations are the second observed by our group for each object, and will be used to improve the results obtained on the previous events. The occultation by 2003 AZ84 is the first multi-chord event recorded for this object. From the single chord event on January 8th 2011, Braga-Ribas et al. 2011 obtained a lower limit of 573 +/- 21 km. From the 2012 occultation the longest chord has a size of 662 +/- 50 km. The other chords will permit to determine the size and shape of the TNO, and derive other physical parameters, such as the geometric albedo. The Quaoar occultation was observed from south of France (Observatoire de la Côte d’Azur, TAROT telescope and Valensole) and from Gnosca, Switzerland. Unfortunately, all three sites in France are almost at the same Quaoar’s latitude, so in practice, we have two chords that can be used to fit Quaoar’s limb. The resulting fit will be compared with the results obtained by Braga-Ribas et al. 2011. Braga-Ribas F., Sicardy B., et al. 2011, EPSC-DPS2011, 1060.Ribas F., Sicardy B., et al. 2011, EPSC-DPS2011, 1060.

402.02 1000 Km Size Tnos (50000) Quaoar And (90482) Orcus Observed With Herschel Space Observatory
- Pablo Santos-Sanz1, S. Fornasier2, E. Lellouch3, T. G. Müller4, P. Panuzzo5, C. Kiss6, T. Lim7, M. Mommert8, J. Stansberry9, M. Mueller10, E. Vilenski10, J. L. Ortiz11, A. Thirouin17, R. Duffard11, TNOs are Cool Team

1LESIA, Observatoire de Paris, CNRS, UPMC Univ Paris 06, Univ. Paris-Diderot, France / Instituto de Astrofísica de Andalucía-CSIC-Granada, Spain, 2LESIA, Observatoire de Paris, CNRS, UPMC Univ Paris 06, 3LESIA, Observatoire de Paris, CNRS, UPMC Univ Paris 06,
We present results on the trans-Neptunian objects (TNOs) Quaoar and Orcus from Herschel Space Observatory within the key program "TNOs are Cool" (Muller et al. 2009, EM&P 105). These TNOs have been observed in the 70, 100 and 160 micron bands of the PACS instrument (spanning the peak of the thermal emission), and the 250, 350 and 500 micron bands of the SPIRE instrument. Each target was observed twice to remove the sky background in order to obtain the best photometry. Radiometric fluxes from Spitzer-MIPS at 24 and 70 microns have been combined with the Herschel thermal fluxes in the analysis. We apply the Near Earth Asteroid Thermal Model (NEATM- Harris 1998, Icarus 131) and thermo-physical models (TPMs) to these observations in order to obtain diameters, albedos and to constrain thermal inertia and emissivity. NEATM and the TPM require precise knowledge of the absolute visual magnitude and the phase integral of the objects. The TPM also includes knowledge or assumptions about the rotational period, lightcurve amplitude, pole orientation, and shape model. The NEATM combines these effects in the so-called "beaming factor". Our derived diameters for Quaoar and Orcus are very close to 1000 km and the Quaoar one is consistent with the value from occultation presented at the DPS-EPSC 2011 by Braga-Ribas et al. As both TNOs are binaries we can derive the bulk densities obtaining values near 2.3 g/cm3 for Quaoar/Weywot and 1.5 g/cm3 for Orcus/Vanth. The beaming factor of Quaoar and Orcus are somewhat higher and lower, respectively, than the TNO average, but still within the typical ranges of the individual subpopulation. This may hint to thermal inertia effects confirmed with the TPM. Emissivity effects for longer wavelengths (>160 micron) will be discussed.

402.03 TNOs are Cool: Analysis of Classical Kuiper Belt Objects from Herschel Space Observatory Data
- Esa Vilenius, C. Kiss, M. Mommert, T. Muller, P. Santos-Sanz, A. Pal, J. Stansberry, M. Mueller, N. Peixinho, S. Fornasier, E. Lellouch, A. Delsanti, A. Thirouin, R. Duffard, J. Ortiz

We present results from the sample analysis of classical Kuiper belt objects (CKBO) observed within the open time key program "TNOs are Cool" (Muller et al. 2009, Earth, Moon, Planets 105) of Herschel Space Observatory. About half of this sample was published in Vilenius et al. (2012, A&A 541) and together with earlier Spitzer Space Telescope results [Stansberry et al. 2008, in "Solar System Beyond Neptune" and Brucker et al. 2009, Icarus 201] the number of CKBOs with radiometric diameter/albedo solutions is increased to almost 40. About one quarter of these targets are dynamically cold. For the binaries (∼10) the effective radiometric size of the system is acquired to infer bulk densities. Our 3-band (70, 100, 160 μm) photometric observations with PACS cover the wavelength range where thermal emission from trans-Neptunian objects has its maximum. Each target was observed twice in order to characterize and remove the sky background, which is required in doing photometry of these faint targets. In order to derive simultaneously diameters and albedos from thermal-IR observations a thermal model is used in combination with absolute visual magnitudes and an assumed form of the phase integral. We use complementary data from Spitzer when available. The thermal model requires assumptions on the temperature distribution on the surface. We use the Near-Earth Asteroid Thermal Model [Harris 1998, Icarus 131] and fit the beaming parameter whenever data quality permits. We analyse correlations between the measured diameters and geometric albedos as well as between physical properties and colors or orbital elements for both the dynamically cold and hot CKBOs. We also analyse separately the correlations of large objects (D > ∼500 km). The anti-
correlation found between diameter and geometric albedo of dynamically hot CKBOs [Vilenius et al., 2012] will be re-investigated. We acknowledge support from German DLR, project 50 OR 1108.

402.04 Thermal Properties Of Trans-neptunian Objects And Centaurs From Combined Herschel And Spitzer Observations
- Emmanuel Lellouch¹, P. Santos-Sanz¹, M. Mommert², S. Fornasier¹, J. Stansberry³, T. Müller⁴, R. Duffard⁵, J. Ortiz⁵, C. Kiss⁶, E. Vilenius⁴, M. Mueller⁷, P. Lacerda⁸, A. Harris², TNOs are Cool Team
  ¹Obs. de Paris, France, ²DLR, Germany, ³Stewart Observatory, ⁴MPE, Germany, ⁵IAA, Spain, ⁶Konkoly Obs., Hungary, ⁷SRON, Netherlands, ⁸QUB, United Kingdom.

We present a study of the thermal properties of about 70 trans-Neptunian objects (TNOs) and Centaurs observed with Herschel Space Observatory (either PACS or PACS/SPIRE) and Spitzer (MIPS). The combined wavelength range is 24-160 μm and additionally up to 500 μm for a few targets. We apply radiometric modeling techniques (NEATM) to the measured fluxes to derive diameter, albedo and beaming factor (η). The latter parameter is a proxy for the combined effects of surface thermal properties (thermal inertia), surface roughness, and rotation properties. We examine the results and search for trends in the inferred η values with several parameters, including heliocentric distance, albedo, and rotational properties. In particular, the distribution of η as a function of heliocentric distance reveals a large dispersion in the η values, but also shows that there are no objects with large beam factors at low distances. This is an expected ensemble behaviour for a population of objects with low thermal inertia (probably less than 0-20 J m⁻² s⁻¹/² K⁻¹), consistent with thermo-physical modeling of a few selected objects, which suggests that these objects are covered with low-conductivity regolith.

402.05 The Sensitivity to Trans-Neptunian Dwarf Planets of the Siding Spring Survey
- Michele Bannister¹, M. E. Brown², B. P. Schmidt¹, P. Francis¹, R. McNaught¹, G. Garrad¹, S. Larson³, E. Beshore¹
  ¹The Australian National University, Australia, ²Caltech, ³University of Arizona.

The last decade has seen considerable effort in assessing the populations of icy worlds in the outer Solar System, with major surveys in the Northern and more recently, in the Southern Hemisphere skies. Our archival search of more than ten thousand square degrees of sky south of the ecliptic observed over five years is a bright-object survey, sensitive to dwarf-planet sized trans-Neptunian objects. Our innovative survey analyses observations of the Siding Spring Survey, an ongoing survey for near-Earth asteroids at the 0.5 m Uppsala telescope at Siding Spring Observatory. This survey observed each of ~2300 4.55 square degree fields on between 30 and 90 of the nights from early 2004 to late 2009, creating a dataset with dense temporal coverage, which we reprocessed for TNOs with a dedicated pipeline. We assess our survey’s sensitivity to trans-Neptunian objects by simulating the observation of the synthetic outer Solar System populations of Grav et al. (2011): Centaurs, Kuiper belt and scattered disk. As our fields span approx. -15 to -70 declination, avoiding the galactic plane by 10 degrees either side, we are particularly sensitive to dwarf planets in high-inclination orbits. Partly due to this coverage far from the ecliptic, all known dwarf planets, including Pluto, do fall outside our survey coverage in its temporal span. We apply the widest plausible range of absolute magnitudes to each observable synthetic object, measuring each subsequent apparent magnitude against the magnitude depth of the survey observations. We evaluate our survey’s null detection of new dwarf planets in light of our detection efficiencies as a function of trans-Neptunian orbital parameter space. MTB appreciates the funding support of the Joan Duffield Postgraduate Scholarship, an Australian Postgraduate Award, and the Astronomical Society of Australia.

402.06 Discovery and Characterization of an LS Neptune Trojan in the Search for a New Horizons Encounter Candidate
- Alex Parker¹, M. Buie², D. Osip³, S. Gwyn², M. Holman¹, D. Borncamp², J. Spencer², S. Benecchi⁵, R. Binzel⁶, F. DeMeo⁵, F. Fabbro⁴, C. Fuentes⁴, P. Gay², J. Kavelaars⁴, B. McLeod⁴, J. Petit⁹, S. Sheppard⁵, A. Stern², D. Tholen¹⁰, D. Trilling¹, D. Ragozzine¹, L. Wasserman¹¹, Ice Hunters
  ¹Harvard-Smithsonian Center for Astrophysics, ²Southwest Research Institute, ³Carnegie Observatories, ⁴Canadian Astronomy Data Center, Canada, ⁵Department of Terrestrial Magnetism, ⁶MIT, ⁷Northern
After its encounter with Pluto in July of 2015, New Horizons will be capable of performing a course change to target a more distant Kuiper Belt Object. We are currently engaged in a search for one or more candidate Kuiper Belt Objects to visit. In the course of this search, we identified a new L5 Neptune Trojan. This Trojan is as bright as the largest L5 Jupiter Trojan (H ~ 8.2), and has an inclination higher than any other known Neptune Trojan, at 29.4 degrees. We have performed numerical integrations of its orbit and confirmed that it is stably resonant for a large fraction of the age of the Solar System, making it only the second stable L5 Neptune Trojan known. Given our survey’s characteristics, the detection of this object confirms that the L5 Neptune Trojans are a large, highly excited population. In addition, we have obtained its photometric colors, a first for an L5 Neptune Trojan, and confirmed that it has a moderately-red color similar to the L4 Neptune Trojan cloud, which are similar to the Jupiter Trojan colors. In late 2013 this object passes within approximately 1.2 AU of the New Horizons spacecraft, and may be within the limits of detection of the LORRI imager. We present the discovery circumstances and our characterization of this Neptune Trojan, and its implications for the Neptune Trojan population. We also introduce a novel statistical technique for debiasing the Neptune Trojan orbit distribution, and compare these debiased orbit distributions to those of other minor planet populations.

The Deep Ecliptic Survey (DES) discovered nearly 500 Kuiper belt objects during 1998-2005 (Elliot et al. 2005, AJ, 129, 1117). Of these objects, 146 objects are classified as Classical, 44 as Scattered, 18 as Centaurs, and 104 as resonant objects in 16 different resonances, the most populous of which is the 3:2, with 52 objects. The search fields used by DES are fully characterized, enabling us to calculate the probability that an object with the discovered orbital and physical parameters would have been detected by the DES. These probabilities can be used to estimate the true populations of objects in different dynamical classes. Knowing the true populations allows characterization of the current dynamical distributions and constraint of the current total mass of the Kuiper Belt, important keys to understanding the evolution of the outer solar system. One method for calculating probabilities is to use a maximum-likelihood model characterized by probability density functions for H-magnitude, semimajor axis (a), eccentricity (e) and inclination (i), within the ranges of these parameters defined by the DES discoveries. We have employed this method to estimate the numbers of objects in the most populated DES dynamical classes. We will present the methodology, limitations to our technique, and the results to date.

With it being approximately 2000 x 1600 x 1000 km in size, (136108) Haumea’s extreme elongation makes it unique among known dwarf planets. The shape of this fascinating Kuiper Belt Object (KBO) is the result of a rotational deformation due to its extremely short 3.9-hour rotation period (Rabinowitz et al. 2006) which could be explained by a past dramatic collision (Brown et al. 2007 ; Ragozzine & Brown 2007; Snodgrass et al. 2010). Although a high bulk density estimated at a range of 2.6 to 3.3 g.cm−3 (Rabinowitz et al. 2006) suggests a more rocky composition than other KBOs, Haumea and its satellites are considered by a crystalline water-ice multiple system (Dumas et al. 2011). Moreover, Haumea has become the second Kuiper Belt Object after Pluto to show observable signs of surface features. Indeed, a region darker and redder than average on the surface of Haumea has been identified (Lacerda, 2010). In this contribution, we present Spectro-Imaging observations of Haumea obtained in the Near Infra-Red [1.6 to 2.4 μm] with the integral-field spectrograph SINFONI mounted on UT4 at the ESO Very Large Telescope. We present some results combining data from several epochs.
402.09 Ice Mineralogy Across and Into the Surfaces of Pluto, Triton, and Eris
  1Northern Arizona Univ., 2Lowell Obs., 3Southwest Research Institute, 4Univ. of Oklahoma, 5Missouri State Univ., 6California State University.

We present three near-infrared spectra of Pluto taken with the IRTF and SpeX, an optical spectrum of Triton taken with the MMT and the Red Channel Spectrograph, and previously published spectra of Pluto, Triton, and Eris. We combine these observations with a two-phase Hapke model, and gain insight into the ice mineralogy on Pluto, Triton, and Eris. Specifically, we measure the methane-nitrogen mixing ratio across and into the surfaces of these icy dwarf planets. In addition, we present a laboratory experiment that demonstrates it is essential to model methane bands in spectra of icy dwarf planets with two methane phases - one highly-diluted by nitrogen and the other rich in methane. For Pluto, we find bulk, hemisphere-averaged, methane abundances of 9.1 ± 0.5%, 7.1 ± 0.4%, and 8.2 ± 0.3% for sub-Earth longitudes of 10 deg, 125 deg, and 257 deg. Application of the Wilcoxon rank sum test to our measurements finds these small differences are statistically significant. For Triton, we find bulk, hemisphere-averaged, methane abundances of 5.0 ± 0.1% and 5.3 ± 0.4% for sub-Earth longitudes of 138 deg and 314 deg. Application of the Wilcoxon rank sum test to our measurements finds the differences are not statistically significant. For Eris, we find a bulk, hemisphere-averaged, methane abundance of 10 ± 2%. Pluto, Triton, and Eris do not exhibit a trend in methane-nitrogen mixing ratio with depth into their surfaces over the few cm range probed by these observations. This result is contrary to the expectation Grundy and Stansberry (2000) that since visible light penetrates deeper into a nitrogen-rich surface than the depths from which thermal emission emerges, net radiative heating at depth would drive preferential sublimation of nitrogen leading to an increase in the methane abundance with depth. NASA Planetary Astronomy and Outer Planets Research supported this project.

403 The Great Saturn Storm of 2010/2011 and its Aftermath
Thursday, 10:30 AM - 12:00 PM, Tahoe Room

403.01 The Evolution and Fate of Saturn’s Stratospheric Vortex: Infrared Spectroscopy from Cassini
  1University of Oxford, United Kingdom, 2Department of Astronomy, University of Maryland, 3NASA/Goddard Spaceflight Center, 4Department of Physics, The Catholic University of America, 5Jet Propulsion Laboratory, California Institute of Technology.

The planet-encircling springtime storm in Saturn’s troposphere (December 2010-July 2011) produced dramatic perturbations to stratospheric temperatures, winds and composition at mbar pressures that persisted long after the tropospheric disturbance had abated. Observations from the Cassini Composite Infrared Spectrometer (CIRS), supported by ground-based imaging from the VISIR instrument on the Very Large Telescope, is used to track the evolution of a large, hot stratospheric anticyclone between January 2011 and the present day. The evolutionary sequence can be divided into three phases: (I) the formation and intensification of two distinct warm airmasses near 0.5 mbar between 25 and 35N (one residing directly above the convective storm head) between January-April 2011, moving westward with different zonal velocities; (II) the merging of the warm airmasses to form the large single ‘stratospheric beacon’ near 40N between April and June 2011, dissociated from the storm head and at a higher pressure (2 mbar) than the original beacons; and (III) the mature phase characterised by slow cooling and longitudinal shrinkage of the anticyclone since July 2011, moving west with a near-constant velocity of 2.70±0.04 deg/day (1.4.5±0.4 ms at 40N). Peak temperatures of 220 K at 2 mbar were measured on May 5th 2011 immediately after the merger, some 80 K warmer than the quiescent surroundings. Thermal windshear calculations in August 2011 suggest clockwise peripheral velocities of 200-400 m/s at 2 mbar, defining a peripheral collar with a width of 65 degrees longitude (50,000 km in diameter) and 25 degrees latitude. Stratospheric acetylene (C2H2) was uniformly enhanced by a factor of three within the vortex, whereas ethane (C2H6) remained
unaffected. We will discuss the thermal and chemical characteristics of Saturn’s beacon in its mature phase, and implications for stratospheric vortices on other giant planets.

403.02 New Results of Visible Lightning on Saturn

- Ulyana A. Dyudina1, A. Ingersoll1, S. Ewald1, C. Porco3, G. Fischer3, Y. Yair4
  1Caltech, 2CICLOPS, Space Science Institute, 3Austrian Academy of Sciences, Austria, 4The Open University of Israel, Israel.

Visible lightning flashes on Saturn were first detected by Cassini camera during the August 2009 equinox*. We report new observations of visible lightning in 2009, and in 2010-2011, during the giant lightning storm in the North hemisphere. The 2009 lightning flashes are detected on the night side of Saturn at latitude around 35 degrees South, in broadband clear filter. The 2011 flashes are detected on the day side in blue wavelengths only. The energies of individual flashes range up to 8×10^9 Joules, larger than the published estimate of 1.7×10^9 Joules, which was derived from the first optical lightning observation on Saturn. The size of the flashes is similar to the previous detections, with diameter ∼200 km. Assuming that light from the lightning diffuses through the clouds above it, lightning occurs 125-250 km below the cloud tops. We discuss implications of blue-only detections of dayside lightning in 2011 on the lightning spectrum, and simultaneous observations of Saturn lightning in radio wavelengths. This research was supported by the NASA Cassini Project. *Dyudina, et al., 2010. Detection of visible lightning on Saturn. GRL 37, 9205.

403.03 Dynamics of Saturn’s 2010 Great White Spot from high-resolution Cassini ISS observations

- Ricardo Hueso1, A. Sánchez-Lavega1, T. del Río-Gaztelurrutia1
  1UPV/EHU, Spain.

On December 5th 2010 a storm erupted in Saturn’s North Temperate latitudes which were experiencing early spring season. The storm quickly developed to a planet-wide disturbance of the Great White Spot type. The ISS instrument onboard Cassini acquired its first images of the storm on 23th December 2010 and performed repeated observations with a variety of spatial resolutions over the nearly 10 months period the storm continued active. Here we present an analysis of two of the image sequences with better spatial resolution of the mature storm when it was fully developed and very active. We used an image correlation algorithm to measure the cloud motions obtained from images separated 20 minutes and obtained 16,000 wind tracers in a domain of 60 degrees longitude per 20 degrees in latitude. Intense zonal and meridional motions accompanied the storm and reached values of 120 m/s in particular regions of the active storm. The storm released a chain of anticyclonic and cyclonic vortices at planetocentric latitudes of 36º and 32º respectively. The short time difference between the images results in estimated wind uncertainties of 15 m/s that did not allow to perform a complete analysis of the turbulence and kinetic spectrum of the motions. We identify locations of the updrafts and link those with the morphology in different observing filters. The global behaviour of the storm was examined in images separated by 10 hours confirming the intensity of the winds and the global behaviour of the vortices. Acknowledgments: This work was supported by the Spanish MICIN project AYA2009-10701 with FEDER funds, by Grupos Gobierno Vasco IT-464-07 and by Universidad País Vasco UPV/EHU through program UFI11/55.

403.04 Slicing The 2010 Saturn’s Storm: Upper Clouds And Hazes

- Santiago Perez-Hoyos1, J. F. Sanz-Requena2, A. Sanchez-Lavega1, R. Hueso1
  1UPV/EHU, Spain, 2Universidad Europea Miguel de Cervantes, Spain.

At the end of 2010 a small storm erupted in Saturn’s northern mid-latitudes. Starting from a localized perturbation, it grew up to be a global-scale disturbance and cover the whole latitude band by February, 2011 (Fletcher et al. 2011, Science 332; Sánchez-Lavega et al. 2011, Nature 475; Fischer et al. 2011, Nature 475). By June, 2011 the storm was facing its end and gradually disappeared (Sánchez-Lavega et al. 2012, Icarus 220). In this work we use the observations acquired by the Cassini ISS instrument during the whole process to investigate the vertical cloud and haze structure above the ammonia condensation level (roughly 1 bar). Cassini ISS observations cover visual wavelengths from the blue to the near-infrared including two methane absorption bands. Such observations have been modeled using a radiative transfer code which reproduces the atmospheric reflectivity as a function of
observation/illumination geometry and wavelength together with a retrieval technique to find maximum likelihood atmospheric models. This allows to investigate some atmospheric parameters: cloud-top pressures, aerosol optical thickness and particle absorption, among others. We will focus on two aspects: (1) maximum likelihood models for the undisturbed reference atmosphere in the 15ºN to 45ºN band before and after the disturbance; (2) models for particular structures during the development of the global-scale phenomenon. Our results show a general increase of particle density and single-scattering albedo inside the storm. However, some discrete features showing anomalous structure and related to the storm peculiar dynamics will also be discussed. Acknowledgments: This work was supported by the Spanish MICIIN project AYA2009-10701 with FEDER funds, by Grupos Gobierno Vasco IT-464-07 and by Universidad País Vasco UPV/EHU through program UFI11/55.

403.05 The Evolution of Hydrocarbons in Saturn’s Northern Storm Region
- Gordon Bjoraker1, B. E. Hesman2, R. K. Achterberg2, P. N. Romani1
  1NASA/GSFC, 2Univ. Of Maryland.

The massive storm at 40N on Saturn that began in December 2010 has produced significant and lasting effects in the northern hemisphere on temperature and species abundances (Fletcher et al. 2011). The northern storm region was observed on several occasions between March 2011 and April 2012 by Cassini’s Composite Infrared Spectrometer (CIRS) at a spectral resolution (0.5 cm⁻¹) which permits the study of trace species in Saturn’s stratosphere. During this time period, stratospheric temperatures in regions referred to as “beacons” (warm regions at specific longitudes at the latitude of the storm) became significantly warmer than pre-storm values of 140K, peaking near 220K, and subsequently cooling. These warm temperatures led to greatly enhanced infrared emission due to C₄H₂, C₃H₄, C₂H₂, and C₂H₆ in the stratosphere as well as the first detection of C₂H₄ on Saturn in the thermal infrared (Hesman et al. 2012). Using CH₄ as a thermometer of Saturn’s stratosphere in the beacon regions, we can derive the mixing ratios of each of these molecules. The most common hydrocarbons (C₂H₂ and C₂H₆) serve as dynamical tracers on Saturn and their abundances may constrain vertical motion in the stratosphere. All of these hydrocarbons are products of methane photolysis. Since many of the photochemical reactions that produce heavier hydrocarbons such as C₄H₂ and C₃H₄ are temperature sensitive, the beacon region provides a natural laboratory for studying these reactions on Saturn. We will discuss the time evolution of the abundances of each of these hydrocarbons from their pre-storm values, through the period of maximum heating, and during the period of cooling that is taking place in Saturn’s stratosphere. References: Fletcher, L. N. et al., 2011. Thermal Structure and Dynamics of Saturn’s Northern Springtime Disturbance. Science 332, 1413-1417. Hesman, B. E. et al., 2012. Elusive Ethylene Detected in Saturn’s Northern Storm Region (submitted).

403.06 Ethylene Emission in the Aftermath of Saturn’s 2010 Northern Storm
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The massive eruption at 40N (planetographic latitude) in December 2010 has produced significant and long-lived changes in temperature and species abundances in Saturn’s northern hemisphere (Fletcher et al. 2011). The northern storm region has been observed on many occasions between January 2011 and June of 2012 by Cassini’s Composite Infrared Spectrometer (CIRS). In this time period, temperatures in regions referred to as “beacons” (warm regions in the stratosphere at certain longitudes in the storm latitude) became significantly warmer than pre-storm values of 140K. A significant finding in the beacon region has been ethylene emission; a molecule that has been challenging to detect on Saturn but is an important species in Saturn’s photochemistry. The derived ethylene profile from the CIRS data gives a C₂H₄ mole fraction of 5.9 ± 4.5x10⁻⁷ at 0.5 mbar. Ground-based observations were performed using the high-resolution spectrometer Celeste to study ethylene’s spectral signatures at higher spectral resolution than available with CIRS. Analysis of the May 2011 Celeste data finds a C₂H₄ mole fraction of 2.7 ± 0.45x10⁻⁶ at 0.1 mbar. The ethylene abundances derived from CIRS and Celeste observations are two orders of magnitude higher than predicted by photochemical models, indicating that perhaps another production mechanism is required or a loss mechanism is being inhibited. To investigate the source of ethylene in the beacon region the temporal evolution of this molecule will be presented based on data collected by CIRS,

403.07 Herschel Temporal Monitoring Observations Of H2O In Saturn's Hot Stratospheric Vortex Between 2011 And 2012
- Thibault Cavalié1, H. Feuchtgruber2, B. Hesman3, E. Lellouch4, R. Moreno4, T. Fouchet4, R. Achterberg3, A. Moullet5, P. Hartogh6
1Laboratoire D’Astrophysique De Bordeaux, France, 2Max Planck Institute für Extraterrestrische Physik, Germany, 3University of Maryland/NASA GSFC, 4Observatoire de Paris, France, 5NRAO, 6Max Planck Institute für Sonnensystemforschung, Germany.

The planetary-scale storm that perturbed Saturn’s seasonal cycle in its northern hemisphere in 2010-2011 has left a hot stratospheric vortex at 40°N. This large vortex is still observable as of mid-2012. Cassini and ground-based observations have shown that the temperature and the chemistry of hydrocarbons have been perturbed in the vortex. We have observed Saturn when the vortex was visible with the Herschel Space Observatory in July 2011, February and July 2012 to map H2O at 66 and 67 microns and CH4 at 120 microns with the PACS instrument and CH4 at 159 microns with the HIFI instrument. We use the CH4 maps as a temperature probe and the H2O maps to check if the chemistry of oxygen compounds has also been perturbed by the vortex. In this paper, we will present the observations and their analysis to illustrate the temporal evolution of the abundance of H2O in the vortex. For instance, we inferred an increase by a factor of 30-100 of the H2O column in the vortex with Herschel/PACS in July 2011 in a preliminary analysis. T. Cavalié is supported by funding from CNES.

403.08 Numerical models of Saturn’s 2010 Great White Spot
- Enrique Garcia-Melendo1, J. Legarreta2, A. Sánchez-Lavega3, R. Hueso4
1Fundació Observatori Esteve Duran - Institut Ciencies Espai (CSIC-IEEC), Spain, 2EUITIB, Universidad del País Vasco, Spain, 3ETSIB, Universidad del País Vasco, Spain.

The last big storm outbreak, of the Great White Spot type, took place in December 2010 and was the best ever observed Saturn’s great storm thanks to ground-based and space-based Cassini Mission follow-up. The enormous activity of the storm was followed by large-scale phenomena, some of them new, such as very intense electrostatic discharge activity, a warming by ~40K of the higher stratosphere above the storm, and a turbulent belt-like region that encircled the whole planet in a few months altering the regular planet’s cloud morphology. We performed non-linear numerical simulations of the storm by using the EPIC model, a GCM which uses potential temperature as the vertical coordinate, and accounts for stratification and vertical thermal and vertical wind shear structures. We also used a shallow water model, a simplification of the primitive Navier-Stokes equations after imposing special conditions to the fluid, but able to retain some of the fundamental dynamics. Both models were able to reproduce general aspects of the observed storm’s cloud morphology and dynamics, such as the initial development of the storm, and the high horizontal velocities around the storm’s head surrounding the ascending convective cells. Simulations indicate that the event transported big amounts of mass up to the visible cloud top level, close to the tropopause, which formed cell-like anticyclonic regions whose north limit developed high velocity winds.

Acknowledgments: This work was supported by the Spanish MICIIN project AYA2009-10701 with FEDER funds. We are thankful to the ICE computer facilities. We also used computing facilities at CESCA (Barcelona) supported by MICIIN.

403.09 Seasonal Changes in Vortex Behavior on Saturn
- Harold J. Trammell1, L. Li1, M. A. Smith1, X. Jiang1, A. R. Vasavada2
1University of Houston, 2Jet Propulsion Lab (JPL).

The multi-filter images from the Imaging Science Subsystem (ISS) onboard Cassini are utilized to explore the vortex behavior on Saturn during the time period of 2004-2011 (starting in northern winter, moving through equinox, into northern spring). Our exploration is concentrated in the northern hemisphere, which is a follow-up study of the
vortex survey in the southern hemisphere (Vasavada et al., 2006). We mainly utilize ISS images from two filters (i.e., MT3 and CB2), which probe the pressure levels around the tropopause and upper troposphere, respectively. Our exploration based on the maps in 2005 and 2008 suggests that there are significantly different vortex behaviors (i.e., size, spatial distribution, and vertical structure) between the two hemispheres. We are exploring more global maps after Saturn’s spring equinox (August, 2009) to see if there are seasonal effects on the vortex behavior.

404 Mars: Organics, Biomarkers, and Climate Change

Thursday, 10:30 AM - 11:30 AM, Carson 1/2

404.01 Mars Organic Molecule Analyzer: The Search For Biosignatures And Biohints On Mars
- Arnaud Buch¹, C. Freissinet², A. Brault³, R. Sternberg³, C. Rodier³, C. Szopa³, P. Coll³, V. Pinnick³, MOMA Team
  ¹Ecole Centrale Paris, France, ²NASA Goddard Space Flight Center, ³LISA, UPEC, France.

The joint ESA-Roscosmos Exo-Mars-2018 rover mission seeks the signs of past or present life on Mars. The Mars Organic Molecule Analyzer (MOMA) aboard the ExoMars rover will be a key analytical tool in providing chemical (molecular) information from the solid samples, with particular focus on the characterization of organic content. One of the instruments aboard MOMA is a gas chromatography-mass spectrometry (GC-MS) which provides a unique ability to characterize a broad range of compounds allowing chemical analyses on volatile and non-volatile species. The key challenge with the analysis of refractory organic compounds contained in soil is their extraction and subsequent analysis by GC-MS. Since the extraction of organic matter is not possible by liquid solvent extraction, thermodesorption followed by derivatization has been developed. The goal of the thermodesorption is to quickly extract the organic matter before degradation. One of the main focus is to determine the chirality of amino acids. Indeed, on earth homochirality (especially the L-form) is an indicator for the presence of life. However, other refractory compounds can be analyzed: nucleobases, carboxylic acids, PAHs, etc. Thermodesorption occurs within a range of temperatures from 150 °C to 300 °C over a period of 30 s to 10 min, depending on the chemical compound. Under these conditions, we have shown that amino acids are not degraded and that their chirality is preserved. Once extracted, refractory molecules with labile hydrogens (e.g. amino acids, nucleobases, carboxylic acids, etc.) were derivatized. General and sensitive derivatization occurs with a silylated compounds N,N-methyl-tert-butyl-dimethylsilyl-trifluoroacetamide (MTBSTFA). Derivative compounds were separated on an RTX-5 (Restek) column. If a chiral separation was targeted, then dimethylformamide dimethylacetamide derivatization (DMF-DMA) was utilized. With DMF-DMA 11 of the 19 proteinic amino acids were separated on the Chirasil-b-dex (Varian) chiral column.

404.02 Laboratory Simulation of Organic Molecules Evolution at the Surface of Mars
- Olivier Poch¹, A. Noblet¹, M. Jaber², J. Lambert², T. Georgelin³, C. Szopa³, P. Coll³
  ¹LISA, CNRS, Université Paris Diderot, Université Paris Est Créteil, France, ²LRS, CNRS, Université Pierre et Marie Curie, France, ³LATMOS, CNRS, Université Pierre et Marie Curie, Université Versailles St-Quentin, France.

Understanding the evolution of organic matter on Mars is a major goal since no carbonaceous compound has been definitely detected so far on Mars. In this context, we developed the MOMIE project (for Mars Organic Molecules Irradiation and Evolution) dedicated to simulate the processes which potentially drive the evolution of organics, and evaluate the stability of organic molecules under current environmental conditions at the surface of Mars. The laboratory experiment we developed enables us to study the impact of Martian-like UV irradiation and oxidation processes on organic molecules likely to be found at the surface of Mars (from endogeneous or exogeneous sources). Our samples consist of 10 to 1000 nm thick layers of pure organic molecules or organic molecules adsorbed on minerals. The evolution of the sample is monitored by in situ FTIR spectroscopy and mass spectrometry in order to have access to kinetic data along with a characterization of solid and gaseous products potentially present at the surface of Mars. We can assess the relative stability of several organic layers under UV
irradiation and reproduce mineralogical driven oxidation pathways known to be important at Mars. In the frame of the search for organics in Gale crater by the MSL Curiosity rover, we plan to study the evolution of organics adsorbed in nontronite synthesized iron rich clay. Because clay minerals, spotted from orbit, have likely been host for organic compounds since early Mars -when prebiotic chemistry might have flourished-, it seems essential to test the processes these organics may have undergone in these preferential mineral matrixes. Hence, Earth-based testing of the degradation or preservation of organic molecules in mineral matrixes submitted to oxidation and/or irradiation will provide essential insights to guide and discuss in situ analyses at Mars.

404.03 Alkaline Hydrothermal Vents on Wet Rocky Planets: "Geochemical Fuel Cells" driving the Emergence of Life

- Laura Barge
  1Caltech / Jet Propulsion Laboratory.

Alkaline hydrothermal vents on wet rocky worlds, formed by serpentinization reactions when a liquid water ocean is in contact with a rocky layer, generate energy that may be sufficient to drive the emergence of a primitive metabolism. These vents are thought to have existed on the early Earth and may also be present on Europa. The electrochemical and pH gradients between ocean and hydrothermal solutions at a vent interface form a "geochemical fuel cell" that may be able to drive prebiotic reactions such as formation of polyphosphates or peptides, and/or reduction of carbon dioxide. We have simulated alkaline hydrothermal systems in a membrane fuel cell setup in the laboratory, using electrochemical/chemical analysis techniques to investigate the energy generation and prebiotic chemistry that could occur within the hydrothermal mound. The membrane interface between simulated ocean / hydrothermal fluids in our fuel cell generated electrical potentials between 0.2-0.6 V, forming an iron sulfide precipitate that may be sufficiently catalytic to drive redox reactions of carbon species. We also observed formation of polyphosphate energy storage molecules within the pH gradients in the iron sulfide membrane, possibly indicating the influence of an ambient proton motive force. Our laboratory fuel cells are analogous in many ways to biological cells as well as geochemical environments in which life may emerge on wet rocky worlds. (Funded by the NASA Astrobiology Institute Icy Worlds team.)

404.04 The Sample Analysis At Mars Gas Chromatograph (sam-gc) Ability To Detect Organic Molecules At The Mars Surface

- Pascaline Francois
  1, P. Coll
  2, C. Szopa
  3, A. Buch
  4, R. Sternberg
  5, M. Cabane
  6, P. Mahaffy
  7Caltech / Jet Propulsion Laboratory.

The environmental conditions on Mars might have been favorable for the emergence of Life. The search for clues of a prebiotic chemistry or a biological activity represents one of the main objectives of the Mars Science Laboratory (MSL) mission. The Sample Analysis at Mars Gas Chromatograph (SAM-GC), aboard Curiosity rover, is dedicated to organic molecules research in atmospheric and solid samples. This instrument is constituted of six complementary chromatographic columns which have been selected to provide a broad range of separation and detection capability (volatile, refractory and chiral molecules). In order to treat and interpret the SAM-GC in situ results, it is necessary: (1) to determine the instrument ability to detect targets molecules under the instrument operating conditions and (2) to create a chromatographic and mass spectra data base to help their identification. With this aim we first selected molecules which might be analyzed with SAM-GC using the following criteria: (1) abundance at the Mars surface (2) astrobiological interest, (3) formation during the sample preparation. Then we characterized these target molecules on a laboratory gas chromatograph mass spectrometer (GC-MS) using a Chirasildex (30m x 0,25mm x 0,25μm) column dedicated to the enantiomeric separation and a CLP (30m x 0,25mm x 0,25μm) generalist columns which will be probably the first to be used on Mars. In a second step, we will use a SAM-GC mock-up to mimick the environmental conditions (pressure and temperature) inside Curiosity rover and study its variation impact on analyzes. Finally, we will present a study carried out on a Martian analogs, as Atacama samples.

404.05 In-situ Measurements Of The Radiolytic Destruction Of Glycine In Ices: Applications To The Martian Subsurface
Amino acids and other organic molecules are thought to be easily destroyed on the surface of Mars by the high flux of incident ultraviolet rays or by chemical interactions with oxidizing substances in the soil. However, organic molecules may survive in the subsurface, where chemical processes are driven by penetrating galactic cosmic rays such as MeV protons. Models of the radiation dose as a function of depth on Mars have shown that the contribution of galactic cosmic rays dominates from about one centimeter to a few meters [1]. Theoretical models have also been published to aid in understanding molecular destruction at these depths, but these usually are based on room-temperature laboratory data, studies of single-component samples, and ex-situ methods of chemical analysis. Recent studies of amino-acid survivability include those involving UV photolysis [2, 3] and gamma radiolysis [4], but nearly all chemical and kinetic analyses from such experiments involved room-temperature measurements on samples irradiated and then removed from sealed containers. We report new laboratory studies of the radiation-induced destruction of glycine-containing ices. In-situ infrared spectroscopy was used to study decay rates as a function of temperature and initial glycine concentrations. Our results indicate that glycine’s destruction rate depends on temperature, the presence of H2O-ice, and the initial relative abundance of glycine. These trends are not obvious in previous work, suggesting that room-temperature measurements on pure glycine’s radiation stability are not directly applicable to Mars and other environments. This work has been supported by the Goddard Center for Astrobiology. [1] Dartnell, L. R., et al., 2007. Geophys. Res. Letters 34:L02207. [2] ten Kate, I. L., et al., 2006. Planet. Space Sci. 54, 296-302. [3] Orzechowska, G. E., et al., 2007. Icarus 187, 584-591. [4] Kminek, G., Bada, J. L., 2006. Earth Planet. Sci. Lett. 245, 1-5.
We present photometric observations of 2010 WG9, an unusual high-inclination trans-Neptunian object (TNO) discovered at ~40 deg ecliptic latitude by the La Silla - QUEST Kuiper Belt Survey (Rabinowitz et al. 2012, Schwamb et al. 2012). With perihelion q = 18.8 AU, aphelion = 89 AU, and inclination i = 70.2 deg, 2010 WG9 is the brightest of only three known TNOs with q near Uranus and i > 60 deg. Along with 2002 XU92 and 2008 KV42, 2010 WG9 likely migrated in from the Oort cloud via galactic perturbations and was then captured by Uranus and/or Neptune within the last few 100 Myr (Brasser et al. 2012). It may be one of the best-preserved observable objects from the Oort cloud after Sedna. * We observed 2010 WG9 in BVRI with the 1.3-m SMARTS telescope at Cerro Tololo (26 nights from 2010 Dec 3 to 2011 Mar 26) and with the 3.5-m NTT telescope at La Silla (2011 Feb 5, 6, and 8). With 60 R-band observations spanning these dates, we measure a likely 1.22-d period (single-peaked). We also measure a reflectance spectrum with modest slope shortward of the V-band, comparable to the slopes measured by Sheppard (2010) for 2002 XU92 and 2008 KV42. At longer wavelengths, however, the slope is significantly steeper, comparable to the more highly reddened KBOs and Sedna. We discuss the implications of these observations for compositional diversity in the Oort cloud and the influence of solar radiation on surface color. * Rabinowitz, D. et al. 2012, submitted to AJ (astroph/1205.5214); Schwamb, M. et al. 2002, AAS meeting 219, #301.03; Brasser, R. et al. 2012, MNRAS, 420, 3396; Sheppard, S. et al. 2010, AJ 139, 1394

405.02 The Ultra-Red Color of Kuiper Belt Objects in the 5:3 and 7:4 Mean Motion Neptune Resonances
- Scott S. Sheppard
  Carnegie Inst. of Washington.

New optical colors of objects in mean motion resonances with Neptune show the various resonant populations have significantly different color distributions. The 5:3 and 7:4 resonances have semi-major axes near the middle of the main Kuiper Belt and both are dominated by ultra-red material. The 5:3 and 7:4 resonances have statistically the same color distribution as the low inclination "cold" classical belt. The inner 4:3 and distant 5:2 resonances have objects with mostly moderately red colors, similar to the scattered and detached disk populations. The 2:1 resonance, which is near the outer edge of the main Kuiper Belt, has a large range of colors with similar numbers of moderately red and ultra-red objects at all inclinations. The inner 3:2 resonance, like the outer 2:1, has a large range of objects from neutral to ultra-red. The Neptune Trojans (1:1 resonance) are only slightly red, similar to the Jupiter Trojans. The inner 5:4 resonance only has four objects with measured colors but shows equal numbers of ultra-red and moderately red objects. The 9:5, 12:5, 7:3, 3:1 and 11:3 resonances do not have reliable color distribution statistics, though it appears noteworthy that all three of the measured 3:1 objects have only moderately red colors, similar to the 4:3 and 5:2 resonances. The different color distributions are likely a result from the disruption of the primordial Kuiper Belt from the scattering and migration of the giant planets. The few low inclination objects known in the outer 2:1 and 5:2 resonances are mostly only moderately red. This suggests if the 2:1 and 5:2 have a cold low inclination component, the objects likely had a significantly different origin than the ultra-red dominated cold components of the cold classical belt and 5:3 and 7:4 resonances. This work has been accepted for publication in the Astronomical Journal.

405.03 Near-infrared Photometric Search For Volatile Ices On The Surfaces Of Cold Classical Kuiper Belt Objects
- Daine M. Wright
  J. Emery, D. Cruikshank, C. Dalle Ore, Y. Fernandez, J. Stansberry, M. Brown, W. Fraser, R. McGuire, D. Trilling
  University of Tennessee, NASA Ames Research Center, University of Central Florida, University of Arizona, California Institute of Technology, University of Victoria, Canada, Northern Arizona University.

The surprisingly complex dynamic distribution of small bodies among and beyond the orbits of the planets has changed our understanding of Solar System evolution. Compositional information about the small bodies in the Solar System provides constraints for emerging models of Solar System formation. The cold classical Kuiper Belt population is particularly interesting; according to the Nice model, cold classicals have not migrated much from where they formed, 42 - 45 AU. At these distances, the cold classicals have undergone little thermal evolution and we expect them to be rich with volatile ices of diverse composition (H2O, N2, CH4, light hydrocarbons, e.g. CH3OH). Despite this expectation, Barucci et al. (2011) find no evidence for ices in their sample (3 objects) of cold classical objects. Broad absorption features from most, if not all, volatile ices occur at λ > 2.5 μm. Absorptions are identified using a combination of JHK bands on terrestrial IR telescopes and the 3.6 μm and 4.5 μm channels of the Infrared
Array Camera (IRAC) on the *Spitzer Space Telescope*. Increasing the wavelength range of data with IRAC observations further constrains the composition of materials on KBO surfaces. We report IRAC measurements of reflectances of 45 cold classical KBOs. These longer wavelength albedos are added to ground-based NIR data to extend the KBOs' known spectra to a broader range. Upper limits for the bands at which the objects were not detected provide useful constraints as well. Compositional spectral modeling is used to match the observed photometry from the more completely observed objects with laboratory spectra. We expect volatiles to be uniformly distributed with respect to orbital parameters, such as semi-major axis, inclination, eccentricity, and perihelion, and physical properties, such as absolute magnitude and size. Support for this work was provided by NASA through an award issued by JPL/Caltech.

**405.04 Methanol On The Extra-red Tnos And Centaurs**  
- **Maria Antonieta Barucci**\(^1\), C. Dalle Ore\(^2\), J. Emery\(^3\), F. Merlin\(^1\), D. Cruikshank\(^4\), D. Perna\(^1\), C. de Bergh\(^1\)  
  \(^1\)LESIA-Obs. de Paris, France, \(^2\)SETI/NASA Ames Research Center, \(^3\)University of Tennessee, \(^4\)NASA Ames Research Center.

We present an analysis of the reddest objects of the transneptunian and centaur populations, following the taxonomical class RR. A statistical analysis was performed by Barucci et al. (2011) including all existing data in the literature (76 objects) covering the spectral range from 0.4 to 2.3μm. The subgroup of RR class of objects (23) contains more than ¼ of the whole studied populations, including Centaurs, detached, classical, pluto and scattered objects. In the whole studied sample, the CH3OH ice was detected spectroscopically only on three objects (Pholus, 2002VE95 and Sedna). These objects which are among the reddest ones, belong to different dynamical classes, and have different sizes. To further investigate the presence of CH3OH as part of the composition of the entire RR class we used the Spitzer data available for the RR class for a subgroup of nine objects. Both methanol and methane have a strong absorption at 3.6μm, the first of the Spitzer IRAC channels, and a much brighter albedo at the following channel at 4.5μm. Our technique makes use of a large database of models including H2O, CH3OH, CH4, and N2 ices combined with tholins, amorphous carbon, and silicates. We find that models containing some hydrocarbon ices are possible matches to the spectrum of almost all objects in our sample. Laboratory irradiation experiments show a strong reddening of the spectra of methanol. The presence of methanol on the extra-red objects could imply that these objects exhibit an almost primordial surface. Following the Brown et al (2011) hypothesis, the TNO surface composition and colors are established by formation-location in the early solar system. This would support the idea that objects formed further in the solar planetary disk could retain methanol. These results are in agreement with the hypothesis that substantial mixing has occurred after the TNOs formation.

**405.05 Formation of High Mass Hydrocarbons on Kuiper Belt Objects**  
- **Brant M. Jones**\(^3\), C. Bennett\(^1\), X. Gu\(^2\), R. Kaiser\(^2\)  
  \(^1\)University of Hawaii at Manoa.

We present recent results from the newly established W.M. Keck Research Laboratory in Astrochemistry regarding the formation of high molecular weight (~ C\(_{15}\)) hydrocarbons starting from pure, simple hydrocarbons ices upon interaction of these ices with ionizing radiation: methane (CH\(_4\)), ethane (C\(_2\)H\(_6\)), propane (C\(_3\)H\(_8\)) and n-butane (C\(_4\)H\(_{10}\)). Specifically, we have utilized a novel application of reflection time-of-flight mass spectrometry coupled with soft vacuum ultraviolet photoionization to observe the nature of high mass hydrocarbons as a function of their respective sublimation temperature. The Kuiper Belt is estimated to consist of over 70,000 icy bodies, which extend beyond the orbit of Neptune at 30 AU. These bodies are thought to have maintained low temperatures (30-50 K) since the formation of the solar system and are regarded as frozen relics that may preserve a record of the primitive volatiles from which the solar system formed. In particular, methane has been detected on the surfaces of Sedna, Quaoar, Triton (thought to be a captured KBO) and Pluto along with ethane being tentatively assigned to on Quaoar, Pluto, and Orcus. The surfaces of these bodies have undergone 4.5 Gyr of chemical processing due to ionizing radiation from the solar wind and Galactic Cosmic Radiation. Our research has been focused on trying to understand how these ices have evolved over the age of our solar system by simulating the chemical processing via ionizing radiation in an ultrahigh vacuum chamber coupled with a variety of optical analytical spectroscopies (FT-IR, Raman, UV-Vis) and gas phase mass spectroscopy. Our results indicate that larger, more complex hydrocarbons
up to C15 are formed easily under conditions relevant to the environment of Kuiper Belt Objects which may help elucidate part of the puzzle regarding the ‘colors’ of these objects along with the formation of carbonaceous material throughout the interstellar medium.

405.06 The Origin Of Resonant Kuiper Belt Objects
- Kathryn Volk¹, R. Malhotra²
  ¹University of Arizona.

The orbital migration history of Neptune is important in the origin of the resonant Kuiper belt objects (KBOs). Proposed models for giant planet migration differ in terms of both the smoothness of Neptune’s outward migration and Neptune’s eccentricity evolution during this migration. Smooth migration of Neptune on a low eccentricity orbit is expected to yield a distribution of resonant KBOs with libration amplitudes and eccentricities that correlate with the magnitude of the migration. However, if the resonant KBOs originate via gravitational scattering from an eccentric Neptune, such correlations are not expected. Are the distributions of eccentricities and libration amplitudes of resonant KBOs distinguishable in the different migration scenarios? We report the preliminary results from a suite of numerical simulations of the different migration scenarios, and we discuss comparisons with observations for the most populated resonances.

405.07 Resonant Transneptunian Binaries: Evidence for Slow Migration of Neptune
- Keith S. Noll¹, W. M. Grundy², H. E. Schlichting³, R. A. Murray-Clay⁴, S. D. Benecchi⁵
  ¹NASA GSFC, ²Lowell Obs., ³MIT, ⁴CfA, ⁵DTM.

As Neptune migrated, its mean-motion resonances preceded it into the planetesimal disk. The efficiency of capture into mean motion resonances depends on the smoothness of Neptune’s migration and the local population available to be captured. The two strongest resonances, the 3:2 at 39.4 AU and 2:1 at 47.7 AU, straddle the core repository of the physically distinct and binary-rich Cold Classicals, providing a unique opportunity to test the details of Neptune’s migration. Smooth migration should result in a measurable difference between the 3:2 and 2:1 resonant object properties, with low inclination 2:1s having a high fraction of red binaries, mirroring that of the Cold Classicals while the 3:2 will would have fewer binaries. Rapid migration would generate a more homogeneous result. Resonant objects observed with HST show a higher rate of binaries in the 2:1 relative to the 3:2, significant at the 2σ level. This suggests slow Neptune migration over a large enough distance that the 2:1 swept through the Cold Classical region. Colors are available for only a fraction of these targets but a prevalence of red objects in outer Resonances has been reported. We report here on ongoing observations with HST in cycle 19 targeting all unobserved Resonants with observations that will measure color and search for binary companions using the WFC3.

405.08 Orbital Evolution and Determination of Trans-Neptunian Binaries and Multiples
- Simon Porter¹, W. Grundy¹
  ¹Lowell Observatory.

Numerous binary systems have been observed in the solar system beyond Neptune, including approximately one third of cold classical objects. These systems can be strongly perturbed by solar tides (Kozai cycles), dissipative body tides, spin-orbit interactions, and shape effects. Such perturbations can rapidly destabilize binary orbits, constraining both the allowed orbital solutions and the objects’ physical properties. In addition, two hierarchical multiple systems are known, Pluto and (47171) 1999 TC36, and more will likely be discovered in the future. The hierarchical nature of these systems can cause rapid and complex orbital evolution over timescales fast enough to confuse a Keplerian fit. Precise modeling of these systems therefore requires a simulation that takes all these factors into account and which can easily interface with observational data. We are developing such a model by building an n-body simulator with shape-effects, torques, and body tides. In the process of fitting, it can constrain otherwise unobservable physical properties, such as shape, tidal dissipation, and masses for small satellites. In addition to better orbital determination, this model can also be used to test the stability of complex systems. Recent simulations have shown that a combination of Kozai cycles, body tides, and shape effects can dominate the
evolution of trans-Neptunian binaries. This model can similarly determine which evolutionary paths can produce more complex trans-Neptunian systems.

405.09 Mutual Orbits of Transneptunian Binaries
- William M. Grundy\textsuperscript{1}, K. S. Noll\textsuperscript{2}, H. G. Roe\textsuperscript{1}, S. B. Porter\textsuperscript{3}, C. A. Trujillo\textsuperscript{4}, S. D. Benecchi\textsuperscript{5}, M. W. Buie\textsuperscript{6}
\textsuperscript{1}Lowell Obs., \textsuperscript{2}NASA GSFC, \textsuperscript{3}Lowell Obs. & Arizona State Univ., \textsuperscript{4}Gemini Obs., \textsuperscript{5}Carnegie Inst. of Washington, Dept. of Terrestrial Magnetism, \textsuperscript{6}Southwest Research Inst.

We report the latest results from a program of high spatial resolution imaging to resolve the individual components of binary transneptunian objects. These observations use Hubble Space Telescope and also laser guide star adaptive optics systems on Keck and Gemini telescopes on Mauna Kea. From relative astrometry over multiple epochs, we determine the mutual orbits of the components, and thus the total masses of the systems. Accurate masses anchor subsequent detailed investigations into the physical characteristics of these systems. For instance, dynamical masses enable computation of bulk densities for systems where the component sizes can be estimated from other measurements. Additionally, patterns in the ensemble characteristics of binary orbits offer clues to circumstances in the protoplanetary nebula when these systems formed, as well as carrying imprints of various subsequent dynamical evolution processes. The growing ensemble of known orbits shows intriguing patterns that can shed light on the evolution of this population of distant objects. This work has been supported by an NSF Planetary Astronomy grant and by several Hubble Space Telescope and NASA Keck data analysis grants. The research makes use of data from the Gemini Observatory obtained through NOAO survey program 11A-0017, from a large number of Hubble Space Telescope programs, and from several NASA Keck programs.

406 Planetary Rings: Structure and Mass
Thursday, 11:30 AM - 12:00 PM, Carson 1/2

406.01 Towards an Understanding of Radiative Factors on Planetary Rings: a Perspective from Cassini CIRS Observations at Saturn Equinox
- Shawn M. Brooks\textsuperscript{1}, L. Spilker\textsuperscript{1}, S. G. Edgington\textsuperscript{1}, E. Déau\textsuperscript{1}, S. H. Pilorz\textsuperscript{2}
\textsuperscript{1}JPL, \textsuperscript{2}SETI.

Since arriving at Saturn in 2004, Cassini’s Composite Infrared Spectrometer has recorded tens of millions of spectra of Saturn’s rings (personal communication, M. Segura). CIRS records far infrared radiation (16.7-1000 microns) at focal plane 1 (FP1). Thermal emission from Saturn’s rings peaks at FP1 wavelengths. CIRS spectra are well characterized as blackbody emission at an effective temperature $T_e$, multiplied by a scalar factor related to ring emissivity (Spilker et al. [2005, 2006]). CIRS can therefore characterize the rings’ temperature and study the thermal environment to which the ring particles are subject. We focus on CIRS data from the 2009 Saturnian equinox. As the Sun’s disk crossed the ring plane, CIRS obtained several radial scans of the rings at a variety of phase angles, local hour angles and distances. With the Sun’s rays striking the rings at an incidence angle of zero, solar heating is virtually absent, and thermal radiation from Saturn and sunlight reflected by Saturn dominate the thermal environment. These observations present an apparent paradox. Equinox data show that the flux of thermal energy radiated by the rings is roughly equivalent to or even exceeds the energy incident upon them as prescribed by thermal models (Froidevaux [1981], Ferrari and Leyrat [2006], Morishima et al. [2009, 2010]). This apparent energy excess is largest in the C ring and Cassini Division. Conservation principles suggest that models underestimate heating of the rings, as it is clearly unphysical for the rings to radiate significantly more energy than is incident upon them. In this presentation, we will attempt to resolve this paradox and determine what this can teach us about Saturn’s rings. This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract with NASA. Copyright 2012 California Institute of Technology. Government sponsorship acknowledged.

406.02 The Vertical Structure of Saturn’s F Ring from a Cassini Ring-Plane Crossing
- Britt Scharringhausen\textsuperscript{1}, M. Crumrine\textsuperscript{1}, S. Storck-Post\textsuperscript{1}, M. Rehnberg\textsuperscript{1}, S. Sans\textsuperscript{1}, S. Wolfe\textsuperscript{1}
\textsuperscript{1}Beloit College.
Our photometric model of Saturn's F ring and main rings reproduces the observed brightness of the vertically-unresolved rings in Visual and Infrared Mapping Spectrometer (VIMS) images taken during the 1-2 December 2005 ring-plane crossing (RPX) by the Cassini Spacecraft. 150 VIMS QUBs were taken at intervals of less than 10 minutes at ring-opening angles of -0.014 to 0.016 degrees with a solar ring-opening angle of -19.5 degrees. We compare model profiles of vertically-integrated I/F (VIF) and radially-averaged VIF to data at 0.88 and 0.90 microns. The best-fit model's vertical thickness of the rings is consistent with that derived from simpler photometric models of the 1995 Earth RPX, but, due to the fine time resolution of this observation and the fact that the far side of the F ring emerges slowly from behind the main ring near RPX, the radially-averaged VIF lightcurve is very sensitive to the vertical structure of the F ring.

406.03 Saturn's Gravitational Field And Ring Mass Sensitivity Study From The F-ring And The Proximal Orbits Of The Solstice Mission

- Marina Brozovic\(^1\), R. A. Jacobson\(^1\), D. C. Roth\(^1\), P. D. Nicholson\(^2\), M. M. Hedeman\(^2\)

\(^1\)Jet Propulsion Laboratory/Caltech, \(^2\)Cornell.

"Solstice" mission is the 7-year extension of the Cassini-Huygens spacecraft exploration of the Saturn system. Beginning in late 2016, the spacecraft is scheduled to execute 20 F-ring and 22 proximal orbits during which the spacecraft trajectory will be perturbed by the gravitational field of Saturn as well as the ring mass. F-ring orbits bring the spacecraft close to the ring plane during the descent/ascent from the periapses that is just outside the F-ring, while the proximal orbits, with their periapses between the innermost D-ring and the upper layer of Saturn's atmosphere, bring the spacecraft close to the innermost part of the ring. We used an optical depth profile in combination with estimates of opacity to obtain a surface mass density profile for the rings. The ring mass \(GM\approx 2.3 \text{ km}^3\text{s}^{-2}\) was subdivided into 6 major parts: A-ring, C-ring, and 3 parts for B-ring. The orbital model includes various sources of non-gravitational perturbations on the spacecraft. Furthermore, we simulate two-way Doppler radio-tracking of the spacecraft. Our analysis shows that both proximal orbits and F-ring orbits have ring mass sensitivity and that the Doppler measurements from 3-6 orbits can estimate the overall ring mass to within 10%. F-ring and proximal orbits have different geometry with respect to the ring plane, but there is still a significant correlation between the individual rings when we try to estimate their separate masses. Ring mass estimate is not correlated with the zonal harmonics, but the higher zonal harmonics are correlated between themselves. Our analysis shows that it is best to use proximal tracks separately for the zonal harmonics measurements, as the geometry of F-ring orbits does not bring the spacecraft close enough to the planet. We can expect that \(J_{8, 10, 12}\) measurements all have better than \(10^{-8}\) sensitivity which translates to better than 10% accuracy.

407 Planetary Aeronomy of the Outer Solar System

Thursday, 1:30 PM - 2:20 PM, Reno Ballroom

407.01 Planetary Aeronomy of the Outer Solar System

- Darrell Strobel\(^1\)

\(^1\)Johns Hopkins Univ..

This talk will give a historical tour of the highlights of my research on atmospheres in the outer solar system and their interaction with the magnetospheric plasma. Topics include atmospheric photochemistry, the Io plasma torus, the Galilean satellites, and the nitrogen atmospheres on Titan, Triton, and Pluto. The important role of observations combined with theory will be emphasized. The talk will finish with current research on the role that atmospheric escape plays on atmospheric structure in the outer solar system.

408 Cassini Science Highlights: Surprises in the Saturn System

Wednesday, 2:20 PM - 2:55 PM, Reno Ballroom

408.01 Cassini Science Highlights: Surprises in the Saturn System
Cassini’s exploration of the Saturn system has generated a treasure trove of scientific data on Saturn, Titan, Enceladus, and other diverse icy satellites, the rings, and magnetosphere. After eight years of close study of this exceptionally complex and dynamic environment, Cassini is still unveiling new scientific discoveries that continue to amaze us. Standout recent highlights include aftereffects from Saturn’s huge storm, a possible subsurface ocean on Titan, close flybys of icy satellites, migrating ring “propellers”, and unexpected variations in Saturn kilometric radiation periodicities. Current observations show seasonal changes including the formation of a polar vortex at Titan’s south pole. To date, Cassini has observed Saturn from just after northern winter solstice through northern spring equinox and now is observing the Saturn system in the previously unobserved period leading up to northern summer solstice. In the remaining five years of the on-going Solstice Mission, Cassini will continue to study seasonally and temporally dependent processes. Given the long Saturnian year (~30 years) the longevity of Cassini is essential for elucidating seasonal change in the Saturn system. The grand finale of the mission occurs in 2017, when a series of inclined orbits brings Cassini between the innermost D ring and the upper regions of Saturn’s atmosphere. This geometry will offer unique opportunities for new discoveries and ground-breaking science, including Saturn interior structure science from otherwise unobtainable gravity and magnetic field measurements and unprecedented determination of the ring mass, currently uncertain by an order of magnitude. This Proximal orbit phase is similar to Juno’s mission at Jupiter. Comparing Jupiter and Saturn is the first step toward the next great leap in solar system origins research. This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract with NASA. Copyright 2012 California Institute of Technology. Government sponsorship acknowledged.

409 Highlights/Results from GRAIL Mission
Thursday, 2:55 PM - 3:30 PM, Reno Ballroom

409.01 Science Highlights/Results from GRAIL Mission
- Gregory Neumann\textsuperscript{,} GRAIL Science Team
\textsuperscript{\textsuperscript{1}NASA.}

The Gravity Recovery and Interior Laboratory (GRAIL) Mission is a component of the NASA Discovery Program. GRAIL is a twin-spacecraft lunar gravity mission that has two primary objectives: to determine the structure of the lunar interior, from crust to core; and to advance understanding of the thermal evolution of the Moon. GRAIL launched successfully from the Cape Canaveral Air Force Station on September 10, 2011, executed a low-energy trajectory to the Moon, and inserted the twin spacecraft into lunar orbit on December 31, 2011 and January 1, 2012. A series of maneuvers brought both spacecraft into low-altitude (55-km), near-circular, polar lunar orbits, from which they perform high-precision satellite-to-satellite ranging using a Ka-band payload along with an S-band link for time synchronization. Precise measurements of distance changes between the spacecraft are used to map the lunar gravity field. GRAIL completed its primary mapping mission on May 29, 2012, collecting and transmitting to Earth >99.99% of the possible data. Spacecraft and instrument performance were nominal and has led to the production of a high-resolution and high-accuracy global gravity field, improved over all previous models by two orders of magnitude on the nearside and nearly three orders of magnitude over the farside. The field is being used to understand the thickness, density and porosity of the lunar crust, the mechanics of formation and compensation states of lunar impact basins, and the structure of the mantle and core. GRAIL’s three month-long-extended mission will initiate on August 30, 2012 and will consist of global gravity field mapping from an average altitude of 22 km.

410 Mercury and Moon: Atmospheres
Thursday, 3:30 PM - 6:00 PM, Exhibit Hall

410.01 Observation of Neutral Sodium above Mercury During the Transit of November 8, 2006

- Linda J. Spilker\textsuperscript{1}
\textsuperscript{\textsuperscript{\textsuperscript{1}JPL.}}
Andrew E. Potter¹, R. M. Killen², K. P. Reardon¹, T. A. Bida³
¹National Solar Obs.,²NASA GSFC,³Lowell Observatory.

We mapped the absorption of sunlight by sodium vapor in the exosphere of Mercury during the transit of Mercury on November 8, 2006, using the IBIS Interferometric Bldimensional Spectrometer at the Dunn solar telescope operated by the National Solar Observatory at Sunspot, New Mexico. The measurements were reduced to line-of-sight equivalent widths for absorption at the sodium D2 line, and mapped in thirty degree increments around the shadow of Mercury. We observed north and south polar enhancements of sodium absorption. The sodium absorptions fell off exponentially with altitude up to about 600 km, and we analyzed the altitude distributions to determine surface densities, zenith column densities, temperatures and scale heights for sodium. The average surface concentration of sodium atoms was about 900 atoms/cm³, and the average zenith column density was 0.8 x 1010 atoms/cm². The average temperature was about 1100 K, with excursions to 1750 and 700 K. The 2003 transit was observed by Schleicher et al. [2004], using instrumentation similar to that employed for this research. They reported the appearance of a streamer-like feature extending a thousand kilometers above the north polar region, and a similar but smaller feature above the south polar region. Our observations did not detect similar features. They observed considerably more sodium absorption over the dawn terminator than over the dusk terminator. In contrast, we observed slightly larger sodium absorption on the dawn relative to the dusk side. The difference might be due to the slow advance of the dawn terminator at during the 2006 transit (0.13 degrees/day) relative to the 2003 transit (3.27 degrees/day). Reference Schleicher, H.; Wiedemann, G.; Wöhl, H.; Berkefeld, T.; Soltau, D. (2004), Detection of neutral sodium above Mercury during the transit on 2003 May 7. Astronomy and Astrophysics, 425, 1119-1124.

410.02 The Effects of Localized Sources on the Formation of Lunar Sodium Exosphere
- Dong Wook Lee¹, S. Kim, D. Lee¹
¹Kyung Hee University, Korea, Republic of.

The sodium exosphere is a common phenomenon of the planets and the satellites of the solar system. Mercury, the Moon, and Io, are of observational interest due to the their prominence of the exospheres. In particular, Mercury has been known to have complicated local sodium sources (e.g., Potter and Killen, 2011). Although such a local source has not been reported for the Moon, we present a preliminary diagnostic simulation considering different source productions of the lunar surface depending on the local concentrations of sodium. Future coronagraph observations on the low altitudinal regions of the Moon will provide important observational constraints on the sources. Reference Potter, A.E. and Killen, R.M. Sodium velocity maps on Mercury, vol. 6, EPSC-DPS2011-337, 2011.

410.03 Modeling the Sodium Atmosphere of the Moon
- Orenthal Tucker¹, V. Tenishev¹, M. Rubin¹, M. R. Combi¹, M. Sarantos²
¹University of Michigan, ²NASA Goddard Space Flight Center.

Presented are preliminary results obtained using a 3D gas kinetic simulation of the Moon’s sodium atmosphere. We model the evolution of the atmosphere by considering the dynamics of the Moon-Earth-Sun system. To this end, the NASA SPICE toolkit is incorporated into the model to accurately calculate body orientations, velocities and rotation states. This information is used for calculation of source rates, solar radiation pressure and gravitational acceleration, and to account for collisions of sodium atoms with the Earth. In the model, micrometeoroids deliver sodium to the lunar surface, and the atmosphere is produced by thermal desorption (TD), solar wind sputtering (SWS), impact vaporization (IV) and photon simulated desorption (PSD). The recycling and loss of atmospheric sodium due to PSD and SWS redistribute the sodium content of the surface and atmosphere supplied by IV. Because PSD is the dominant source process, the maximum of the injection flux and surface density occurs at the sub-solar point. The model is used to simulate ground-based observations of the exosphere and tail, for comparison. We model the dynamics of the system to examine time variation of sodium production rates, surface density and exospheric morphology in relation to the Moon’s changing heliocentric distance. In addition, we study the effect of PSD from a regolith versus a smooth surface on exospheric morphology. Finally, the model is used to
analyze the effect of Earth’s gravity on the extended sodium tail during new moon phase. This work was supported by grant NNX11AB24G from the NASA Lunar Advanced Science and Exploration Research Program.

410.04 New Upper Limits on Numerous Lunar Atmosphere Gases
- Jason C. Cook¹, S. A. Stern¹, K. Retherford¹, C. C. C. Tsang¹
  ¹Southwest Research Institute.

In September 2009, Lunar Reconnaissance Orbiter (LRO) entered a polar orbit around the Moon. The sensitive Lyman Alpha Mapping Project (LAMP) instrument on LRO has observed the permanently shadowed regions (Gladstone et al. 2012), measured the composition of the material excavated by the LCROSS impact (Gladstone et al. 2010) and detected and measured variations of He in the Lunar atmosphere (Stern et al., 2012, Feldman et al., 2012). The LAMP instrument is typically oriented to view the surface. There are periods during the orbit when the surface is in darkness, but space below LRO is in sunlight. These “twilight” observations occur twice per orbit, about 11-12 times per day. In a typical orbit, the duration in twilight is about 600 seconds and the observations are concentrated around the north and south poles of the moon (>80° latitude). These periods are longest around solstices, reaching over 3600 seconds per orbit and examine all latitudes. The total integration time for these LAMP nadir observations in twilight is about 9×10⁶ seconds over the lifetime of the mission. We bin these observations by the height of the lunar shadow (shadow height) and the altitude of the spacecraft. From September 2009 to December 2010, the altitude rage during this period was between 30 and 80 km. After December 2010, the orbit of LRO was changed to make it more elliptical, reaching a maximum of nearly 200 km. Using these data, we determine the upper limits for 30 neutrals (e.g., H, O, Ne), ions (e.g., O⁺) and molecules (e.g., H₂) that were either detected in the LCROSS plume (Gladstone et al., 2010), suggested by the mass spectrometer LACE (Hoffman & Hodges, 1975) or predicted previously (Flynn & Stern, 1996). We will present these upper limits, compare to previous values where appropriate and discuss their significance.

410.05 Hemispheric Asymmetries in Mercury’s Exosphere
- Carl Schmidt¹, J. Baumgardner¹, M. Mendillo¹
  ¹Boston University.

Observations of Mercury’s sodium tail by Potter and Killen (2008) frequently show enhanced emission in the northern lobe. Anderson et al. (2011) have established that Mercury’s magnetic dipole is offset from the planet’s center by .2 RM to the north, while approximately aligned with the spin axis. Such a configuration produces an asymmetry in the magnetosphere cusp whereby more plasma has direct access to the planet’s southern hemisphere than in the north (Winslow et al., 2012). Using time-dependent, 3-D simulations, we demonstrate that ion precipitation, enlarged in the south, can actually result in the observed profiles across the tail, which are typically brighter to the north. Additionally, sources located at high latitude cusp footprints at on the dayside were unable match the observed width of the asymmetric profiles across the tail. Instead, our simulations provide evidence for sources near the dawn terminator at lower latitudes, resulting from the accumulation of sodium during the night. Desorption, rather than ion sputtering, is determined to be the responsible mechanism for this sodium population’s release and escape from the planet surface.

411 Education, Public Outreach, and History
Thursday, 3:30 PM - 6:00 PM, Exhibit Hall

411.01 Discovering the 50 Years of Solar System Exploration: Sharing Your Science with the Public
- Sanlyn Buxner¹, H. Dalton², S. Shipp², C. Shupla², E. Halligan², D. Boonstra³, A. Wessen⁴, G. Baerg⁴, P. Davis⁴, A. Burdick⁴, R. Zimmerman Brachman⁴
  ¹Planetary Science Institute, ²Lunar and Planetary Institute, ³Sustainability Schools Consulting, LLC, ⁴Jet Propulsion Laboratory, ⁵Raytheon.

The Year of the Solar System (YSS) offers ways for scientists to bring NASA’s science discoveries to their audiences! YSS and the continuing salute to the 50-year history of solar system exploration provide an integrated picture of
our new understanding of the solar system for educators and the general public. During the last five decades, NASA has launched a variety of robotic spacecraft to study our solar system. Over that time, our understanding of planets has been revolutionized, as has the technology that has made these discoveries possible. Looking forward, the numerous ongoing and future robotic missions are returning new discoveries of our solar system at an unprecedented rate. YSS combines the discoveries of past NASA planetary missions with the most recent findings of the ongoing missions and connects them to related topics based on the big questions of planetary science, including solar system formation, volcanism, ice, and possible life elsewhere. Planetary scientists are encouraged to get involved in YSS in a variety of ways:

- Give a talk at a local museum, planetarium, library, or school to share YSS and your research
- Partner with a local educational institution to organize a night sky viewing or mission milestone community event
- Work with a classroom teacher to explore one of the topics with students
- Connect with a planetary science E/PO professional to identify ways to participate, like creating podcasts, vodcasts, or contributing to monthly topics
- Share your ideas for events and activities with the planetary E/PO community to identify partners and pathways for distribution
- And more!

Promotional and educational materials, updates, and a space to share experiences are available at NASA’s Solar System website: http://solarsystem.nasa.gov/yss. This is an exciting time in planetary sciences as we learn about New Worlds and make New Discoveries!

411.02 Opportunities and Resources for Scientist Participation in Education and Public Outreach

Sanlyn Buxner¹, E. CoBabe-Ammann², S. Shipp³, B. Hsu³


Active engagement of scientists in Education and Public Outreach (E/PO) activities results in benefits for both the audience and scientists. Most scientists are trained in research but have little formal training in education. The Planetary Science Education and Public Outreach (E/PO) Forum helps the Science Mission Directorate support scientists currently involved in E/PO and to help scientists who are interested in becoming involved in E/PO efforts find ways to do so through a variety of avenues. We will present current and future opportunities and resources for scientists to become engaged in education and public outreach. These include upcoming NASA SMD E/PO funding opportunities, professional development resources for writing NASA SMD E/PO proposals (webinars and other online tools), toolkits for scientists interested in best practices in E/PO (online guides for K-12 education and public outreach), EarthSpace (a community web space where instructors can find and share about teaching space and earth sciences in the undergraduate classroom, including class materials news and funding opportunities, and the latest education research), thematic resources for teaching about the solar system (archived resources from Year of the Solar System), and an online database of scientists interested in connecting with education programs. Learn more about the Forum and find resources at http://smdepo.org/.

411.03 Partnerships between Professional and Amateur Astronomers: A Shift in Research Paradigm

Padma A. Yanamandra-Fisher¹, G. S. Orton², P. Casquinha³, A. Coffelt⁴, M. Delcroix⁵, C. Go⁶, R. Hueso⁷, W. Jaeschke⁸, M. Kardasis⁹, E. Kraaijkamp¹⁰, E. Morales¹¹, D. Peach¹², J. Rogers¹², A. Wesley¹³, F. Willems¹⁴, T. Wilson¹⁵

¹Space Science Institute, ²Jet Propulsion Laboratory, CIT, ³Portuguese Association of Amateur Astronomers, Portugal, ⁴Atlanta Astronomy Club, ⁵French Astronomical Society (SAF), France, ⁶University of San Carlos, Philippines, ⁷UPV/EHU, Spain, ⁸Johnson and Johnson, ⁹Hellenic Amateur Astronomy Association, Greece, ¹⁰JWTT Astronomy, Netherlands, ¹¹Sensormatic, ¹²BAA, United Kingdom, ¹³Canberra Astronomical Society, Australia, ¹⁴Hawaiian Astronomy Society, ¹⁵Boy Scouts of America.

"Citizen Astronomy” can be thought of as the paradigm shift transforming the nature of observational astronomy. The night sky, with all its delights and mysteries, enthralls professional and amateur astronomers, and students who will form the next generation of scientists and engineers. These students are matriculating in an era of reduced funding for core competencies such as science, technology, mathematics and engineering (STEM) sciences and an ongoing general decline in these sciences. How then do we re-generate their interest and engage students while we perform cutting-edge planetary science in a fiscally constrained environment? One promising solution is to promote the emerging partnerships between professional and dedicated proficient amateur astronomers, that rely on creating a niche for long timeline of multispectral remote sensing. In the past decade, it is the collective
observations and their analyses by the ever-increasing global network of amateur astronomers that has discovered interesting phenomena and provided the reference backdrop for observations by professional ground-based professional astronomers and spacecraft missions. We shall focus on our collaboration or "Citizen Astronomy: Jupiter and Saturn" for the past five years and illustrate the strong synergy between the two groups that has produced new scientific results. With the active inclusion and use of emerging social media (Facebook, Twitter, etc.), the near daily communication and updates (via email, Skype, Facebook) between the two groups is becoming a powerful tool for ground-based remote sensing. However, what is sorely lacking in this paradigm is the inclusion of teachers and students and, therefore, its inclusion in the secondary and tertiary classrooms. We will provide various scenarios to address this issue, and emphasize the various aspects of STEM learning/teaching that is necessary for students and teachers - all that can be performed at low cost; and showcase some of our contributors and current science investigations.

411.04 The NASA Tournament Laboratory ("NTL"): Improving Data Access at PDS while Spreading Joy and Engaging Students through 16 Micro-Contests

Andy LaMora\textsuperscript{1}, A. Raugh\textsuperscript{2}, K. Erickson\textsuperscript{3}, E. J. Grayzeck\textsuperscript{3}, W. Knopf\textsuperscript{3}, M. Lydon\textsuperscript{1}, K. Lakhani\textsuperscript{4}, J. Crusan\textsuperscript{3}, T. H. Morgan\textsuperscript{5}

\textsuperscript{1}TopCoder, Inc, \textsuperscript{2}University of Maryland, \textsuperscript{3}NASA Headquarters, \textsuperscript{4}Harvard Business School, \textsuperscript{5}Goddard Space Flight Center.

NASA PDS hosts terabytes of valuable data from hundreds of data sources and spans decades of research. Data is stored on flat-file systems regulated through careful meta dictionaries. PDS’s data is available to the public through its website which supports data searches through drill-down navigation. While the system returns data quickly, result sets in response to identical input differ depending on the drill-down path a user follows. To correct this issue, to allow custom searching, and to improve general accessibility, PDS sought to create a new data structure and API, and to use them to build applications that are a joy to use and showcase the value of the data to students, teachers and citizens. PDS engaged TopCoder and Harvard Business School through the NTL to pursue these objectives in a pilot effort. Scope was limited to Small Bodies Node data. NTL analyzed data, proposed a solution, and implemented it through a series of micro-contests. Contest focused on different segments of the problem; conceptualization, architectural design, implementation, testing, etc. To demonstrate the utility of the completed solution, NTL developed web-based and mobile applications that can compare targets, regardless of mission. To further explore the potential of the solution NTL hosted “Mash-up” challenges that integrated the API with other publically available assets, to produce consumer and teaching applications, including an Augmented Reality iPad tool. Two contests were also posted to middle and high school students via the NoNameSite.com platform, and as a result of these contests, PDS/SBN has initiated a Facebook program. These contests defined and implemented a data warehouse with the necessary migration tools to transform legacy data, produced a public web interface for the new search, developed a public API, and produced four mobile applications that we expect to appeal to users both within and without the academic community.

411.05 "Discoveries in Planetary Sciences": Slide Sets Highlighting New Advances for Astronomy Educators

David Brain\textsuperscript{1}, N. Schneider\textsuperscript{1}, K. Molaverdikhani\textsuperscript{1}, F. Afsharahmadi\textsuperscript{2}

\textsuperscript{1}LASP / University of Colorado, \textsuperscript{2}Zanjan Astronomy And Science Center, Iran, Islamic Republic of.

We present two new features of an ongoing effort to bring recent newsworthy advances in planetary science to undergraduate lecture halls. The effort, called 'Discoveries in Planetary Sciences', summarizes selected recently announced discoveries that are ‘too new for textbooks’ in the form of 3-slide PowerPoint presentations. The first slide describes the discovery, the second slide discusses the underlying planetary science concepts at a level appropriate for students of ‘Astronomy 101’, and the third presents the big picture implications of the discovery. A fourth slide includes links to associated press releases, images, and primary sources. This effort is generously sponsored by the Division for Planetary Sciences of the American Astronomical Society, and the slide sets are available at http://dps.aas.org/education/dpsdisc/ for download by undergraduate instructors or any interested party. Several new slide sets have just been released, and we summarize the topics covered. The slide sets are also being translated into languages other than English (including Spanish and Farsi), and we will provide an overview.
of the translation strategy and process. Finally, we will present web statistics on how many people are using the slide sets, as well as individual feedback from educators.

411.06 Using Models to Address Misconceptions in Size and Scale Related to the Earth, Moon, Solar System, and Universe

- Larry A. Lebofsky¹, N. R. Lebofsky¹, D. W. McCarthy¹, M. L. Higgins², K. Salthouse², T. L. Canizo³

¹The University of Arizona, ²Girl Scouts of Southern Arizona, ³Planetary Science Institute.

Many children and adults have misconceptions about space-related concepts such as size and distance: Earth-Moon size and distance, distances between the planets, distances to the stars (including the Sun), etc. Unfortunately, when images are used to illustrate common phenomena, such as Moon phases and seasons, they may do a good job of explaining the phenomenon, but may reinforce other misconceptions. For topics such as phases and seasons, scale (size and distance) can easily lead to confusion and reinforce misconceptions. For example, when showing Moon phases, the Moon is usually represented as large relative to the Earth and the true relative distance cannot be easily shown. Similarly, when showing the tilt of the Earth’s axis as the reason for the seasons, the Earth is usually almost as large as the Sun and the distance between them is usually only a few times Earth’s diameter. What lessons have we learned? It is critical with any model to engage the participants: if at all possible, everyone should participate. A critical part of any modeling needs to be a discussion, involving the participants, of the limitations of the model: what is modeled accurately and what is not? This helps to identify and rectify misconceptions and helps to avoid creating new ones. The activities highlighted on our poster represent programs and collaborations that date back more than two decades: The University of Arizona, Tucson Unified School District, Science Center of Inquiry, Girl Scouts of Southern Arizona, and the Planetary Science Institute. Examples of activities that we will present on our poster include: •Earth/Moon size and distance •Macramé model of the Solar System •Human orrery and tabletop orrery •3-D nature of the constellations •Comparing our Solar System to other planetary systems •Origin of the Universe: scale of time and distance

411.07 Strengthening Communication and Scientific Reasoning Skills of Graduate Students Through the INSPIRE Program

- Donna M. Pierce¹, K. S. McNeal¹, S. P. Radencic¹, D. W. Schmitz¹, J. Cartwright¹, D. Hare¹, L. M. Bruce¹

¹Mississippi State Univ.

Initiating New Science Partnerships in Rural Education (INSPIRE) is a five-year partnership between Mississippi State University and three nearby school districts. The primary goal of the program is to strengthen the communication and scientific reasoning skills of graduate students in geosciences, physics, chemistry, and engineering by placing them in area middle school and high school science and mathematics classrooms for ten hours a week for an entire academic year as they continue to conduct their thesis or dissertation research. Additional impacts include increased content knowledge for our partner teachers and improvement in the quality of classroom instruction using hands-on inquiry-based activities that incorporate ideas used in the research conducted by the graduate students. Current technologies, such as Google Earth, GIS, Celestia, benchtop SEM and GCMS, are incorporated into many of the lessons. Now in the third year of our program, we will present the results of our program to date, including an overview of documented graduate student, teacher, and secondary student achievements, the kinds of activities the graduate students and participating teachers have developed for classroom instruction, and the accomplishments resulting from our four international partnerships. INSPIRE is funded by the Graduate K-12 (GK-12) STEM Fellowship Program (Award No. DGE-0947419), which is part of the Division for Graduate Education of the National Science Foundation.

411.08 Uncovering What Our Students Really Think About Science and Society -- Are We Doomed?

- Johanna Teske¹, E. E. Prather², C. S. Wallace², M. Meyers¹, Collaboration of Astronomy Teaching Scholars (CATS)

¹University of Arizona, ²Center for Astronomy Education (CAE), Steward Observatory, University of Arizona.

We present initial results from our study of how science does or does not influence the worldviews of introductory, general education college astronomy students. Our data were gathered over one course (one
semester), and examine students' ideas on provocative topics such as the relationship between science and religion, comparisons between the return on investment from different government programs, the limits of scientific inquiry, and how/if science can help to solve critical problems facing our society today. Since this is the last formal science course many of these general education astronomy students will ever take, the experience they have during this course is crucial for developing an accurate and well-informed worldview that includes the role of science in society. With our research we aim to answer the question, “Can teaching help shape this worldview to incorporate science more positively?” This material is based in part upon work supported by the National Science Foundation under Grant No. 0715517, a CCLI Phase III Grant for the Collaboration of Astronomy Teaching Scholars (CATS). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

411.09 Mars Science Laboratory; A Model for Event-Based EPO
- Louis Mayo1, E. Lewis1, T. Cline1, B. Stephenson1, K. Erickson2, C. Ng1
  1NASA’s GSFC, 2NASA HQ.

The NASA Mars Science Laboratory (MSL) and its Curiosity Rover, a part of NASA’s Mars Exploration Program, represent the most ambitious undertaking to date to explore the red planet. MSL/Curiosity was designed primarily to determine whether Mars ever had an environment capable of supporting microbial life. NASA’s MSL education program was designed to take advantage of existing, highly successful event based education programs to communicate Mars science and education themes to worldwide audiences through live webcasts, video interviews with scientists, TV broadcasts, professional development for teachers, and the latest social media frameworks. We report here on the success of the MSL education program and discuss how this methodological framework can be used to enhance other event based education programs.

411.10 Print, Web, And Podcast Tov Public Outreach
- Jay M. Pasachoff1
  1Williams College and Caltech.

As part of alerting the general public to the subtly spectacular transit of Venus as an intellectual marvel not available to us from Earth until AD 2117/2125, in addition to our scientific plans (Pasachoff et al., this meeting), I provided: (1) an article in the children's magazine Odyssey (May/June 2011); (2) a discussion in National Geographic Society’s Breaking Orbit blog (March 1, 2011); (3) and a year’s advance notice as "June 5: Transit of Venus," 365days of astronomy.org. (4) Nantes DPS: I participated in "Transits of Venus in Public Education and Contemporary Research" (http://transitofvenus.nl/wp/2011/10/16/four-giants-talk-about-transits). (5) 22-minute lecture on the Phi Beta Kappa website: http://www.pbk.org/home/playpodcast.aspx?id=772. (6) E/PO summary at Historical Astronomy Division News, #79, October. Closer to the event, I had a (7) Comment in Nature (“Transit of Venus: Last Chance to See," Nature 485, 303-304) and (8, 9) articles in Physics World, 25, 36-41; and Scientific American, http://www.scientificamerican.com/article.cfm?id=transit-venus-june-5). The day before the transit, (10) I had a radio/podcast Academic Minute (http://www.wamc.org/post/dr-jay-pasachoff-williams-college). (11) On transit day, I had an Op-Ed piece in The New York Times ("Learning from Celestial Beauty," http://www.nytimes.com/2012/06/05/opinion/learning-from-celestial-beauty.html) that was seen by largely a non-scientific audience. Subsequently, (12) I gave a Keck-Observatory-sponsored Waimea general-public lecture (http://keckobservatory.org/news/video_venus_transits_past_present_future), and (13) an invited public lecture at the AAS meeting in Anchorage (http://aas.org/meetings/aas220/video_session_127). I had a podcast on (14) 365 days of astronomy.org (June 29). (15) My article for Sky & Telescope appeared in its October issue. (16) My editorial “Syzygy x 3” will be in RASC Observer’s Handbook 2013. (16) These efforts as well as links to history and science of transits of Mercury and Venus are at http://sites.williams.edu/transitofvenus2012/links/ as part of my website http://www.transitofvenus.info. Acknowledgments: My expeditions to the 2004 and 2012 transits of were supported by grants from the Committee for Research and Exploration of the National Geographic Society.

411.11 Understanding Stellar Variations in the Eighteenth Century: Transits of Exoplanets or Starspots?
- Linda M. French1
  1Illinois Wesleyan Univ.
In 1783, John Goodricke and Edward Pigott suggested that the variations in light of the star Algol (Beta Persei) might be caused "either by the interposition of a large body revolving round Algol, or some kind of motion of its own, whereby part of its body, covered with spots or such like matter, is periodically turned towards the earth (Goodricke 1783)". Today we recognize Algol as the archetype of an eclipsing binary system. Transits such as those seen in the Algol system are regularly used to discover exoplanets. Yet, in the eighteenth century, astronomers such as William Herschel preferred to explain stellar variability in terms of starspots, rather than transits (or eclipses). This paper will investigate how and why the notion of stellar variability began to evolve.

411.12 Wet Mars, Dry Mars
- Matthew Fillingim¹, D. Brain², L. Peticolas³, D. Yan³, K. Fricke³, L. Thrall³
  ¹Space Sciences Laboratory, University of California, Berkeley, ²Laboratory for Atmospheric and Space Physics, University of Colorado, ³Center for Science Education, Space Sciences Laboratory, University of California, Berkeley.

The magnetic fields of the large terrestrial planets, Venus, Earth, and Mars, are all vastly different from each other. These differences can tell us a lot about the interior structure, interior history, and even give us clues to the atmospheric history of these planets. This poster highlights the third in a series of presentations that target school-age audiences with the overall goal of helping the audience visualize planetary magnetic field and understand how they can impact the climatic evolution of a planet. Our first presentation, "Goldilocks and the Three Planets," targeted to elementary school age audiences, focuses on the differences in the atmospheres of Venus, Earth, and Mars and the causes of the differences. The second presentation, "Lost on Mars (and Venus)," geared toward a middle school age audience, highlights the differences in the magnetic fields of these planets and what we can learn from these differences. Finally, in the third presentation, "Wet Mars, Dry Mars," targeted to high school age audiences and the focus of this poster, the emphasis is on the long term climatic affects of the presence or absence of a magnetic field using the contrasts between Earth and Mars. These presentations are given using visually engaging spherical displays in conjunction with hands-on activities and scientifically accurate 3D models of planetary magnetic fields. We will summarize the content of our presentations, discuss our "lessons learned" from formative evaluation, and show (pictures of) our hands-on activities and 3D models.

411.13 Building an Automated Observatory for Undergraduate Research
- Laura Woodney¹, P. B. Gardner²
  ¹Cal State Univ, San Bernardino, ²Caltech Optical Observatories.

The Murillo Family Observatory at California State University, San Bernardino is the culmination of more than 20 years of planning and fundraising to build a privately funded state of the art facility for undergraduate research on a public campus which serves predominately minority students. This observatory allows us to bring a hands on approach to astronomy to traditionally underrepresented and underserved groups. Our two telescopes have been equipped with CCD cameras and standard BVRI filters which will allow the students to do a wide variety of research projects from extra-solar planet transits to asteroid colors and lightcurves. Both telescopes have been designed to run both remotely and in an automated mode. This has been achieved entirely with commercially available software products. The remote and automated modes enhance not only the functionality of our facility for research but will allow us to increase the reach of our programs into the local public schools.

411.14 Teaching Planetary Sciences with the Master in Space Science and Technology at Universidad del País Vasco UPV/EHU: Theory and Practice works
- Agustin Sanchez-Lavega¹, R. Hueso¹, S. Perez-Hoyos¹
  ¹Universidad País Vasco UPV/EHU, Spain.

The Master in Space Science and Technology is a postgraduate course at the Universidad del País Vasco in Spain (http://www.ehu.es/aula-espazio/master.html). It has two elective itineraries on space studies: scientific and technological. The scientific branch is intended for students aiming to access the PhD doctorate program in different areas of space science, among them the research of the solar system bodies. The theoretical foundations
for the solar system studies are basically treated in four related matters: Astronomy and Astrophysics, Physics of the Solar System, Planetary Atmospheres, and Image Processing and Data Analysis. The practical part is developed on the one hand by analyzing planetary images obtained by different spacecrafts from public archives (e.g., PDS), and on the other hand from observations obtained by the students employing the 50 cm aperture telescope and other smaller telescopes from the Aula EspaZio Gela Observatory at the Engineering Faculty. We present the scheme of the practice works realized at the telescope to get images of the planets in different wavelengths pursuing to study the following aspects of Planetary Atmospheres: (1) Data acquisition; (2) Measurements of cloud motions to derive winds; (3) Measurement of the upper cloud reflectivity at the different wavelengths and position in the disk to retrieve the upper cloud properties and vertical structure. The theoretical foundations accompanying these practices are then introduced: atmospheric dynamics and thermodynamics, and the radiative transfer problem. Acknowledgments: This work was supported by Departamento de Promoción Económica of Diputación Foral Bizkaia through a grant to Aula EspaZio Gela at E.T.S. Ingeniería (Bilbao, Spain).

412 Jovian Planets: Atmospheres and Laboratory Measurements
Thursday, 3:30 PM - 6:00 PM, Exhibit Hall

412.01 Spot Dynamics
- Howard Houben
  Bay Area Environmental Research Institute.

What is the Great Red Spot? What are “spots” in general? The presence of many spots and similar features on Jupiter, the other giant planets, and the sun argues for a simple explanation based on conditions common to these bodies (but generally absent in terrestrial atmospheres). Consider two nearly conserved quantities: potential temperature (θ) and potential vorticity (PV). θ is a measure of entropy, which can only be modified by diabatic processes, and therefore atmospheric motions are predominantly along θ-surfaces. PV is the component of the vorticity perpendicular to the θ-surface. It therefore describes most of the motion along these θ-surfaces. It can be rigorously demonstrated that PV cannot be transported across θ-surfaces. In the deep atmospheres of the giant planets and the sun, the tropopause is a level of minimum θ (with convectively unstable negative θ gradients below in the troposphere and stable gradients above in the stratosphere). These fluid bodies also have strong variations of θ with latitude (belts and zones). Baroclinic instability is a process which leads to longitude variations of θ. So it is possible for θ-surfaces to close on themselves around a minimum, with PV confined to these surfaces. The enclosed volume is a spot. The integrated PV over the spot is 0! (Low PV corresponds to anti-cyclonic motion.) The closed θ-surfaces extend above the tropopause and can have deep roots (since θ gradients in the troposphere are generally smaller in magnitude than those in the stratosphere). Details of the flow within the spot depend on boundary conditions (i.e., the surrounding flow and, for sunspots, magnetic fields) and the horizontal/vertical aspect ratio of the spot. Interactions with other spots depend on the θ values of their respective boundaries. In terrestrial atmospheres, the intersection of many low-θ surfaces with the ground inhibits spot formation.

412.02 Numerical Simulations Of Vortex-cloud Interactions On Jupiter
- Csaba J. Palotai, T. E. Dowling, G. Chappell
  Univ. Of Central Florida, University Of Louisville.

We have studied the atmospheric physics and dynamics of Jupiter’s Great Red Spot (GRS) and BA vortices using the Explicit Planetary hybrid-ISENTROPIC Coordinate (EPIC) model (Dowling et al., 2006. Icarus, 182, 259–273). The model employs an ammonia cycle that includes interactive vapor, cloud and precipitation phases and accounts for latent heating and cooling (Palotai and Dowling, 2008. Icarus, 194, 303–326). The pressure-based coordinate in this version of the EPIC model allows us to use high vertical resolution in our simulations. The typical model configuration uses 45–50 non-uniformly spaced layers ranging from about 10 mb down to 15 bars, with extra resolution placed in the expected ammonia cloud-forming region. The resulting horizontal and vertical cloud and temperature structures in our simulations are in good agreement with observational data. Our model reproduces the relatively cloud-free regions West and Northeast of the GRS and the elevated clouds over the vortex that was observed by the Galileo Near Infrared Mapping Spectrometer (NIMS). The thermal structure of the simulated
vortices is being compared to ground-based and spacecraft observations, as well. Fletcher et al. (2010, Icarus, 208, 306--328) discovered inhomogeneities in the horizontal temperature field over the GRS and correlated it to observations of clouds. Our numerical model produces similar inhomogeneities that we overlay on the simulated cloud field for direct comparison with the observations. Data also suggests that clouds cover a larger area over the vortices than the area encircled by their high-velocity collars, the simulated collars in our model reproduce these observations. Additional comparisons with observations and results from our latest findings will be presented. The resulting EPIC model is available as open source software from NASA’s PDS Atmospheres Node. This research is supported by NASA’s Cassini Data Analysis and Planetary Atmospheres Programs.

412.03 Change In The Drift Velocity Of A Jupiter Anticyclone In The SSSTC
- Richard W. Schmude
  1Gordon College.

Richard W. Schmude, Jr., Gordon College, 419 College Dr., Barnesville, GA 30204 A white oval (anticyclone) in Jupiter’s South South South Temperate Current (SSSTC) was tracked between 10 July 2011 and 19 January 2012. Tracking was accomplished with the software package WinJUPOS. The northern, southern eastern and western extremities of the anticyclone were measured on 83 different visible light images. All images were on the ALPO Japan Latest website. The longitude, latitude, north-to-south and east-to-west dimensions were measured over the time period. The main findings were that the drift velocity of the anticyclone changed abruptly on about 1 October. The average drift velocity before this date was 5.6 m s⁻¹ and the average rate after this date was -2.1 m s⁻¹. At about the same time as the drift velocity changed the latitude of the center of the anticyclone changed from 50.93° S (0.10°) to 49.79° S (0.09°) and the north-to-south dimension changed from 2.12° (0.06°) to 2.47° (0.06°). Uncertainties are in parentheses. It is suggested that the change in latitude led to the change in drift velocity. An interaction with a folded filamentary region nearby may have led to the change in latitude. Acknowledgements: This work was supported by a grant from the President’s Faculty Development Initiative at Gordon College. The writer is also grateful to the 37 individuals who submitted their images for analysis.

412.04 Jovian Impact Modeling: Impact Angle Variation and Remapping for Later Phases
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We present our latest results built upon our previous numerical simulations of the Shoemaker Levy-9 (SL9) impact event (Palotai et al. 2011 ApJ 731. 3) and of several Jovian impacts that could possibly explain the 2009 bolide (Pond et al. 2012 ApJ 745. 113). There are significant differences between impactor terminal depths and plume development in our SL9 and 2009 impact simulations; thus, we have continued our work by exploring the effect of varying angles of incidence on Jovian impacts. Bolides possessing impact angles ranging from 00.0 to 80.0 degrees are modeled using ZEUS-MP 2 (Hayes et al. 2006 ApJ.SS. 165. 188-228). We investigate how varying the angle of incidence affects the terminal depths of the impactors, plume development, and ejection velocities, in addition to tracking the thermodynamic history of impactor tracer particles. As was explored with the entry of cometary nuclei of SL9 into Jupiter (Korycansky et al. 2006 ApJ 646. 642-652) and in our 2009 simulations, the effects of chaos on these results are investigated as well. We also developed a conservative algorithm for remapping different variable fields onto larger, coarser computational grids, which are needed to investigate wave propagation and the plume flight phase. This algorithm also preserves important impact characteristics, such as expanding impact shocks, during a remapping from one grid to another. Results from our latest simulations will be shown. This research was supported by National Science Foundation Grant AST-1109729 and NASA Planetary Atmospheres Program Grant NNX11AD87G.

412.05 Polar Atmospheric Dynamics of Jupiter
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We investigate the transition in Jupiter’s atmospheric dynamic regime between mid-latitudes to polar regions. Spacecraft observations of Jupiter have identified three distinct dynamical regimes in the cloud-top winds. In the equatorial region, a fast, broad jetstream blows eastward where no vortices are found. In the mid-latitudes, many vortices exist between the numerous jetstreams that alternate in wind direction between eastward and westward. On Jupiter, vortices become increasingly prevalent with latitude; poleward of ~65 degree N/S latitudes, the banded structure that characterizes the lower latitudes becomes indiscernible, and the flow acquires an increasingly turbulent appearance with little zonal organization— we identify this regime as polar turbulence. Saturn also has a very similarly organized atmosphere, except that it maintains zonally organized cloud bands up to the poles and lacks polar turbulence. The zonal structure of Saturn culminates in the southern hemisphere with a hurricane-like cyclonic vortex residing precisely at south pole. Here, we focus on the transition from the mixed jet-vortex regime in the mid-latitudes to the vortex-dominated polar-regime of Jupiter. Using an idealized shallow-water model in a beta-plane channel, we test the stability of various scenarios that range between a jet-dominated flow and vortical turbulence. Since we are simulating a zone on the sphere rather than the full circulation, we test the sensitivity of the dynamics to latitude by varying the model’s beta-plane parameters, namely, the background Coriolis parameter $f_0$ and its gradient beta. In addition, as we employ a 1 1/2-layer shallow-water model, we also vary the layer thickness and the bottom-layer topography to mimic a steeply varying thermal stratification (i.e., a potential vorticity front) by exploiting the topographic beta effects. We use the EPIC model (Dowling et al. 1998) to perform our numerical experiments. Our study is supported by a NASA Outer Planets Program grant (NNX11AM45G).

**412.06 Predictions of Thermal and Gravitational Signals of Jupiter’s Deep Zonal Winds**

- Junjun Liu, T. Schneider, Y. Kaspi

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NASA’s Juno spacecraft will make microwave and gravity measurements of Jupiter. These can reveal information about the composition of Jupiter’s atmosphere and about the temperature and density structure below the visible clouds. Here we show that there exist strong physical constraints on the structure of the deep zonal winds, and these imply dynamical constraints on the thermal and gravitational signals Juno will measure. The constraints derive from the facts that Jupiter is rapidly rotating, has strong intrinsic heat fluxes emanating from the deep interior, and has nearly inviscid flow. Because of the strong intrinsic heat fluxes, Jupiter’s interior is convecting, but the rapid rotation and weak viscosity constrain the convective motions to occur primarily along cylinders parallel to the planet’s spin axis. Convection is expected to approximately homogenize entropy along the spin axis and adjust the interior to a convectively and inertially nearly neutral state. Additionally, thermal wind balance relates entropy gradients perpendicular to the spin axis to the zonal wind shear between the observed cloud-level winds and winds in the deep interior, which must be much weaker because otherwise Ohmic dissipation produced by the interaction of zonal winds with planetary magnetic field would exceed the planetary luminosity. Combining these physical constraints with thermal and electrical properties of the atmosphere, we obtain that zonal winds likely extend deeply into Jupiter (to a depth between 0.84 and 0.94 Jupiter’s radius) but have strengths similar to cloud level winds only within the outer few percent of Jupiter’s radius. Meridional equator-to-pole temperature contrasts in thermal wind balance with the zonal winds increase with depth and reach 1~2 K at 50 bar; they would reach O(10 K) if the winds were shallowly confined. Such temperature contrasts and associated gravitational signals of zonal winds will be detectable by Juno’s microwave and gravitational instruments.

**412.07 Characterization of Jupiter’s Deep Circulation and Static Stability through Wide Channel Numerical Simulations of the Dynamics and Interactions of Southern Midlatitudes Vortices**

- Raul Morales-Juberias, T. E. Dowling

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Previous studies have shown that the observed features and dynamics of Jovian vortices are sensitive to the underlying environmental structure of Jupiter’s atmosphere, in particular to the vertical wind shear and the static stability, and that forward modeling techniques can be successfully used to eliminate a large range of possibilities in a self-consistent manner and hence constrain the atmospheric structure below the cloud regions (Youseff and Marcus 2003, Morales-Juberias et al. 2005). However, these studies have generally been done on a narrow latitude-band basis (~15°). Here we present wide channel simulations (~40°) of two major meteorological events.
observed in the southern atmosphere of Jupiter involving the interaction of the Great Red Spot (GRS) with other nearby vortices. Namely, the spots associated with the recirculation of the South Tropical Disturbance of 1979 (Smith et al. 1979) and the White Ovals (WOS) in 2000 when ovals BE and FA merged to form BA (Sanchez-Lavega et al. 2001). By studying these two events using wide channel simulations, not unlike the strategy used in terrestrial synoptic meteorology, we show that we can gain new insights into the patterns governing Jupiter’s global circulations, drawing a coherent picture of the vertical structure of the atmosphere for the whole southern mid-latitude regions of Jupiter over time. In particular, we find that the model output best captures the dynamics of the individual vortices and the morphology of their interactions when the deformation length in this region is like that derived by Read et al. 2006 and the deep winds vary following a dependence like that derived by Dowling 1995 in which the westward jets remain constant with depth but the eastward jets increase with depth. Computational resources were provided by the New Mexico Computing Applications Center and NMT. This work was supported by PATM grants NNX08AE91G and NNX08AE64G.

**412.08 Attenuation of Radio Waves by Saturn's Ionosphere**

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Using contemporary models and observations, we estimate the attenuation of radio waves by Saturn's ionosphere. Electron density profiles are specified based on the 31 published radio occultation observations by Cassini's Radio Science Subsystem. Neutral background parameters are taken from the Saturn Thermosphere Ionosphere Model (STIM), a general circulation model of Saturn's upper atmosphere constrained by Voyager and Cassini observations. The degree of attenuation of radio waves by Saturn's ionosphere is found to vary strongly with frequency and electron density, with minimal attenuation above 10 MHz and maximum attenuation of a few hundred dB below 0.1 MHz for some Cassini electron density profiles. Finally, we evaluate the impact of the calculated attenuations on analysis of Saturn Electrostatic Discharge (SED) observations, as the measured SED cutoff frequency (and ultimately the derived peak electron density) depends on the intensity of the SEDs above the background noise level.

**412.09 Temperature And Density Structure In Saturn's Thermosphere From Cassini/uvis Solar Occultations**

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Stellar and solar occultations obtained by the Cassini/UVIS instrument probe Saturn’s upper atmosphere at altitudes between 300 km and 3000 km above the nominal 1 bar level. The stellar occultations can be used to retrieve the density profiles of various hydrocarbon species below the homopause and of H2 in the lower thermosphere. The solar occultations, on the other hand, can be used to constrain the density of H2 and temperatures at the highest altitudes in Saturn’s thermosphere. However, the analysis of the solar occultations is challenging because of the large projected size of the solar disk as seen by Cassini through Saturn’s atmosphere and the need for a detailed instrument model that is required to forward model the observations. We have developed new methods to analyze the data that are capable of overcoming these challenges, and present densities and temperatures in the thermosphere based on 9 solar occultations that took place between 2007 and 2008 towards the end of the southern summer on Saturn. The equatorial temperatures in Saturn’s thermosphere are significantly higher than those expected based on solar heating alone, and redistribution of auroral energy is one of the possible solutions commonly invoked to explain these high temperatures. The solar occultations that we have analyzed provide temperature estimates for latitudes ranging from 70N to 70S and thus they provide constraints for models of global redistribution of energy in the thermosphere. Density profiles at high altitudes can also be used in planning the end of the Cassini Solstice mission that includes a descent of the satellite into the atmosphere of Saturn.

**412.10 The Zonal Mean Structure of Clouds and Haze on Saturn from Cassini/CIRS Observations**

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- \(^1\)University of Florida.
We analyze Cassini/CIRS observations of Saturn at 1392 cm⁻¹ including data from 2005 to 2007. In the absence of clouds and haze, the atmosphere of Saturn at this wavelength is expected to be transparent at pressure levels as deep as 900 mbar. We use CIRS MIRMAPs to study the latitudinal distribution of clouds and haze both in the southern and northern hemispheres. The constructed zonal mean average of the brightness temperature at 1392 cm⁻¹ is consistent with the presence of a gray absorber in the upper troposphere and lower stratosphere with the strongest signature seen in latitudes higher than 60°S. No such polar enhancement is seen in the northern hemisphere. Strong day-to-day variations in the zonally averaged data indicate a significant noise level in the observations in this part of the spectrum, which results in large uncertainties for the derived vertical cloud/haze distribution.

412.11 Changes in Saturn’s Zonal-Mean Tropospheric Structure After the 2010 Great White Spot

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In early December 2010, a large convective storm erupted at approximately 40°N planetographic latitude on Saturn, lasting until early July 2011 (Sánchez-Lavega et al. 2012, Icarus, 220, 561-576). Retrievals of upper tropospheric (100 to 800 mbar) temperature and hydrogen para-fraction from far-IR (20 to 100 μm) Cassini Composite Infrared Spectrometer (CIRS) data show that between January and April 2011 the hydrogen para-fraction decreased by about 0.04 at latitudes between 25°N and 45°N and pressures greater than about 300 mbar. Within this same latitude band, temperatures have increased at a rate of about 2.5 K per year since the storm started, again at pressures greater than 300 mbar, and continued to increase through April 2012, months after the visible convection ceased. The decrease in hydrogen para-fraction can likely be explained by the convective plume advecting low para-fraction hydrogen upward from the several bar level, where the equilibrium para-fraction is 0.25, and the subsequent mixing of the low para-fraction hydrogen with the ambient atmosphere. Heat released from the conversion of ortho-hydrogen to para-hydrogen may then explain the observed temperature increase. Continued monitoring of the para-fraction as it relaxes toward thermodynamic equilibrium may provide constraints on the timescales for ortho- to para-hydrogen equilibration.

412.12 Latitudinal Variation Of Upper Tropospheric NH3 On Saturn Derived From Cassini/cirs Far-infrared Measurements

- Jane Hurley¹, L. N. Fletcher¹, P. G. J. Irwin¹, S. B. Calcutt¹, J. A. Sinclair¹, C. Merlet¹
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Ammonia (NH3) has been detected both on Saturn and Jupiter, and although its concentration and distribution has been well-studied on Jupiter, it has proven more difficult to do so on Saturn due to higher sensitivity requirements resulting from Saturn’s lower atmospheric temperatures and the dominance of Saturn’s phosphine (PH3) which masks the NH3 signal. Using far-infrared measurements of Saturn taken by Cassini/CIRS between February 2005 and December 2010, the latitudinal variations of upper tropospheric NH3 on Saturn are studied. Sensitivity to NH3 in the far-infrared is explored to provide estimates of temperature, para-H2 and PH3, from 2.5 cm–¹ spectral resolution measurements alone, 0.5 cm–¹ spectral-resolution measurements alone, and 0.5 cm–¹ measurements degraded to 2.5 cm–¹ spectral resolution. The estimates of NH3 from these three different datasets largely agree, although there are notable differences using the high emission angle 0.5 cm–¹ data, which are asserted to result from a reduction in sensitivity at higher emission angles. For low emission angles, the 0.5 cm–¹–retrieved values of NH3 can be used to reproduce the 2.5 cm–¹ spectra with similar efficacy as those derived directly from the 2.5 cm–¹ resolution data itself, and vice versa. Using low emission angle data, NH3 is observed to have broad peak abundances at ±25° latitude, attributed to result from condensation and/or photolytic processes. Lack of data coverage at equatorial latitudes precludes analysis of NH3 abundance at less than about 10° latitude. Noise levels are not sufficient to distinguish fine zonal features, although it seems that NH3 cannot trace the zonal belt/zone structure in the upper troposphere of Saturn.

412.13 Evolution of a Dark Anti-Cyclone on Saturn Associated with the Great Lightning Storm of 2010/2011 Through the Eyes Of Cassini/VIMS
A massive dark anti-cyclonic storm system on Saturn spanning some 7° of longitude and 2° of latitude was observed by Cassini/VIMS at a planetocentric latitude of ~37° on 4 January 2012 and 26 January 2012. During this time, it drifted some 54° of longitude at a speed of 23.1 ± 0.2 m/s prograde, a drift speed which correlates well with the canonical Voyager (and VIMS) wind profiles for Saturn at this latitude. The spot also drifted northward during this time by ~1° and became noticeably "squished" in morphology. Using this drift rate and extrapolating backward, we find that the position corresponds to the large (> 5,000 km) anti-cyclone observed by VIMS on 11 May 2011 at 35.4° latitude (pc) and 49.4° W. longitude. This would represent ~8 months of observation of this titanic feature, which was associated with the major lightning storm of 2010-2011, following the spot as it changed in size and morphology and drifted northward. The spot underwent a dramatic shift in shape in the 3 weeks of January, changing from roughly oval to a highly elongated pancake shape as it apparently bumped up against the dark band at 40° latitude and experienced a powerful shear. The evolution suggests that we are watching the death throes of this feature in our most recent observations. Finally, the dark spot was darker than surrounding regions in May 2011 and maintained its dark color across all pseudo-continua from 1.0 to 4.0 μm between May 2011 and early January 2012.

412.14 Photochemistry in Saturn’s Ring Shadowed Atmosphere: Production Rates of Key Atmospheric Molecules and Haze Observations
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Cassini has been orbiting Saturn for over eight years. During this epoch, the ring shadow has moved from shading a large portion of the northern hemisphere (the ring plane was inclined by ~24 degrees relative to the Sun-Saturn vector) to shading mid-latitudes south of the equator and continues southward. At its maximum extent, the projection of the ring plane shadow onto Saturn can reach as far as 48N (~58N at the terminator). The net result, is that the intensity of both ultraviolet and visible sunlight penetrating onto any particular northern/southern latitude will vary depending on Saturn’s tilt relative to the Sun and the optical thickness of each ring system. Our previous work has examined the variation of the solar flux as a function of solar inclination, i.e. season on Saturn. Here we report on the impact of the oscillating ring shadow on the photolysis and production rates of key hydrocarbons in Saturn’s stratosphere and upper troposphere, including ethane, acetylene, propane, benzene. We investigate the impact on production and loss rates of the long-lived, photochemical hydrocarbons leading to haze formation at several latitudes over one Saturn year. Similarly, we assess the impact on the abundance of phosphine, a disequilibrium species whose presence in the upper troposphere is a tracer of convection processes in the deep atmosphere. Along with the above, we present preliminary analysis of Cassini’s UVIS and VIMS datasets that provide an estimate of the evolving haze content of the northern hemisphere. The research described in this paper was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

412.15 Clouds and Hazes in Saturn’s Troposphere and Stratosphere
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We present new results from the analysis of Saturn’s near-infrared spectra measured with the Visual and Infrared Mapping Spectrometer (VIMS) instrument on the Cassini orbiter. VIMS near-infrared data are particularly relevant for the study of clouds and hazes in the troposphere and stratosphere of Saturn. Thermal emission in the 4.5-5.1 wavelength range is absorbed and scattered mainly by tropospheric clouds and radiatively active gases. The vertical structure as well as the optical and physical properties of tropospheric aerosols are obtained from Saturn’s thermal emission spectra by using the retrieval algorithm Nemesis. The distribution of tropospheric phosphine and
ammonia in gas phase will also be presented here. We managed to break the degeneracies inherent to the retrieval problem by analysing Saturn's thermal emission simultaneously at various viewing geometries. By using this method, we found that VIMS spectra at 4.5-5.1 microns are also sensitive to the hazes formed above the cloud layers. Saturn's reflected sunlight spectra at 0.8-3.5 microns measured with VIMS were also analysed in order to constrain the haze properties in the upper troposphere and lower stratosphere of the planet. Results from both the 0.8-3.5 and 4.5-5.1 wavelength ranges were combined to determine the cloud and haze model most consistent with VIMS spectroscopy over a wide range of viewing geometries and lighting conditions. An increase of temperature below the tropopause, often referred to as the temperature knee, was retrieved from Cassini/CIRS spectra. Seasonal variations of the knee and haze structure are compared, and as a result the assumption of local heating by the hazes to explain this feature will be discussed.

412.16 The Post-Equinox Latitudinal Distribution of the Methane Absorption on Saturn in 2011-2012
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In 2011 and 2012 there were continued perennial spectral observations of Saturn to studying the seasonal spatial and temporal variations of molecular absorption on the disk of the planet. During the last two seasons of observations were recorded over 3300 CCD-spectra of Saturn's central meridian and zonal spectra by scanning the disk of the planet from the south pole to the north. On the basis of a preliminary sample of this extensive observational material there were prepared the atlases of the band profiles and latitudinal variations of their intensity. The general character of the latitudinal variation of the absorption in this period compared to those observed in 2010 remains without especial changes. As in preceding years the ratio of equivalent width W619nm/W725nm at N-temperate latitudes was in 2011 about 27-30 per cent more than at S-temperate latitudes. In the northern hemisphere in 2011 the difference between the CH₄ absorption maximum at the latitudes 35-45 N and a minimum at latitudes 55-65 N noticeably increased. In 2012 this maximum of absorption moved southward and the difference decreased. Since this less pronounced difference was observed in previous years also, it is unlikely it can be associated with the effects of the Great Northern Storm, which appeared in December 2010. One feature may be interesting - the central depth of 725 nm band almost does not show this absorption difference in contrast to the depths of weaker absorption bands, whereas its equivalent width shows a latitudinal difference. It may be explained in suggestion that the central absorption in the 725 nm band with residual intensity about 0.25 or less is formed at lower effective optical depth, where the differences in the cloud volume density or the haze altitude are smaller in the range of these latitudes.

412.17 Inhibition of Convection by Condensation in the Ice Giants: The Role of Diffusive Convection
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We explore the conditions under which ordinary thermal convection may be inhibited by water condensation in the hydrogen atmospheres of the ice giants and examine the consequences. Guillot (1995, Science 269, 1697) first showed that condensation of high molecular weight species could inhibit convection in these atmospheres. This can occur when the saturation of vapor in the condensation layer induces a vertical gradient in the mean molecular weight that stabilizes the layer against thermal instability when the abundance of vapor exceeds a critical value. In this instance, the temperature gradient can become superadiabatic and heat must be transported vertically by another mechanism. On Uranus and Neptune, water and methane are both inferred to be sufficiently abundant for inhibition of convection to take place in their respective condensation zones. Here we focus on the role of water. If ordinary convection is suppressed, heat must be transported across the saturated layer by diffusive convection, or if diffusive convection is inefficient, by radiative transport. We are currently exploring the efficiency of diffusive convection for transferring heat across the layer. The efficiency of dry diffusive convection is largely controlled by the ratio of the mean molecular weight gradient to the superadiabatic temperature gradient. Relatively efficient layered convection occurs when this ratio is small, inefficient oscillatory convection when it is large. We estimate this ratio for the water saturation zones in Uranus and Neptune as a function of the assumed mole fraction of water in their interiors and discuss the implications for the efficiency of diffusive convection. We also explore the effects of condensation. Finding the diffusive convection to be inefficient would have important
consequences for thermal evolution models of the ice giants and for understanding Uranus’ anomalously low intrinsic heat flow. This research is supported by the NASA Outer Planet Research Program.

412.18 A Closer Examination of the Joint Behavior of Dark Spots and their Companion Clouds on the Ice Giants
- Raymond P. Le Beau¹, S. W. Warning¹, C. Palotai², X. Deng³
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Starting with the Voyager observations of the Great Dark Spot-Bright Companion duo on Neptune, discrete cloud features have been linked to vortices on the Ice Giants. Building on these observations, numerical simulations of these features have begun to reveal a complex physical interaction in which the vortex can generate clouds which in turn influence the behavior of the vortex. For example, simulations in the EPIC general circulation model of a vortex similar to the Uranian Dark Spot can generate companion clouds from a cloud-free initial condition. These clouds are generated orographically, with a region of upwelling on the leading edge of vortex lifting methane from the warmer lower atmosphere to cooler conditions above the vortex. This increases the local humidity to the point where condensation can occur. The upwelling is perceptible in some simulations a scale height above the vortex with vertical velocities on the order of 0.01-0.1 m/s. The strength of this upwelling is dependent on the local humidity as well as the vortex characteristics; likewise, the meridional drift rate of these vortices is affected by the changes in methane distribution. While the described UDS simulation provides an illustration of the interactive physics underlying vortex-cloud phenomena, there are other, more perplexing observations that require further explanation. These range from the changing shape of the original bright companion cloud above and about the drifting, oscillating Great Dark Spot to the meridional drift and time-varying cloud structure of the “Berg” on Uranus. Ongoing numerical examination of these vortex-cloud pairings will provide further insight into these features and the overall atmospheric physics of the Ice Giants. This research is supported by NASA Planetary Atmospheres grant NNX11AC01G.

412.19 Analysis Of Irtf Spex Near-infrared Observations Of Uranus: Aerosol Optical Properties And Latitudinally Variable Methane
- Dane Tice¹, P. G. J. Irwin¹, L. N. Fletcher¹, N. A. Teanby², J. Hurley¹, G. S. Orton³, G. R. Davis⁴
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We present results from the analysis of near-infrared spectra of Uranus observed in August 2009 with the SpeX spectrograph at the NASA Infrared Telescope Facility (IRTF). Spectra range from 0.8 to 1.8 μm at a spatial resolution of 0.5" and a spectral resolution of R = 1,200. This data is particularly well-suited to characterize the optical properties of aerosols in the Uranian stratosphere and upper troposphere. This is in part due to its coverage shortward of 1.0 μm where methane absorption, which dominates the features in the Uranian near-infrared spectrum, weakens slightly. Another particularly useful aspect of the data is it’s specific, highly spectrally resolved (R > 4,000) coverage of the collision-induced hydrogen quadrupole absorption band at ~825 nm, enabling us to differentiate between methane abundance and cloud opacity. An optimal-estimation retrieval code, NEMESIS, is used to analyze the spectra, and atmospheric models are developed that represent good agreement with data in the full spectral range analyzed. Aerosol single-scattering albedos that reveal a strong wavelength dependence will be discussed. Additionally, an analysis of latitudinal methane variability is undertaken, utilizing two methods of analysis. First, a reflectance study from locations along the central meridian is undertaken. The spectra from these locations are centered around 825 nm, where the collision-induced absorption feature of hydrogen is utilized to distinguish between latitudinal changes in the spectrum due to aerosol opacity and those due to methane variability. Secondly, high resolution retrievals from 0.8 - 0.9 μm portion of the spectrum and spectral resolutions between R = 4,000 and 4,500 are used to make the same distinction. Both methods will be compared and discussed, as will their indications supporting a methane enrichment in the equatorial region of the planet.

412.20 Uranus High Signal-to-noise Ratio Near-IR Imaging: Recent Results
High signal-to-noise imaging of Uranus, using specially-designed observations and special image combination techniques (Fry, P. M., et al. 2012, Astron. J. 143, 150-161) has now been applied to H and Hcont filtered images from Keck II NIRC2 and Gemini-North NIRI instruments, and F845M images from the HST WFC3 camera. Uranus' zonal wind profile has been updated as the viewing of more northerly latitudes improves, and the presence of high-latitude northern clouds has raised the possibility of fundamentally different large-scale meridional circulation patterns in the north and south hemispheres (L. A. Sromovsky et al. 2012, Icarus 220, 694-712). Detection of the low-contrast polar clouds and their altitude determination (by H/Hcont contrast ratios) is only possible using high-SNR imaging techniques. Though high-SNR imaging is not required to detect extremely bright features on Uranus, such as the variable-brightness interacting systems observed in late 2011, it has proved valuable in allowing tracking of persistent features to aid in investigation of their genesis, evolution, and dissipation (L. A. Sromovsky et al. 2012, Icarus 220, 6-22). Characterization of fine details of the latitudinal band structure can also be improved by these observations. We will show how this band structure has recently evolved, using H-band imagery from 2003 to the present, and HST F845M images from 2009 to 2011. Our 2011 Keck II observations were productive, in spite of sub-par image quality. Assuming normal image quality, we expect our upcoming Keck II observations (24, 28 July 2012, 14-15 August 2012) to reveal exceptional detail in small low-contrast polar cloud features, to allow tracking of extremely low-contrast low latitude features, and to show the current fine structure of Uranus' bands. Sample results will be shown if observations are successful. This research was supported by the NASA Planetary Astronomy program, the W. M. Keck Observatory, and STScI.

412.21 Mid-IR Observations of Uranus' H2 Quadrupole Emission Near Equinox

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The dominant process causing the high thermospheric temperatures observed for the major planets remains an unsolved problem. Uranus is of particular interest for identifying this source of heating because of its extreme obliquity and weak internal heat source, which permit large seasonal extremes driven by radiative and dynamical processes. Sources of thermospheric heating may be investigated indirectly through the energy balance of the offsetting line emission, which radiates the generated heat to space. The cooling rate can be characterized by observing the line emission vs. position over the planet. The primary coolant in Uranus' thermosphere is emission in the rotational H2 quadrupole lines. We report observations of Uranus' rotational H2 quadrupole line emission obtained near the 2007 equinox using TEXES at Gemini in late October, 2007. Good data were obtained for the H2 S(1) line, which was scanned longitudinally across Uranus' disk to make an emission map showing all latitudes. This map shows bimodal emission along Uranus' central meridian with the brightest peak in the northern (end of winter) hemisphere. Intermittent clouds interfered with the observation of the relatively faint S(2) line, which precluded scanning, thus leaving the observations vulnerable to pointing uncertainties. We combine these data with non-equinox observations of Uranus obtained with TEXES at the IRTF to estimate the positional variation of Uranus' thermospheric cooling rate, ultimately to help constrain the unknown dominant source of heating.

412.22 Constraining the Origins of Neptune's Carbon Monoxide Abundance with CARMA Millimeter-wave Observations

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We present observations of Neptune's 1- and 3-mm spectrum from the Combined Array for Research in Millimeter-wave Astronomy (CARMA). Radiative transfer analysis of the CO (2-1) and (1-0) rotation lines was performed to constrain the CO vertical abundance profile. We find that the data are well matched by a CO mole fraction of 0.1+0.3-0.1 parts per million (ppm) in the troposphere, and 1.1+0.7-0.3 ppm in the stratosphere. A flux of 0.5-20 x 10^8 CO molecules cm^-2 s^-1 to the upper stratosphere is implied. Using the Zahnle et al. (2003) estimate for cometary impact rates at Neptune, we calculate the CO flux that could be formed from (sub)kilometer-sized comets; we find that if the diffusion rate near the tropopause is slow, these impacts could produce a flux as high as
We also revisit the calculation of Neptune’s internal CO contribution using revised calculations for the CO $\rightarrow$ CH$_4$ conversion timescale in the deep atmosphere. We find that an upwelled CO mole fraction of 0.1 ppm implies a global O/H enrichment of at least 400 times the protosolar value. Finally, we present maps of Neptune in the CO (2-1) line with a spatial resolution of 0.3", and discuss the implications of the latitudinal CO distribution.

**412.23 Long-term Observations Of Neptune's Mid-infrared Ethane Abundance**

Heidi B. Hammel¹, M. L. Sitko², L. S. Bernstein³, R. W. Russell⁴, D. K. Lynch⁵

¹AURA, ²U. Cincinnati, ³Spectral Sciences Inc., ⁴The Aerospace Corp., ⁵Caltech.

Hammel et al. (2006) reported mid-infrared spectral observations of Neptune spanning more than a decade. The data indicated an increase in Neptune’s atmospheric 12-μm ethane emission from 1985 to 2003, with the simplest explanation being a stratospheric temperature increase of 1.2 K per year. We report here continued mid-IR low-resolution spectroscopy at the NASA Infrared Telescope Facility using the Broadband Array Spectrograph System (BASS; Hackwell et al. 1990). With the model described by Hammel et al. (2006; a single-layer, line-by-line radiative transfer model with fixed mixing ratios for ethane and acetylene), we retrieved effective stratospheric temperatures as a function of year. In 2005, 12-μm images showed Neptune’s ethane emission to be concentrated near the south pole, as well as distributed around the planet’s limb (Hammel et al. 2007; Orton et al. 2007). The trend from the new spectra suggests the long-term variations may be due in part to viewing angle: more of the pole was revealed during Neptune’s 2005 solstice. We will present the most recent observations (through 2011), and compare with the long-term data base to try to distinguish whether the continued variation is seasonally-driven or stochastic. HBH acknowledges support for this work from NASA grants NNX06AD12G and NNA07CN65A. This work was supported at The Aerospace Corporation by the Independent Research and Development Program. LSB acknowledges the support of Spectral Sciences, Inc. (SSI) IR and D funding.

**412.24 An Investigation of the Seasonal Changes of Neptune's Atmosphere via a July 2008 Stellar Occultation Event**

Kyle Uckert¹, N. Chanover¹, C. Miller¹, C. Olkin², L. Young², H. Hammel³, J. Bauer⁴

¹New Mexico State University, ²Southwest Research Institute, ³Association of Universities for Research in Astronomy, ⁴Jet Propulsion Laboratory.

We extract physical atmospheric parameters from a July 23, 2008 single-chord stellar occultation of the star USNO-B1.0 0759-0739128 by Neptune using both light curve model fitting and numerical inversion techniques. We observed the occultation event using the Agile CCD camera mounted on the Astrophysical Research Consortium 3.5m telescope at Apache Point Observatory. We acquired a series of 13,340 0.5 second images from approximately 07:14 to 09:05 UT. Neptune was observed through an airmass ranging from 1.57 to 1.46, with atmospheric seeing of approximately 0.6" throughout the event. We used the Johnson I-band filter, which was chosen to reduce the contribution of scattered light from Neptune. Methane absorption at 0.89 μm in Neptune’s upper stratosphere causes Neptune to appear darker at this bandpass, reducing the amount of scattered light in the image. A 0.5 second integration time with negligible frame-transfer provides an atmospheric sampling at the microbar pressure level of approximately 4 samples per scale height. Stellar occultations of Neptune were observed extensively in the 1980’s to search for evidence of a ring system around the planet prior to the arrival of Voyager 2. No new occultations of Neptune have been published since 1990, due in part to the diffuse star field the planet has been traveling though. We compare the stratospheric temperature derived from the 2008 occultation to published temperatures of Neptune at similar atmospheric pressures derived from previous stellar occultations and from mid-IR spectral data collected within the last decade. The two leading hypotheses for explaining the observed temperature variations of Neptune are seasonal variability and variations in the Lyman-alpha flux received at Neptune due to the 11-year solar cycle. We investigate the effect each of these mechanisms may have on the gradual changes of Neptune’s average stratospheric temperature. This work is supported by funds from NASA grant NAG5-1247.

**412.25 Extension Of The Hitran Database To Aid Remote Sensing Of Diverse Planetary Atmospheres**
Studies of the spectroscopic signatures of planetary atmospheres are a powerful tool for extracting detailed information concerning their constituents and thermodynamic properties. The HITRAN molecular spectroscopic database has traditionally served researchers involved with terrestrial atmospheric problems, including remote-sensing of constituents in the atmosphere. In collaboration with laboratories across the globe, an extensive effort is currently underway to extend HITRAN database to have capabilities for studying a variety of planetary atmospheres. Spectroscopic parameters for gases and spectral bands of molecules that are germane to the studies of planetary atmospheres are being assembled. A major accomplishment of the effort is the assembly and recent release of the HITEMP database, which included spectral parameters suitable for simulating high-temperature and NLTE spectra for H2O, CO2, CO, NO and OH gases. A number of new molecules, such as H2, CS, C4H2, HC3N and C2N2 are being incorporated for the HITRAN2012 release of the database, while several other molecules are pending. For some of the molecules, additional parameters, beyond what is currently considered for the terrestrial atmosphere will be archived. In particular, collision-broadened halfwidths due to various foreign partners will now be provided. In that regard not only do we collect, evaluate and extrapolate available experimental and theoretical data, but also create a new structure to the database for user convenience. Collision-induced absorption data for H2-H2, H2-N2, H2-He, H2-CH4, CH4-CH4, N2-N2, N2-O2, O2-O2, O2-CO2 and N2-CH4 were also recently released. Partition sums that are necessary for applications at a wide range of temperature have recently been calculated for a wide variety of molecules of planetary interest. Current accomplishments and future efforts will be reviewed at the meeting. This effort is supported by the NASA Planetary Atmospheres program, under the grant NNX10AB94G.

412.26 Line Positions and Intensities of Monodeuterated Methane Between 2.2 and 2.5 Microns

- Linda R. Brown1, K. Sung2, A. V. Nikitin3, M. H. Smith3, A. W. Mantz4, V. G. Tyuterev5, M. Rey6
  1Jet Propulsion Laboratory, 2Laboratory of Theoretical Spectroscopy, V.E. Zuev Institute of Atmospheric Optics, Russian Federation, 3NASA Langley Research Center, 4Connecticut College, 5GSMA, Université de Reims, France.

A new study of 12CH3D line positions and intensities was performed for the upper portion of the Enneadecad polyad between 4000 and 4550 cm⁻¹. For this, FTIR spectra were recorded with D-enriched methane samples (at 80 K with a Bruker 125 IFS at 0.005 cm⁻¹ resolution and at 291 K with the McMath-Pierce FTS at 0.011 cm⁻¹ resolution, respectively). Line positions and intensities were retrieved by least square curve-fitting procedures and analyzed using the effective Hamiltonian and the effective Dipole moment expressed in terms of irreducible tensors operators adapted to symmetric top molecules. Initially, only the cold spectrum was used to identify quantum assignments and predict 12CH3D relative intensities in this region. Combining the two temperature datasets confirmed the assumed quantum assignments and also demonstrated the relative accuracies to be better than ±0.0002 cm⁻¹ for line positions and at least ±6% for ~1160 selected features. Including additional assignments from the room temperature spectra alone permitted 1362 line intensities of 12 bands (involving 23 vibrational symmetry components) to be reproduced with an RMS of 9%. Over 4085 selected positions for 12 bands were modeled to 0.008 cm⁻¹. More work is needed to obtain a complete characterization of this complex polyad. This work is part of the ANR project “CH4@Titan” (ref: BLAN08-2_321467). Research described in this paper was performed at the Jet Propulsion Laboratory, California Institute of Technology, the NASA Langley Research Center and Connecticut College under contracts and grants with the National Aeronautics and Space Administration. We acknowledge the LEFE-CHAT INSU project APOA1 (CNRS, France); the Groupement de Recherche International SAMIA between CNRS (France), RFBR (Russia) and CAS (China).

412.27 Line Positions, Intensities And Line Shape Parameters Of PH3 Near 4.4 μm

- Malathy Venkataraman1, D. C. Benner1, I. Kleiner2, L. R. Brown3, R. L. Sams4, L. N. Fletcher5
  1College of William and Mary, 2Laboratoire Interuniversitaire des Systems Atmospheriques (LISA), France, 3Jet Propulsion Laboratory, California Institute of Technology, 4Pacific Northwest National Laboratory, 5University of Oxford, Clarendon Laboratory, United Kingdom.
Accurate knowledge of spectral line parameters in the 2000 to 2400 cm\(^{-1}\) region of PH\(_3\) is important for the CASSINI/VIMS exploration of dynamics and chemistry of Saturn and for the correct interpretation of future Jovian observations by JUNO and ESA’s newly-selected mission JUICE. Since the available intensity information for phosphine is inconsistent, we measured line positions and intensities for over 4000 individual transitions in the 2\(\nu_2\), \(2\nu_2 + \nu_6\), \(2\nu_4\), \(2\nu_3\) and the \(\nu_3\) bands from analyzing high-resolution, high S/N spectra recorded at room temperature using two Fourier transform spectrometers (FTS); the Bruker IFS 125 HR FTS at PNNL and the Kitt Peak FTS at the National Solar Observatory in Arizona. In addition to line positions and intensities, self-broadened half width and self-induced pressure-shift coefficients were also measured for about 800 transitions for the various bands. The strong Coriolis and other types of interactions occurring among the various vibrational levels result in a large number of forbidden transitions as well as cause A+A- splittings in transitions with K\(^\prime\) that are multiples of 3. Line mixing was detected between several A+A- pairs of transitions; and self- line mixing coefficients were measured for several such pairs of transitions by applying the off-diagonal relaxation matrix formalism of Levy et al.\(^1\) A multispectrum nonlinear least squares technique\(^2\) employing a non-Voigt line shape including line mixing and speed dependence was used in fitting all the spectra simultaneously. Present results are compared with other reported values. This research is supported by NASA’s Outer Planets Research Program. References [1] A. Lévy et al., In "Spectroscopy of the Earth’s Atmosphere and Interstellar Medium", Ed. K, Narahari Rao and A. Weber, Boston, Academic Press; p, 261-337 (1992). [2] D. C. Benner et al., J Quant. Spectrosc. Radiat. Transfer 53, 705, 1995.

412.28 Laboratory Measurements of the 5-20 cm Wavelength Opacity of Ammonia Pressure-Broadened by Methane under Jovian Conditions
- Garrett Chinsomboon\(^1\), P. G. Steffes\(^1\)
\(^1\)Georgia Institute of Technology.

In order to fully understand the role methane (CH\(_4\)) plays in the microwave emission spectra of the deep atmospheres of the outer planets, over 280 laboratory measurements of the opacity of ammonia in a methane environment have been made in the 5-20 cm wavelength range. All opacity measurements were made with either 100 or 200 mbars of ammonia and with 1 to 3 bars of added methane in the 330-450K temperature range. A formalism for the absorptivity of ammonia broadened by methane has now been developed and had been applied to the Hanley et al. (Icarus, v. 202, 2009) model for the opacity of ammonia. Due to methane’s relatively low abundance at Jupiter (~0.2% by volume), its effect on the microwave spectrum which will be observed by the Juno MWR (Microwave Radiometer) will be minimal. However, these experimental results will significantly improve the understanding of the microwave emission spectrum of Uranus and Neptune where methane plays a more dominant role. This work was supported by NASA Contract NNM06AA75C from Marshall Space Flight Center supporting the Juno Mission Science Team, under Subcontract 699054X from the Southwest Research Institute.

412.29 Modeling Seasons in the Outer Solar System: Enabling EPIC to Roar on 1 Watt
- Timothy E. Dowling\(^4\), M. G. Sussman\(^3\), T. K. Greathouse\(^3\), N. J. Chanover\(^3\)
\(^3\)Univ. of Louisville, \(^4\)Univ. of Arizona, \(^3\)Southwest Research Institute, \(^3\)New Mexico State University.

We describe solutions to key technical problems that arise in GCMs when modeling the circulations of Uranus and Neptune, and provide an update to the EPIC model radiative transfer (RT) package, with application to seasonal forcing of Saturn and Uranus. The primary challenges in ice-giant circulation modeling stem from the low value of the solar insolation (~1 Wm\(^{-2}\)), which results in slow (~10\(^{-7}\) ms\(^{-1}\)) meridional-plane circulations that are coupled to fast (~10\(^3\) m\(^{-1}\)) zonal winds. Computational modes that are negligible for inner solar-system atmospheric modeling because of high insolation are not negligible for Uranus and Neptune, and hence must be reduced or eliminated. We describe a new, high-order hyperviscosity algorithm that is non-dimensional, efficient, and has well-behaved boundary conditions at the poles. A 12\(^{th}\) application to Uranus permits EPIC to run for multiple Uranus years without degrading the 11\(^{th}\)-order zonal-wind model of Sromovsky et al. (2009). Additional EPIC (Ver. 5.0) improvements include a runtime RT package based on the Greathouse et al. (2010 EGU) Saturn seasonal model that employs our fast and accurate DISORT c_twostr rewrite, a pressure vertical-coordinate option, a dynamic convective adjustment scheme which incorporates improvements to the turbulent Prandtl number by Zilitinkevich et al. (2007), and an accurate analemma, or Sun-in-sky position as a function of time and location on the planet, for
Earth, Mars, Jupiter, Saturn, Uranus and Neptune. These improvements make EPIC a versatile tool for dynamic 3D modeling of stratospheric temperatures and hydrocarbon distributions. This research is funded by the NASA Planetary Atmospheres Program, Grant NNX08AEG4G.

413 Jovian Planets: Magnetospheres and Aurorae
Thursday, 3:30 PM - 6:00 PM, Exhibit Hall

413.01 Azimuthal Variations in the Io Plasma Torus and the Role of Hot Electrons
- Andrew J. Steffl
- A. B. Shinn

Southwest Research Institute.

Much of our current understanding of the Io plasma torus comes from the analysis and modeling of observations made by the Ultraviolet Imaging Spectrograph (UVIS) during the Cassini spacecraft’s flyby of Jupiter (October 2000 through March 2001). The sensitivity of Cassini UVIS coupled with the temporal coverage of the observations made it possible to separate temporal variations in the Io torus from true spatial variations. However, previous work has focused almost exclusively on the first 45 days of the Cassini flyby, from 2000 October 1 to 2000 November 14. Here, we present results from the remaining 122 days of UVIS observations of the Io plasma torus. In particular, we focus on how these new results show a more nuanced picture of the Io torus than that which emerged from the analysis of data from the initial flyby period: namely, that longitudinal variations in electron temperature, electron density, and plasma ionization state are an omnipresent feature in the Io torus and are caused by a sub-corotating source of hot (~100 eV) electrons that is modulated by its position in System III longitude.

413.02 Variability in the Flow of Mass & Energy in the Magnetosphere of Saturn
- Fran Bagenal
- R. Wilson

Univ. of Colorado.

We present a simple model of the plasma disk surrounding Saturn based on analysis of Cassini CAPS ion data. We derive radial profiles of the distribution of plasma mass, pressure, thermal energy density, and kinetic energy density (as per Bagenal & Delamere, JGR, v.116, A05209, 2011). We estimate the mass outflow rate as well as the net sources and sinks of plasma. We also calculate the total energy budget of the system, estimating the total amount of energy that must be added to the system. We show a factor of ~3-5 variation over the 2004 to 2009 period.

413.03 New Results on the Seasonal Variations in Saturn’s Thermal Plasma
- Meredith Elrod
- W. Tseng
- R. E. Johnson

University of Virginia, Southwest Research Institute.

The region of the magnetosphere from the main rings to inside the orbit of Enceladus is populated by oxygen from the Saturn’s ring atmosphere and water products from Enceladus. Therefore, we examined the CAPS plasma data for several equatorial periapsis passes from 2004 to 2012 for the region from 2.4 to 3.8 Saturn radii including Voyager 2 data in order to separate the contributions from these sources and to understand the temporal variations in the plasma. Because of the high background in this region, only eight orbits were used in this study. Using Voyager II data and CAPS data from 2004, and 2012 we show that large variations in ion density, temperature, and composition occur. Although the Enceladus plumes are variable, we proposed that the large change in the ion density from 2004 to equinox near 2010 was due to the seasonal variation in the ring atmosphere. This interpretation of the plasma data was supported by a simple photochemical model which combined water products from Enceladus and with the seasonally variable oxygen from the ring atmosphere. When comparing the recent 2012 passes with the 2010 passes, where are much closer to Enceladus, and likely dominated by the water sources from this moon, we still see an increase in the signal between 2010 and 2012 indicating that there is likely still a seasonal variation throughout the region. In this presentation we will compare the results of our analysis of the 2012 data with our model for seasonal variations in the plasma source in this region.
A 2-dimensional Physical Chemistry Model of Saturn's Neutral-plasma Torus

- Bobby L. Fleshman, P. Delamere, F. Bagenal, T. Cassidy

University of Oklahoma, University of Colorado.

Ion densities and temperatures in Saturn's inner magnetosphere are largely determined by the combined effects of hot (suprathermal) electrons, radial diffusion, and neutral cloud distributions. We combine a 2-dimensional plasma chemistry model with a neutral cloud model to investigate the consequence of these aspects on ion properties between 4 and 10 Rs. Relative ion abundances provided can be used for future Cassini CAPS analyses, while model sensitivity to diffusion timescales and hot electron density will be useful for relating these phenomena to observations. Selected results are: (1) Electron impact ionization and charge exchange conspire to produce H3O+ in the Enceladus neutral torus, wherein diffusion is found to be ignorable. (2) Hot electrons comprise at least 0.5% (but not more than 1%) of the total electron density at Enceladus. (3) The range over which Saturn's neutral clouds extend determines the relative abundances of water-group ions as well as their respective temperatures. (4) Total mass production rates (integrated over a flux shell) agree well with estimates of the momentum lost by the solar wind at Saturn.

Ultraviolet Auroral Pulsations on Saturn from Cassini UVIS


Central Arizona College, University of Colorado, University of Liege, Belgium, University of Central Florida, University of Leicester, United Kingdom, JHU/APL, JPL.

Cassini Ultraviolet Imaging Spectrograph (UVIS) observations of Saturn were obtained on 2009 days 278-280 with the UVIS long slit aligned east-west along the northern auroral oval. Bright quasi-periodic localized bursts of UV emission were often observed with ~1 hour spacing that slowly moved sub-corotationally along the main auroral arc. We will report on an apparent correlation of the bursts with the locations of Saturn's moons, and a search for other such examples. We will also compare the UVIS results with simultaneous Cassini Imaging Science Subsystem (ISS) auroral images.

Effect of the Solar UV/EUV Heating on the Intensity and Spatial Distribution of Jupiter's Synchrotron Radiation

Hajime Kita, H. Misawa, F. Tsuchiya, C. Tao, A. Morioka

Planetary Plasma and Atmospheric Research Center, Tohoku University, Japan, ISAS/JAXA, Japan.

Jupiter’s synchrotron radiation (JSR) is the emission from relativistic electrons, and it is the most effective probe for remote sensing of Jupiter’s radiation belt from the Earth. Recent observations reveal short term variations of JSR with the time scale of days to weeks. Brice and McDonough (1973) proposed that the solar UV/EUV heating for Jupiter’s upper atmosphere causes enhancement of total flux density. If such a process occurs at Jupiter, it is also expected that diurnal wind system produces dawn-dusk asymmetry of the JSR brightness distribution. Preceding studies confirmed that the short term variations in total flux density correspond to the solar UV/EUV. However, the effect of solar UV/EUV heating on the brightness distribution has not been confirmed. Hence, the purpose of this study is to confirm the solar UV/EUV heating effect on total flux density and brightness distribution. We made radio imaging analysis using the National Radio Astronomy Observatory (NRAO) archived data of the Very Large Array (VLA) obtained in 2000, and following results were shown. 1, Total flux density varied corresponding to the solar UV/EUV. 2, Dawn side emission was brighter than dusk side emission almost every day. 3, Variations of the dawn-dusk asymmetry did not correspond to the solar UV/EUV. In order to explain the second result, we estimate the diurnal wind velocity from the observed dawn-dusk ratio by using the model brightness distribution of JSR. Estimated neutral wind velocity is 46+/-11 m/s, which reasonably corresponds to the numerical simulation of Jupiter’s upper atmosphere. In order to explain the third result, we examined the effect of the global convection electric field driven by tailward outflow of plasma in Jupiter’s magnetosphere. As the result, it is suggested that typical fluctuation of the convection electric field strength was enough to cause the observed variations of the dawn-dusk asymmetry.
414 Planetary Rings
Thursday, 3:30 PM - 6:00 PM, Exhibit Hall

414.01 Keck and VLT AO Observations and Models of the Uranian Rings During the 2007 Ring Plane Crossings
- Imke de Pater1, D. E. Dunn2, D. Stam3, M. Showalter4, M. Min5, H. Hammel6, K. Matthews7, S. Gibbard8, M. van Dam9, M. Hartung10
1 UC, Berkeley, 2 Sierra College, 3 SRON, Netherlands, 4 SETI, 5 UVA, Netherlands, 6 AURA, 7 Caltech, 8 LLNL, 9 Flat Wavefronts, New Zealand, 10 Gemini, Chile.

We observed the uranian rings at and near the ring plane crossing (RPX) of 16 August 2007 using the Keck and VLT telescopes, both equipped with near-infrared cameras coupled to adaptive optics systems. The rings are partially obscuring each other when they are close edge-on; we therefore developed a model to analyze the observations. The model was tested by Dunn, de Pater and Stam (2010) against observations of the uranian rings that were taken in July 2004. In this poster we present results based on a comparison of the RPX Keck and VLT observations with models. Main conclusions: 1) The zeta ring appears to be vertically extended (full width 860 km); 2) the zeta ring is centrally condensed; 3) the extension of the eta ring is optically thin, but contains macroscopic material; 4) there is a broad dust sheet throughout the system that contains very small dust grains (g=0.85 rather than 0.7). This work has been funded through NASA’s Planetary Astronomy Program and the National Science Foundation Science and Technology Center for Adaptive Optics.

414.02 Lost in Jupiter’s Shadow: Can Resonant Charge Variations Explain Dust Grain Sizes in the Main Ring?
- Daniel Jontof-Hutter1, D. P. Hamilton1
1 University of Maryland.

Interplanetary impacts onto the tiny moons Metis and Adrastea replenish Jupiter’s main ring with dusty ejecta of all sizes. The equilibrium size distribution present in the rings at a given time is a function of production and loss mechanisms, both of which may be vary with particle size. Loss mechanisms include collisions and dynamical processes. Here we explore some of the latter. Grains tend to pick up negative electric charges due to motion through Jupiter’s plasma environment, and positive charges from the photoelectric effect of sunlight. The periodic interruption of sunlight in Jupiter’s shadow causes the equilibrium electric charge, and hence the Lorentz force, to resonate with the Kepler orbital frequency. The eccentricity increases for grains moving radially inwards during the shadow transit, and decreases when grains move outward in the shadow, hence the azimuthal location of pericenter is important. For smaller grains, the eccentricity increases monotonically until they collide with Jupiter. For much larger grains, precession due to both the Lorentz force and planetary oblateness causes the eccentricity to oscillate periodically. We explore the shadow instability in the main ring for a variety of uniform plasma density models, comparing numerical data with a semi-analytic approximation. We find that the effect of the shadow dwindles in importance for plasma that is either too sparse or too dense. In sparse plasma, the charging timescale slows, limiting the change in electric potential from sunlight to shadow. In dense plasma, charging currents from the plasma overwhelm the photoelectric effect in sunlight, also resulting in a small change in electric potential. Between these two regimes, the shadow resonance efficiently removes grains up to a particular size threshold in the main ring. This size-dependent loss mechanism may contribute to the observed flattening in the size distribution index for smaller grains.

414.03 Measuring the Particle Size Distribution in the Saturnian Rings by Diffraction of Starlight
- Rebecca A. Harbison2, P. D. Nicholson1
1 Cornell University.

Occultations of Saturn’s rings have proven to be a useful way to measure the particle-size distribution of the bodies making up the ring. The Cassini spacecraft, in orbit around Saturn, has been measuring stellar occultations with the Visible-Infrared Mapping Spectrometer (VIMS), with a total of 74 observed during the period 2004-2009. During these occultations, we have observed ‘gap overshoots’: places near a sharp edge of the rings, such as the
gaps in the C Ring, Cassini Division, and A Ring, and at the outer edges of the A and B Rings, where the transmission of starlight appears to exceed unity. This excess light is due to starlight forward-scattered from the nearby ring into the detector. In this work, we model these 'overshoots' in terms of a truncated power law particle-size distribution. Due to the geometry of the observations and the observation wavelength of 2.92 microns, chosen to minimize reflected ringlight, our observations are most sensitive to particles from 1 to 10 cm, and due to the exquisite time resolution, we are able to sample smaller regions of the rings than other types of occultation experiments. We observe the trans-Keeler region of the A ring as having a steeper particle-size distribution from the regions inward of the Keeler Gap, correcting preliminary results presented in 2011. We also measure the power-law index of the particle-size distribution as being nearly constant across the Cassini Division (from the Barnard and Bessel gaps at 120,300 km to the Huygens Gap at 117,900 km) and around the Dawes, Maxwell and Colombo in the C Ring.

414.04 Cassini Images A Propeller In Saturn's B-ring
- Joseph N. Spitale¹, M. Tiscareno²
  ¹Planetary Science Institute, ²Cornell University.

In 2009 July, close to Saturn equinox, an isolated shadow-casting object was imaged in Saturn's B-ring at an orbital radius of about 116910 km. Spitale and Porco (2010, AJ) interpreted it as an embedded satellite, whose diameter, inferred by the length of the shadow, would have been ~300 m. Although the object does not appear in any other images, which is not surprising since that radius/co-rotating longitude was only imaged once during the equinox period, it was assigned a provisional designation of S/2009 S1 by the IAU. However, if there is indeed a 300-m diameter body orbiting in the middle of the B-ring, then why does the body not seem to be perturbing the ring at all? Why was no propeller-shaped structure (e.g., Tiscareno et al. 2006, Nature) seen surrounding the object, as the simulations of Michikoshi and Kokubo (2011, ApJL) indicated it should? The answer may be that the ring is indeed perturbed and the bright feature at the base of the shadow is in fact the propeller, with the body itself not resolved. That hypothesis is further supported by an analysis of the shadow that implies that the object casting the shadow is roughly spherical (and therefore 300 m wide), much smaller than the 2-km-wide projected point-spread, while the bright feature at the base of the shadow is larger than the point-spread, and is at least 10 times wider than the height of the shadow caster. Moreover, the bright feature is slightly canted in a direction consistent with Keplerian shear. Based on the assumption that the bright feature is the only propeller to have been imaged in the B-ring to date, we will discuss what can be learned by comparing B-ring and A-ring propellers, as well as the origin, evolution and fate of the observed body.

414.05 Probing Periodic Patterns In Saturn's Inner A Ring With Cassini-VIMS
- Matthew M. Hedman¹, P. D. Nicholson¹, H. Salo²
  ¹Cornell Univ., ²University of Oulu, Finland.

During the spring of 2009, the Visual and Infrared Mapping Spectrometer (VIMS) onboard the Cassini spacecraft observed two occultations of the star gamma Crucis by Saturn's rings. The occultation tracks reached a minimum radius in the inner A ring, so these observations yielded optical-depth profiles with exceptionally fine radial sampling of the region between 124,200 km and 124,800 km from Saturn’s center. These cuts reveal highly periodic structures with wavelengths of order a few hundred meters. Similarly periodic patterns were previously observed in this region by the Cassini radio science experiment (Thomson et al. 2007 GRL), and have been interpreted as evidence for viscous overstabilities (periodic oscillations in surface density that grow from small perturbations driven by over-effective restoring forces, see Schmidt et al. 2009). However, the theory of nonlinear overstabilities in self-gravitating rings is still in its infancy, and it is not yet clear exactly what determines the wavelength, amplitude, or the coherence length of an overstable wave. The combination of high signal-to-noise and radial resolution of the VIMS data permit detailed investigations of the variations in these structure’s wavelength and phase that can help test theoretical models of these periodic structures. For example, regions with higher optical depth appear to possess periodic patterns with longer wavelengths, strongly suggesting that these structures are influenced by their local particle number density. At the same time, abrupt shifts in the pattern’s wavelength and phase occur at various locations within each profile, and the measurements made at the same
location at different times and longitudes exhibit differences in the patterns' wavelengths and phase. Such shifts and variations most likely reflect the finite coherence lengths and propagation speeds of these disturbances.

414.06 Analysis of Longitudinal Variation in Saturn's F Ring Using Wavelets
  1SETI Institute, 2University of Illinois.

Saturn's F ring exhibits dramatic radial and longitudinal variation, ranging from the kinks and clumps (diffuse bright features around 5-20 degrees in longitudinal extent) found by Voyager to the more recently discovered kinematic spirals, fans, streamers, and channels. These features change over short time spans ranging from hours to months. While some features are understood to be caused by the interaction of the ring with the inner shepherd moon Prometheus, the sources of others are as yet unexplained. Previous work by Showalter (2004, Icarus, 171, 356) used Voyager imagery to study the occurrence of clumps and track their movement relative to the F ring's core over time. Here we build on that work using 6 years' worth of images from Cassini. We use wavelet analysis, a process uniquely suited to characterizing aperiodic features, to automatically detect clump candidates. We will present our current progress and future plans.

414.07 On the Linear Damping Relation for Density Waves in Saturn's Rings
  1University of Oulu, Finland, 2University of Central Florida, 3University of Potsdam, Germany, 4Cornell University.

We revisit the equation for viscous damping of density waves derived from linearized theory. We show that in addition to the coefficient of shear viscosity itself the dependence of this coefficient on the rings' surface mass density appears, as well as the coefficient of bulk viscosity. This was noted more than thirty years ago by Goldreich and Tremaine [1978]. These terms are usually neglected when fitting the viscosity from observations, but the physical effects associated with them might well be quantitatively and qualitatively important. There might even be cases when density waves do not damp but become unstable.

414.08 The Cassini Division and Mimas' eccentricity: A Common History
- Valery Lainey, S. Charnoz, L. Reboussin, B. Noyelles, K. Baillié
  1IMCCE, France, 2Paris Diderot, France, 3FUNDP, Belgium.

Possible Mimas' orbital decay has been revealed recently from astrometric measurements of the main Saturnian moons (Lainey et al. 2012). Based on this assumption, we studied Saturn's ring evolution over 20 Myr, taking into account resonances associated with Mimas, like the 2:1 resonance currently placed at the outer edge of the B-ring. Depending on the typical size of the particles, we show that the Cassini division and its structures could be explained by Mimas orbital decay. Simultaneously, we examined the behavior of Mimas orbit while it shrank from 190,000 up to its current position. We found its current eccentricity can be explained by a recent resonance crossing with Tethys. This work is supported by Campus Spatial (Paris Diderot) and partly supported by EMERGENCE-UPMC grant (contract number: EME0911).

414.09 Coefficient of Restitution of Adhesively Bound Aggregates
- Yernur Baibolatov, F. Spahn
  1Univ. of Potsdam, Germany.

Dry granular gases are characterized by dissipative interactions of grains whereas usually attractive forces are neglected. Here we concern attractive-adhesive contacts between the constituents of the granular gas in order to quantify their influence on the cluster formation and the establishment of a steady aggregate size-distribution in driven systems. In this context the dynamics of dense planetary rings is our major concern. These disks are dynamically dominated by a balance between viscous (collisional) heating, driven by the Kepler-shear, counteracted by granular collisional cooling so that a stationary granular temperature may establish. In this work we concentrate on the aggregate aggregate collisions, where we try to analyze the dependence of the coefficient
of restitution of the aggregate on its size and internal configuration. We show that the coefficient of restitution of a single constituent differs drastically when we combine them into an aggregate. We believe that this effect plays a crucial role on the collision dynamics of the ring material. We gratefully acknowledge financial support from the grant Sp384/22-1 (DFG).

414.10 Extremely Large Simulations Of The Viscous Over-stability
- Hanno Rein1, H. Latter2
  1Institute for Advanced Study, 2DAMTP, United Kingdom.

The viscous over-stability is thought to be responsible for coherent structures observed in Saturn's rings with typical wavelength of a few hundred meters. We present results from new large scale non-linear particle simulation of the over-stability. These are the largest direct N-body simulations of the viscous over-stability that have ever been performed. The width of our simulations is more than 4 orders of magnitude larger than the typical particle size. A direct comparison of Cassini occultation observations is intriguing as it could allow the measurements of a wide number of particles properties such as size, density and coefficient of restitution. We observe non-linear standing and traveling waves. Defects such as sources and sinks can persist for more than ten thousand orbits. We show that the instability can occur in rings with a background surface density gradient. Both the wavelength and amplitude are correlated with the mean local optical depth. We also show how ring edges spread due to the over-stability.

414.11 Optimizing Polyhedra Collision Detection and Handling for Planetary Ring Simulations
- Mark C. Lewis1, D. G. Korycansky2, J. E. Colwell3
  1Trinity Univ., 2University of California, Santa Cruz, 3University of Central Florida.

Planetary ring simulations typically represent particles as perfect spheres. This assumption simplifies the numerics and makes it easier to compare simulation results with analytic work. However, true ring particles inevitably have irregular shapes and flat faces. This allows particles to rest against one another in preferred orientations. This is a factor which could be particularly significant in dense regions, or in the behavior of gravity wakes in the A ring. Separations between polyhedra are determined using the Gilbert-Johnson-Keerthi (GJK) algorithm. These distances are used to drive a root finding algorithm similar to those used for spherical particles on curved paths. Rotation of particles and how that alters the time of contact is also considered. Speed analysis compared to perfect spheres and preliminary simulation results are presented.

- Mitchell K. Gordon1, M. R. Showalter, B. Wells1, L. Ballard1, N. Heather1
  1SETI Institute.

In the past few years, the PDS Rings Node developed the Outer Planets Unified Search (OPUS), along with preview images or footprint diagrams for all OPUS supported data, and enhanced geometric metadata for Cassini ISS Saturn system data. Typically, geometric metadata for outer planets remote sensing observations is available only for the center of the instrument field of view. In our first effort at generating enhanced metadata, we calculated values for a fine grid of points over the entire field of view of Cassini ISS images using the most current SPICE kernel files. That project produce enhanced metadata specific to the rings; consequently the metadata was tied to the ring plane of Saturn. The combination of OPUS and the data base of enhanced geometric metadata provided a powerful, well received tool, and resulted in additional funding to extend metadata generation. We are developing a set of tools to produce geometric metadata for Cassini ISS, VIMS, UVIS, and CIRS Saturn data. This metadata will not be restricted to ring plane calculations and will support searches based on latitude and longitude for the planet and satellites as well as parameters such as viewing and illumination geometry. We also identify all known bodies and rings in the field of view, so target based search results will be comprehensive rather providing a subset based on the designated primary target. This autumn we have begun the incremental inclusion of the new metadata in the OPUS data base. In a subsequent phase we intend to expand our web services to include on-the-fly production of user selected geometric backplanes for each product returned by OPUS. http://pds-rings.seti.org/search/
Acknowledgments: This development has been supported by the Planetary Data System, by JPL through a special grant from the Cassini Project, and by research grants from STScI and NASA.

414.13 Analysis of a Triple Star System Occulted By Saturn's Rings
- Allison Bratcher\(^1\), J. E. Colwell\(^1\), B. Bolin\(^2\)
  \(^1\)University of Central Florida, \(^2\)Institute for Astronomy, University of Hawaii.

On January 4, 2012, the Ultraviolet Imaging Spectrograph aboard the Cassini Spacecraft observed Saturn’s rings as they occulted the triple star system, Iota Orionis. Remarkably, the brightest star was occulted by the moon Prometheus, and we provide the timing information of first and last contact for navigation purposes and a chord across the moon. The large separation of the individual stars projected in the ring plane makes it possible to measure the profiles of narrow features in the rings as they were occulted by each of the three stars. This occultation thus provides a unique opportunity to measure short-scale longitudinal variations in narrow ringlets with stellar occultation data that usually provide only a single longitudinal sample. Iota Orionis has a low elevation angle (B=1.4 degrees) above the plane of the rings, enhancing the sensitivity of the occultation (by a factor of 1/sin(B)=41) to the optically thin regions of the rings such as the C Ring and the Cassini Division as well as faint ringlets in the Encke gap. We distinguished the three signals by creating a model triple star signal using data from another occultation. We were able to identify several faint, narrow ringlets, including two in the Encke gap, occulted by two of the three stars and more prominent ringlets, such as the Huygens ringlet, in all three stellar light curves. We present the equivalent widths of these ringlets in the data from this triple star system and limits on ring variability over the azimuthal separation of the stars that ranges from 6000 km at the inner C ring to 200 km at the outer A ring.

415 Solar System Origin, Planet and Satellite Formation
Thursday, 3:30 PM - 6:00 PM, Exhibit Hall

415.01 The Formation and Evolution of Gas Giant Satellites During Nice Model Orbital Migration
- Christopher R. Fuse\(^1\), R. Verboncoeur\(^1\)
  \(^1\)Rollins College.

The unique orbital configurations and mass distributions observed in the satellite systems of Jupiter and Saturn provide a means to assess outer Solar system evolution theories. The Nice model (Tsiganis et al. 2005) has been successfully and extensively tested. An in-depth analysis of the effects planetary ejection has on a system of forming moons is needed to further assess the validity of the Nice model. Using an N-body planetary code, we simulated the formation of gas giant moons in an unperturbed state, absent from migration of proto-Uranus and proto-Neptune. Formation of satellites around Jupiter and Saturn was also simulated during orbital migration, where Uranus and Neptune migrated from outside of Saturn’s orbit to their current locations. We propose that the gravitational influences of Uranus and Neptune caused the collapse of Saturn’s satellite disk, resulting in a system of moons dominated by a single body, Titan. We find that in the absence of proto-planet migration, Jupiter and Saturn retain systems of four satellites, similar to the Galilean moons. In 85% of the simulations with planetary ejection, the final satellite configuration for Saturn’s moons closely resembles the present-day Saturn system. The simulations of Jupiter’s moons resulted in Galilean-like systems in ~88% of the unperturbed simulations. We will compare the results of moon formation in the Nice model with gas giant moon formation during Uranus and Neptune’s migration in the Thommes model (Thommes et al. 2001).

415.02 The Fate of Regular Satellites during the Nice Model’s Planetary Close Encounters
- Rodney S. Gomes\(^1\), E. C. Nogueira\(^1\), R. Brasser\(^2\)
  \(^1\)Observatorio Nacional, Brazil, \(^2\)Institute for Astronomy and Astrophysics, Academia Sinica, Taiwan.

One of the basic assumptions of the Nice Model is the existence of a chaotic era of planetary close encounters that triggered the Late Heavy Bombardment (LHB) and eventually placed the giant planets on their present orbits. A natural question is whether the regular satellites could survive this catastrophic epoch. Although this problem has
been pursued in previous works, we intend to pursue a more systematic study also taking into account the likely close encounters of ice giants with Jupiter. A comprehensive answer to this question must also include the possible difference between pre and post-LHB orbits of the regular satellites. Another worthwhile investigation pertains to the survivability of Neptune's satellite Triton, which was supposedly captured during the late stages of Neptune's formation. After analyzing some possible Nice model planetary evolutions during its dynamical instability, and introducing regular satellites just before the close encounters, our preliminary results show that roughly 35% of Tritons would have their orbits unbound from Neptune. We assume that Neptune was the planet that had the close encounters with Jupiter. We also assume that Triton’s orbit had already been circularized due to tides raised on the satellite, and that it had the same inclination and a semimajor axis roughly one Neptune’s radius larger than current value. If we consider that Uranus was the planet that had close encounters with Jupiter, then in roughly 40% of the cases at least one satellite would have been discarded and in roughly 14% of the cases all satellites would be lost. For the cases where all satellites survive, in around 25% of the cases at least one satellite would have \( e > 0.1 \) after the instability phase. These results suggest that the regular satellite systems would usually survive intact.

415.03 The Formation Environment of the Galilean Moons
  1JPL/Caltech, 2Hong Kong University, China, 3Osaka University, Japan.

We show that the disks of gas and dust orbiting gas giant protoplanets are subject to turbulence driven by the magneto-rotational instability, provided (1) sufficient X-rays reach them from the vicinity of the host star, and (2) the surface densities are substantially less than in minimum-mass models constructed by augmenting Jupiter’s satellites to Solar composition, but not so low that ambipolar diffusion decouples the neutral gas from the plasma. We compute the conductivities in a range of circumjovian models, treating ionization by protosolar X-rays, interstellar cosmic rays, and radionuclide decay. Charge transfer to gas-phase metals is included. Recombination occurs in dissociative and radiative gas-phase reactions and on grain surfaces. The results are consistent with both minimum-mass and gas-starved models of the protojovian disk: (1) The minimum-mass models have negligible internal angular momentum transfer by magnetic forces, as required for the material to remain in place while the satellites form. (2) If stellar X-rays reach the planet, the gas-starved models have magnetically-active surface layers and a decoupled interior "dead zone", analogous to the Solar nebula. The active layers yield accretion stresses in the range assumed in constructing the gas-starved models. However: (1) In the quiescent minimum-mass models, the loss of dust from the surface layers through settling could lead to the accretion of dust-depleted material onto the planet, and an increase over time in the solid mass fraction. (2) The gas-starved models suffer from bottlenecks in the accretion flow that will lead to material piling up at certain radii, and potentially to time-variable accretion on the planet.

415.04 A Carbon-rich Jupiter from Nebular Water Depletion: Constraints from the Satellites
- Jonathan I. Lunine, O. Mousis, N. Madhusudhan, T. V. Johnson
  2CRSR, Cornell University, 2Institut UTINAM, Université de Franche-Comté, France, 3Dept. of Astronomy, Yale University, 4JPL.

Evolutionary nebular models predict water abundances in gas and grains that are variable as a function of time and location (for example, Ciesla and Cuzzi, 2006 Icarus 181 178), and at least partly decoupled from carbon-bearing species. Therefore it is possible that the C/O ratio in the material from which the giant planets formed was not the solar value and as first considered by K. Lodders (2004, Ap.J. 611, 538), might be enriched where and when Jupiter formed. We found (Mousis et al 2012, Ap.J. 751, L7) that a nebular value C/O ∼ 1 reproduces the Galileo-measured Jovian elemental abundances at least as well as the hitherto canonical model of Jupiter formed in a disk of solar composition (C/O = 0.54). The resulting O abundance in Jupiter’s envelope is then moderately enriched by a factor of ∼ 2 × solar (instead of ∼ 7 × solar). However, consistency with the rock-to-ice ratio of the Galilean moons is difficult to obtain, unless the formation of those objects occurred later (plausible) and thus from material that had a different C/O ratio than that which contributed to the envelope of Jupiter (for example from a larger distance). Tests of this idea will come from the measurement of the water abundance by the Juno microwave radiometer.
experiment, and also by determination of the oxygen abundance for Saturn, which will require measuring
disequilibrium species in the atmosphere.

415.05 A Collisional Model of the "Pristine Zone" of the Main Asteroid Belt and the Dynamics of LHB Families
Located There
- Miroslav Broz¹, H. Cibulkova¹, M. Rehak¹
  ¹Charles University, Czech Republic.

Modifying the Boulder code (Morbidelli et al. 2009), we construct a new collisional model of the Main Asteroid
Belt, which is divided to six parts (inner, middle, outer, pristine zone, Cybele region and high-inclination region) in
order to study relations between them and check the number of families observed in each of them. We focus on
the so-called "pristine zone" between 2.825 and 2.955 AU - bounded by the 5:2 and 7:3 resonances with Jupiter -
because this region is relatively empty and we may thus spot very old/eroded families. We model long-term
dynamical and collisional evolution of the Itha family (around the asteroid (918) Itha) and we interpreted it as an
old, dispersed and comminutioned cluster, likely dated back to the Late Heavy Bombardment ~3.8 Gyr ago. We
thus extend our collisional models and include the effects of the LHB too. In the framework of the Nice model, the
flux of comets during the LHB is mostly controlled by the original size-frequency distribution of the cometary disk
beyond Neptune and a rate at which comets disrupt when they approach the Sun. To this point we provide a
related discussion of various cometary disruption laws.

415.06 The Formation Of The First Solids In The Solar System: An Investigation Of CAI Diversity
- Esther Taillifet¹, K. Baillié¹, S. Charnoz¹, J. Aléon²
  ¹Laboratoire AIM / Sap / CEA Saclay. Université Paris Diderot, France, ²CSNSM, CNRS/IN2P3. Université
  Paris Sud, France.

Chondritic meteorites are primitive bodies and therefore an important source of information on the first moments
of planets formation. Chondrites contain several materials especially calcium and aluminum rich inclusions (CAIs),
known to be the oldest objects of the solar system (4.567 Gyr - Amelin et al., 2002; Connelly et al., 2008) and thus
the first solids to be formed. CAIs appear in various textures, sizes and compositions in chondrites. Though, all of
them should have formed at high temperature (1300-1800 K) in the same region of the solar nebula by
condensation from the gas (e.g. Grossman, 1972; Yoneda & Grossman, 1995; Petaev & Wood, 1998; Ebel &
Grossman 2000). To answer this problem we study the CAI formation within the solar nebula using numerical
simulations. For this work we developed a self consistent thermodynamical model of the solar nebula (see
associated talk from Baillié et. al ) based on previous works (Calvet et. al, 1991; Hueso & Guillot, 2005; Dullemond,
Dominik and Natta, 2001). Using this model, we simulate the young system with Lagrangian Implicit Disk Transport
code (LIDT - Charnoz et. al, 2010). We will focus on the very first instants of the CAIs within the few years following
their condensation. We will report our first results in terms of thermal history and investigate if turbulence-driven
transport may explain the CAI diversity.

415.07 Circumplanetary Disks: Mass Evolution and Observability with ALMA
- Eric B. Ford¹, M. Shabram¹, A. C. Boley¹
  ¹Univ. of Florida.

Using radiation hydrodynamics simulations, we explore the evolution of circumplanetary disks around wide-orbit
substellar companions. At large distances from the star (~100 AU), gravitational instability followed by disk
fragmentation can form gas giants and/or brown dwarfs that are likely to host large, circumplanetary disks. These
subdisks are affected by the tidal potential of the primary, and may be gravitationally unstable, leading to
nonaxisymmetric spiral structure. Spiral waves redistribute circumplanetary disk mass and can cause repeated
heating events in an otherwise cold subdisk. We examine the evolutionary timescales for these circumplanetary
disks, as well as the role that they play in regulating the growth of the substellar companions. In addition, we
explore the effects that the resulting shock structures have on the thermal history of the gas, with application to
ice grain physics, disk chemistry and moon composition. Finally, the time scale for disk evolution affects the
observability of these objects. Extended circumplanetary disks will have flux densities detectable well within the
capabilities of ALMA, and will be markers of host planets in their early stages of formation. We find that these subdisks evolve to a steady state within three orbital periods, accreting ~0.2 Jupiter masses of material per orbit. This increases the size of the host planet by ~20% as the subdisk evolves away from an initially massive state. We also find that the disks are truncated between 1/3 and 2/5 the Hill radius of the substellar companion. This places constraints on the size of resultant in situ moon system formation that might occur at later stages in the circumplanetary disk’s lifetime.

415.08 Capture of Planetesimals by Gas Drag from Circumplanetary Disks
- Tetsuya Fujita¹, K. Ohtsuki¹, T. Tanigawa²
  ¹Department of Earth & Planetary Sciences, Kobe University, Japan, ²Institute of Low Temperature Science, Hokkaido University, Japan.

The regular satellites of the giant planets (e.g. Galilean satellites) have nearly circular and coplanar prograde orbits, and are thought to have formed by accretion of solid particles in the circumplanetary disk. Because a significant amount of gas and solids are likely to be supplied to growing giant planets through the circumplanetary disk, the amount of solid material in circumplanetary disks is important not only for satellite formation but also for the growth and the origin of the heavy element content of giant planets. Solid particles smaller than meter-scale are strongly coupled with the gas flow from the protoplanetary disk and delivered into the disk with the gas. On the other hand, trajectories of large planetesimals are decoupled from the gas. When these large planetesimals approach a growing giant planet, their orbits can be perturbed by gas drag from the circumplanetary disk depending on their size and random velocity, and some of them would be captured by the disk. In the present work, we examine orbital evolution of planetesimals approaching a growing giant planet with a circumplanetary disks by integrating Hill’s equation including the gas drag term. We assume that the gas in the disk rotates in circular orbits around the planet. We found that the condition for capture of planetesimals approaching in the prograde direction (i.e., trajectory in the same direction as the circular motion of the gas) is different from that for those approaching in the retrograde trajectories. We obtained analytic expressions for energy dissipation, critical approach distance from the planet for capture, and capture probability for prograde and retrograde orbits in the coplanar case. We will discuss results of orbital integration for capture rates, including the cases of inclined orbits of planetesimals.

415.09 Dynamical Friction on Satellites
- Rogerio Deienno¹, T. Yokoyama², A. F. B. A. Prado¹
  ¹Instituto Nacional de Pesquisas Espaciais - INPE/DMC, Brazil, ²Universidade Estadual Paulista - IGCE/DEMAC, Brazil.

Deienno et al 2011 (A&A, v.536, A57) investigated the effects of the planetary migration on the satellites of Uranus. We concluded that Uranus might have had more satellites than those observed today. However, due to the Late Heavy Bombardment (LHB) phenomenon, those satellites beyond Oberon were destabilized mostly by collisions involving themselves or with some regular ones. In this work we apply the same methodology for the Saturnian system. We found that the satellites with orbits inside Titan’s orbit are immune to the LHB phenomenon. On the other hand, Hyperion, Iapetus, and even Titan, in some cases are strongly affected by the LHB, and depending on the value of Saturn’s obliquity, Iapetus might not have resisted to the LHB event. We also found that, the final orbital elements of the surviving satellites differ from what we see today, mainly in inclination. While eccentricity and orbital semi-major axis can be easily damped by tides, for orbital inclinations, tidal effects are not so efficient. Thus, considering that eccentricity and orbital semi-major axis will still evolve by tides, to study the problem of the orbital inclination we consider that: according to our simulations, during the LHB event, collisions between planetesimals and satellites are a common event, causing in some cases destruction of satellites. So, we hypothesized that the material delivered by these catastrophic events could form a disc of particles around the remaining of satellites’ orbits. This disc interacts with the remaining satellites and by dynamical friction phenomenon the orbital inclination can be damped. Some preliminary results have shown that, indeed, this tentative can be a viable way to damp conveniently the inclination of some satellites. Acknowledgement: FAPESP-CNPq.
Orbital Migration of Giant Protoplanets in a Marginally Gravitationally Unstable Disk
- Alan P. Boss\textsuperscript{1}
\textsuperscript{1}Carnegie Inst.

Orbital Migration of Giant Protoplanets in a Marginally Gravitationally Unstable Disk Alan Boss
Core accretion and disk instability require giant protoplanets to form in the presence of the disk gas, possibly experiencing orbital migration through gravitational interactions with the gas. Studies of the interactions of protoplanets with disk gas generally assume a disk mass low enough that the disk's self-gravity can be neglected. However, disk instability requires a disk massive enough to be marginally gravitationally unstable (MGU). Even for core accretion, a FU Orionis outburst may require a brief MGU disk phase. In both cases, the self-gravity of the disk must be taken into account when following the subsequent orbital evolution. We present here a new set of three dimensional gravitational radiation hydrodynamics models of MGU disks with two or four embedded protoplanets. The protoplanets interact gravitationally with the disk and each other, undergoing orbital evolution and mass accretion as a result. The initial protoplanet masses are 0.1, 0.33, 0.5, 1.0, or 3.0 Jupiter masses, for disks with masses of 0.09 solar masses orbiting a solar-mass protostar. The protoplanets start on circular orbits with radii of 6, 8, 10, or 12 AU inside a disk extending from 4 AU to 20 AU. The evolutions are followed for 1000 to 4000 yr and involve phases of relative stability (eccentricity $e \sim 0.1$) interspersed with chaotic phases ($e \sim 0.4$) of rapid orbital exchanges and ejections. Monotonic inward or outward orbital motion is not seen. Over half of the protoplanets are ejected, while a system with masses similar to our Solar System (1.0, 0.33, 0.1, 0.1) was stable for over 1000 yr. Similarly, a Jupiter-Saturn-like system with masses of 1.0 and 0.33 was stable for 3800 yr, implying that our giant planets might well survive a MGU disk phase.

Rapid Formation Of Saturn Induced By Jupiter Formation
- Hiroshi Kobayashi\textsuperscript{1}, C. W. Ormel\textsuperscript{2}, S. Ida\textsuperscript{3}
\textsuperscript{1}Nagoya University, Japan, \textsuperscript{2}UC Berkeley, \textsuperscript{3}Tokyo Tech, Japan.

We have investigated Saturn's core formation at a radial pressure maximum in the solar nebula, which is created by gap opening by Jupiter. A large core induces collisional fragmentation of surrounding planetesimals, which generally inhibits further growth of the core by removal of the resultant fragments due to radial drift caused by gas drag. However, the emergence of the pressure maximum halts the drift of the fragments, while their orbital eccentricities and inclinations are efficiently damped by gas drag. As a result, the core of Saturn rapidly grows via accretion of the fragments near the pressure maximum. We have found that in the minimum-mass solar nebula, kilometer sized planetesimals can produce a core larger than 10 Earth masses within two million years. Since Jupiter may not have undergone significant type II inward migration, it is likely that Jupiter's formation was completed when the local disk mass has already decayed to a value comparable to or less than Jovian mass. The expected rapid growth of Saturn's core on a timescale comparable to or shorter than observationally inferred disk lifetime enables Saturn to acquire the current amount of envelope gas before the disk gas is completely depleted. The high heat energy release rate onto the core surface due to the rapid accretion of the fragments delays onset of runaway gas accretion until the core mass becomes somewhat larger than that of Jupiter, which is consistent with the estimate based on interior modeling. Therefore, the rapid formation of Saturn induced by gap opening of Jupiter can account for the formation of multiple gas giants (Jupiter and Saturn) without significant inward migration and larger core mass of Saturn than that of Jupiter.

Conditions for Organic Haze Formation in Planetary Atmospheres - A Case Study in Archean Earth
- Eric Wilson\textsuperscript{1}, S. Atreya\textsuperscript{2}
\textsuperscript{1}Space Environment Technologies, \textsuperscript{2}University of Michigan at Ann Arbor.

Atmospheric haze can serve as a vital component in the prebiotic synthesis of organic compounds. In many planetary atmospheres, haze is a product of complex organic chemistry, initiated by the deposition of ultraviolet photons, forming compounds that can serve as key components in the propagation of prebiotic chemistry. Saturn's moon, Titan, provides the prime example of the significance of haze in a planetary atmosphere in our present-day Solar System due to its intricate chemical interaction between aromatic hydrocarbons, nitrogen-bearing species, and complex ions. Titan has long been considered as an analogue for the environment possibly experienced by
Archean Earth, and recent studies demonstrate that, like Titan, early Earth may have had an organically-furnished haze layer, facilitated by an enhanced ultraviolet solar flux during this period, protecting greenhouse gases and biota early in their development from harmful ultraviolet radiation and allowing the Earth to maintain temperatures necessary for their development during the faint young Sun period. This primordial haze may have had a different composition than present-day Titan due to the CO2 content and possibly large amounts of H2 in prebiotic Earth. Furthermore, the amount of CO2 and H2 in the early terrestrial atmosphere would have had large implications in the efficiency of organic haze formation. A photochemical model employing complex neutral and ion chemistry is used to examine the mechanisms and efficiency of haze formation in a variety of conditions, focusing on sensitivity to factors such as atmospheric composition, and atmospheric temperature profile, and vertical mixing. These results can be used to assess the impact of atmospheric haze on the evolution of planetary atmospheres in our Solar System as well as viability of organic haze formation in the atmospheres of exoplanets.


415.13 Using Oxygen Isotopes in Meteorites to Constrain the Far UV Environment of the Solar Nebula
- James R. Lyons
- UCL.

CO photodissociation in the solar nebula and/or parent cloud has been proposed to be the mechanism responsible for forming the 16O-poor reservoir of the CAI mixing line. Photochemical models of a turbulent solar nebula and collapsing cloud core have previously demonstrated the plausibility of this scenario. Laboratory experiments, however, have found massive isotope fractionation, with a wavelength-dependence in the oxygen isotope ratios of the product O atoms, with $\delta^{17}\text{O}/\delta^{18}\text{O} \sim 0.6$ to 1.4 for product O atoms. These results were attributed to isotopic differences in photodissociation dynamics. Photochemical simulations of the experiments using computed CO spectra to identify the origin of the wavelength dependence can explain much of the experimental results, without the need for unusual photodissociation dynamics (Lyons, submitted). Applying the same line-by-line isotopic spectra to CO photodissociation in a model solar nebula reveals the temperature dependence of the $\delta^{17}\text{O}/\delta^{18}\text{O}$ ratio for the product O atoms, which form H2O on grains in the outer solar system. For disk gas temperatures ~ 50 K and above, $\delta^{17}\text{O(O)}/\delta^{18}\text{O(O)} \sim 0.85-0.90$, and $\delta^{17}\text{O(O)}/\delta^{18}\text{O(O)} \sim 1.0$ for a 20 K gas temperature. Solar nebula calculations with different stellar sources, TW Hydrae as the central star and HD 36981 a nearby OB star, both yield $\delta^{17}\text{O}/\delta^{18}\text{O} \sim 0.85-0.90$ for nebular water. Computed CO spectra suffer from large uncertainties in band oscillator strengths and linewidths for C17O and C18O, and do not account for interactions with neighboring electronic states, making the model $\delta^{17}\text{O(O)}/\delta^{18}\text{O(O)}$ ratios quite uncertain. Accurate measurement of C17O and C18O absorption cross sections is in progress, and will allow much more precise calculation of isotopic fractionation during CO photolysis. With such cross sections, and with the inherent high precision of radiative transfer calculations, meaningful comparison of model photolytic CO fractionation with mass spectrometry data of CAIs will be possible.

415.14 The Role Of Saturn Initial Position On The Nice Model
- Carlos E. Chavez
- M. Reyes-Ruiz
- H. Aceves
- G. Carrizales
- E. Perez--Tijerina
- Facultad De Ingenieria Mecanica Y Electrica, UANL, Mexico
- Instituto de Astronomia UNAM Sede Ensenada, Mexico
- Facultad De Ciencias Fisico-Matematicas, UANL, Mexico.

It is believed that during the first few hundred million years after the formation of the Solar System the planets migrated significantly. Their original orbits were circular and planar and due to the interaction with the disk of planetesimals located in the outer part of the Solar System they acquired their actual eccentricities and inclinations. This type of model of the early Solar System is called Nice Model (Tsiganis et al. 2005, Gomes et al. 2005 and Morbidelli et al. 2005). We explore in this context the role that the initial position of Saturn has in the outcome of the model.

416 Venus

Thursday, 3:30 PM - 6:00 PM, Exhibit Hall

416.01 Signatures of Weak Planetary Magnetospheres: Is Venus one?
Although Venus is often used to represent the classical induced magnetosphere, there are still observed features that have not been well-explained. For example, although there have been a number of largely qualitative models of the ionospheric flux ropes and nightside ionospheric holes, there is no demonstrated physical understanding of these structures and their variations. Recently, Zhang et al. (2012) have reported the occurrence of features resembling giant flux ropes in the polar ionosphere probed by Venus Express and in parallel we identified a persistent North-South field component in the near-Venus wake observed by the Pioneer Venus Orbiter during its low altitude mission. We use numerical simulations of weak planetary magnetospheres where the intrinsic dipole surface field is comparable to the induced fields to explore what signatures these limiting magnetospheres would produce in a Venus-like environment.

416.02 Coronal Mass Ejections And Their Effect On The Venusian Nightglow

- Candace L. Gray1, N. Chanover1, T. Slanger2
  1New Mexico State University, 2Stanford Research Institute.

Venus has several strong nightglow features, one of which is the O(1S-1D) transition at 5577.3 Å (oxygen green line). This feature is known to be highly temporally variable. When it was first seen in 1999, it had an intensity greater than the terrestrial nightglow, but it was too weak to be detected after 2004. The reason for this variability, and the chemistry producing the emission, are both poorly understood. We propose that the oxygen green line emission is due to coronal mass ejection (CME) impacts from the Sun. CMEs are large plasma ejections usually connected with solar flares. The charged particles of the plasma can interact with the atmosphere of Venus to produce nightglow/aurora, where dissociative recombination of O2+ is the mostly likely source of O(1S). To test our hypothesis, we observed Venus as a Target of Opportunity with the ARCES high resolution echelle spectrograph on the 3.5m Astrophysical Research Consortium telescope at Apache Point Observatory in April, May, and July 2012. We observed after two separate M-class flares and found no green line emission present. We observed Venus less than one day after three separate CME impacts and detected green line emission after each impact. After the largest CME impact, we found the Venusian green line to be stronger than the terrestrial line. It decayed by ~75% at the equator and ~ 40% near the south pole over the subsequent two days. We will present further analysis of these observations and will discuss the role that solar activity plays in the Venus' green line emission. This has implications for the emission mechanism responsible for this nightglow feature in the Venusian atmosphere.

416.03 Densities And Temperatures In The Venus Upper Atmosphere: Comparison Between Soir Profiles And The Vtgcm

- Gwendolyn Hicks1, J. Fischer2, S. W. Bouger3, A. S. Brecht4, C. Parkinson3, A. Mahieux5, V. Wilquet5, A. Vandaele5, J. Bertaux6
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CO2 density and derived temperature profiles have been organized using 79 orbits selected from those collected between 2006-2011 by Venus Express SOIR (e.g. Mahieux et al. 2012). Simulations of the Venus Thermospheric General Circulation Model (VTGCM) were run according to corresponding parameters, e.g. minimum solar flux to match contemporary placement in the solar cycle. Comparison with SOIR data was conducted to identify and analyze the balance among contributing physical processes that underlie observed temperature and density trends. Both VTGCM and SOIR were binned latitudinally to increase resolution (0-30N, 30-60N, 60-70N, 70-80N, and 80-90N). Because the SOIR instrument uses solar occultation to measure CO2 absorption, data represent a vertical profile of the atmosphere at each Venussian terminator (6:00 and 18:00 hours LST respectively), covering an altitude range of ~70-170 km. Taking into account the asymmetrical influence of the thermosphere's retrograde zonal circulation (~100 km), this inherently selective sampling prompted comparison of the atmospheric characteristics as well as model correspondence observed at the two terminators. The shape of the terminators' temperature and CO2 density curves approximately parallel each other, differing slightly with regard to
temperature and altitude of characteristic maximums and minimums. This parallel movement, when combined with the fact that the SOIR profiles tend to reach greater extremes of temperature, allows neither terminator to more closely resemble model output consistently. Closer correspondence instead lies with whichever of the two happens to be more mild at any given altitude. This value demonstrates a tenuous correlation with latitude, which variability is not yet reflected in VTGCM runs. It should be noted that, since VTGCM is less interested in recreating individual profiles than establishing mean trends, these observations are complicated by a scarcity of available data, particularly at low latitudes.

416.04 Study On The Upper Atmosphere Of Venus At The Terminator
- Johanna-Laina Fischer¹, S. W. Bougher², G. A. Hicks³, A. S. Brecht⁴, C. Parkinson⁵, A. Mahieux⁵, V. Wilquet⁵, A. Vandaele⁵, J. Bertaux⁶
  ¹Florida Institute of Technology, ²University of Michigan, ³Columbia University, ⁴NASA ARC, ⁵Belgian Institute for Space Aeronomy, Belgium, ⁶LATMOS, France.

Observations have been made using the SOIR instrument aboard the Venus Express (VEx) mission characterizing the temperature and carbon dioxide profiles at the terminators. Using the Venus Thermospheric General Circulation Model (VTGCM), these profiles can also be modeled at the terminators for many latitudes. For this research, the SOIR and VTGCM profiles are averaged in the following northern latitude bins; 0-30, 30-60, 70-80, 80-90. Using the data from SOIR and outputs from the VTGCM, one can determine how well the current model reproduces the observations at the terminator. In the current VTGCM model, the temperature maximum and minimums characteristic of the data profiles are the same if not very similar with the exception of the magnitude of these characteristic features. The SOIR data tends to reveal more extreme maximum and minimum temperatures as compared to the simulated VTGCM values. Some assumptions made in the data processing technique used to determine the SOIR profile retrievals may not be valid. This causes temperatures around 125 km and above 140 km to not be as accurately represented. VTGCM thermal balance plots help address this problem. In addition, these balances provide insight as to why the model may not be in complete agreement with these SOIR profiles while also determining any missing physical processes that are not included in the current VTGCM framework. Data-model comparisons will also be considered for variable VTGCM parameters, including solar minimum and moderate fluxes as well as extremes of the wave drag parameter yielding minimum and maximum terminator winds. Using the VTGCM model in correspondence with data collected from the SOIR instrument, this study will characterize the overall climate at the Venus terminators and give insight into the physical mechanisms responsible.

416.05 Incorporation of a Gravity Wave Momentum Deposition Parameterization into the Venus Thermosphere General Circulation Model (VTGCM)
- Angela M. Zalucha¹, A. S. Brecht², S. Rafkin³, S. W. Bougher⁴, M. J. Alexander⁵
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The gravity wave drag parameterization of Alexander and Dunkerton [1999] was implemented into a Venus Thermosphere General Circulation Model (VTGCM) to investigate breaking gravity waves as a source of momentum deposition in Venus' thermosphere. Previously, deceleration of zonal jets on the morning and evening terminators in models was accomplished via Rayleigh friction, a linear drag law that is not directly linked to any physical mechanism. The Alexander and Dunkerton [1999] parameterization deposits all of the momentum of a breaking wave at the breaking altitude and features a spectrum of wave phase speeds whose amplitudes are distributed as a Gaussian about a center phase speed. We did not find a combination of wave parameters (namely center phase speed, amplitude at center phase speed, and distribution width) to produce sufficient drag in the jet cores that would bring VTGCM density and nightglow emissions into agreement with Venus Express observations. The zonal wind shear from 100 to 120 km altitude is very strong. Gravity waves launched below 100~km either break in the strong shear zones below 115 km or are reflected, and do not propagate into the jet core regions where drag is needed. The results we present suggest that either some other mechanism besides gravity wave breaking causes the deceleration of winds in the jet cores, or that there are additional wave sources in the high
atmosphere within or above the strong shear zones between 100-115 km generating waves that break in the jet cores. We thank the NASA Venus Express Participating Scientist Program (NNX10AI35G) for support.

416.06 Laboratory Measurements of the 3.7-20 cm Wavelength Opacity of Sulfur Dioxide and Carbon Dioxide under Simulated Conditions for the Deep Atmosphere of Venus

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  ¹Georgia Institute of Technology.

In the past two decades, multiple observations of Venus have been made at X band (3.6 cm) using the Jansky Very Large Array (VLA) and maps have been created of the 3.6 cm emission from Venus. Since the emission morphology is related both to surface features and to deep atmospheric absorption from CO₂ and SO₂ (see, e.g., Butler et al., Icarus 154, 2001), knowledge of the microwave absorption properties of sulfur dioxide in a carbon dioxide atmosphere under conditions for the deep atmosphere of Venus is required for proper interpretation. Except for a single measurement campaign conducted at a single wavelength (3.2 cm) over 40 years ago (Ho et al., JGR 71, 1966), no measurements of the centimeter-wavelength properties of any Venus atmospheric constituent have been conducted under conditions characteristic of the deep atmosphere (pressures from 10-92 Bars and temperatures from 400-700 K). New measurements of the microwave properties of SO₂ and CO₂ at wavelengths from 3.7-20 cm are now being conducted under simulated conditions for the deep atmosphere of Venus, using a new high-pressure system. Initial results from this measurement campaign conducted at 430 K and at pressures up to 92 Bars will be presented. This work is supported by the NASA Planetary Atmospheres Program under Grant NNX11AD66G.

Friday, 19 October, 2012

500 Jupiter and Saturn: Seasonal Variability, Clouds and Interiors

Friday, 8:30 AM - 10:00 AM, Reno Ballroom

500.01 Seasonal And Non-seasonal Variations Of Jupiter’s Atmosphere From Observations Of Thermal Emission, 1994-2011

- Glenn S. Orton¹, L. Fletcher², P. Yanamandra-Fisher³, T. Greathouse⁴, B. Fisher¹, J. Greco⁵, L. Wakefield⁶, E. Snead⁷, K. Boydstun⁸, G. Arzumanyan⁹, J. Christian⁵
  ¹JPL, ²University of Oxford, United Kingdom, ³Space Science Institute, ⁴Southwest Research Institute, ⁵Caltech, ⁶Calif. State University, Pomona, ⁷Northeastern Univ., ⁸Ohio State Univ., ⁹Glendale Community College.

We analyzed mid-infrared images of Jupiter’s thermal emission, covering ~1.5 Jovian years, acquired in discrete filters between 7.8 and 24.5 μm. The behavior of stratospheric (~10-mbar) and tropospheric (~100-400 mbar) temperatures is generally consistent with predictions of seasonal variability, with differences between 100-mbar temperatures ±50-60° from the equator on the order of ±2 K. Removing this effect, there appear to be long-term periodicities of tropospheric temperatures, with amplitude, phase and period dependent on latitude. Temperatures near and south of the equator vary least (< ±1 K). At some higher latitudes, the amplitudes vary by as much as ±2.5 K with peak periodicities still showing a 12-year signature with other periods ranging from 3 to 8 years. The ~4-year variation of stratospheric temperatures known as the quasi-quadrennial oscillation or “QQO” (Leovy et al. 1991, Nature 354, 380) continued during this period. There were no variations of zonal mean temperatures associated with any of the “global upheaval” events that have produced dramatic changes of Jupiter’s visible appearance and cloud cover, although there are colder discrete regions associated with updrafts, e.g. the early stages of the re-darkening (“revival”) of the South Equatorial Belt (SEB) in late 2010. On the other hand increases in the visible albedos (“fades”) of belts are accompanied by increases in cloudiness at 700 mbar (most likely an NH₃ ice cloud layer) and higher pressures, together with the mixing ratio of NH₃ gas near 400 mbar (above its condensation level). These quantities decrease during re-darkening (“revival”) episodes, during which
we note exceptions to the general correlation between dark albedos and minimal cloudiness. In contrast to all these changes, the meridional distribution of the 240-mbar para-H$_2$ fraction appears to be time-invariant.

500.02 Variability of Jupiter’s Five-Micron Hot Spot Inventory

- Padma A. Yanamandra-Fisher$^1$, G. S. Orton$^2$, L. Wakefield$^3$, J. H. Rogers$^4$, A. A. Simon-Miller$^5$, K. Boydstun$^6$
  $^1$Space Science Institute, $^2$Jet Propulsion Laboratory, CIT, $^3$Cal Poly, $^4$BAA, United Kingdom, $^5$NASA/GSFC, $^6$Ohio State Univ.

Global upheavals on Jupiter involve changes in the albedo of entire axisymmetric regions, lasting several years, with the last two occurring in 1989 and 2006. Against this backdrop of planetary-scale changes, discrete features such as the Great Red Spot (GRS), and other vortices exhibit changes on shorter spatial- and time-scales. We track the variability of the discrete equatorial 5-μm hot spots, semi-evenly spaced in longitude and confined to a narrow latitude band centered at 6.5°N (southern edge of the North Equatorial Belt, NEB), abundant in Voyager images. Tantalizingly similar patterns were observed in the visible (bright plumes and blue-gray regions), where reflectivity in the red is anti-correlated with 5-μm thermal radiance. Ortiz et al. (1998, GRL, 103) characterized the latitude and drift rates of the hot spots, including the descent of the Galileo probe at the southern edge of a 5-μm hot spot, as the superposition of equatorial Rossby waves, with phase speeds between 99 - 103m/s, relative to System III. We note that the high 5-μm radiances correlate well but not perfectly with high 8.57-μm radiances. Because the latter are modulated primarily by changes in the upper ammonia (NH$_3$) ice cloud opacity, this correlation implies that changes in the ammonia ice cloud field may be responsible for the variability seen in the 5-μm maps. During the NEB fade (2011 - early 2012), however, these otherwise ubiquitous features were absent, an atmospheric state not seen in decades. The ongoing NEB revival indicates nascent 5-μm hot spots as early as April 2012, with corresponding visible dark spots. Their continuing growth through July 2012 indicates the possible re-establishment of Rossby waves. The South Equatorial Belt (SEB) and NEB revivals began similarly with an instability that developed into a major outbreak, and many similarities in the observed propagation of clear regions.

500.03 Seasonal Variations of Temperature, Acetylene and Ethane in Saturn’s Stratosphere from 2005 to 2010

- James Sinclair$^1$, P. G. J. Irwin$^1$, L. N. Fletcher$^1$, J. I. Moses$^2$, T. K. Greathouse$^3$, A. J. Friedson$^4$, B. Hesman$^5$, J. Hurley$^1$, C. Merlet$^1$
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Acetylene (C$_2$H$_2$) and ethane (C$_2$H$_6$) exemplify by-products of complex photochemistry in Saturn’s stratosphere. Their relative stability together with their strong vertical gradients in concentration allow for their use as tracers of vertical motion in Saturn’s lower stratosphere. Earlier studies of Saturn’s hydrocarbons have provided only a snapshot of their behaviour with temporal variations remaining to be determined. In this study, we investigate how the thermal structure and concentrations of acetylene and ethane have evolved on Saturn with the changing season. We use FIRMAP (15.5 cm$^{-1}$ spectral resolution) Cassini-CIRS observations, initially retrieve temperature and subsequently retrieve the abundances of acetylene and ethane. In comparing 2005, 2009 and 2010 results, we observe the disappearance of Saturn’s southern warm polar hood with cooling of up to 18.6 K ± 0.9 K at 1.1 mbar south of 75°S (planetographic). This suggests dissipation of Saturn’s south polar vortex in addition to an autumnal cooling. We observe a 20% ± 9% enrichment of acetylene and a 30% ± 10% enrichment of ethane at 2.1 mbar at 25°N, together with a 14% ± 9% depletion of acetylene and an 18% ± 7% depletion of ethane at the same altitude at 15°S. This suggests the presence of localised downwelling and upwelling at these latitudes, respectively. These vertical motions are consistent with a recently-developed GCM (global circulation model) of Saturn’s tropopause and stratosphere, which predicts this pattern of upwelling and downwelling as a result of seasonally-reversing Hadley circulation.

500.04 Saturn’s Equatorial Plumes At Depth Observed By Cassini/VIMS and Radar: Some Ammonia-wet, Some Dry

- Kevin H. Baines$^1$, T. W. Momary$^1$, M. A. Janssen$^1$, A. P. Ingersoll$^2$, L. N. Fletcher$^3$, R. H. Brown$^4$, B. J. Buratti$^1$, R. N. Clark$^5$, P. D. Nicholson$^6$, C. Sotin$^1$
Large (> 3000 km), discrete clouds and ammonia vapor features buried under Saturn’s ubiquitous equatorial haze have been mapped contemporaneously in Cassini/VIMS 5-micron spectra and 2-cm raster-scan imagery by the Cassini/RADAR used in passive mode. Since 2008 these features have been clearly observed on four occasions - October 14-15, 2009, December 8-10, 2009, July 24-25, 2010, and March 19-21, 2011 - from a vantage point close to the knife-edge of the rings, which reduced the ring obscuration to just ± 3 degrees of latitude about the equator. Spectral modeling indicates that the cloud features are primarily located in the 2-3 bar region, and thus are likely to be comprised of ammonia hydrosulfide (NH₄SH) with perhaps an admixture of water, but not of pure ammonia condensate. RADAR imagery reveals variations of the local ammonia humidity in the same 2-3 bar region, assuming constant temperatures at depth to within a few degrees. Observations acquired March 19-21, 2011 clearly show correlations of ammonia-humid air with NH₄SH cloud features, consistent with the idea that NH₄SH clouds form from updrafts of ammonia-humid air, akin to the formation of convective water clouds on Earth in regions of high humidity. However, observations acquired December 8-10, 2009 show the opposite behavior, with localized cloud features largely coinciding with regions of low ammonia humidity. One possible explanation is that in the case of weaker updrafts, the rising NH₃ is significantly depleted as it creates the NH₄SH clouds, leaving ammonia-depleted holes in the background ammonia vapor. Alternatively, the supply of H₂S in updrafts may vary relative to NH₃, thus regulating the formation of both NH₄SH aerosols and the left-over NH₃ vapor. Finally, clouds in ammonia-dry regions may just indicate mature clouds no longer undergoing formation, as observed in the downwind “comet tail” clouds of the major northern storm of 2010-2011.
Several distinct features of Saturn’s magnetic field have been revealed in a recent study based on in-situ magnetic field measurements made by the Cassini spacecraft (Cao et al. 2012). The field at the dynamo surface is found to be strongly concentrated near the spin-poles with little hemispherical asymmetry. This is in contrast to the field properties at the outer core surface of the Earth, where the field near the spin-poles is at a relative minimum compared to field at mid-latitude. Could the magnetic field observed at Saturn be used to reveal the inner core size and outer boundary heat flow pattern? To answer these questions, we performed a series of numerical simulations of convection-driven spherical shell dynamos. Five inner core sizes $\chi = 0.20, 0.35, 0.50, 0.75, 0.90$, ($\chi$ here is the inner core to outer core radius ratio), and four outer boundary heat flux patterns, with varying degrees of heat flux concentrations towards the poles, are tested. Higher heat flow at high latitude could result from the inhibited radial transport of heat at the equatorial region by the quasi-geostrophic zonal flows in the molecular envelope. Our numerical studies suggest that within the thick shell geometry ($\chi \leq 0.50$), both the inner core size and the outer boundary heat flow pattern contribute to determining the field geometry at the dynamo surface. With stronger heat flow at high latitudes, zonal flow in the equatorial region is enhanced. The enhanced zonal flow removes the radial magnetic field in the equatorial region, to minimize the magnetic shear (Ferraro’s law of corotation). Thus the observed magnetic field of Saturn favors a small core ($\leq 10$ Earth Masses) inside this planet.

500.08 Energy Budgets of the Giant Planets and Titan

As a fundamental property, the energy budget affects many aspects of planets and their moons, such as thermal structure, meteorology, and evolution. We use the observations from two Cassini spectrometers (i.e., CIRS and VIMS) to explore one important component of the energy budget - the total emitted power of Jupiter, Saturn, and Titan (Li et al., 2010, 2011, 2012). Key results are: (1) The Cassini observations precisely measure the global-average emitted power of three bodies: $14.10\pm0.03$ W m$^{-2}$, $4.952\pm0.035$ W m$^{-2}$, and $2.834\pm0.012$ W m$^{-2}$ for Jupiter, Saturn, and Titan, respectively. (2) The meridional distribution of emitted power displays a significant asymmetry between the northern and southern hemispheres on Jupiter and Saturn. On Titan, the meridional distribution of emitted power is basically symmetric around the equator. (3) Comparing with the Voyager measurements, the new Cassini observations reveal a significant temporal variation of emitted power on both Jupiter and Saturn: i) The asymmetry between the two hemisphere shown in the Cassini epoch (2000-2010) is not present in the Voyager epoch (1979-1980); and ii) From the Voyager epoch to the Cassini epoch, the global-average emitted power appeared to increase by $\sim3.8\%$ for Jupiter and $\sim6.4\%$ for Saturn. (4) Together with previous measurements of the absorbed solar power on Titan, the new Cassini measurements of emitted power provide the first observational evidence of the global energy balance on Titan. The uncertainty in the previous measurements of absorbed solar energy places an upper limit on its energy imbalance of 6.0% on Titan. The exploration of emitted power is the first part of a series of studies examining the temporal variability of the energy budget on the giant planets and Titan. Currently, we are measuring the absorbed solar energy in order to determine new constraints on the energy budgets of Jupiter, Saturn, and Titan.

500.09 The Centimeter-Wavelength Opacity of Ammonia Broadened by Water Vapor under Deep Jovian Atmospheric Conditions
Over 850 laboratory measurements of the 5-20 cm wavelength opacity of ammonia broadened by water vapor under deep jovian atmospheric conditions (temperature between 373-503 K and pressure between 0.01-97 bar) have been made to investigate water vapor’s role in broadening ammonia absorption spectrum. These measurements have been used to empirically estimate the broadening of ammonia by water vapor and a model has been developed for the centimeter-wavelength opacity of ammonia broadened by water vapor in a hydrogen/helium atmosphere at temperatures up to 500 K and pressures up to 100 bar. The model corrects for the non-ideal behavior of gases and fits about 70% of the measurements within the 3-sigma uncertainty. The model indicates that water vapor broadens the centimeter-wavelength absorption spectrum of ammonia five times more than the equivalent amount of hydrogen, and about nine times as much as helium. Depending on the abundance of water vapor in Jupiter, its effect on the ammonia absorption spectrum may compare with its intrinsic opacity in affecting the centimeter-wavelength emission spectrum. This work will improve retrievals of the atmospheric abundance of water vapor and ammonia at Jupiter from the Juno microwave radiometer (MWR) measurements and also aid in the accurate interpretation of the observed centimeter-wavelength emission spectra of the other jovian planets. This work was supported by NASA Contract NNM06AA75C from the Marshall Space Flight Center supporting the Juno Mission Science Team, under Subcontract 699054X from the South-west Research Institute.

501 Planetary Rings: Particle Properties
Friday, 8:30 AM - 10:00 AM, Carson 1/2

501.01 Multi-wavelength Studies Of Saturn's Rings To Constrain Ring Particle Properties And Ring Structure
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The characteristics of Saturn’s ring particles and their regoliths are examined by modeling variations in brightness, color, temperature and spectral parameters with changing viewing geometry over a wide range of wavelengths. Data from Cassini CIRS, ISS, VIMS and UVIS scans of the lit and unlit main rings at multiple geometries and solar elevations are used. Using multi-wavelength data sets allows us to test different thermal models by combining effects of particle albedo, regolith grain size and surface roughness with thermal emissivity and inertia, and particle spin rate and spin axis orientation. Over a range of solar elevations the CIRS temperature and ISS color variations are confined primarily to phase angle with only small differences from changing spacecraft elevation. Color and temperature dependence with varying solar elevation angle are also observed. Brightness dependence with changing solar elevation angle and phase angle is observed with UVIS. VIMS observations show that IR water ice absorption band depths are a very weak function of phase angle, out to ~140 deg phase, suggesting that interparticle light scattering is relatively unimportant except at very high phase angles. These results imply that the individual properties of the ring particles may play a larger role than the collective properties of the rings, in particular at visible wavelengths. The temperature and color variation with phase angle may be a result of scattering within the regolith and on possibly rough surfaces of the clumps, as well as a contribution from scattering between individual particles in a many-particle-thick layer. Preliminary results from our joint studies will be presented. This research was carried out in part at the Jet Propulsion Laboratory, California Institute of Technology, under contract with NASA. Copyright 2012 California Institute of Technology. Government sponsorship is acknowledged.

501.02 Comparison of Optical and Thermal Opposition Surges in the C Ring: Unveiling the Nature of the Opposition Effect
- Estelle Deau1, L. J. Spilker1, S. Pilorz2, R. Morishima1, S. Brooks1
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The opposition effect (OE) is a non-linear increase of the brightness near zero phase angle. So far, the rings’ OE is observed in reflected light (as the Visible Opposition Effect or VOE) and temperature from thermal emission (as the Thermal Opposition Effect or TOE). The nature of the origin of rings VOE and TOE is still a matter of debate. Indeed, the most common hypothesis is that VOE and TOE are caused by SH (Shadow Hiding of regolith surface irregularities and/or ring particles), although VOE should be partly due to CB (Coherent backscatter, i.e., constructive interferences at the exact backscattering direction). The bulk of the debate lies in the predominant, partial or null contribution of CB in VOE. To help solve this puzzle, our approach is to study the discrepancies of OE morphology from reflected and emitted lights. We use data from the ISS (Image Science Subsystem) onboard Cassini spacecraft, as well as those from the three Focal Planes (FP1, FP3 and FP4) of CIRS (Composite InfraRed Spectrometer). Using the original and improved parametric model of Bobrov (1970, Dollfus Editions, pp376), our first comparisons of brightness VOE from Deau et al. (2012 Icarus, final review) and temperature TOE from Altobelli et al. (2007, Icarus vol191, pp691), show that both surges are different in the C ring plateaux. This supports the idea that either VOE and TOE could have different origin; or TOE is not appropriately compared to VOE. We then investigate TOE in radiance units (W.cm⁻².sr⁻¹/cm⁻¹) and derived the first CIRS spectrograms for the C ring. Results of comparison of TOE in radiance units and VOE in I/F will be presented. This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract with NASA. Copyright 2012 California Institute of Technology. Government sponsorship is acknowledged.

501.03 Particle Size Distribution in Saturn’s Ring C

- Essam A. Marouf¹, K. Wong¹, R. French², N. Rappaport³
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Information about particle sizes in Saturn’s rings is provided by two complementary types of Cassini radio occultation measurements. The first is differential extinction of three coherent sinusoidal signals transmitted by Cassini through the rings back to Earth (wavelength = 0.94, 3.6, and 13 cm, respectively). The differential measurements strongly constraint three parameters of an assumed power-law size distribution \( n(a) = n_0 (a/a_0)^q \), \( a_{min} \leq a \leq a_{max} \): namely, the power law index \( q \), the minimum radius \( a_{min} \), and reference abundance \( n_0 \) at reference radius \( a_0 \). The differential measurements are particularly sensitive to radii in the range \( 0.1 \text{ mm} < a < 1 \text{ m} \). Complementing this capability, is a second type of measurements that is particularly sensitive to the larger radii \( 1 \text{ m} < a < 20 \text{ m} \) and their abundance. Signature of the collective near-forward scattering by these particles is captured in power spectrum measurements as broadened component of width, shape, and strength that depend on ring particle sizes, their spatial distribution, and observation geometry. Contributions of ring features of width as small several hundred kilometers can be identified and isolated in the measured spectra for a small subset of Cassini orbits of favorable geometry. We use three inverse scattering algorithms (Bayes, constrained linear inversion, generalized singular-value-decomposition) to recover the size distribution of particles of resolved ring features over the size range \( 1 \text{ m} < a < 20 \text{ m} \) without assuming an explicit size distribution model. We also investigate consistency of the results with a single power-law model extending over \( 0.1 \text{ mm} < a < 20 \text{ m} \) and implications to the spatial distribution of ring particles normal to the ring plane (vertical ring thickness). We present example results for selected features across Saturn’s Ring C where little evidence for gravitational wakes is present, hence the approaches above are applicable.

501.04 Particle Sizes in Saturn’s F Ring and Strands from Cassini Solar Occultation

- Tracy Michelle Becker¹, J. E. Colwell¹, L. W. Esposito²
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A misalignment of the Cassini spacecraft’s Ultraviolet Imaging Spectrograph (UVIS) with the Sun during a solar occultation in 2005 resulted in the serendipitous detection of diffracted sunlight from the smallest particles in Saturn’s F Ring. UVIS detected a solar signal of \(~1\%\) the value measured in other solar occultations, which confirms the pointing analysis showing the Sun was outside the UVIS solar port field of view. The solar disk was thus largely occulted by the instrument aperture enabling the detection of light that was forward-scattered by micron-sized particles in the F Ring region. This phenomenon is also occasionally observed at ring edges in UVIS stellar occultation data. We model the diffracted light in a forward model of the solar occultation. The model uses the geometry of the solar occultation and misaligned UVIS solar port with an optical depth profile of the F Ring from a
UVIS stellar occultation made less than 8 hours prior to the solar occultation to calculate the flux according to Fraunhofer diffraction. We vary the particle sizes of the ring to reproduce the shape and intensity of the diffraction signature in the data. We find that the bulk, if not all, of the observed diffracted signal comes from the broad strands straddling the F ring at that time rather than from the F ring core region. This is consistent with the model of the origin of the strands due to the physical collision of a moonlet with the F Ring core releasing a cloud of smaller particles. We will present the numerical results from this model and data from solar occultations scheduled for later in 2012 to reproduce the 2005 pointing.

501.05 Particle Sizes and Small-Scale Structure in Saturn’s Rings from Stellar Occultation Statistics

- Joshua E. Colwell\(^1\), J. H. Cooney\(^1\), L. W. Esposito\(^2\), M. Sremcevic\(^2\)

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The Cassini Ultraviolet Imaging Spectrograph (UVIS) has observed more than 100 occultations of stars by Saturn’s rings. The finite sizes of particles and clumps within the rings results in increased variance in the observed photon counts above that due to counting statistics. We relate this excess variance to an autocorrelation length (L) within the rings. We find that L in the plateaus of the C ring is \(\sim1/2\) the value in the rest of the C ring indicating smaller particles (in some average sense) in the plateaus. The values of L in the rest of the C ring are correlated with the optical depth suggesting particle size segregation. The values of L in the Cassini Division, on the other hand, suggest several different particle populations in this region. The inner \(\sim700\) km of the B ring shows a smaller L than the rest of the “B1” region of the B ring. In the A ring, L varies with viewing geometry due to the presence of self-gravity wakes. Higher-order moments of the data show the presence of rare gaps or holes in some regions of the rings.

501.06 Haloes Seen In UVIS Reflectance Spectra

- Larry W. Esposito\(^1\), E. Bradley\(^2\), J. Colwell\(^2\), M. Sremcevic\(^1\)

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UVIS SOI reflectance spectra show bright ‘haloes’ around the locations of some of the strongest resonances in Saturn’s A ring (Esposito et al 2005). UV spectra constrain the size and composition of the icy ring particles (Bradley et al 2010, 2012). We investigate the Janus 4:3, 5:3, 6:5 and Mimas 5:3 inner Lindblad resonances as well as at the Mimas 5:3 vertical resonance (bending wave location). Models of ring particle regolith evolution (Elliott and Esposito 2010) indicate the deeper regolith is made of older and purer ice. The strong resonances cause streamline crowding (Lewis and Stewart 2005) which damps the interparticle velocity, allowing temporary clumps to grow, which in turn increase the velocity, eroding the clumps and releasing smaller particles and regolith (see the predator-prey model of Esposito et al 2012). This cyclic behavior, driven by the resonant perturbation from the moon, can yield collision velocities greater than 1m/sec, sufficient to erode the aggregates (Blum 2006), exposing older, purer materials. Thus, the radial location of the strongest resonances can be where we find both large aggregates and disrupted fragments, in a balance maintained by the periodic moon forcing. If this stirring exposes older, purer ice, the velocity threshold for eroding the aggregates can explain why only the strongest Lindblad resonances show haloes. UVIS spectra can determine the relative contributions of particle size and purity at these locations, for comparison to estimates from the regolith evolution models.

501.07 Analysis of Cassini UVIS Far Ultraviolet Reflectance Spectra to Constrain the Non-Ice Material in Saturn’s Rings and Icy Moons

- Eric Todd Bradley\(^1\), J. E. Colwell\(^1\), L. W. Esposito\(^2\), A. R. Hendrix\(^3\)

\(^1\)Univ. of Central Florida, \(^2\)Laboratory for Atmospheric and Space Physics, Univ. of Colorado, \(^3\)Jet Propulsion Laboratory/California Institute of Technology.

The FUV spectra of Saturn’s icy ring particles and moons show the presence of an absorbing constituent that presumably is delivered to the system via micrometeoroid bombardment. Understanding the properties of the non-icy material plays into broader questions regarding the age and evolution of the rings. The FUV spectrum contains a water ice absorption edge at 165 nm. The reflectance shortward of the water ice absorption edge is determined by the composition and abundance of the non-icy material whereas the reflectance longward of the
absorption edge is determined by both water ice and non-icy material. We have taken two approaches to constrain the properties of the non-ice component of the rings using FUV spectra taken by the Cassini UVIS. In one approach we compare the ring particle Bond albedo, \(A_0\), to spectral models with varying abundances and compositions of non-ice components. We first determine \(A_0\) across the water ice absorption edge using the classical Chandrasekhar radiative transfer model for the C Ring and Cassini Division with the scattering function replaced by a self-gravity wake model for the A and B rings. We then compare the retrieved values of \(A_0\) to spectral models of intimate mixtures where the free parameters are the fractional abundances of the ice and non-ice constituents, grain size, and grain asymmetry parameter for scattering. In the second approach we compare FUV color ratios (180/155 nm) across Saturn’s rings, as well as to icy moons, in order to investigate relative variations in water ice abundance in these objects. We find that \(A_0\) longward of the absorption edge peaks in the outer B ring and reaches a minimum in the C Ring and Cassini Division, consistent with the purest water ice being found in the B Ring and the most polluted in the C Ring and Cassini Division.

501.08 Regolith Grain Sizes of Saturn’s Rings Inferred from Cassini-CIRS Far-infrared Spectra
- Ryuji Morishima\(^1\), L. Spilker\(^1\), S. Edgington\(^1\)
  \(^1\)Jet Propulsion Laboratory.

We analyze far-infrared (10-650 cm\(^-1\)) emissivity spectra of Saturn’s main rings obtained by the Cassini Composite Infrared Spectrometer (CIRS). In modeling of the spectra, the single scattering albedos of regolith grains are calculated using Mie theory, diffraction is removed with the delta-Eddington approximation, and the hemispherical emissivities of macroscopic ring particles are calculated using Hapke’s isotropic scattering model. Only pure crystalline water ice is considered and the size distribution of regolith grains is estimated. We find that good fits are obtained if the size distribution is broad ranging from 1 \(\mu\)m to 1-10 cm with a power law index of \(-3\). The apparent relative abundance of small grains increases with decreasing solar phase angle (or increasing mean temperature). This trend is particularly strong for the C ring and is probably caused by the effect of eclipse cooling, by which thermal emission from grains larger than the thermal skin depth (\(\sim 1\) mm) is relatively suppressed at high temperatures.

501.09 Particle Properties in Saturn’s Phoebe Ring
- Douglas P. Hamilton\(^1\), A. J. Verbiscer\(^2\), M. F. Skrutskie\(^2\)
  \(^1\)Univ. of Maryland, \(^2\)Univ. of Virginia.

Saturn’s diffuse outer Phoebe Ring is an immense disk-like structure oriented edge-on as viewed from Earth; it is 30 million km (500 Saturn radii) wide and 2.5 million km (40 Saturn radii) thick. The ring’s particles are thought to originate primarily from the planet’s dark irregular satellite Phoebe. The ring was discovered by Spitzer 24-micron imaging (Verbiscer et al., Nature 2009) and recently recovered by WISE (Skrutskie et al., DPS 2011) at 22 microns. The WISE images, which show the full extent of the ring for the first time, nicely complement the more sensitive but spatially-limited Spitzer data. As WISE and Spitzer observations of the Phoebe ring are extremely limited both in wavelength and phase, we rely on dynamical arguments to constrain particle sizes. Small particles in the Phoebe ring are driven to eccentricities in excess of Phoebe’s e=0.16 by radiation pressure over 30-year timescales. Over million-year timescales, the dust migrates inward via Poynting-Robertson drag, and most of the material finds its way onto the dark side of Iapetus. We model these processes numerically and build up synthetic ring profiles, making various assumptions about the unknown particle size distribution. We produce radial intensity profiles which we compare to the WISE data as well as vertical profiles which are most constrained by Spitzer. Our procedure is extremely robust because it allows for the non cylindrically-symmetric rings expected when radiation pressure is important. We find that the WISE data cannot be fit by a simple power law particle size distribution as is commonly assumed. Instead, that the majority of the flux in the outer parts of the ring must be due to a significant excess of particles with sizes larger than several centimeters. We present additional evidence that implies that the small grains have higher temperatures than large ones.

502 Trans-Neptunian Objects 3: Populations
Friday, 8:30 AM - 9:00 AM, Tahoe Room
502.01 Detection of a Divot in the Scattering Population's Size Distribution
- Cory Shankman¹, B. Gladman¹, N. Kaib², J. Kavelaars³, J. Petit⁴
  ¹The University of British Columbia, Canada, ²Queens University, Canada, ³National Research Council, Canada, ⁴Institut UTINAM, CNRS - Université de franche-compté, France.

Via joint analysis of the calibrated Canada France Ecliptic Place Survey (CFEPS, Petit et al 2011, AJ 142, 131), which found scattering Kuiper Belt objects, and models of their orbital distribution, we show that there should be enough kilometer-scale scattering objects to supply the Jupiter Family Comets (JFCs). Surprisingly, our analysis favours a divot (an abrupt drop and then recovery) in the size distribution at a diameter of ~100 km, which results in a temporary flattening of the cumulative size distribution until it returns to a collisional equilibrium slope. Using the absolutely calibrated CFEPS survey we estimate that there are 2 x 10^9 scattering objects with H_g < 18, which is sufficient to provide the currently estimated JFC resupply rate. We also find that the primordial disk from which the scattering objects came must have had a "hot" initial inclination distribution before the giant planets scattered it out. We find that a divot, in the absolute magnitude number distribution, with a bright-end logarithmic slope of 0.8, a drop at a g-band H magnitude of 9, and a faint side logarithmic slope of 0.5 satisfies our data and simultaneously explains several existing nagging puzzles about Kuiper Belt luminosity functions (see Gladman et al., this meeting). Multiple explanations of how such a feature could have arisen will be discussed. This research was supported by the Natural Sciences and Engineering Research Council of Canada.

502.02 Ramifications of a Divot in the Kuiper Belt's Size Distribution
- Brett Gladman¹, C. Shankman¹, N. Kaib², J. Kavelaars³, J. Petit⁴
  ¹Univ. of British Columbia, Canada, ²Queen’s University, Canada, ³National Research Council, Canada, ⁴Institut UTINAM, CNRS - Université de franche-compté, France.

Our recent detection (see Shankman et al., this meeting) of a divot in the distribution of numbers of Scattering TNOs as a function of absolute magnitude would, if extended to all Kuiper Belt sub-populations, simultaneously explain several outstanding curiosities in the literature. We examine these puzzles in the context of our proposed divot scenario and provide a cohesive picture of the "hot" Trans-Neptunian populations (the scattering, inner belt, hot main belt, outer/detached, and resonant populations). We explore the observed rollover in the Kuiper Belt’s luminosity function, the "missing" Neptune Trojans, the source of the Jupiter Family Comets, and patterns seen in the hot/cold ratio as a function of magnitude. Our interpretation is that a detected divot is a preserved relic of the size distribution made by planetesimal formation, now "frozen in" to portions of the Kuiper Belt which share a "hot" orbital inclination distribution. This research was supported by the Canadian National Sciences and Engineering Research Council.

502.03 The Absolute Magnitude Distributions of the Cold and Hot Kuiper Belt Populations
- Wesley Fraser⁵, M. E. Brown⁶, A. Morbidelli⁷, A. Parker⁵, K. Batygin⁵
  ⁵Herzberg Institute of Astrophysics, Canada, ⁶California Institute of Technology, ⁷Observatoire de Nice, France, ⁸Center for Astrophysics.

Here we present measurements of the absolute magnitude distributions of the cold and hot Kuiper Belt populations. From the literature we compiled data from all past surveys from which reliable photometry and detection efficiency, as well as measures of distance and inclination were available for each observed source. We de-biased the observed absolute magnitude and radial distributions in two ways. The first made use of the radial distribution predicted by the CFEPS Kuiper Belt model. The second utilized the radial distribution determined from a simultaneous maximum likelihood fit of both the radial and absolute magnitude distributions to the observed data. Both methods produced nearly identical results. We will demonstrate that the absolute magnitude distributions of both the cold and hot populations exhibit steeper bright object slopes than that previously found from the apparent magnitude distributions, with slopes of α∼1.4 and α∼0.9 for the cold and hot populations respectively. Both populations exhibit breaks to a shallower slope of α∼0.3 at magnitudes H(r')=7.2. We will present a comparison of the hot and cold absolute magnitude distributions to that of the Jupiter Trojans and discuss implications of these results for the cosmogony of the planetesimal populations of the outer Solar system.
The final stage of terrestrial planet formation is thought to begin with a few tens to a few hundred planetary embryos with sizes comparable to the Moon or Mars. Simulations of late-stage accretion usually rely on N-body integrations to follow the complex orbital evolution of these embryos, which determines which objects collide and what their final orbits will be. However, most simulations to date have used a greatly simplified model for the collisions themselves, assuming that colliding bodies merge, conserving mass and momentum. Recently, Leinhardt and Stewart (2012, Astrophys. J. 745, 79) have performed a detailed study of the outcome of collisions between planetary embryos, allowing simulations of planetary accretion to include more realistic collisions as a result. Here, I will describe the results of a new set of N-body simulations of late-stage planetary growth that include a range of impact outcomes such as fragmentation, and hit and run collisions, as well as simple mergers. The results will be compared with simulations that assume all collisions yield a merger, paying particular attention to growth timescales, planetary compositions, and the kind of final systems that form. The use of a realistic collision model also makes it possible to examine core-mantle fractionation over time for different objects.

We present simulations of the formation of the terrestrial planets using a new Lagrangian code known as LIPAD (Levison, Duncan, and Thommes, 2012, AJ, in press). LIPAD, which stands for ‘Lagrangian Integrator for Planetary Accretion and Dynamics,’ is the first particle based code that can accurately follow the collisional/accretional/dynamical evolution of a large number of km-sized planetesimals through the entire growth process to become planets. Here we report on simulations of a region of a minimum mass solar nebula disk that extends from 0.5 to 1.5 AU. Initially the solids in this disk are planetesimals with radii between 10 and 50 km. Preliminary analysis of these simulations shows that a significant amount of material is lost due to collisional grinding indicating that the mass of the disk from which the planets formed was probably larger than previously believed. Other differences from the standard model will be discussed.

The current orbits of the terrestrial planets are rather circular and fairly coplanar. A measure for the system’s deviation from being circular and coplanar is the Angular Momentum Deficit (Laskar, 1997). For the terrestrial system its normalised current, long-term average value is 0.0018. It remains an open question as to how the terrestrial system obtained its AMD. There are two viable sources: either it is a remnant of their formation or it was acquired during late-stage giant planet migration. The low current AMD of the terrestrial planets led Brassier et al. (2009) and Agnor & Lin (2012) to conclude that the divergent late migration of Jupiter and Saturn had to occur on a timescale of $\tau \sim 0.1$ Myr or shorter. However, Agnor & Lin (2012) suggested that the migration could have been slower if the AMD modes exhibited enough destructive interference during the migration of the giant planets, and they suggested that this be explored numerically. Here we report on the results of numerical simulations where we start the terrestrial system with a primordial AMD ranging from 10% to 250% of the current value and subject it to a few cases of fast ($\tau < 0.1$ Myr) giant planet migration. We find that the current value of 0.0018 is marginally reproduced only for systems whose primordial AMD was 10% or less of the current value. We always report an increase in the AMD, even when starting with higher primordial values than the current one. Thus
the interference of the modes is primarily constructive. The necessary low primordial AMD imposes a formidable constraint on future studies of terrestrial planet migration.

503.04 A New Model for the Origin of the Moon
- Sarah T. Stewart
  - M. Ćuk
  - Harvard University.

The Moon and Earth are identical in their oxygen, tungsten, chromium, and titanium isotopes. These isotope systems show significant variations between most meteorite groups and planetary bodies; thus, the simplest explanation for the isotopic similarity is that the Moon was formed from Earth’s mantle. In contrast, giant impact simulations find that the lunar disk is predominantly (>60 wt%) composed of material originating from the impactor. Because the impactor is expected to have a different isotopic signature than Earth, the observations and models are in conflict. Post-impact isotopic equilibration between Earth and the proto-lunar disk has been proposed as a means to mitigate an initial compositional difference; however, recent measurements of the neon, xenon and tungsten isotopes in the deep mantle demonstrate that the early Earth was not completely mixed. Previous Moon-formation studies assumed that the angular momentum after the impact was similar to present day, but N-body simulations of the growth of Earth-mass planets typically find higher spin rates at the end of accretion. Here, we present a new model for the origin of the Earth-Moon system. A late erosive impact onto a fast-spinning proto-Earth produced a disk that was massive enough to form the Moon and composed primarily of material from Earth, but the system had more angular momentum than today. Subsequently, the excess angular momentum was lost during tidal evolution of the Moon via a resonance between Earth’s orbital period and the period of precession of the Moon’s perigee. Our model reproduces the observed isotopic homogeneity and present angular momentum of the Earth-Moon system. This work is supported by NASA Origins of Solar Systems.

503.05 Lunar Accretion and the Moon’s Initial Thermal State
- Julien Salmon
  - R. M. Canup
  - Southwest Research Institute.

Previous models of lunar formation from an impact-generated disk predict the Moon accretes in less than a year (Ida et al. 1997, Kokubo et al. 2000). Such a rapid accretion implies a fully molten initial Moon (e.g., Pritchard & Stevenson 2000). However, the lack of global faults on the Moon has been interpreted as constraining the depth of initial melting to the Moon’s outer few hundred kilometers (Solomon & Chaiken 1976). Depth estimates for the lunar magma ocean (250 to 1000 km; e.g., Shearer et al. 2006) are also typically less than the Moon’s full radius (1738 km). Taken at face value, such observations appear most consistent with a partially molten initial Moon. We have developed a new lunar accretion model that includes a more accurate description of the inner protolunar disk, taking into account thermal processes that limit the disk’s evolution rate (Salmon and Canup 2012). Our model predicts a 3-phase accretion of the Moon, in which material initially orbiting in the outer disk accumulates rapidly, followed by a much slower evolution of the vapor/liquid inner disk and a final phase of accretion of inner disk material onto the Moon. The Moon’s total accretion then occurs over about 100 years, which could be compatible with partial cooling of protolunar material. We have coupled our accretion model to a simple model for the Moon’s initial thermal state. We use a 3D spherical grid to model the forming Moon. We estimate heating due to each accretionary event using the impactor properties predicted by our accretion model, assuming that a fixed fraction (“h”) of each impactor’s kinetic energy is retained locally within the Moon’s interior, and include cooling from the Moon’s surface. We use this model to estimate the Moon’s initial thermal state as a function of h and specific accretionary histories.

503.06 On The Composition and Structure of Planetesimals
- Linda Elkins-Tanton
  - R. R. Fu
  - Carnegie Institution for Science, Massachusetts Institute of Technology.

Increasing evidence exists for partial differentiation in planetesimals in the early solar system and, by extension, for the existence of partially differentiated asteroids today. Remanent magnetism in angrites, meteorites from Vesta, and the Allende CV chondrite indicates that their parent bodies had core dynamos, requiring internal
melting and core formation. Ceres, Pallas, and Lutetia have densities and moments of inertia consistent with internal differentiation. Lutetia also has a largely intact chondritic surface overlying a possibly differentiated interior. The hypothesis of a partially differentiated body, with a primitive lid overlying a differentiated interior, relies on the physics and chemistry that preserves the lid and is the topic of this abstract. Some of the least constrained but most important processes are release and transport of hydrous fluids, rise and eruption of silicate magma, and survival of any conductive lid. Here we will present detailed calculations of melt and crustal densities, taking into account the role of volatile release and time-dependent porosity to constrain the eruption or suppression of rising magmas in the primitive lid of a heating, internally differentiating body. We will also discuss the mechanical disruption of the primitive crust due to impacts and viscous traction from an underlying convective layer. Together, these investigations constrain the final composition and structure of the conductive lid of the planetesimal, which govern the body’s long-term thermal evolution and hold implications for the capacity of planetesimals to deliver volatiles to growing planets early in solar system formation. Derived stratigraphies of planetesimal crusts help to identify the origin of meteorite groups and to evaluate the plausibility of shared parent bodies amongst distinct meteorites classes. Finally, our work further elucidates the relationship between asteroid surface compositions and interior structure, thereby informing the interpretation of telescopic observations of small bodies.

504 Jovian Planets: The Ice Giants
Friday, 10:30 AM - 11:30 AM, Reno Ballroom

504.01 First Views of North Polar Clouds and Circulation on Uranus
- Lawrence A. Sromovsky\textsuperscript{1}, P. M. Fry\textsuperscript{1}, H. B. Hammel\textsuperscript{1}, I. de Pater\textsuperscript{3}, K. A. Rages\textsuperscript{4}
\textsuperscript{1}Univ. of Wisconsin-Madison, \textsuperscript{2}AURA, \textsuperscript{3}Univ. of California, Berkeley, \textsuperscript{4}SETI Institute.

Post-equinox high S/N imaging of Uranus, by HST in 2009-10 and by Keck and Gemini telescopes in 2011, provide the first detailed views of its high northern latitudes. These images reveal numerous small cloud features from which we were able to extend the zonal wind profile of Uranus into its north polar region and accurately characterize its 60° N 250-m/s prograde jet. We also found a large N-S asymmetry in the morphology of polar cloud features (Sromovsky et al. 2012, Icarus 220, 694-712). The variation of wind speed with latitude in the north polar region is consistent with solid body rotation at a rate of 4.3°/h relative to the interior. When new measurements are combined with measurements from 1997 onward, there remains a small but significant asymmetry at middle latitudes, peaking near 35°, where southern hemisphere winds are 20 m/s more westward than corresponding northern hemisphere winds. The discovery of polar discrete cloud features is significant because of their possible connection to large scale meridional mass flows. Analysis of 2002 HST STIS spectra shows that the southern high latitudes are depleted of methane in the upper troposphere (Karkoschka & Tomasko 2009 Icarus 202 287-309; Sromovsky et al. 2011, Icarus 215, 292-312), suggesting an upper tropospheric downwelling in the south polar region that would tend to depress convective cloud formation there. Indeed, no comparable features have ever been seen in high southern latitudes. On the other hand, the existence of numerous small, possibly convective, features at high northern latitudes suggests that the predominant meridional flow there is not downwelling and that CH₄ may not yet be depleted there. New HST STIS observations are expected to resolve this issue. This research was supported by grants from NASA Planetary Atmospheres and Astronomy programs, and from the Space Telescope Science Institute.

504.02 Seasonal Circulation Modeling of Uranus
- Michael Sussman\textsuperscript{1}, T. E. Dowling\textsuperscript{1}, T. K. Greathouse\textsuperscript{2}, N. J. Chanover\textsuperscript{3}
\textsuperscript{1}University of Louisville, \textsuperscript{2}Southwest Research Institute, \textsuperscript{3}New Mexico State University.

We have modified the Explicit Planetary Isentropic Coordinate (EPIC) general circulation model (GCM) to include a computationally efficient radiation scheme to study seasonal effects on the circulation of Uranus over multi-year simulations. In addition to potentially observable seasonal changes in low-latitude zonal winds, we present evidence that changes in the structure of the tropospheric meridional circulation is predominantly seasonally controlled. Our model predicts that the greatest hemispheric asymmetry in both circulation and temperature
occurs approximately one season after the time of largest asymmetry in insolation. For example, temperatures show the greatest latitudinal symmetry during Uranian solstice. Similarly, meridional circulation demonstrates the greatest cross-equator flow near equinox. Results at the 1-2 bar level are particularly noteworthy, showing a delicate balance between radiative equilibrium and convection within our model. With the winter hemisphere receiving no insolation to maintain the temperature structure at this altitude, this region cools to become superadiabatic late in the season, leading to significant convective events. These results suggest a Uranus orbiter with significant night-side observation capabilities would yield fundamentally new information on ice giant atmospheric dynamics. This work was funded by NASA Planetary Atmospheres Grant NNX08AE64G and the National Science Foundation through award number 0807989.

504.03 Haze, Methane And Para-hydrogen Distributions On Uranus And Neptune
- Michael Roman$^1$, D. Banfield$^1$, P. J. Gierasch$^1$, D. M. Stam$^2$
  $^1$Cornell University, $^2$SRON Netherlands Institute for Space Research, Netherlands.

The distribution of aerosols, methane, and molecular hydrogen-para fraction on Uranus and Neptune are investigated from spatially resolved near-IR spectra. For reasons not yet understood, Neptune is one of the most meteorologically active planets in the solar system. Uranus, which appeared relatively featureless in Voyager 2 images, has shown increased activity in recent years [1], presumably revealing seasonal changes. The advent of the HST and adaptive optics technology has allowed researchers to map clouds and retrieve chemical abundances [2,3], providing clues to the dynamics driving these worlds. For this study, latitude resolved H- and K-band spectra and images were obtained using adaptive optics on the 200" Hale telescope at the Palomar Observatory. Data was acquired nearly annually from 1999 to 2007, with several longitudes covered each year. We use an objective, systematic retrieval algorithm (using singular value decomposition) to minimize differences between observed and modeled spectra. Best fitting vertical profiles of aerosol and methane abundance are retrieved, along with the molecular hydrogen para-fraction. Most observations suggest two layers of aerosols, with a stratospheric depletion of methane, and roughly equilibrium para-fractions, each varying with latitude. These parameters are tracers of atmospheric motions and can provide insight into the atmospheric circulations. Variations in latitude suggest regions of stronger upwelling while temporal changes suggest seasonal change. This project was funded under the NASA Outer Planets Research program. [1] Rages, K.A., H.B. Hammel and A.J. Friedson, 2004. Evidence for temporal change at Uranus’ south pole. Icarus, 172, 548-554. [2] Sromovsky, L.A. and P.M.Fry, 2008. The methane abundance and structure of Uranus’ cloud bands inferred from spatially resolved 2006 Keck grism spectra. Icarus, 193, 252-266 [3] Karkoschka, E., 2011. Neptune’s cloud and haze variations 1994-2008 from 500 HST-WFPC2 images. Icarus 215. 759-773.

504.04 Probing The Atmospheres Of Uranus, Neptune And Titan With Herschel Observations Of The CH4(J=6-5) Transition
- Raphael Moreno$^1$, E. Lellouch$^1$, P. Hartogh$^1$, T. Cavalie$^1$, R. Courtin$^1$, H. Feuchtgruber$^4$, C. Jarchow$^3$, L. M. Lara$^5$, G. S. Orton$^6$, M. Rengel$^1$, S. Vinatier$^1$
  $^1$Obs. de Paris-Meudon, France, $^2$MPIS, Germany, $^3$Univ. Bordeaux, France, $^4$MPIE, Germany, $^5$IAA-CSIC, Spain, $^6$JPL/Caltech.

Methane is a key species in the Outer Planets. It is the third most abundant molecule in all four Giant Planets, with a deep tropospheric abundance increasing from 0.2-0.4% (of the hydrogen-helium mix) at Jupiter and Saturn and about 2% in Uranus and Neptune. Its abundance is even larger in Titan, reaching 5% (of N2) at the surface. Related to its large abundance, methane plays a dominant role in governing the stratospheric chemistry of all the Outer Planets. In the thermal infrared, the methane 7.7 microns nu4 band has been widely observed. This band is more sensitive to temperature than to the methane abundance, however. On the other hand, weak pure rotational lines of methane at ~50-250 microns are much more sensitive to the methane abundance. Therefore, the opening of the submillimeter range with Herschel represented an excellent opportunity for an improved determination of methane abundance and vertical profile in the Outer Planets. Observations of Neptune and Titan were performed in the winter 2011/2012 with the HIFI heterodyne submm instrument on board of the Herschel Space Observatory. The four main components of the CH4(J=6-5) rotational transition at 1882 GHz (i.e. 159.3 micron), were detected in emission. This represents the first times these lines are resolved spectrally (R~10^6). Moreover, observations of
Uranus were performed in the same period, with the PACS spectrometer (R~1400) also on board of Herschel. A weak absorption of the CH4(J=6-5) transition was detected, but without resolving the four main component. These lines probe mainly the stratosphere of Neptune and Titan, and the tropopause of Uranus. We will present the methane abundance retrieved from these observations.

504.05 Modeling the Neptunian Troposphere at Microwave Wavelengths
- James Norwood1, M. Hofstadter1, B. Butler2
  1Jet Propulsion Laboratory, 2National Radio Astronomy Observatory.

Neptune’s microwave spectrum is shaped by the temperature profile of the planet’s troposphere, and emission and absorption by various chemical species, particularly H2S and NH3. The abundances of these chemical species are key to understanding Neptune's formation, evolution, and its similarities and differences with fellow ice giant Uranus. To further these goals, we have developed a radiative transfer code to model Neptune's deep troposphere and generate brightness temperature spectra from 0.7 to 20 cm. We have compared our results with previously acquired full-disk Neptune observations (including four unpublished data points), as well as spatially resolved data acquired at the EVLA. Our models address absorption and emission from H2 (collision-induced), H2O (both vapor and condensed), H2S, NH3, and PH3, using current line models. Neptune's temperature profile was assumed to be that derived from Voyager 2 to a depth of 2 bars, below which we follow a wet adiabat. Treating the deep mixing ratios of most species as variables, we performed a methodical search of physically plausible parameter space. Our best-fit solutions to Neptune's microwave spectrum fall into two categories, depending on whether H2S or NH3 is the absorber present above the NH4SH cloud. We describe the optimum values of both solutions, and evaluate their strengths and weaknesses.

504.06 The Deep Atmosphere of Neptune From EVLA Observations
- Bryan J. Butler1, M. Hofstadter2, M. Gurwell3, G. Orton2, J. Norwood1
  1NRAO, 2JPL, 3CfA.

Observations of Neptune at radio wavelengths probe down to depths of bars to 10’s of bars, and are thus unique in their ability to sense the deep atmosphere of the planet. Emissions at these wavelengths are sensitive to a combination of temperature and composition at these depths (notably the abundance of minor species like NH3, PH3, H2S, etc.). Radio wavelength imaging has been used to map the distribution of emission from the planet for quite some time (Martin et al. 2006; DeBoer et al. 1996; de Pater et al. 1991), but with the superb sensitivity of the upgraded VLA, much more detailed maps can now be made. We observed Neptune with the EVLA in August, 2011, at a wavelength of 1 cm, making such detailed and sensitive maps. They were taken in the most spread out configuration of the EVLA, yielding a resolution of better than 0.1 arcseconds. We see a very broad south polar bright cap - extending up to latitudes of roughly 70 deg. This bright south polar cap has been seen before (Hofstadter et al. 2008; Martin et al. 2006), but never with this sensitivity (and to this extent). It is very similar to the excess of emission seen at the poles of Uranus (Hofstadter & Butler 2003), though weaker, and not extending as far equatorward. We see a distinct equatorial brightening, which is not seen so clearly on Uranus. We see hints of southern mid-latitude brightness enhancements, but they are much less pronounced than at the pole and equator. We will present these results and discuss their implications on the atmospheric properties (temperature, composition, and dynamics) of Neptune. A related presentation (Norwood et al. 2012) will discuss global averages for temperature and abundances in the atmosphere.

505 Solar System Origin, Planet and Satellite Formation 2
Friday, 10:30 AM - 12:00 PM, Carson 1/2

505.01 Numerical Investigation of Circumplanetary Disks
- Tyler R. Mitchell1, G. R. Stewart2
  1University of Colorado Boulder, 2Laboratory for Atmospheric and Space Physics.
The regular satellites of Jupiter and Saturn are believed to have formed in circumplanetary disks that were present during the late stages of giant planet formation. At present, there is a large amount of uncertainty in both the structure of these disks and the nature of angular momentum transport within them. In circumstellar disks, magnetorotational rotational instability (MRI) is generally invoked as a mechanism to transfer angular momentum and drive accretion. It is unclear whether circumplanetary disks are sufficiently ionized for the MRI to be active. In an effort to better understand the physical nature of circumplanetary disks, we present 1+1D numerical models of Jovian and Saturnian circumplanetary disks. Our models include viscous diffusion, infall from the solar nebula and external photoevaporation. The combination of these three processes allow for steady-state, truncated disks roughly consistent with the present state of the regular satellite systems of Jupiter and Saturn (Mitchell & Stewart, 2011). Unlike recent models of tidal truncation (Martin & Lubow, 2010), our initial models showed that photoevaporation is able to truncate circumplanetary disks to a small fraction of the Hill radius. One goal of this work is to verify our previous results and confirm that truncated disks can be formed using models with more realistic viscous processes. In order to simplify the problem, our initial models employed a viscosity that was linearly dependent on radius. Our current disk models use a viscosity that is calculated locally based on the midplane temperature that is determined from detailed vertical structure calculations. These models are used to conduct an initial investigation of the viability of an active MRI as well as baroclinic instability and other instabilities that may exist.

505.02 Self-consistent Dynamical And Thermodynamical Evolutions Of Protoplanetary Disks.
- Kevin Baillie$^1$, S. Charnoz$^1$, E. Taillifet$^1$, L. Piau$^2$
  $^1$Universite Paris 7 - Denis Diderot, France, $^2$Michigan State University.

Astronomical observations reveal the diversity of protoplanetary disk evolutions. In order to understand the global evolution of these disks from their birth, during the collapse of the molecular cloud, to their evaporation because of the stellar radiation, many processes with different timescales must be coupled: stellar evolution, thermodynamical evolution, photoevaporation, cloud collapse, viscous spreading...By modeling the results of large scale simulations and coupling them with models of viscous evolution, we have designed a one dimension full model of disk evolution for which most parameters are self-consistently calculated at each time step. We integrate the Hueso and Guillot, 2005 model of disk evolution and couple the radiative transfer description of Calvet et al, 1991 allowing us to handle a non-isothermal disk. We also take into account the collapse of the molecular cloud that feeds the disk. Using the same temperature model in the vertical direction, we estimate 2D thermal maps of the disk. The central star itself is modeled using recent stellar evolution code described in Piau et al, 2011. We first test our model in the case of an already formed Minimum Mass solar Nebula, trying to match the observational constraints on the radial surface density gradients and photosphere height profiles of the Taurus-Auriga or Ophiucus disks for instance. We then follow the full long-term evolution of a disk fed by the collapse of the molecular cloud. We estimate disk temperatures and accretion rates and try to constrain the favourable zone for the formation of the first solids. This will help targeting future JWST observations.

505.03 Origin of Giant Planet Instabilities
- Elena Lega$^1$, A. Morbidelli$^1$, D. Nesvorny$^2$
  $^1$Observatoire de la Cote d’Azur, France; $^2$Southwest research Institute.

The observed eccentricity distribution of extrasolar giant planets has been successfully reproduced (e.g. Juric and Tremaine, 2008; Chatterjee et al., 2008) assuming that said planets formed in systems of at least three planets that became unstable. However, these works placed the planets initially on circular and non-resonant orbits that were too close to each other to be stable. In reality, giant planets form in disks of gas, and their orbits should be the result of migration and eccentricity-damping processes induced by their gravitational interaction with said disks. In this work we simulate the evolution of systems of three planets as they grow in sequence to Jupiter mass. We use the hydro-dynamical code FARGO (Masset, 2000) that we modified to implement the algorithm Symba (Duncan et al., 1998) to solve the gravitational interactions among the planets, handling also close-encounters and mutual collisions. We start our simulations with sets of three embryos of 20 Earth masses in resonant configuration. The growth of each embryo to Jupiter mass leads to a global instability, but the damping action of the gas eventually re-stabilizes the system into a new orbital configuration. However, once the three planets are all giants, their
orbital eccentricities can grow to large values on short timescales through their mutual resonant interactions, while migrating towards the star. We study their subsequent evolution as a function of the disk mass and dissipation time. We conclude that the observed large eccentricities of many extrasolar planets are best reproduced if planets become giants towards the end of the disk lifetime, when the density of gas is rapidly decaying. Instead, if they form in massive disks, their orbital instabilities lead to systems with fewer planets and/or separated orbits with small eccentricities, due to the strong damping action of the disk, as in Marzari et al (2010).

505.04 Dynamics Of Pebbles In The Vicinity Of A Growing Planetary Embryo: Hydro-dynamical Simulations Of The Growth Of A Giant Planet Core.
- Alessandro Morbidelli\textsuperscript{1}, D. Nesvorny\textsuperscript{2}
\textsuperscript{1}CNRS, France, \textsuperscript{2}SWRI.

Understanding the growth of the cores of giant planets is a difficult problem. Recently, Lambrechts and Johansen (2012; LJ12) proposed a new model in which the cores grow by the accretion of pebble-size objects, as the latter drift towards the star due to gas drag. We investigate the dynamics of pebble-size objects in the vicinity of planetary embryos of 1 and 5 Earth masses and the resulting accretion rates. We use hydrodynamical simulations, in which the embryo influences the dynamics of the gas and the pebbles suffer gas drag according to the local gas density and velocities. We find that the pebble dynamics in the vicinity of the planetary embryo are not trivial, and that they change significantly with the pebble size. Nevertheless, the accretion rate of the embryo that we measure is within an order of magnitude of the rate estimated in LJ12 and tends to the estimated value as the size of the pebbles increase. We conclude that the model by LJ12 has the potential to explain the rapid growth of giant planet cores. The actual accretion rates however, depend on the surface density of pebble-size objects in the disk, which is unknown to date.

505.05 Statistical Study of the Early Solar System's Instability with 4, 5 and 6 Giant Planets
- David Nesvorny\textsuperscript{1}, A. Morbidelli\textsuperscript{2}
\textsuperscript{1}Southwest Research Institute, \textsuperscript{2}Observatoire de la Cote d'Azur, France.

Several properties of the Solar System, including the wide radial spacing and orbital eccentricities of giant planets, can be explained if the early Solar System evolved through a dynamical instability followed by migration of planets in the planetesimal disk. Here we report the results of a statistical study, in which we performed nearly ten thousand numerical simulations of planetary instability starting from hundreds of different initial conditions. We found that the dynamical evolution is typically too violent, if Jupiter and Saturn start in the 3:2 resonance, leading to ejection of at least one ice giant from the Solar System. Planet ejection can be avoided if the mass of the transplanetary disk of planetesimals was large, but we found that a massive disk would lead to excessive dynamical damping, and to smooth migration that violates constraints from the survival of the terrestrial planets. Better results were obtained when the Solar System was assumed to have five giant planets initially and one ice giant, with the mass comparable to that of Uranus and Neptune, was ejected into interstellar space by Jupiter. The best results were obtained when the ejected planet was placed into the external 3:2 or 4:3 resonance with Saturn. The range of possible outcomes is rather broad in this case, indicating that the present Solar System is neither a typical nor expected result for a given initial state, and occurs, in best cases, with only a few percent probability. The case with six giant planets shows interesting dynamics but does offer significant advantages relative to the five planet case.

505.06 Impact of Volatiles on Giant Planet Core Formation
- Katherine A. Kretke\textsuperscript{1}, H. F. Levison\textsuperscript{1}
\textsuperscript{1}Southwest Research Institute.

According to the core accretion model, gas giant planets form by initially accreting a $\sim 10 \, M_\oplus$ rocky/icy core while still embedded in a gaseous disk. Once these cores become more massive than around a lunar mass, they begin attracting an atmosphere from the gaseous nebula. This increases the planetary embryo's cross-section to incoming planetesimals, thus aiding growth. The atmosphere also retains some of the energy from the accretion process, significantly increasing the temperature and pressure and the core's surface. To date, models of planet formation
have treated the planetary cores as inert solids, despite the fact that accretional heating can easily create conditions such that significant quantities of volatile ices can sublimate from the core. We present new 1d models of the evolution of volatiles during the giant planet core formation process and discuss how volatile loss from the core and subsequent enrichment of the atmosphere will alter the efficiency of core growth and impact the planet formation process.

505.07 Composition and Internal Structure of Gas Giant Planets: Connection to Formation Scenarios
- Ravit Helled
  
  Tel-Aviv University, Israel.

The large number of extrasolar giant planets, in particular the ones discovered by the transit method, offers us the opportunity to improve our understanding of the formation mechanism, evolutionary path, and interior structure of giant planets in general. The two current models for giant planet formation are core accretion and disk instability. We present the core masses and overall planetary enrichment in heavy elements predicted by the two formation models, and show that both formation models could lead to a large range of final compositions and internal structures. For example, both can form giant planets with nearly stellar compositions. However, low-mass giant planets, enriched in heavy elements compared to their host stars, are more easily explained by the core accretion model. The concept of discriminating between the two models based on the core mass is challenged by addressing the possibility of core erosion and grain settling. Nevertheless, we show that the inferred compositions of transiting gas giant planets, as well as the solar-system giants, provide clues on the formation mechanism.

505.08 Final Origin of the Saturn System
- Erik Asphaug, A. Reufer
  
  UC, Santa Cruz, University of Bern, Switzerland.

Saturn’s middle-sized moons (MSMs) are of diverse geology and composition, totaling 4.4% of the system mass. The rest is Titan, with more mass per planet than Jupiter’s satellites combined. Jupiter has four large satellites with 99.998% of the system mass, and no MSMs. Models to explain the discrepancy exist (e.g. Canup 2010; Mosqueira et al. 2010; Charnoz et al. 2011) but have important challenges. We introduce a new hypothesis, in which Saturn starts with a comparable family of major satellites (Ogihara and Ida 2012). These satellites underwent a final sequence of mergers, each occurring at a certain distance from Saturn. Hydrocode simulations show that galilean satellite mergers can liberate ice-rich spiral arms, mostly from the outer layers of the smaller of the accreting pair. These arms gravitate into clumps 100-1000 km diameter that resemble Saturn’s MSMs in diverse composition and other major aspects. Accordingly, a sequence of mergers (ultimately forming Titan) could leave behind populations of MSMs at a couple of formative distances, explaining their wide distribution in semimajor axis. However, MSMs on orbits that cross that of the merged body are rapidly accumulated unless scattered by resonant interactions, or circularized by mutual collisions, or both. Scattering is likely for the first mergers that take place in the presence of other resonant major satellites. Lastly, we consider that the remarkable geophysical and dynamical vigor of Titan and the MSMs might be explained if the proposed sequence of mergers happened late, triggered by impulsive giant planet migration (Morbidelli et al. 2009). The dynamical scenario requires detailed study, and we focus on analysis of the binary collisions. By analysis of the hydrocode models, we relate the provenance of the MSMs to their geophysical aspects (Thomas et al. 2010), and consider the geophysical, thermal and dynamical implications of this hypothesis for Titan’s origin.

505.09 The Impact Rate on Solar System Satellites During the Late Heavy Bombardment
  
  Southwest Research Institute.

Nimmo and Korycansky (2012; henceforth NK12) found that if the outer Solar System underwent a Late Heavy Bombardment (LHB) in the Nice model, the mass striking the icy satellites at speeds up to tens of km/s would have vaporized so much ice that moons such as Mimas, Enceladus, and Miranda would have been devolatilized. NK12’s possible explanations of this apparent discrepancy with observations include (1) the mass influx was a factor of 10 less than that in the Nice model; (2) the mass distribution of the impactors was top-heavy, so that luck might have

506 Comets 1: Hartley 2 and Garradd
Friday, 10:30 AM - 12:00 PM, Tahoe Room

506.01 Ice and Refractories in the Inner Coma of 103P/Hartley 2
- Silvia Protopapa¹, J. M. Sunshine¹, L. Feaga¹, M. S. Kelley¹, S. Besse¹, O. Groussin², F. Merlin³, T. L. Farnham¹, J. Li⁴, M. F. A’Hearn¹
  ¹University of Maryland, ²Laboratoire d’Astrophysique de Marseille, Université d’Aix-Marseille & CNRS, France, ³Université Paris 7, LESIA, France, ⁴Planetary Science Institute.

The Deep Impact eXtended Investigation (DIXI) to comet 103P/Hartley 2 culminated in a closest approach (CA) of 700 km on November 4th, 2010, when the comet was at 1.064 astronomical units (AU) from the Sun. In visible images at closest approach, comet Hartley 2 displays jets off the end of the smaller lobe of the nucleus and beyond the terminator along the edge of the larger lobe. Spatially resolved near-IR spectra of comet Hartley 2 have been acquired in the wavelength range 1.05-4.85 micron. These data provide an unprecedented opportunity to characterize and map the spatial distribution of the ice and dust in the coma of Hartley 2. The spectra are well reproduced by a linear mixture of water ice with a dark and featureless refractory component (e.g., amorphous carbon), implying that water ice is relatively pure in the coma of Hartley 2. The best fit modeling is obtained with particle diameters on the order of 1 micron for both components. Water ice is not uniformly distributed in the coma, being enriched where the jets are observed in the visible. The relation between visible brightness and water ice abundance is not the same all over the cometary coma. Contrary to the dust, the ice does not present evidence of fragmentation or sublimation in the inner coma. Several pieces of evidence support the idea of water ice grains being dragged out from the subsurface into the coma by CO2.

506.02 Dust Expansion Speed of Comet 103P/Hartley 2
- Jianyang Li¹, M. S. Kelley², J. Williams², D. Bodewits², J. M. Sunshine², S. Besse², T. L. Farnham², C. M. Lisse³, M. F. A’Hearn³, DIXI Science Team
  ¹Planetary Science Institute, ²University of Maryland, ³Johns Hopkins University, Applied Physics Laboratory.

The Deep Impact eXtended Investigation (DIXI) redirected the Deep Impact Flyby (DI) spacecraft to fly past Comet 103P/Hartley 2 on November 4th, 2010. During the approach and departure, the DI spacecraft continuously monitored Hartley 2 with its imaging instruments. We measured the broadband visible lightcurves of the comet through various aperture diameters from 3 to 40 pixels. The coma dominates the total brightness of the comet measured in all aperture sizes, and the changes in the dust production rate due to the rotation of the nucleus causes lightcurve variations. The propagation of the coma dust particles causes variations in the timing of lightcurve extrema determined at consecutively larger annulus apertures. In order to measure the expansion speed of coma particles, we measured the timing variations of these lightcurve extrema during ~20 days bracketing the closest encounter. Our analysis shows that the apparent expansion speed of dust particles in the inner coma is between 20 and 100 m/s. However, the apparent expansion speed may not represent the actual
expansion speed, and is affected by several factors, including radiation pressure, multiple speed components, and possibly other factors such as outgassing from the nucleus and sublimation of icy particles. We also found spatial and temporal variations of the apparent expansion speed, evidently related to the periodic variations in dust production rate. We constructed numerical models to reproduce the observed dust expansion speed measurements, and to help us understand how the dust particles propagate away from the nucleus in the inner coma of Hartley 2.

506.03 Coma Morphology and Rotational Dynamics of Comet 103P/Hartley 2 during the DIXI Encounter


1Planetary Science Institute, 2U. P. & M. Curie, Sorbonne Universites, France, 3National Central University, Taiwan, 4University of Hawaii, 5Osservatorio Astrofisico di Arcetri, Italy, 6Astronomical Observatory of the Jagiellonian University, Poland, 7University of Mayland, 8Institute of Astronomy of the Bulgarian Academy of Sciences, Bulgaria, 9University of California, 10Osservatorio Astronomico di Capodimonte, Italy, 11University of Maryland, 12European Southern Observatory, Germany, 13Instituto de Astrofisica de Andalucia - CSIC, Spain, 14Instituto de Astrofisica de Canarias, Spain, 15Assam University, India, 16UNS-CNRS-Observatoire de la Cote d’Azur, France, 17Cornell University.

The target of the NASA DIXI mission, comet 103P/Hartley 2 is in a non-principal-axis (NPA) rotational state that was observed to be varying with time. However, there is still no consensus on the specific NPA rotational state during the 103P/Hartley 2 encounter by DIXI. We analyze the continuum features observed in ground-based images bracketing the time of the DIXI encounter taken from a number of observatories located at different time zones to provide a dense temporal coverage. The continuum features are present at nearly all rotational phases (for the published periodicities of ~18-hours and ~55-hours). Therefore, we suggest the following possibilities for the origin of the continuum features and the implications. (a) If the features are originating from fixed source regions on the nucleus, short-axis-mode NPA states are more likely than the long-axis-mode NPA states, as the position angles of the observed features are restricted to a small range (~65 degrees) in the sunlit side. (b) If the features are due to the aggregate effect of the sunward emission from the nucleus, then the continuum features cannot be used to exclude a particular mode of NPA rotation. However, the correct rotational model together with the activity model should be able to reproduce the observed coma features as a function of time. Dynamically, the moments of inertia of the near-prolate nucleus based on the shape model place severe constraints on the range of short-axis-mode states that are feasible. We will explore how non-uniform density distributions would affect the plausible NPA states and how they contrast with the case of uniform density. We will discuss both our analysis of the multi-observatory continuum images as well as the implications of non-uniform density distributions on the rotational state.

506.04 The Source Of Dust Jets Seen In Comet 103p/hartley 2.

Michael J. S. Belton

1Belton Space Explor. Initiatives, LLC.

Comet 103P/Hartley 2 displays at least three different types of jet phenomena: highly structured CO2 driven jets seen in EPOLXI encounter images (A’Hearn et al 2011), large scale jet phenomena that show in CN emission (e.g. Knight and Schleicher, 2012), and fainter dust jet or “cloud” structures seen in ground-based images (Lara et al., (2011), Mueller et al., (2012), Tozzi et al., 2012, Knight and Schleicher, 2012). The dust jets are observed to change their projected orientations slowly from night-to-night, and even during a night. From this behavior Knight and Schleicher (2012) have suggested that the source of the jets might be located near the comet’s total angular momentum vector and that they might be driven by CO or more likely, CO2. In this paper we investigate the source of the dust jets using the shape model of the comet’s nucleus (Thomas et al 2012) and a model of the comet’s complex spin state (Belton et al 2012) based on EPOLXI observations. We show that the reason why the dust jet changes its projected direction is most likely the changing orientation of the surface at the sub-solar region during the spin cycle. In this scenario the jet source is not tied to the surface and is most likely driven by H2O.

506.05 Deep Impact MRI Observations Of Comet Garradd (C/2009 P1)
- Tony Farnham, D. Bodewits, M. F. A’Hearn, L. M. Feaga
- Univ. of Maryland.

The Deep Impact spacecraft observed comet C/2009 P1 Garradd with the Medium Resolution Instrument at ~hourly intervals from 2012 Feb 20 to Mar 7, with additional observations between Mar 25 and Apr 8. Images were obtained with the broadband CLEAR filter and narrowband CN, OH, C2 and Green Continuum filters. During the time of the observations, the comet ranged from 1.75 to 2.11 AU from the Sun and 1.87 to 1.30 AU from the spacecraft. These images were used to measure the coma lightcurve, which showed a 1% peak-to-peak variation in the CLEAR filter measurements and a 4% variation in the continuum-subtracted CN observations. Periodicity analyses of the two lightcurves reveal a 10.4±0.05 hour period. Because the variation is produced by changes in the comet’s activity, it is assumed that this is a single peaked lightcurve, with the 10.4 hour value representing the rotation period of the nucleus. The photometry was also used to compute the CN and OH production rates and Af_p for the times of observation. Average production rates derived from a 50-arcsec aperture for Feb 23, Mar 6 and Apr 6, were 2.3e28, 1.9e28, and 1.4e28 molecules/s for OH and 3.2e26, 2.7e26, and 1.5e26 molecules/s for CN, with relative and systematic uncertainties of 10% and 25%, respectively. Af_p of 3657, 3270, and 2946 cm, (±5%) were computed for the same dates. We will discuss these results in comparison with the DI High Resolution Instrument IR spectra obtained on Mar 26 and Apr 2, and with other ground-based observations.

506.06 SWIFT Observations of the Long Term Activity of Comet C/2009 P1 (Garradd)
- Dennis Bodewits, T. L. Farnham, M. F. A’Hearn
- University of Maryland.

We report on space-borne observations of comet C/2009 P1 (Garradd) using Swift’s UV-Optical Telescope (UVOT). C/2009 P1 is a dynamically new comet and this is likely its first journey to the inner solar system since its emplacement in the Oort cloud. It was discovered in 2009 and clearly exhibited a dust coma as far as 8.5 AU from the Sun. We observed the comet on part of its inbound trajectory and found that at a distance of 3.5 AU from the Sun it produced several tons of gas and dust per second. Between 3.5 and 2.5 AU the comet’s dust production rate steadily increased with the heliocentric distance as rh^{-2}, but at the same time we noted a steep increase in the comet’s OH production rate, suggesting the onset of a new source of OH. Swift/UVOT observed comet C/2009 P1 (Garradd) at regular intervals at heliocentric distances between 3.5 and 1.7 AU on its inbound trajectory, and will continue to do as the comet is moves away from the Sun. We used the UV grism on Swift-UVOT to quantitatively measure gas and dust content in the coma (Bodewits et al., AJ 141, p12, 2011). Broadband UVW1 and V-filter observations provide context to our grism observations and allow for independent measures of the OH and dust content in the coma. The sensitivity of Swift’s grisms permits the observation of a comet far away from the Earth and the Sun when it is outside the grasp of most ground based observatories.

506.07 Development Of Primary Volatile Production In Comet C/2009 P1 (garradd) During Its 2011-2012 Apparition
- Goddard Center for Astrobiology, NASA’s GSFC, Goddard Center for Astrobiology, Catholic University of America, MPI - Solar System Research, Germany, Institute for Astronomy, University of Hawaii, Division of Geological and Planetary Sciences, Calif. Inst. Tech..

We quantified primary volatiles in comet C/2009 P1 (Garradd) through pre- and post-perihelion observations acquired during its apparition in 2011-12 [1, 2, 3]. Detected volatiles include H2O, CO, CH4, C2H2, C2H6, HCN, NH3, H2CO, and CH3OH. We present production rates and chemical abundance ratios (relative to water) for all species,
and 1-D spatial profiles for multiple primary volatiles. We discuss these findings in the context of an emerging taxonomy based on primary volatiles in comets [4]. We used three spectrometer/telescope combinations. On UT 2011 August 7 (R_h 2.4 AU) and September 17-21 (R_h 2.0 AU), we used CRRES at ESO’s Very Large Telescope (VLT) [1]. On September 8 and 9 (R_h 2.1 AU), we used NIRSPEC at Keck-2 and CSHELL at IRTF [2]. Using NIRSPEC on October 13 and 2012 January 08 (R_h 1.83 and 1.57 AU, respectively), we detected nine primary volatiles pre-perihelion, and six post-perihelion [3]. CO was enriched in Garradd while C_2H_2 was strongly depleted. C_2H_6 and CH_3OH displayed abundances close to those measured for the majority of Oort cloud comets observed to date. The high fractional abundance of CO identifies comet C/2009 P1 as a CO-rich comet. Spatial profiles revealed notable differences among individual primary species. Given the relatively large heliocentric distance of C/2009 P1, we explored the effect of water not being fully sublimated within our field of view and we identify the “missing” water fraction needed to reconcile the retrieved abundance ratios with the mean values found for “organics-normal” comets. We acknowledge support from NASA’s Postdoctoral, Planetary Atmospheres, Planetary Astronomy, and Astrobiology Programs, and from the NSF Astronomy and Astrophysics Research Grants Program. [1] Paganini et al. 2012, ApJ Lett. 748, L13. [2] Villanueva et al. 2012, Icarus 220:291. [3] DiSanti et al. 2012, in prep. [4] Mumma & Charnley 2011, ARAA 49:471.

506.08 A Chemical Model of the Coma of Comet C/2009 P1 (Garradd)
- Daniel C. Boice1, H. Kawakita2, H. Kobayashi2, C. Naka2, L. Phelps3
  1Southwest Research Inst., 2Kyoto Sangyo University, Japan, 3University of Texas at San Antonio.

Modeling is essential to understand the important physical and chemical processes that occur in cometary comae. Photochemistry is a major source of ions and electrons that further initiate key gas-phase reactions, leading to the plethora of molecules and atoms observed in comets. The effects of photoelectrons that react via impacts are important to the overall ionization. We identify the relevant processes within a global modeling framework to understand simultaneous observations in the visible and near-IR of Comet C/2009 (Garradd) and to provide valuable insights into the intrinsic properties of its nucleus. Details of these processes are presented in the collision-dominated, inner coma of the comet to evaluate the relative chemical pathways and the relationship between parent and sibling molecules. Acknowledgements: We appreciate support from the NSF Planetary Astronomy Program.

506.09 Infrared and Optical Spectroscopy of Comet C/2009 P1 Garradd: CO Abundance and Implications for the Atomic Oxygen Yield from CO Photodissociation
- Adam McKay1, N. Chanover1, M. DiSanti3, J. P. Morgenthaler3, A. Cochran4, W. Harris5, N. Dello Russo6, R. J. Vervack, Jr.6
  1New Mexico State University, 2NASA Goddard Space Flight Center, 3Planetary Science Institute, 4University of Texas at Austin, 5University of California Davis, 6Johns Hopkins University Applied Physics Laboratory.

Comet C/2009 P1 Garradd has been identified as a CO-rich comet from both NIR and radio observations. We present production rates and abundance ratios for CO in comet C/2009 P1 Garradd over the September 2011-March 2012 time frame, which corresponds to a heliocentric distance range of 1.6-2.0 AU both pre- and post-perihelion. We obtained infrared spectra of Garradd using the CSHELL infrared spectrometer on NASA’s Infrared Telescope Facility (IRTF) on Mauna Kea. We will discuss whether any asymmetry in the absolute production rate of CO and/or in the mixing ratio of CO relative to H2O with respect to perihelion is present. Many of these observations were obtained nearly coincident with optical observations of atomic oxygen we obtained using the ARCES echelle spectrometer mounted on the Astrophysical Research Consortium 3.5-meter telescope at Apache Point Observatory. As both CO and H2O are candidate parent molecules for atomic oxygen in cometary comae, we use these observations to place constraints on the relative importance of each of these species in supplying the atomic oxygen population in Comet Garradd. This work is supported by the NASA GSRP program through grant number NNX11AO03H.

507 Venus: Length of Day, Dissipation, and Lightning Chemistry
Friday, 11:30 AM - 12:00 PM, Reno Ballroom
507.01 Dissipation in Planetary Atmospheres
- Gerald Schubert¹, J. Mitchell¹

¹UC, Los Angeles.

The net radiative entropy flux of a planet is negative because atmospheres absorb solar radiation at a higher temperature than the temperature at which they re-emit an equal amount of longwave radiation to space. If in the long term the entropy of an atmosphere is constant, the radiative entropy loss must be balanced by the entropy production associated with thermally direct heat transports and dissipation. Given estimates of the thermally direct sources of entropy production and the temperature at which dissipation occurs, this determines the rate of dissipation in an atmosphere. It is estimated that the entropy production due to dissipation in the atmospheres of Venus, Earth, Mars, and Titan occurs at the rate, respectively, of ≤23, 29, 2, and ≤4 mW m⁻² K⁻¹. If the dissipation in Earth’s atmosphere occurs between temperatures of 250 K and 288 K the dissipation rate must lie between 7.3 and 8.4 W m⁻², consistent with other recent estimates. The terrestrial heat engine operates with an efficiency of about 60% of the Carnot efficiency. Sources of dissipation in planetary atmospheres are highly uncertain, even for Earth. For Earth, frictional dissipation in rainfall is comparable to the turbulent dissipation of kinetic energy. Rainfall might also be a significant source of dissipation on Titan but it is not likely to be important for Mars or Venus. The breaking of upward propagating internal gravity waves generated by convection and flow over the surface topography is another source of dissipation and is possibly dominant on Venus.

507.02 Venus Length-of-Day Variations
- Jean-Luc Margot¹, D. B. Campbell², S. J. Peale³, F. D. Ghigo⁴

¹University of California, Los Angeles, ²Cornell University, ³University of California, Santa Barbara, ⁴National Radio Astronomy Laboratory.

Since 2004 we have been monitoring the instantaneous spin state of Venus with the goals of measuring the precession of the rotation axis and of quantifying daily, seasonal, and secular changes in length-of-day. We use the Goldstone and Green Bank Telescopes for these observations. The spin period of Venus is thought to be set by a delicate balance between solid-body tides and atmospheric torques that must vary as insolation and orbital parameters change [Bills 2005]. Our measurements to date reveal length-of-day (LOD) variations of ~50 ppm. None of the models can be reconciled with the Magellan ~500-day-average spin period of 243.0185 +/- 0.0001 days [Davies et al. 1992], nor with a ~16-year-average estimate of 243.023 +/- 0.002 days [Mueller et al. 2012], nor with any other constant spin period. With our nominal solution we can rule out a constant spin period with over 99.9% confidence. When allowances are made for uncertainties in spin axis orientation and instantaneous spin measurement epochs, the confidence is reduced but remains higher than 99%. We attribute the LOD variations primarily to angular momentum exchange between the atmosphere and solid planet. Because there are so few constraints on the internal dynamical structure of the Venusian atmosphere, a time history of atmospheric angular momentum changes can be used to address questions related to the dynamics of the atmosphere, including its super-rotation, and climatic variations.

507.03 Storms On Venus: Lightning-induced Chemistry And Predicted Products
- M. L. Delitsky¹, K. H. Baines²

¹California Specialty Engineering, ²University of Wisconsin.

Observations by many spacecraft that have visited Venus over the last 40 years appear to confirm the presence of lightning storms in the Venus atmosphere. Recent observations by Venus Express indicate that lightning frequency and power is similar to that on Earth. While storms are occurring, energy deposition by lightning into Venus atmospheric constituents will immediately dissociate molecules into atoms, ions and plasma from the high temperatures in the lightning column (>30,000 K) and the associated shock waves and heating, after which these atom and ion fragments will recombine during cooldown to form new sets of molecules. Lightning will re-sort the atoms of C, O, S, N, H to create highly energetic new products. Spark and discharge experiments in the literature suggest that lightning effects on the main atmospheric molecules CO₂, N₂, SO₂, H₂SO₄ and H₂O will yield new molecules such as mixed carbon oxides (CₙOₘ), mixed sulfur oxides (SₙOₘ), oxygen (O₃), elemental sulfur (Sₙ).
nitrogen oxides (NO, N₂O, NO₂, NO₃), sulfuric acid clusters (HₙSₙOₓ⁻ₐHₙSₙOₓ; e.g. HSO₄⁻.mH₂SO₄), polysulfur oxides, carbon soot, and also halogen oxides from HCl or HF and other exotic species. Many of these molecular species may be detectable by instruments onboard Venus Express. We explore the diversity of new products likely created in the storm clouds on Venus.

508 Venus: Latest Results from Venus Express and Venus Solar Transit
Friday, 1:30 PM - 3:00 PM, Reno Ballroom

508.01 Venus Express - Recent Results and Future Plans
- Hakan Svedhem¹, D. Titov¹
  ¹ESA/ESTEC, Netherlands.

Since arriving at Venus in April 2006 Venus Express has provided a wealth of information on a large variety of topics on the atmosphere, surface and plasma environment of the planet. The atmosphere in the southern hemisphere has been studied in detail by three instruments dedicated to atmospheric investigations, from the near IR to the UV and additional information has been derived from radio science measurements. The structure and composition of the atmosphere has been mapped in three dimensions from 40 km to 140 km altitude. Significant temporal and spatial variations have been found, both in composition, density and temperature. Imaging in the UV has revealed strong latitudinal variations and significant temporal changes in the global cloud top morphology as well as identification of various types of waves in the cloud layer. Recent results include the discovery of ozone in the upper atmosphere, detection of highly variable abundance of SO₂, both spatially and temporally, and the discovery of a very cold layer, with temperatures down to well below 100K, at an altitude of about 125 km, and new insights in the behavior of the rotation of the polar vortex. A new measurements technique has been applied since 2010, whereby in situ data on the atmospheric density is acquired at high spatial resolution, by monitoring the torque and drag that the atmosphere is exerting on the spacecraft itself. The mission is presently funded for operation until end of 2014. Decision for an additional extension for one more year is pending. The scope of the operations will change somewhat for the next two years with focus on campaigns of different investigations with high spatial and temporal measurements. Operations in 2015 will focus on aerobraking, and in particular on the unique science the associated low altitudes will offer for in situ measurements.

508.02 Temperatures In The Venus Mesosphere And Thermosphere: Comparison of SOIR and VTGCM Profiles at the Terminator
- Stephen W. Bougher¹, J. Fischer², G. Hicks³, A. Brecht⁴, C. Parkinson¹, A. Mahieux⁵, V. Wilquet⁵, A. Vandaele⁶, J. Bertaux⁶
  ¹Univ. of Michigan, ²Florida Institute of Technology, ³Columbia University, ⁴NASA ARC, ⁵Belgian Institute for Space Aeronomy, Belgium, ⁶LATMOS, France.

Venus Express SOIR terminator profiles of CO₂ densities and temperatures have been organized and presented for 79-selected orbits obtained between 2006-2011 (e.g. Mahieux et al. 2012). The SOIR instrument measures CO₂ absorption across a broad spectral window. The observed atmospheric transmittance spectra are subsequently inverted to obtain vertical density (and inferred temperature) profiles. This compilation provides a global view of the atmospheric characteristics at the Venusian terminator over approximately 70 to 170 km. These initial measurements show a striking permanent temperature minimum (at 125 km) and a weaker temperature maximum (over 100-115 km). These features are reflected in the corresponding CO₂ density profiles, and provide detailed constraints for global circulation models of the upper atmosphere of Venus (e.g. Brecht and Bougher, 2012). New Venus Thermospheric General Circulation Model (VTGCM) simulations are conducted for conditions appropriate to these SOIR measurements. In particular, solar minimum fluxes are specified and mean values of eddy diffusion and wave drag parameters are utilized. VTGCM temperature profiles are extracted from the terminator that correspond to five latitude bins (0-30N, 30-60N, 60-70N, 70-80N, and 80-90N) presently used in the SOIR data analysis. Averaging of VTGCM temperature profiles in each of these bins (at each side of the terminator) is conducted to match SOIR sampling. Comparisons of these SOIR and VTGCM temperature profiles are
made. Most notably, the observed temperature minimum near 125 km and the weaker temperature maximum over 100-115 km are generally reproduced by the VTGCM at the correct pressure level. However, magnitudes of simulated and measured temperatures are somewhat different. In addition, the underlying thermal balance processes are identified that give rise to the VTGCM simulated temperatures. This research is funded in part by the Venus Express Participating Science program.

508.03 Understanding Ground based and VEx Observations: Modeling Venus’ Upper Atmosphere and Its Variability

Chris Parkinson¹, S. Bougher¹, A. Brecht², A. Mahieux³, V. Wilquet³, A. Vandaele³, J. Bertaux⁴
¹Univ. of Michigan, ²NASA ARC, ³Belgian Institute for Space Aeronomy, Belgium, ⁴LATMOS, France.

Utilising recent VEx (SPICAV-SOIR and VIRTIS) measurements, it is possible to establish an atmospheric mean state and characterize the variability of the Venus upper mesosphere and thermosphere circulation for solar minimum conditions. This can be done by analyzing available nightglow emissions (NO-UV, O2-VISIBLE, O2-IR), temperatures, and species (e.g. CO2, CO, O2, O) distributions. These tracers together yield new information about the middle-upper atmosphere wind system over ~70-150 km. New Venus Thermospheric General Circulation Model (VTGCM) simulations are conducted for conditions appropriate to the SOIR measurements where solar minimum fluxes are specified and mean values of eddy diffusion and wave drag parameters are utilized. We are able to better match the observed temperature, T, and number density, n, of different chemical species in the Venus upper atmosphere by using the latest radiative transfer cooling and heating rates (15μm CO2 and 4.3μm in near IR, respectively) in the VTGCM. Variability about this mean state can be addressed by varying eddy diffusion, boundary conditions, temperature profiles and other “tunable” parameters for different cases. We can then bracket variability of datasets about this mean and adjust the various tunable parameters in models to quantify the magnitude of those processes that may drive these observed variations.

508.04 Generation of Small-Mode Particles via Nucleation of Meteoric Dust in the Upper Haze of Venus

Yuk Yung¹, P. Gao¹, X. Zhang¹, D. Crisp², C. G. Bardeen³
¹California Institute of Technology, ²Jet Propulsion Laboratory, California Institute of Technology, ³National Center for Atmospheric Research.

Observations by the SPICAV/SOIR instruments aboard Venus Express has revealed that the Upper Haze of Venus is populated by two particle modes, as reported by Wilquet et al. (J. Geophys. Res., 114, E00B42, 13pp, 2009). In this work we posit that the large mode is due to the upwelling of cloud particles, while the smaller mode is generated by the nucleation of meteoric dust. We test this hypothesis by using version 3.0 of the Community Aerosol and Radiation Model for Atmospheres, first developed by Turco et al. (J. Atmos. Sci., 36, 699-717, 1979) and upgraded by Bardeen et al. (The CARMA 3.0 microphysics package in CESM, Whole Atmosphere Working Group Meeting, 2011). Using the meteoric dust production profile of Kalashnikova et al. (Geophys. Res. Lett., 27, 3293-3296, 2000), the sulfur/sulfate condensation nuclei production profile of Imamura and Hashimoto (J. Atmos. Sci., 58, 3597-3612, 2001), and sulfuric acid vapour production profile of Zhang et al. (Icarus, 217, 714-739, 2012), we numerically simulate a column of the Venus atmosphere from 40 to 100 km above the surface. Our aerosol number density results agree well with Pioneer Venus data from Knollenberg and Hunten (J. Geophys. Res., 85, 8039-8058, 1980), while our gas distribution results match that of Kolodner and Steffes (Icarus, 132, 151-169, 1998). There is a mediocre agreement between our cloud deck size distribution and Pioneer Venus data. The Upper Haze size distribution shows two lognormal distributions overlapping each other, possibly indicating the presence of two modes, though more analysis is required at this time. Finally, we treat the simulated aerosol particles as Mie scatterers and compute their optical parameters. The results show a minimum in the optical depth at a wavelength of 300 nm, comparable to the results of Lacis (J. Atmos. Sci., 32, 1107-1124, 1975).

508.05 Effects of a Large ICME on Atmospheric Escape at Venus

Tess McEnulty¹, J. G. Luhmann¹, C. Möstl¹, T. Zhang², C. T. Russell³, L. K. Jian³, A. Fedorov⁴, Y. Futaana⁵, I. de Pater⁶
¹SSL, University of California, Berkeley, ²Space Research Institute, Austrian Academy of Sciences, Austria,
Understanding the effects of large solar wind disturbances on the ion escape rate at Venus is critical for bounding the history of water on the planet. Previous studies have suggested that solar wind disturbances can cause an enhancement in the ion escape rate, but did not look specifically at the effect of the sheath region of Interplanetary Coronal Mass Ejections, when the highest dynamic pressures in the solar wind are encountered. The high dynamic pressure region is of specific interest because it pushes the ionopause to a lower altitude exposing more ions to the magnetic fields in the solar wind. We will present a case study from a large (fast and high magnetic field) ICME that hit Venus on November 5, 2011. This event had the highest piled up magnetic field yet encountered by VEX (>250 nT) and also is the best event for studying the effects of the high dynamic pressure sheath region on escape because VEX was near the planet measuring escaping ions during the time period when the ICME sheath passed Venus. During this time period MESSENGER and STEREO B were aligned with Venus, allowing additional measurements of this event. We will present details of this ICME with data from VEX, MESSENGER and STEREO B. The ion escape was enhanced during this event, which we will show by comparison with undisturbed days with similar Interplanetary Magnetic Field directions and orbit geometry.

508.06 The 2012 Transit of Venus for Cytherean Atmospheric Studies and as an Exoplanet Analog

508.07 The Venus Twilight Experiment: Probing The Mesosphere In 2004 And 2012

We worked to assemble as complete a dataset as possible for the Cytherean atmosphere in collaboration with Venus Express in situ and to provide an analog of spectral and total irradiance exoplanet measurements. From Haleakala, the whole transit was visible in coronal skies; our “B” images showed the evolution of the visibility of Venus’s atmosphere and of the black-drop effect, as part of the Venus Twilight Experiment’s 9 coronagraphs distributed worldwide with “BVRI. We imaged the Cytherean atmosphere over two minutes before first contact, with subarcsecond resolution, with the coronagraph and a separate refractor. The IBIS imaging spectrometer at Sacramento Peak Observatory at H-alpha and carbon-dioxide also provided us high-resolution imaging. The NST of Big Bear Solar Observatory also provided high-resolution vacuum observations of the Cytherean atmosphere and black drop evolution. Our liaison with UH’s Mees Solar Observatory scientists provided magneto-optical imaging at calcium and potassium. Spaceborne observations included the Solar Dynamics Observatory’s AIA and HMI, and the Solar Optical Telescope (SOT) and X-ray Telescope (XRT) on Hinode, and total-solar-irradiance measurements with ACRIMSAT and SORCE/TIM, to characterize the event as an exoplanet-transit analog. Our expedition was sponsored by the Committee for Research and Exploration/National Geographic Society. Some of the funds for the carbon-dioxide filter for IBIS were provided by NASA through AAS’s Small Research Grant Program. We thank Rob Lucas, Aram Friedman, and Eric Pilger ‘82 for assistance with Haleakala observing, Rob Ratkowski of Haleakala Amateur Astronomers for assistance with equipment and with the site, Stan Truitt for the loan of his Paramount ME, and Steve Bisque/Software Bisque for TheSky X controller. We thank Joseph Gangestad ‘06 of Aerospace Corp., a veteran of our 2004 expedition, for assistance at Big Bear. We thank the Lockheed Martin Solar and Astrophysics Laboratory and Hinode science and operations teams for planning and support.
During the Venus transit in 2004 several observers collected data useful to the characterization of the mesosphere of the planet, by observing the solar light refracted at the corresponding altitude range. The "aureole" thus formed, is observable during the ingress and egress phases of the transit, when Venus is crossing the solar limb. For the 2012 opportunity we prepared a set of coronagraphs to obtain multi-wavelength, space- and time-resolved photometry of the aureole, in collaboration with other space- and ground-based campaigns. The coronagraphs were distributed in the visibility area around the Pacific, over eight sites where local logistic support and scientific expertise were present. Several sites obtained useful data at frame rates of several images/sec. We will give an account of the campaign presenting first results obtained at 450, 535, 607 and 760 nm (FWHM 10 nm). A comparison with data collected at the 2004 transit shows that variations in the aspects of the aureole are present. These can be linked to variations in the vertical distribution of the absorbers (aerosols and cloud-top level). A common feature in both the recent transits is the presence of a brightness peak at high latitude, which was imaged several minutes before and after first and last contact, respectively. The historical record of the aureole contains hints of varying features and a constant polar-spot presence, which can now be interpreted in the light of the measurements obtained in 2004 and 2012.

508.08 Assymetry in the Polar Mesosphere Revealed by the 2012 Venus Transit Aureole

- Thomas Widemann
- P. Tanga
- K. P. Reardon
- S. Limaye
- C. Wilson
- A. Vandaele
- V. Wilquet
- A. Mahieux
- S. Robert
- J. M. Pasachoff
- G. Schneider

Observatoire de Paris/LESIA, CNRS, UPMC, Université Paris-Diderot, France, Laboratoire Lagrange, Obs. de la Côte d’Azur, France, Arcetri Observatory, Italy, U. of Wisconsin, Dept. of Atmospheric, Oceanic and Planetary Physics, Oxford University, United Kingdom, Belgian Institute for Space Aeronomy (BISA), Belgium, Williams College—Hopkins Obs. and Caltech, Steward Obs., U. Arizona.

Close to ingress and egress phases, the fraction of Venus disk projected outside the solar photosphere appears outlined by an irregular thin arc of light called the “aureole”. We have shown that the deviation due to refraction and the aureole intensity are related to the local density scale height and the altitude of the refraction layer (Tanga et al. 2012). Since the aureole brightness is the quantity that can be measured during the transit, an appropriate model allows us to determine both parameters. We now compare this model developed for the 2004 data to the first results of 2012 campaign. Ingress pictures of NASA’s SDO/HMI observations, OP-OCA/VTE coronagraph observations at Haleakala and Lowell stations, and Dunn/IBIS observations at Sacramento Peak, NM, show latitudinal structure of the aureole during the ingress phase of the Venus transit. For the HMI data, the temporal cadence is 3.75 sec and the pixel scale is 0.5 arcsec/pixel. The polar region, significantly brighter in initial phases due to the larger scale height of the polar mesosphere, appears consistently offset toward morning terminator by about 15 deg. latitude, peaking at 75N at 6:00 local time. This result reflects local latitudinal structure in the polar mesosphere, either in temperature or aerosol altitude distribution. Relation with ESA / Venus Express / SOIR simultaneous measurements and dynamical interpretation will be discussed at the meeting. Tanga et al. 2012, Icarus 218, 207-219.

508.09 A Diurnal Dichotomy in Venus Upper Atmospheric Circulation: June 2012 Solar Transit Observations

- R. T. Clancy
- B. J. Sandor
- J. Hoge

Space Science Inst., Joint Astronomy Centre.

We obtained sub-millimeter line absorption spectra of $^{12}$CO (346 GHz) and $^{13}$CO (330 GHz) around the atmospheric limb of Venus; as illuminated by the Sun during the June 5, 2012 solar transit, and as observed from the James Clerk Maxwell Telescope (JCMT) on Mauna Kea, Hawaii. Doppler line shifts retrieved around the Venus atmospheric limb, associated with upper mesospheric/lower thermospheric (90-115 km) winds, indicate strong axisymmetric subsolar-to-antisolar (SSAS) circulation across the circumdisk terminator of Venus. This SSAS
circulation contrasts with the full nightside circulation revealed by on-disk Doppler wind measurements, obtained before, during, and after solar transit, that indicate a strong retrograde zonal wind component. These unique Venus solar transit observations thus demonstrate a striking dichotomy in the dayside and nightside circulations of the Venus upper atmosphere.

509 Moon: Messing up the Surface
Friday, 1:30 PM - 2:30 PM, Carson 1/2

509.01 Secondary Cratering as the Primary Mechanism for Ray Formation on the Moon and Mercury
- Catherine Neish1, D. T. Blewett1, J. K. Harmon1, E. I. Coman4, J. T. S. Cahill2
  1NASA Goddard Space Flight Center, 2The Johns Hopkins University Applied Physics Laboratory, 3National Astronomy and Ionosphere Center, Arecibo Observatory, 4Washington University.

Observations of rayed craters at optical and radar wavelengths provide insight into the processes that lead to ray formation and degradation on terrestrial planets. We have compared optical maturity and S-Band radar data for several large (>20 km diameter), young craters on the Moon and Mercury, and we find evidence that crater rays are formed primarily through secondary cratering, consistent with the mechanism first proposed by Oberbeck in 1971. Regions where rays appear optically and radar bright correspond to dense concentrations of secondary craters, and the observed enhancement appears to be a result of the deposition of blocky, immature ejecta from the secondary craters, and/or the rocky, immature interior walls of the craters. On Mercury, rays in radar and optical images correspond closely, indicating that the rays are rich in centimeter to decimeter-sized clasts. Rays on the Moon are less prominent at radar wavelengths, suggesting that they are currently composed of smaller clasts, centimeter-sized or less. This difference implies that (1) secondary craters are capable of excavating more decimeter-sized clasts on Mercury, or (2) craters and their rays are less eroded on Mercury than those on the Moon. Furthermore, observations of rayed craters provide an opportunity to assign relative ages to the youngest craters on the Moon and Mercury. Rayed craters have a range of ages, and the youngest can be distinguished from the oldest through their optical maturity and S-Band circular polarization ratio. Given the differences in impact velocity and surface gravitational acceleration between the Moon and Mercury, it is difficult to compare directly the ages of craters on the two worlds, but the rayed craters on Mercury appear most similar to the youngest craters on the Moon (<100 Ma).

509.02 General Properties of Secondary Craters: Preliminary Modeling Results
- James E. Richardson1, D. A. Minton1
  1Purdue University.

Understanding the production, geographic distribution, and size-frequency distribution of secondary craters relative to a given primary crater population is critical to the proper interpretation of an observed crater population on the Moon and other solar-system bodies more than a few hundred kilometers in diameter, particularly when small crater statistics are used to determine absolute ages or the relative relationships between different geologic units on a given surface. However, modeling or predicting the manner in which secondary craters are produced remains a long-standing problem in the study of cratered terrains. Recent advances in computing technology and our understanding of the cratering process (crater formation, excavation flow, and ballistic ejecta emplacement) have put into place the ingredients for a comprehensive model of secondary crater production and distribution. In this presentation, we show our initial steps in developing this secondary cratering model and then integrating it into our already existing, three-dimensional surface model of primary crater production and erasure. This integration will link the production of secondary craters directly to the primary craters emplaced on a given surface, and thus permit detailed statistical analysis of the resulting (combined and separate) crater populations, as a function of time and bombardment history. Our ongoing study aims to significantly advance our knowledge level regarding the secondary cratering process and its relative effect on observed crater populations, therefore permitting secondary cratering to be taken into account much more effectively than can be done currently.
The near side of the Moon has several areas with a high concentration of domes, which are evidence that some volcanic lavas were more viscous than the mare flood basalts that make up most of the lunar volcanic flows. Variable surface textures have been observed among the domes, which likely indicate a range of styles of late-stage volcanism, or possibly differences in how the erupted materials were altered over time. In particular, radar data of the domes reveal both very rough and very smooth surfaces. To date, very few domes have been found to have anomalously low radar circular polarization ratio (CPR) values that would suggest a coating of fine-grained pyroclastics. At S-band (12.6 cm wavelength), the Manilius 1 and Cauchy 5 domes have the lowest measured CPR values. We use a combination of ground-based radar data acquired with Arecibo Observatory and the Green Bank Telescope, Lunar Reconnaissance Orbiter (LRO) Camera images, and LRO Mini-RF radar data to map changes in surface textures across these features. The domes have very different morphologies. The Manilius 1 dome has a uniform, cratered surface with a circular central caldera, whereas the Cauchy 5 dome has very low topographic relief and an elongate central vent with jagged edges and pits similar to some features seen in high-resolution images of the unusual Ina D caldera. Although both domes have some similar radar reflection properties, they likely formed via significantly different processes.

Geothermal heat flow probes were part of the ALSEP package deployed by astronauts at the Apollo 15 and 17 landing sites. The heat flow probes operated from 1971 to 1977, and were used to determine the internal heat flow at both sites. However, the validation of the initial heat flow determination has been questioned because of an unexplained long-term warming trend evident in the sub-surface temperature records at both sites. It is thought to be caused by either a drift in the probes’ thermal characteristics, altered properties of the lunar surface caused by the astronauts’ activities, or an increase in total radiative energy reaching the sites with time. Subsequent research has shown the first two possibilities to be unlikely causes. A mechanism that can increase the total radiative energy is self-heating on the lunar surface, which is caused by the exchange of radiative heat between interfacing surface elements, and has previously been unexplored. To investigate the effects of self-heating, LRO LOLA digital terrain models of both landing sites were combined with the Advanced Thermophysical Model (Rozitis & Green, 2011, MNRAS, 415, 2042). The ATPM determines sub-surface temperatures for discrete surface elements by solving 1D heat conduction with a boundary condition that includes direct and multiple scattered solar radiation, projected shadows, and re-absorption of emitted thermal radiation between interfacing surface elements. Assuming a lunar pole perpendicular to the ecliptic, model temperatures were derived with and without self-heating effects included for comparison purposes. It was found that self-heating enhanced temperatures at both sites by ~1K in general and by up to ~5K near sunrise and sunset, which is an amount comparable to the long-term warming trend. Further on-going tests including precession of the lunar pole are being performed to determine if self-heating can reproduce the warming trend in time.

We applied phase-ratio imaging to study the landing sites of the Soviet Luna 23 and Luna 24 using data from surveys of the lunar surface, which was carried out with the narrow-angle camera of the Lunar Reconnaissance Orbiter (LRO). The phase-ratio images clearly show diffuse spots associated with structural perturbations of the lunar regolith. The perturbations are caused by the impact of gas jets from the lander engines. The character of the photometric anomalies around the landing sites implies that the impacts smooth out the surface, destroying the “fairy castle” structure that produces the shadow-hiding effect. These same characteristics have been found
previously for the Apollo spacecraft landings, as well as for the Luna-16 and Luna-20 sites. All the spots are approximately centered at the landers. The only exception is for the landing site of the probe Luna 24, for which the spot of the possible impact of gas jets is shifted by about 150 m to the northwest. As the Luna 24 descent module worked in the regular mode and could not allow such a shift, one possible explanation is that the sites of Luna 23 (an unsuccessful sample return mission) and Luna 24 are confused, since they are very close to each other. The distance between the sites is about 2 km, which is within the uncertainty of their coordinate determination. We suggest that incorrect processing of the radar distance-measuring-system caused the engines and/or thrusters of Luna 23 to disengage incorrectly, resulting in the structural perturbation to occur at a 150 m lateral drift from the landing site.

509.06 The Circular Polarization Ratio Test For The Lunar Coherent Backscatter Enhancement

- Gorden Videen1, D. Petrov2, Y. Shkuratov2

1Space Science Institute, 2Kharkov Astronomical Institute, Ukraine.

According to Hapke et al. (Icarus 1998, 133, 89-97), the importance of the coherent-backscattering effect is confirmed by laboratory measurements of the phase curves of the circular polarization ratio μC for lunar samples. The parameter μC is defined as the ratio of the same-helicity intensity to the reverse-helicity intensity. The curves demonstrate conspicuous surges at phase angles α < 10º. This is considered as an argument indicative the coherent backscattering enhancement. However, it is not exclusive, since such behavior also may be produced by single-particle scattering, which is independent of the coherent-backscatter enhancement. We have computed μC for independent particles of irregular shapes, averaged over size and orientation using an advanced T-matrix approach. Our calculation shows the same phase-angle behavior of the parameter μC at α < 10º for single particles. Different distributions of the particle gyration radius R were considered, the complex refractive index m0 = 1.5 + 0i, and the size parameter X = 2πR/λ ranged from Xmin = 3 to Xmax = 16. It should be emphasized that unlike the aggregate particles, the calculated curves correspond to particles without internal structure. This means that the surge of μC(α) cannot be the result of coherent backscattering. The average particle size of the lunar regolith is about 60 μm; whereas, we made calculations for much smaller particles. However, the regolith consists of particles that are mainly aggregates of small grains. The lunar regolith also includes a significant portion of dust. Thus, the calculations of the parameter μC(α) for small particles seem to be relevant.

510 Comets 2: Volatiles
Friday, 1:30 PM - 3:00 PM, Tahoe Room

510.01 Optically Thick Spectral Models for Coma Volatiles in Comets Tempel 1, Hartley 2 and Garradd

- Alan Gersch1, M. F. A'Hearn1

1Univ. of Maryland.

We have built a coma model that includes radiative transfer to model comets including optical depth effects. Recent space missions (e.g. Deep Impact & EPOXI) have provided spectra from comets of unprecedented spatial resolution of the regions of the coma near the nucleus and demonstrate the need for better modeling of comae with optical depth effects included. We have adapted the Coupled Escape Probability method of radiative transfer calculations for use in asymmetrical spherical situations and applied it to modeling molecular emission spectra of potentially optically thick cometary comae. We present results of interest for CO, H2O and CO2 focusing on Comets Tempel 1, Hartley 2 and Garradd. Although primarily motivated by the need for modeling comets, our (asymmetric spherical) radiative transfer model could be used for studying other astrophysical phenomena as well, including (exo-)planetary atmospheres.

510.02 Characterizing Abundances of Volatiles in Comets Through Multiwavelength Observations

- Stefanie N. Milam7, S. Charnley5, Y. Kuan7, Y. Chuang5, M. DiSanti2, B. Bonev4, A. Remijan5, I. Coulson6, L. Haynes1, M. Stenborg8

1NASA Goddard Space Flight Center, 2ASIAA, Taiwan, 3National Taiwan Normal University, Taiwan, 4Catholic University, 5NRAO, 6Joint Astronomy Center, 7Harvey Mudd College, 8University of Maryland.
Recently, there have been complimentary observations from multiple facilities to try to unravel the chemical complexity of comets. Incorporating results from various techniques, including: single-dish millimeter wavelength observations, interferometers, and/or IR spectroscopy, one can gain further insight into the abundances, production rates, distributions, and formation mechanisms of molecules in these objects [1]. Such studies have provided great detail towards molecules with a-typical chemistries, such as H2CO [2]. We report spectral observations of C/2007 N3 (Lulin), C/2009 R1 (McNaught), 103P/Hartley 2, and C/2009 P1 (Garradd) with the Arizona Radio Observatory’s SMT and 12-m telescopes, as well as the NRAO Greenbank telescope and IRTF-CSHELL. Multiple parent volatiles (HCN, CH3OH, CO, CH4, C2H6, and H2O) as well as a number of daughter products (CS and OH) have been detected in these objects. We will present a comparison of molecular abundances in these comets to those observed in others, supporting a long-term effort of building a comet taxonomy based on composition. Previous work has revealed a range of abundances of parent species (from “organics-poor” to “organics-rich”) with respect to water among comets [3,4,5], however the statistics are still poorly constrained and interpretations of the observed compositional diversity are uncertain. We gratefully acknowledge support from the NSF Astronomy and Astrophysics Program, the NASA Planetary Astronomy Program, NASA Planetary Atmospheres Program, and the NASA Astrobiology Program. [1] DiSanti, M. et al. (2009), Icarus, 203, 589. [2] Milam, S.N. et al. (2006) ApJ, 649, 1169. [3] Mumma et al. (2003), Adv. Space. Res., 31, 2563. [4] DiSanti, M. A., & Mumma, M. J. (2008), Space Sci. Rev., 138, 127. [5] Mumma, M. J. and Charnley, S.B. (2011), ARA&A, 49, 471.

510.03 Cometary Volatiles and Origins
- Michael F. A'Hearn, L. M. Feaga, Ad Hoc Cometary Team
  University of Maryland.

H2O, CO2, and CO are the three most abundant, inorganic cometary volatiles in nearly all comets. The relative abundances of these three species, in the still small sample of comets for which they have been measured, suggest the abundances are not controlled by thermal evolution but rather are primordial. If so, the snow lines in models of the protoplanetary disk suggest that the both Jupiter-family comets (JFCs) and Long-period comets (LPCs) formed in overlapping regions, probably mostly between present-day Jupiter and Uranus, but with the JFCs extending closer to the proto-sun and the LPCs extending further from the protosun. This then requires that JFCs be transported via planetary migration to the scattered disk, as has been argued by dynamicists for several years.

510.04 Carbon Dioxide In Comets - 65P/Gunn and 74P/Smirnova Chernykh
- Karen Jean Meech, O. R. Hainaut, J. M. Bauer, Y. Fernandez, A. A. S. Gulbis
  University of Hawaii, European Southern Observatory, Germany, Jet Propulsion Laboratory, University of Central Florida, Southern African Large Telescope, South Africa.

Heliocentric photometric light curve observations of comets from a long-term ground-based observing program have been combined with nucleus radii determined from the Spitzer SEPPCoN large program, and with data from the NEOWISE mission to investigate the abundance of carbon dioxide in comets. The EPOXI mission has changed our understanding of the drivers of comet activity near perihelion, showing that for comet 103P/Hartley 2, carbon dioxide is largely responsible. We have combined information from the in-situ encounter with ground-based data to model the heliocentric light curve of comet Hartley 2, showing that modeling is able to make inferences about volatiles that cannot be detected from the ground. Comet Hartley 2 is a member of an unusual class of comets with very high fractional surface area water production, which from EPOXI we know is due to a contribution of sublimation from large icy near-nucleus grains. The SEPPCoN dataset has been combined with published water production rates for comets to identify other comets that have large sublimating surface areas. We suggest that these, like comet 103P/Hartley 2, may be rich in carbon dioxide. To test this, we modeled the light curves for 65P/Gunn and 74P/Smirnova-Chernykh and have compared the inferred production rates to limits on carbon dioxide production inferred from the NEOWISE survey data. We will present these results in the context of a program to investigate volatiles in a large set of Jupiter-family and long-period comets.

510.05 The Dual Origin Of The Nitrogen Deficiency In Comets: Selective Volatile Trapping In The Nebula And Postaccretion Radiogenic Heating
We propose a scenario that explains the apparent nitrogen deficiency in comets in a way consistent with the presence of this molecule in the atmospheres of Pluto and Triton. We use a statistical thermodynamic model to investigate the composition of the successive multiple guest clathrates that may have formed during the cooling of the primordial nebula from the most abundant volatiles present in the gas phase. These clathrates agglomerated with the other ices (pure condensates or stoechiometric hydrates) and formed the building blocks of comets. We report that molecular nitrogen is a poor clathrate former, when we consider a plausible gas phase composition of the primordial nebula. This implies that its trapping into cometesimals requires a low disk temperature (about 20 K) in order to allow the formation of its pure condensate. We find that it is possible to explain the lack of molecular nitrogen in comets as a consequence of their postformation internal heating engendered by the decay of radiogenic nuclides. This scenario is found to be consistent with the presence of nitrogen-rich atmospheres around Pluto and Triton. Our model predicts that comets should present xenon-to-water and krypton-to-water ratios close to solar xenon-to-oxygen and krypton-to-oxygen ratios, respectively. In contrast, the argon-to-water ratio is predicted to be depleted by a factor of about 300 in comets compared to solar argon-to-oxygen, as a consequence of the nitrogen outgassing.

510.06 What Do Nuclear Spin Temperatures Tell Us About The Origin Of Comets? A Multi-molecule Study

- Geronimo Villanueva1, M. J. Mumma2, B. P. Bonev1, M. A. DiSanti2, K. Magee-Sauer3, E. L. Gibb4, L. Paganini5, Y. L. Radeva1

1NASA-GSFC/CUA, 2NASA-GSFC, 3Rowan University, 4University of Missouri, 5NASA-GSFC/NPP.

Comets are true remnants of our primordial Solar System, and provide unique clues to its formation and evolution, including the delivery of organics and water to our planet. A key indicator stored in the molecular structure of the nuclear ices is the spin temperature \( T_{\text{spin}} \), derived from spin-isomeric ratios \( R_{\text{spin}} \), e.g. ortho/para. At the time when cometary ices formed, the prevailing temperature defined the relative abundance of the different spin-isomeric species, and herewith \( R_{\text{spin}} \) and \( T_{\text{spin}} \) are normally treated as “remnant thermometers” probing the formation environments. Most of our knowledge of this indicator comes from measurements of ortho-para ratios in water and \( \text{NH}_2 \), suggesting a common \( T_{\text{spin}} \) near 30K. This information is based on a restricted sample of comets, and the measurements are particularly sensitive to the molecular modeling technique and adopted spectral database. Here, we present new methodologies for extracting spin temperatures from ethane (\( \text{C}_2\text{H}_6 \)), methane (\( \text{CH}_4 \)), and methanol (\( \text{CH}_3\text{OH} \)), and describe advanced new models for ortho/para water (\( \text{H}_2\text{O} \)) and ammonia (\( \text{NH}_3 \)). Our \( \text{H}_2\text{O} \) analysis is based on the most complete fluorescence radiative transfer model to date, which incorporates 1,200 million transitions including those originating from high-energy levels that are activated in comets via non-resonance cascade. In a similar fashion, we developed non-resonance fluorescence models for \( \text{NH}_3 \) and HCN, and quantum band models for the \( \nu_7 \) band of \( \text{C}_2\text{H}_6 \) and \( \nu_3 \) band of \( \text{CH}_3\text{OH} \). All models respect spin symmetry non-conversion radiative rules, and make use of a realistic Solar spectrum for the computation of fluorescence pumps. We applied these new methods to derive spin-isomeric ratios for \( \text{H}_2\text{O} \), \( \text{CH}_4 \), \( \text{C}_2\text{H}_6 \), \( \text{CH}_3\text{OH} \) and \( \text{NH}_3 \) from three high-quality cometary datasets: 1) C/2007 W1 (Boattini), 2) C/2001 A2 (LINEAR), and 3) 8P/Tuttle. We compare our results with the measured organic compositions for these comets, and present possible formation and evolution scenarios.

510.07 First High-Resolution Infrared Spectroscopic Measurements of Comet 2P/Encke: Unusual Organic Composition and Low Rotational Temperatures

- Yana L. Radeva1, M. J. Mumma2, G. L. Villanueva1, B. P. Bonev1, M. A. DiSanti2, M. F. A’Hearn3, N. Dello Russo4

1The Catholic University of America at NASA Goddard Space Flight Center, 2Solar System Exploration Division, NASA Goddard Space Flight Center, 3Department of Astronomy, University of Maryland, 4The Johns Hopkins University Applied Physics Laboratory.
We present the first high-resolution infrared spectra of the ecliptic comet 2P/Encke, acquired on UT 4 - 6 Nov. 2003, with the Near Infrared Echelle Spectrograph (NIRSPEC) on the Keck II telescope. 2P/Encke is a dynamical end-member among comets. Its very short period of 3.3 years (with perihelion at 0.34 AU and aphelion at 4.09 AU) exposes the nucleus to unusually high insolation throughout its orbit, raising the prospect that native ices may have experienced significant fractionation over time. Here, we present flux-calibrated spectra, production rates, and mixing ratios for H\textsubscript{2}O, CH\textsubscript{3}OH, HCN, H\textsubscript{2}CO, C\textsubscript{2}H\textsubscript{2}, C\textsubscript{2}H\textsubscript{6}, CH\textsubscript{4} and CO, and compare the abundance ratios with the “organics-normal” population. We also extracted very low rotational temperatures (20 - 30 K) for H\textsubscript{2}O, HCN, and CH\textsubscript{3}OH in the near-nucleus coma, which correlate with one of the lowest cometary gas production rates (~ 10\textsuperscript{27} molecules s\textsuperscript{-1}) measured thus far in the infrared. We determined that 2P/Encke is enriched in CH\textsubscript{3}OH, but depleted in C\textsubscript{2}H\textsubscript{6}, C\textsubscript{2}H\textsubscript{2}, HCN, CH\textsubscript{4}, H\textsubscript{2}CO and CO. We compared mixing ratios of these organic species measured on separate dates, and found no evidence of macroscopic chemical heterogeneity in this cometary nucleus, however, we are limited by sparse temporal sampling of our observations. The depleted abundances of most measured species but retention of the high temperature volatiles (H\textsubscript{2}O, CH\textsubscript{3}OH) are consistent with fractionation of 2P/Encke’s native ices by thermal processing while in its current orbit. 2P/Encke is unique in terms of its short period, unusual organic composition, low rotational temperatures and low production rates. The discovery of its unusual organic composition is an important contribution to the emerging chemical taxonomy of comets.

510.08 Cometary Jet Collimation Without Physical Confinement

- Jordan Steckloff\textsuperscript{1}, H. Melosh\textsuperscript{1}

\textsuperscript{1}Purdue University.

Recent high-resolution images of comet nuclei reveal that gases and dust expelled by the comet are organized into narrow jets. Contemporary models postulate that these jets collimate when the expanding gases and dust pass through a physical aperture or nozzle [1]. However, recent high-resolution spacecraft observations fail to detect such apertures on cometary surfaces [2]. Additionally, observations of comet nuclei by visiting spacecraft have observed that jet activity is tied to the diurnal rotation of the comet. This suggests that jet emissions are driven by the sun, and therefore must emanate from close to the surface of the comet (order of ~10 cm.) Here we describe a simplified computer model of jets emanating from Comet Tempel 1. We approximate the active areas (vents) of the comet as a region of smooth, level terrain on the order of ~10 m in width. We assume that each element of the active area is emitting gas molecules with the same spatial distribution, and integrate over the active area in order to calculate the gas drag force. We consider two angular emission profiles (isotropic and lambertian), and assume plane-strain geometry. Uniformly sized particles are placed randomly on the surface of the vent, and their positions in time are tracked. For our simulation, spherical particles with radii of 1 μm to 1 cm were considered. We observe that the overwhelming majority of the particles remain close to the central axis of the active area, forming a well-collimated jet, with particles reaching escape velocity. This mechanism may explain cometary jets, given the physical and observational constraints. References: [1] Yelle R.V. (2004) Icarus 167, 30-36. [2] A’Hearn M.F. et al. (2011) Science 332, 1396-1400. [3] Belton M.J.S. and Melosh H.J. (2009) Icarus 200, 280-291.

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510.09 Complex permittivity of porous cometary nuclei, in relation with the Rosetta mission

- Ch. Levasseur-Regourd\textsuperscript{1}, Y. Brouet\textsuperscript{1}, P. Encrênaiz\textsuperscript{2}, S. Gulkis\textsuperscript{3}, M. Gheudin\textsuperscript{2}, J. Munier\textsuperscript{2}, G. Ruffié\textsuperscript{4}, F. Bonnaudin\textsuperscript{4}

\textsuperscript{1}UPMC Univ. Paris 6 / LATMOS, France, \textsuperscript{2}Observatoire de Paris / LERMA, France, \textsuperscript{3}JPL, \textsuperscript{4}IMS, France.

Detailed information about cometary nuclei is still to be revealed by a rendezvous mission, such as Rosetta. Two on-board radiometric experiments, MIRO and CONSORT, will respectively determine the brightness temperature of the surface and subsurface near 190 and 563 GHz, and investigate the deep interior by radar tomography through radio waves at 90 MHz [1,2]. To support mission preparation and data analysis, the dielectric properties of the nucleus of comet 67P/Churyumov-Gerasimenko have to be estimated. They are expected to strongly depend, not only upon the composition and temperature, but also upon the porosity of the different regions encountered by electromagnetic waves. Modelling non-gravitational forces suggests that the nucleus has a density of about 370 kg m\textsuperscript{-3} [3,4]. Such a low bulk density may result from macro-porosity (gravitational aggregates, impact fractures) and
micro-porosity (e.g. fluffy dust aggregates). To study the critical relationship between the dielectric constant and the porosity, we have systematically measured the relative complex permittivity over different frequencies, encompassing CONERT and MIRO frequencies, for 7 samples of highly porous granular materials of volcanic origin (pyroclastic deposits from Etna and NASA JSC-Mars1 simulant), with various sizes ranges between a few tens and hundreds of micrometers. The results, as a function of size (i.e. surface/volume ratio) and frequency (with, e.g., a decrease of the real part of the permittivity with increasing frequency) will be presented and discussed. Additional measurements, under development for other samples of interest for comet nuclei, will also be analyzed. Support from CNES and NASA is acknowledged. [1] Gulkis et al., Space Sci. Rev., 128, 561, 2007. [2] Kofman et al., Space Sci. Rev., 128, 413, 2007. [3] Davidson and Guttiérez, Icarus 176, 453, 2005. [4] Lamy et al., Space Sci. Rev., 128, 23, 2007.

511 Planetary Rings: VIMS Observations of Saturn's Rings
Friday, 2:30 PM - 3:00 PM, Carson 1/2

511.01 VIMS Observations of Saturn’s Rings Investigated by means of Montecarlo Ray Tracing
- Mauro Ciarniello1, G. Filacchione1, F. Capaccioni1
1INAF-IAPS, Italy.

The VIMS instrument onboard Cassini has extensively observed the Saturn’s rings producing a number of mosaics that allow the study of the radial variability of the rings spectral properties at visible and infrared wavelengths. Along with compositional variations some systematic effects induced by observation geometry are observed in the rings spectra, such as phase angle dependence of water ice band depths and spectral reddening. In this paper we investigate the mechanisms at the origin of these photometric effects by adopting a Montecarlo raytracing, in the geometric optics limit. We report about the results obtained from several simulations varying rings physical properties (optical depth, particle size distribution, single particle phase function) in order to investigate the variation of the angular distribution of the light scattered by the ring plane. The results of these simulations indicate that even if the total power reflected by the rings plane is dominated by single scattered light, the multiple scattered fraction (inter-particle scattering) produces a dependence of the spectral features on observation geometry (phase angle) at least for the denser regions of the rings. Moreover using the same Montecarlo code we are able to reproduce the dependence of the spectral features (band depths, spectral slopes) on viewing geometry (incidence, emergence and phase angles). Disentangling illumination effects from rings particle albedo permits a more accurate retrieval of the physical properties (grain size, amount of contaminants) of the regolith that covers the ring particles when radiative transfer models are applied to fit remote sensing spectra. This research is supported by an Italian Space Agency (ASI) grant.

511.02 Water Ice, Chromophores And Organics Distribution Across Saturn’S Rings
- Gianrico Filacchione1, F. Capaccioni1, M. Ciarniello1, P. D. Nicholson2, R. N. Clark3, D. P. Cruikshank4, J. N. Cuzzi5, M. M. Hedman2, B. J. Buratti5, P. Cerroni1, F. Tosi1, R. H. Brown6
1INAF-IAPS, Italy, 2Cornell University, 3USGS, 4NASA-AMES, 5NASA-JPL, 6LPL-UA.

Since 2004 the Visual and Infrared Mapping Spectrometer (VIMS) on Cassini has returned numerous mosaics of Saturn’s main rings. In this work we report about the radial distribution of water ice, chromophores and organics derived from 10 mosaics, for a total of about 130,000 spectra, acquired with solar phases in the 6°-132° range and with spacecraft-ring plane inclination between -49° and +5°. Each observation was projected to build ring spectrograms, e.g. 2D arrays containing the full spectral (0.35–5.1 microns) and spatial (from 73.500 to 141.375 km at 400 km/bin) information. As discussed in Filacchione et al. (2012), spectrograms are an effective tool to build radial compositional profiles across rings to trace the distribution of: 1) water ice, through the 1.25-1.5-2.0 micron band depths; 2) red chromophores, using visible spectral slopes as markers; 3) organic material like CH2 which is characterized by very faint absorption bands caused by aliphatic stretch in the 3.42-3.52 micron interval. We have found that both VIS reddening and water ice band depth increase with solar phase, reaching a maximum at about 70°-100°, therefore confirming our previous result (Nicholson, et al 2008) that the red contaminant is intimately mixed in water ice grains. The detection of the organic material is just possible only in low phase observations.
where the signal-to-noise ratio is sufficient to detect the faint spectral signatures of these materials. The CH2 features appear more intense across A and B rings while in general we observe a decrease across CD and outer C ring. Finally, the PAH aromatic feature at 3.29 micron, detected by VIMS on the dark material units of Iapetus’ leading hemisphere, Phoebe and Hyperion (Cruikshank et al., 2008, Coradini et al., 2008, Dalton et al., 2012), is not evident in spectra of the rings. This research is supported by an ASI grant.

511.03 Density Wave Signatures In VIMS Spectral Data

Philip D. Nicholson¹, M. M. Hedman¹, Cassini VIMS Team
¹Cornell Univ.

Spectral scans of Saturn’s rings by the Cassini VIMS instrument have revealed both regional and local variations in the depths of the water ice bands at 1.5 and 2.0 microns, which have been interpreted in terms of variations in regolith grain size and the amount of non-icy “contaminants” (Filacchione et al. 2012; Hedman et al. 2012). Noteworthy among the local variations are distinctive patterns associated with the four strong density waves in the A ring. Within each wavetrain there is a peak in band strength relative to the surrounding material, while extending on both sides of the wave is a “halo” of reduced band strength. The typical width of these halos is 400-500 km, about 2-3 times the visible extent of the density waves. The origin of these features is unknown, but may involve enhanced collisional erosion in the wave zones and transport of the smaller debris into nearby regions. A similar pattern of band depth variations is also seen at several locations in the more opaque B ring in association with the strong 3:2 ILRs of Janus, Pandora and Prometheus. The former shows a pattern just like its siblings in the A ring, while the latter two resonances show haloes, but without central peaks. In each case, the radial widths of the halo approaches 1000 km, but stellar occultation profiles show no detectable density wavetrain. We suggest that this spectral signature may be a useful diagnostic for the presence of strong density waves in regions where the rings are too opaque for occultations to reveal a typical wave profile. More speculatively, the displacement of the haloes’ central radii from the calculated ILR locations of 600-700 km could imply a surface density in the central B ring in excess of 500 g/cm². This research was supported by the Cassini/Huygens project.

512 Venus: Upper Atmosphere Dynamics and Temporal Variability

Friday, 3:30 PM - 4:00 PM, Reno Ballroom

512.01 Transition from Zonal Wind to Subsolar-to-Antisolar Flow on Venus

Theodor Kostiuk¹, T. A. Livengood², T. Hewagama², K. Fast¹, J. Annen¹
¹NASA’s GSFC, ºUniversity of Maryland/NASA’s GSFC.

We observed Venus on 19-23 Aug 2010 (UT) to investigate equatorial wind velocities from above the cloud tops through the lower thermosphere. Measurements were made from the NASA Infrared Telescope Facility using the NASA Goddard Space Flight Center Heterodyne Instrument for Planetary Winds and Composition. High-resolution spectra were acquired on a CO₂ pressure-broadened absorption feature that probes the lower mesosphere (~70 km altitude) with a non-LTE core emission of the same transition that probes the lower thermosphere (~110 km). The resolving power of λ/Δ λ=2.510⁷ determines line-of-sight velocity from Doppler shifts to high precision. The altitude differential between the features enables investigating the transition from zonal wind flow near the cloud tops to subsolar-to-antisolar flow in the thermosphere. The fully-resolved carbon dioxide transition was measured near 952.8808 cm⁻¹ (10.494 μm) rest frequency at the equator with 1 arcsec field-of-view on Venus (24 arcsec diameter) distributed about the central meridian and across the terminator at ±15° intervals in longitude. The non-LTE emission is solar-pumped and appears only on the daylight side, probing subsolar-to-antisolar wind velocity vector flowing radially from the subsolar point through the terminator, which was near the central meridian in these observations and had zero line-of-sight wind projection at the terminator. The velocity of the zonal flow is approximately uniform, with maximum line-of-sight projection at the limb, and can be measured by the frequency of the absorption line on both the daylight and dark side. Variations in Doppler shift between the observable features and the differing angular dependence of the contributing wind phenomena thus provide independent mechanisms to distinguish the dynamical processes at the altitude of each observed spectral feature. Winds up to
100 m/s were determined in previous investigations with uncertainties of order 10 m/s or less. This work was supported by the NASA Planetary Astronomy Program.

512.02 Observations Of HCl Altitude Dependence And Temporal Variation In The Venus 70-95 km Mesosphere: Implications For Chemistry And Dynamics
- Brad J. Sandor, R. T. Clancy
  Space Science Institute.

The first altitude resolved, low latitude (15S-15N) measurements of HCl in the Venus 70-95 km mesosphere are presented, based upon submm (625.9 GHz) spectroscopic observations in Oct-Dec 2010 (made with JCMT - the James Clerk Maxwell Telescope, Mauna Kea, Hawaii). Abundances below 80 km agree previous measurements (eg. at 74 km, Krasnopolsky, 2010). Above 80 km, measured HCl decreases rapidly with altitude, in strong disagreement with photochemical model prediction (eg. Yung and Demore, 1982). One consequence is that, contrary to model expectation, HCl is not the dominant reservoir of Cl in the upper mesosphere, and therefore upper mesospheric chlorine chemistry must be very different from conventionally accepted understanding. The data also show HCl is time variable above 80 km, based upon observations separated by one month (early Nov vs early Dec). Two local times observed in Dec (5:50-7:50am, dayside, vs 0:30-3:30am, nightside) show no diurnal variation over this range. Above 85 km (but not below), the submm, low latitude (15S-15N) HCl abundances are consistent with North polar (latitude 73-84 N) values reported from SOIR observations (Vandaele et al., 2008). Agreement between low and high latitude HCl measured above 85 km suggests their shared disagreement with theory may be driven by the same physical process. We suggest dynamical downwelling of HCl-poor air from the lower thermosphere as the responsible mechanism. [We acknowledge NASA for their funding of this project.]

512.03 Re-analysis of Sulfur Dioxide Variability in the Venus Atmosphere Using Restored Pioneer Venus Orbiter UVS Data
- Kevin McGouldrick, L. W. Esposito, K. E. Simmons, M. Dorey, C. K. Pankratz
  University of Colorado.

Initial analysis of Pioneer Venus Orbiter Ultraviolet Spectrometer (PVOUVS) data at wavelengths of 207nm and 240nm by Esposito et al. (1988) suggested a significant decline in SO2 concentration at 40mb between 1979 and 1988. More recent observations of Venus by ultraviolet spectrometers on ESA's Venus Express and ground based microwave spectroscopy suggest that SO2 at 40mb is closer to that seen near the start of the Pioneer Venus mission, and/or suggest the existence of a previously undetected reservoir of SO2 at altitudes above about 1mb. We present results of a re-analysis of the PVOUVS data to re-assess the SO2 concentration and distribution in the upper atmosphere of Venus, taking into account the newer knowledge derived in the last twenty years from Venus Express, in orbit since 2006, and groundbased observations. The wavelength range of PVOUVS overlaps with the SPICAV and VIRTIS-M-Vis instruments on Venus Express. The longer wavelength data of PVOUVS, analyzed in detail for the first time by this project, will allow for a direct (though obviously not simultaneous) comparison with the current Venus Express observations. The Laboratory for Atmospheric and Space Physics is carrying out a project to restore and preserve data products from several past missions for archiving and for use by the scientific community. This project includes the restoration of data from the ultraviolet spectrometers on Mariner 6/7, Mariner 9, Pioneer Venus, and Galileo. Restored and PDS-compliant data sets from these missions will soon be made available by the team. Pertinent to this presentation, the PVOUVS data have been restored, including spacecraft pointing and orbit attitude information and preliminary radiometric calibrations. These data cover the range of wavelengths from about 110nm to about 360nm, using a variety of observing modes. This work is funded though the NASA Planetary Mission Data Analysis Program, project number NNH08ZDA001N.

513 Planetary Rings: Dynamics
Friday, 3:30 PM - 5:00 PM, Carson 1/2

513.01 Saturn’s F Ring Core: Calm in the Midst of Chaos
Saturn’s F Ring, or more specifically its stable, narrow, optically thick but clumpy core (Bosh et al. 2002 Icarus 157, 57; Murray et al. 2012, DDA #43, 4.08) is often described as “shepherded”, or confined in its present location, by Pandora and Prometheus much as the Uranian epsilon ring is shepherded by Cordelia and Ophelia. However, the F Ring is closer to the more massive Prometheus, inconsistent with the shepherding principle of torque balance (Showalter and Burns 1982 Icarus, 52, 526). Moreover, orbital calculations show that test particles throughout the F ring region tend to have chaotic orbits caused by the densely spaced resonances of Prometheus and Pandora (Scargle et al. 1983 DPS 25, #26.04, Winter et al. 2007 MNRAS 380, L54 and 2010 A&A 523, A67). We have developed a simple physical model and performed Bulirsch-Stoer orbital integrations containing all the classical satellites and named, close-in ringmoons as gravitational perturbers. We follow thousands of nongravitating test particles for over >30 years (>20000 orbits), covering selected swaths of the F ring region (139500-141500km) at high radial resolution. We find that narrow radial regions of orbital stability, which we term antiresonances, arise midway between first order resonances where these are clearly isolated. In this talk we summarize the situation, and present a simple physical impulse model for the presence of antiresonances. We show time histories of eccentricity and semimajor axis from realistic orbital integrations (perturbed by the gravity of all known moons) that illustrate chaotic behavior in general, with properties consistent with the behavior of S/2004S6 and other sizeable objects in the region. We also show examples of highly stable behavior in a few, very narrow, locations. At these specific locations, particle eccentricities and semimajor axes are largely invariant over periods of at least decades (Whizin et al., this meeting).

513.02 Orbital Evolution of Particles and Stable Zones at the F Ring Core
  1University of Central Florida, 2NASA Ames Research Center, 3(Deceased) BAERI, inc., 4University of California, 5Space Science Institute, 6SETI Institute.

The F ring of Saturn is often thought of as a ‘shepherded’ ring; however, it is closer to the more massive of its two shepherd satellites, Prometheus. Pandora, the outer satellite, is near a 3:2 mean motion resonance with larger Mimas causing periodic fluctuations in its orbit. The perturbations from the Saturnian satellites result in chaotic orbits throughout the F ring region (Scargle et al. 1993 DPS 25, #26.04, Winter et al. 2007 MNRAS 380, L54; 2010 A&A 523, A67). We follow the approach of Cuzzi et al. (abstract this meeting) in exploring zones of relative stability in the F ring region using a N-body Bulirsch-Stoer orbital integrator that includes the 14 main satellites of Saturn. We find relatively stable zones situated among the tightly packed Prometheus and Pandora resonances that we dub “anti-resonances.” At these locations ring particles have much smaller changes in their semi-major axes and eccentricities than particles outside of anti-resonance zones. We present high radial resolution simulations where we track the orbital evolution of 6000 test particles over time in a ~200km region and find that the variance of the semi-major axes of particles in anti-resonances can be less than 1km over a period of 32 years, while just ~5km away in either radial direction the variance can be tens of km’s. More importantly, particles outside of these stable zones can migrate into one due to chaotic orbits, but once they enter an anti-resonance zone they remain there. The anti-resonances act as long-lived sinks for ring particles and explain the location of the F ring core even though it is not in overall torque balance with the shepherd moons.

513.03 Results from N-body Simulations of the Outer Edge of Saturn’s B Ring
- Joseph M. Hahn1, J. N. Spitale2
  1Space Science Institute - Austin, 2Planetary Science Institute.

The outer edge of Saturn’s B ring is confined by satellite Mimas’$m=2$ inner Lindblad resonance, whose perturbations forces the large $m=2$ pattern that the Cassini spacecraft sees there. However Cassini observations also reveal the presence other unforced modes there, where the departure from circularity varies sinusoidally in $m$*longitude for $m=1$ on up to $m=5$ (Spitale & Porco 2010, Nicholson et al 2012). The meaning of these unforced
normal modes is unclear, but they might indicate the viscous overstability (Borderies et al. 1985, Longaretti & Rappaport 1999). We have studied these unforced normal modes in N-body simulations of the B ring, done by seeding the ring-edge with \( m=2 \) or \( m=3 \) shapes and then letting the disturbance evolve over time due to the ring's self gravity. We find that the amplitude of the forced \( m=2 \) pattern due to Mimas, as well as the pattern speeds of the unforced modes, are all consistent with the B ring-edge having a surface density of about 200 \( \text{gm/cm}^2 \). The pattern speeds of unforced normal modes are sensitive to ring surface density, so this technique can also be applied to Saturn's narrow ringlets, many of which exhibit a spectrum of normal modes whose observed pattern speeds could be used to infer ringlet masses. We also note that these unforced normal modes persist in the simulations without any damping for a hundred years or \( 10^5 \) orbits, despite the model ring's viscosity of 100 \( \text{cm}^2/\text{sec} \). Which suggests that these normal modes, which are quite common in Saturn's rings and ringlets, might instead be due to past disturbances in the rings, such as an impact by cometary debris cloud (Hedman et al. 2007, Showalter et al. 2011), or maybe due to the gravitational impulse that can occur during a close encounter with a large comet like Saturn-crossing Chiron.

513.04 Driven Eccentric Modes in the Outer Edge of Saturn's B Ring
- Glen R. Stewart
  Univ. of Colorado.

Cassini imaging, stellar occultations, and radio occultations all show that the outer edge of Saturn's B ring exhibits multiple modes of oscillation in addition to the expected \( m=2 \) signature associated with the inner Lindblad resonance with the satellite Mimas. In particular, the B ring edge has a slowly precessing \( m=1 \) eccentric mode as well as rapidly rotating components with \( m=3, 4 \) and 5 (Spitale and Porco 2010, Hedman et al. 2010). Although previous work suggested that these additional modes were free modes trapped in a resonant cavity, we show how these modes are driven by the nonlinear coupling between linear modes and the resonant forcing by Mimas. The process is analogous to the tidally driven eccentric modes in circumstellar disks in close binary star systems that were described by Lubow (1991). In particular, both a slowly precessing \( m=1 \) mode as well as a rapidly rotating \( m=3 \) mode result from the nonlinear coupling between the gravitational potential of Mimas and the linear response of the ring edge to the \( m=2 \) inner Lindblad resonance with Mimas. This nonlinear coupling exchanges energy between the different modes which may help explain why the amplitude and phase of the \( m=2 \) mode has been observed to vary over time.

513.05 Propeller Peregrinations: Ongoing Observations of Disk-Embedded Migration In Saturn's Rings
- Matthew S. Tiscareno
  Cornell Univ..

The "propeller" moons within Saturn's rings are the first objects ever to have their orbits tracked while embedded in a disk, rather than moving through empty space (Tiscareno et al. 2010, ApJL; hereafter T10). The ~km-sized "giant propellers" whose orbits have been tracked in the outer-A ring, as well as their smaller ~0.1-km-sized brethren swarming in the mid-A ring, are not seen directly; rather, their locations are inferred by means of the propeller-shaped disturbances they create in the surrounding ring material (Tiscareno et al. 2006, Nature; Sremcevic et al. 2007, Nature; Tiscareno et al. 2008, AJ). The orbits of giant propellers are primarily Keplerian, but with clear excursions of the semimajor axis on the order of +/-0.15 degrees longitude for the largest and best-studied, and +/-several degrees longitude for others (T10). Most theories that have been proposed to explain the non-Keplerian motion of propeller moons rely on gravitational and/or collisional interactions between the moon and the surrounding disk, and thus hold out the prospect for directly observing processes that are important in protoplanetary scenarios and other disk systems. One model suggests that the moons migrate due to azimuthal variations in the disk that they themselves create (Pan and Chiang 2010, ApJL; 2012, AJ). Although the classical form of "Type I migration," relying on the asymmetries in the dynamics themselves, is not powerful enough to explain the observed motions (Crida et al. 2010, AJ), modifications of that model relying on temporal (Rein and Papaloizou 2010, A&A, Pan et al. 2012, MNRAS) or radial (Tiscareno 2012, P&SS) variations in the disk have been suggested. The different models make different predictions, and future data will likely distinguish among them. In 2012, after a nearly two-year hiatus, Cassini left Saturn's ringplane and resumed tracking the propellers. We will report early results of the new observing campaign.
513.06 Discovery Of B Ring Propellers In Cassini UVIS, And ISS
- Miodrag Sremcevic, G. R. Stewart, N. Albers, L. W. Esposito
  Univ. of Colorado, Boulder.

We present evidence for the existence of propellers in Saturn's B ring by combining data from Cassini Ultraviolet Imaging Spectrograph (UVIS) and Imaging Science Subsystem (ISS) experiments. We identify two propeller populations: (1) tens of degrees wide propellers in the dense B ring core, and (2) smaller, more A ring like, propellers populating the inner B ring. The prototype of the first population is an object observed at 18 different epochs between 2005 and 2010. The ubiquitous propeller "S" shape is seen both in UVIS occultations as an optical depth depletion and in ISS as a 40 degrees wide bright stripe in unlit geometries and dark in lit geometries. Combining the available Cassini data we infer that the object is a partial gap embedded in the high optical depth region of the B ring. The gap moves at orbital speed consistent with its radial location. From the radial separation of the propeller wings we estimate that the embedded body, which causes the propeller structure, is about 1.5km in size located at a=112,921km. The UVIS occultations indicate an asymmetric propeller "S" shape. Since the object is located at an edge between high and relatively low optical depth, this asymmetry is most likely a consequence of the strong surface mass density gradient. We estimate that there are possibly dozen up to 100 other propeller objects in Saturn’s B ring. The location of the discovered body, at an edge of a dense ringlet within the B ring, suggests a novel mechanism for the up to now illusive B ring irregular large-scale structure of alternating high and low optical depth ringlets. We propose that this B ring irregular structure may have its cause in the presence of many embedded bodies that shepherd the individual B ring ringlets.

513.07 Of Eggs and Arcs
- Joseph A. Burns, P. C. Thomas, P. Helfenstein, M. S. Tiscareno, M. M. Hedman, M. Agarwal
  Cornell Univ.

New scenarios for the origins of Saturn’s rings/interior moons have directed scientific attention to the region just exterior to Saturn’s main rings. Four satellites (Aegaeon = Ae; Anthe = An; Methone = Me; Pallene = Pa) discovered by the Cassini mission on either side of Mimas’s orbit perhaps comprise a distinct class of ring-moon. They are tiny ($R = 0.3-2.5$ km); three (AeAnMe) are trapped in co-rotation resonances with Mimas and reside within ring-arcs; and at least two (MePa) have remarkably regular shapes. Images with pixel scales as fine as 27 m taken in May 2012 reveal Methone to be ovoid within 10 m (from sub-pixel limb detection) and devoid of any craters (>130 m) across its 9 km$^2$ of surface; Pallene and even tiny Aegaeon have similar appearances in lesser-quality images. Numerical simulations demonstrate that particles comprising the surrounding ring-arcs populate the same resonances as their embedded moons; escape speeds from the moons are < 0.5 m/s, smaller than the 2 m/s that dynamically characterize the resonant well. We investigate the gentle transfer of particles back and forth between the ring-arcs and any embedded bodies. In this environment, the moons’ shapes are smooth equipotentials; electrostatic effects may also determine how grains settle to surfaces. Considering these shapes to represent equipotential surfaces for rotating, tidally distorted, homogeneous bodies, we infer mean satellite densities of 250+/-60 (Pa), 310+/-30 (Me), and 540+/-120 (Ae) kg m$^{-3}$. About half of Methone’s leading hemisphere is covered by a sharply bounded, lemon-shaped, relatively dark region, having a form reminiscent of Mimas’s thermal anomaly (Howett et al. 2011). Its (601 nm) albedo is 13% lower than the bounding brighter material. An irregularly shaped, even-darker (by 4%) blotch straddles the apex of the moon’s motion. Impacts with circum-planetary meteoroids and plasma are likely responsible for these features.

513.08 The Anomalous Orbital Motion Of Mab Explained
- Kartik Kumar, I. de Pater, M. R. Showalter
  Delft University of Technology, Netherlands, University of California-Berkeley, SETI Institute.

Showalter and Lissauer (2003) reported the discovery of two previously unknown inner satellites of Uranus (Mab and Cupid), using data from the Hubble Space Telescope (HST). Subsequently, they announced the discovery of an outer ring system composed of the $\nu$-ring and the $\mu$-ring (Showalter and Lissauer, 2006). They showed that the orbit of Mab, embedded in the $\mu$-ring, is not well understood, after comparing its orbital position derived from
Voyager flyby data (1986) to HST data (2003-2006). The observed positions were compared with a Keplerian orbital model that included the gravitational flattening of Uranus. Although this model works well for nine other Uranian moons, for Mab the fitting errors are six times larger. Mab is relatively bright in the data and well isolated from the other moons, suggesting that the measurement errors should not be large. Hence, the magnitude of the orbit fit residual seems to indicate that we are currently overlooking an essential part of the dynamics that determines the orbit of Mab. It is clear from these discoveries that Mab and the μ-ring are intriguing, constituting “a densely packed, rapidly varying, and possibly unstable dynamical system.” We investigated the nature of Mab’s anomalous orbital motion, which has thus far remained unexplained. The dynamical effects we simulated result from the interaction of Mab with a hypothetical ring of undetected moonlets in its neighborhood. We explored the effects of varying the characteristics of such a ring (mass and orbital-element distribution) on Mab’s orbital motion. From these results we are able to highlight a number of interesting dynamical regimes. In particular, our simulations reveal the important role that perturbers occupying horseshoe orbits might play in determining the perturbations experienced by Mab. Further studies will be conducted to investigate the long-term stability of a possible perturber ring.

513.09 Coupling Between Corotation And Lindblad Mean Motion Resonances
- Maryame El Moutamid¹, B. Sicardy², S. Renner³
  ¹LESIA/IMCCE Paris Observatory, France, ²LESIA Paris Observatory, France, ³IMCCE / Lille University, France.

We consider the classical Elliptic Restricted Three-Body Problem with two bodies (particle and satellite) orbiting a central planet. If we take into account the oblateness of the central body through the classical additional terms up to J₆, the secular terms causing the orbit precessions appear in the disturbing potential leading to the presence of two critical resonant arguments: Φ = (m+1)λʹ + mλ + ω and Φʹ = (m+1)λʹ + mλ + ωʹ where m is an integer, λ and ω the mean longitude and the longitude of the periapsis of the particle, and the primed quantities apply to the satellite. The arguments Φʹ and Φ respectively describe the Corotation Eccentric Resonance (CER) and the Lindblad Eccentric Resonance (LER). We developed a new model (the CoraLin model) which encapsulates in a simple adimensional form the coupling between the two resonances. We examine the asymptotic configurations where these resonances are well separated or completely superimposed. Poincaré surfaces of section reveal that in intermediate cases, the strong coupling between the resonances may lead to chaotic behavior. We apply this model to several recently discovered small Saturnian satellites dynamically linked to Mimas through first mean motion resonances: Anthe, Methone, and Aegaeon, all associated with arc material. All satellites are trapped in CER with Mimas and perturbed by the associated LER. We estimate the probability of capturing a satellite into a of CER with Mimas, as the orbit of the latter evolves through tidal effects, and discuss possible scenarios for the dynamical origin of those moons.

514 Comets 3: Comets, including Sungrazers and WISE/NEOWISE Results
Friday, 3:30 PM - 5:00 PM, Tahoe Room

514.01 First Ground-based Infrared Detections Of Volatile Species In The Centaur Comet 29P/Schwassmann-Wachmann 1 At Rh = 6.26 AU
- Lucas Paganini¹, M. J. Mumma², H. Boehnhardt³, G. L. Villanueva⁴, M. A. DiSanti⁵, B. P. Bonev⁶, G. A. Blake⁷
  ¹NASA Goddard Space Flight Center/ORAU, ²NASA Goddard Space Flight Center, ³Max Planck Institute for Solar System Research, Germany, ⁴NASA Goddard Space Flight Center/CUA, ⁵Caltech.

We observed comet 29P/Schwassmann-Wachmann 1 (hereafter 29P) in UT 2012 February and May with CRIRES/VLT (in the Atacama desert, Chile) and NIRSPEC/Keck-2 (atop Mauna Kea, Hawaii) when the comet was placed at 6.26 AU from the Sun and 5.50 AU from Earth. We detected five CO emission lines on several nights, confirming the ubiquitous content and release of carbon monoxide from the comet’s nucleus. This is the first multiple line detection of any gaseous species in 29P, at any wavelength, and the first extraction of a rotational temperature based on the intensities of multiple spectral lines. We present the production rate and (remarkably low) rotational temperature for CO, and compare them with results extracted from previous observations at radio
wavelengths. Along with CO we pursued detections of other volatiles, namely H2O, C2H6, CH4, HCN and CH3OH. Although their detections are not evident in 29P, we present very sensitive upper limits. These results establish a new record for detections by Infrared Spectroscopy of parent volatiles in comets at relatively large heliocentric distances, previously held by detection of CO in C/1995 O1 (Hale-Bopp) at 4.11 AU (with CSHELL/IRTF, DiSanti et al. 1999) and of CO in C/2006 W3 (Christensen) at 4.03 AU (with CRIRES/VLT, Bonev et al. 2012, in prep.). Until now considered to be a somewhat impossible task with IR ground-based facilities, these discoveries open up new opportunities for targeting volatile species in distant comets at low rotational temperatures. · M. A. DiSanti, M. J. Mumma, N. Dello Russo, K. Magee-Sauer, R. E. Novak, T. W. Rettig, Nature 399, 662-665 (1999) ·

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514.02 A Multiwavelength Investigation of Sungrazing Comet Lovejoy (C/2011 W3)


1Lowell Observatory/JHU-APL, 2University of Maryland, 3JHU Applied Physics Laboratory, 4University of Central Florida, 5California Institute of Technology, Jet Propulsion Laboratory, 6Siding Spring Observatory, Australian National University, Australia, 7Las Campanas Observatory, Chile, 8Naval Research Laboratory.

Comet Lovejoy (C/2011 W3) was the first Kreutz sungrazing comet in the modern telescopic era (since 1970) to survive perihelion, although the extent to which the nucleus survived remains unclear. We used observations by SOHO and STEREO obtained near perihelion as well as observations we acquired with the Hubble Space Telescope, Spitzer Space Telescope, Swift, Siding Spring Observatory, Las Campanas Observatory, and Lowell Observatory in the days and weeks after perihelion (2011 December 16) to characterize the effects of the perihelion passage ($q \sim 1.2$ solar radii) and attempt to constrain properties of the nucleus and dust. Lovejoy brightened steadily until perihelion, reaching an apparent magnitude of at least -2.5 in the SOHO field of view. The lightcurve exhibited three peaks shortly after perihelion (~0.35, ~0.85, and ~1.40 days). From the time of the last peak until Lovejoy left the STEREO fields of view more than a week later, the near-nucleus region was ~4 mag brighter post-perihelion than at comparable distances pre-perihelion, and the central condensation became elongated. These behaviors strongly suggest that Lovejoy fragmented (or possibly disintegrated) in one or more events near or shortly after perihelion. Preliminary analysis of Hubble, Swift, and Spitzer images did not reveal any surviving nuclear fragments larger than ~50 m, although the larger than expected uncertainty in the orbit does not conclusively rule out their existence. Significant quantities of dust were still visible in Spitzer data acquired in early 2012 February. Analysis of the data is ongoing and new results will be reported. Support for SOHO and STEREO data analysis was provided by NASA Planetary Mission Data Analysis Program grant NNX10AP75G. Telescope time was granted under HST program DD 12792, Spitzer program 80237, and Swift target ID 32251.

514.03 Dynamical Simulations of the Tidal Disruption of Kreutz-group Sungrazing Comets

Paul R. Weissman1, E. Asphaug2, N. Movshovitz2, E. Rosenberg3

1Jet Propulsion Laboratory, 2University of California, Santa Cruz, 3Weizmann Institute, Israel.

Asphaug and Benz (Nature, 1994; Icarus, 1996) modeled the tidal disruption of comet Shoemaker-Levy 9 (SL9) at Jupiter using an N-body code that simulated the comet nucleus as a gravitationally-bound aggregate or “rubble-pile” of 500-2,000 smaller “cometesimals.” A key result was that most of the cometesimals reformed into “clumps”, with the final number of clumps being a function of the bulk density of the original nucleus. Movshovitz, Asphaug and Korycanski (ApJ, submitted) have developed an advanced tidal disruption code that includes treating the cometesimals as irregularly-shaped polyhedra rather than spheres, for more accurate treatment of friction and dilatation. This gives noticeably different results in their new SL9 simulations. We are using the same code to model the tidal disruption of Kreutz-group sungrazing comets. We believe that the Kreutz group’s mix of a few large and many small cometesimals is analogous to a meteoroid stream or comet trail where cometesimals are released at perihelion and disperse along the Kreutz group orbit after one or more close solar passages. We have begun by exploring the ($q$, $p$) parameter space, where $q$ is the perihelion distance and $p$ is the bulk density of the nucleus. Each simulated rubble-pile nucleus has a radius of 1.0 km and is composed of 4,096 irregularly-shaped
cometesimals with a typical dimension of ~140 meters. The nucleus porosity is 50%. Simulations performed to date show that the final number of clumps increases with decreasing perihelion distance and/or decreasing bulk density, while the mass of the largest clump decreases at lower values of q and p. We will report on our initial analysis of the simulations with attention to the final size distribution of clumps and the dispersion in time of the returning clumps. This work was performed in part at the Jet Propulsion Laboratory under contract with NASA.

514.04 A Stellar Appulse by Exploding Comet 17P/Holmes

- Pedro Lacerda\textsuperscript{1}, D. Jewitt\textsuperscript{2}
- \textsuperscript{1}Queen's University Belfast, United Kingdom, \textsuperscript{2}UCLA.

Comet 17P/Holmes suffered a massive outburst in October 2007. Its total brightness increased from about 17th to 2nd magnitude over a period of only two days as 17P released about 1-10% of its mass into space in the form of dust. Several theories have been proposed to explain the event but the exact cause for the outburst remains unknown. 17P had suffered a similar outburst more than one century ago, which led to its discovery. These unusual and violent explosions have rendered this otherwise unremarkable Jupiter family comet an interesting target of study, because it may provide clues to the activity in other comets. On 29 October 2007, the optocenter of outbursting 17P passed within ~1" of a background star. We used observations taken at the Univ. of Hawaii 2.2m telescope located atop Mauna Kea to measure the brightness of the star as it crossed the coma of 17P in an attempt to estimate the optical depth of the dust. The time sampling was 10-15 min. In addition, we used two-band photometry to look for colour variation as the star crossed the dust cloud. These measurements place the most stringent constraints on the extinction optical depth of any cometary coma.

514.05 The Return of the Andromedids

- Paul Wiegert\textsuperscript{1}, P. G. Brown\textsuperscript{1}, R. J. Weryk\textsuperscript{1}, D. K. Wong\textsuperscript{1}
- \textsuperscript{1}Western University, Canada.

The Andromedid meteor shower, originating from comet 3D/Biela (which disintegrated in the mid-1800's) has been weak or absent since the late 19th Century. Here we report the return of this shower in Dec 2011 with a zenith hourly rate of approximately 50, the strongest return of the shower in a century. The outburst was detected by the Canadian Meteor Orbit Radar (CMOR). The shower outburst occurred during solar longitudes $\lambda=250-252^\circ$ in 2011 (Dec 3-5) and had a statistical significance of $30\sigma$ above the median background, one of only three single-day outbursts reaching this level of significance in CMOR's 10 years of operation. Of particular interest: orbital characteristics indicated that was old material, predating the debris released during the epoch of 3D/Biela's disintegration in the mid-19th century, and which produced the spectacular showers in 1872 and 1885. In total, 122 probable Andromedid radar orbits were recorded during the interval from $\lambda=240^\circ-260^\circ$, the majority (85) occurring between $\lambda=250^\circ-253^\circ$ from a radiant near $\alpha=18^\circ$ and $\delta=56^\circ$. By way of comparison, between $\lambda=250^\circ-253^\circ$ the average number of radials recorded by CMOR within 10 degrees of this location having similar speeds in the years 2001 - 2010 was ~10 per year. The shower displays a slow geocentric speed (16 km/s) and an absence of large particles: mean measured mass from the radar is $\approx 5\times 10^{-7}$ kg corresponding to radii of 0.5mm. Numerical simulations of the parent comet indicate that the 2011 return of the Andromedids shower was produced by material released during Biela's 1649 perihelion passage. The orbital characteristics, radiant, timing as well as the absence of large particles in the streamlet are all confirmed by simulations. Simulations also predict appearances of this radiant in 2008 (seen in CMOR data at ZHR$\approx 30$) and 2018.

514.06 Multi-Wavelength Analysis of Cometary Dust Comae Using WISE/NEOWISE Results

- Rachel Stevenson\textsuperscript{1}, J. M. Bauer\textsuperscript{1}, E. A. Kramer\textsuperscript{2}, A. K. Mainzer\textsuperscript{1}, J. R. Masiero\textsuperscript{1}, T. Grav\textsuperscript{3}, Y. R. Fernandez\textsuperscript{2}, C. M. Lisse\textsuperscript{4}, K. J. Meech\textsuperscript{5}, P. R. Weissman\textsuperscript{1}, D. J. Tholen\textsuperscript{5}, R. G. Walker\textsuperscript{5}, E. L. Wright\textsuperscript{7}, WISE Team
- \textsuperscript{1}Jet Propulsion Laboratory, \textsuperscript{2}University of Central Florida, \textsuperscript{3}Planetary Science Institute, \textsuperscript{4}Applied Physics Laboratory, \textsuperscript{5}Institute for Astronomy, \textsuperscript{6}Monterey Institute for Research in Astronomy, \textsuperscript{7}University of California, Los Angeles.

Cometary dust provides insight into the composition and structure of cometary nuclei, as well as the driving forces behind its ejection. In this work, we examine the similarities and differences between dust ejected from long and
short period comets using data from the Widefield Infrared Survey Explorer (WISE) mission. WISE observed more than 150 comets at near- and mid-infrared wavelengths (3.4, 4.6, 12, and 22 microns) between January and December 2010, with approximately 20 comets observed at multiple epochs. Over 100 comets were observed to have extended surface brightness profiles, indicative of comae, tails, and/or trails. These data are being used to separate the nuclei and dust signals with the goal of characterizing the ejecta. Our multi-wavelength approach allows us to compute thermal fits for the dust, as well as color temperature maps. We will probe the grain size distributions around each comet. Here we will present an overview of our work to date, as well as detailed case studies. This publication makes use of data products from (1) WISE, which is a joint project of UCLA and JPL/Caltech, funded by NASA; and (2) NEOWISE, which is a project of JPL/Caltech, funded by the Planetary Science Division of NASA.

514.07 Characterization of Cometary Dust Tails in the WISE/NEOWISE Data Set

- Emily A. Kramer1, Y. R. Fernandez1, J. M. Bauer1, A. K. Mainzer1, T. Grav1, J. Masiero1, R. G. Walker4, R. Stevenson1, C. M. Lisse5, WISE Team
1University of Central Florida, 2Jet Propulsion Laboratory, 3Planetary Science Institute, 4Monterey Institute for Research in Astronomy, 5Applied Physics Laboratory, Johns Hopkins University.

The Wide-field Infrared Survey Explorer (WISE) mission surveyed the sky in four infrared bands (3.4, 4.6, 12, and 22 μm) between January 2010 and February 2011 [1,2]. By covering the entire sky, WISE observed over 150 comets [3,4,5]. Of these, about 1/3 are long-period comets and about 2/3 are short-period (Jupiter-family and Halley-type) comets, representing a statistically significant number of objects in each population. About half of the over 150 comets observed by WISE displayed a significant dust tail in the 12 and 22 μm (thermal emission) bands. To date, this data set is the largest single survey of infrared emission from comets. The comets in this study sample a range of heliocentric distances (1.09 to 16.31 AU) and orbital parameter space, allowing conclusions to be drawn about variations in activity across different populations. Using Finson-Probstein [6] dynamical models, we have characterized the dust behavior in each of the objects showing a significant dust tail, constraining the size and age of the particles. We present here the results as a statistical set, showing ensemble properties of cometary dust and noting the more interesting correlations. Acknowledgements: This publication makes use of data products from (1) WISE, which is a joint project of UCLA and JPL/Caltech, funded by NASA; and (2) NEOWISE, which is a project of JPL/Caltech, funded by the Planetary Science Division of NASA. The research here was also funded in part by a JPL Graduate Student Fellowship and NASA's Planetary Astronomy program. References: [1] Mainzer, A. et al. (2011) ApJ, 731:1; [2] Wright, E.L. et al. (2010) AJ, 140:6, 1868; [3] Bauer et al. (2011) ApJ, 738, 171; [4] Bauer et al. (2012) ApJ, 747, 49; [5] Bauer et al. (2012) ACM abstract no. 6112; [6] Finson, M. and Probstein, R. (1968) ApJ, 154, 327.

514.08 WISE/NEOWISE Comets: Nucleii and CO/CO2 Emission

- James M. Bauer1, R. Stevenson1, E. A. Kramer1, A. K. Mainzer1, T. Grav1, J. R. Masiero1, Y. R. Fernandez2, C. M. Lisse3, K. J. Meech1, P. R. Weissman1, R. Cutri1, J. W. Dailey1, D. J. Tholen1, R. G. Walker1, A. Lucas1, T. N. Gautier IV1, E. L. Wright8, WISE Team
1Jet Propulsion Laboratory, 2University of Central Florida, 3Planetary Science Institute, 4Monterey Institute for Research in Astronomy, 5Institute for Astronomy, University of Hawaii, 6Infrared Processing and Analysis Center, California Institute of Technology, 7Monterey Institute for Research in Astronomy, 8University of California, Los Angeles.

The Wide-field Infrared Survey Explorer (WISE) mission conducted a survey of the entire sky from January 2010 through January 2011, ending operations on February 1, 2011[1]. The spacecraft imaged over 150 comets, each simultaneously in four bands, at thermal (12 and 22 μm) and mid-IR (3.5 and 4.6 μm) wavelengths. These observations provide a unique opportunity to measure many of the otherwise inaccessible properties of a large sample of comets. Long period comets (LPCs) comprise roughly a third of the sample, along with Jupiter-family and Halley-type comets (JFCs & HTC). This ensemble provides meaningful statistics on comet population sub-types regarding nucleus sizes and albedos, dust characteristics, dust mass loss rates, and emission of gas species. We present here an overview of the ensemble’s nucleus size and 3.5 μm albedo distributions for a subset of the LPCs, HTCs, and JFCs. We also provide CO/CO2 gas emission based on 4.6 μm flux excess [2,3,4]. Related works [5,6] provide comparative analyses of dust properties in the active bodies across different comet populations.

514.09 A Quarter-Century of Observations of Comet 10P/Tempel 2 at Lowell Observatory

- **David G. Schleicher**1, M. M. Knight1, T. L. Farnham2, E. W. Schwieterman3, S. R. Christensen1
  1Lowell Obs., 2University of Maryland, 3University of Washington.

We report on our multi-epoch observations of Comet 10P/Tempel 2, primarily from Lowell Observatory. We obtained narrowband photometry during the 1983, 1988, 1999, and 2010 apparitions. Tempel 2 exhibited a rapid “turn-on” in activity ~90 days prior to perihelion, with the date of turn on varying somewhat from apparition to apparition. Peak production was achieved ~20 days after perihelion, with production decreasing gradually thereafter. The composition was “typical,” in agreement with our own earlier work as well as those of other authors. We also obtained 17 nights of imaging in 1999 and 29 nights of imaging in 2010/11. Tempel 2 exhibited a single, fan-like jet in both gas and dust images. The orientation of the jet varied due to changing viewing geometry during each apparition, but there was little to no change in jet morphology during a rotation period, implying that the source region producing it is near the pole. The pole solutions derived from R and CN data differ systematically, and we adopt RA=162°, Dec=+58° as the preferred solution for the ensemble. Numerical Monte Carlo jet modeling of the faint corkscrew structure evident in some CN images yields a source located only 10° from the pole and having a radius of about 10°, consistent with the source size needed to produce the measured water production. We measured the nucleus lightcurve on 15 nights from 2010 September through 2011 January. This yielded a nucleus rotation period of 8.950±0.002 hr, distinctly different from the rotation periods in 1999 (8.941±0.002 hr) and 1988 (8.932±0.001 hr). This continued spin-down marks only the second time a comet nucleus has been shown to sustain a change in period over multiple apparitions, and is presumably due to asymmetric torquing caused by outgassing. Support was provided by NASA Planetary Astronomy grants NNX09AB51G and NNX11AD95G.

515 Education and Public Outreach

Friday, 4:00 PM - 5:00 PM, Reno Ballroom

515.01 Earthspace: A National Clearinghouse For Higher Education In Space And Earth Sciences

- **Emily CoBabe-Ammann**1, S. Shipp2, H. Dalton2

The EarthSpace is a searchable database of undergraduate classroom materials for undergraduate faculty teaching earth and space sciences at both the introductory and upper division levels. Modeled after the highly successful SERC clearinghouse for geosciences assets, EarthSpace was designed for easy submission of classroom assets - from homeworks and computerinteractives to laboratories and demonstrations. All materials are reviewedbefore posting, and authors adhere to the Creative Commons Non-Commercial Attribution (CC-BY NC 3.0). If authors wish, their EarthSpace materials are automatically cross-posted to other digital libraries (e.g., ComPADRE) and virtual higher education communities(e.g., Connexions). As new electronic repositories come online, EarthSpace materials will automatically be sent. So faculty submit their materials only once and EarthSpace ensures continual distribution as time goes on and new opportunities arise. In addition to classroom materials, EarthSpace provides news and information about educational research and best practices, funding opportunities, and ongoing efforts and collaborations for undergraduate education. http://www.lpi.usra.edu/earthspace

515.02 Teachers Touch the Sky: A Workshop in Astronomy for Teachers in Grades 3-9

- **Bonnie J. Buratti**1, S. Banholzer2, P. A. Dalba1, S. Edberg1
  1JPL, 2California Inst. Technology.
Nine times during the past two decades, JPL technical staff assisted by master teachers conducted a one-week workshop for teachers in grades 3-9. The teachers are walked through hands-on activities that are all based on current projects in astronomy and space science at JPL. The activities are inquiry-based and emphasize the scientific method and fundamental math and science skills. Each year the workshop focuses on a NASA theme: in 2012 it was the Dawn Mission to the asteroid 4 Vesta. Several activities are based on the Lawrence Livermore Lab’s Great Exploration in Math and Science (GEMS) guides. Teachers tour JPL’s facilities such as the Space Flight Operations Center, the Spacecraft Assembly Facility, and the Mars Yard. The integration of the lessons into the teachers’ own curricula is discussed, and a field trip to JPL’s Table Mountain Observatory is included. Teachers learn of the resources NASA makes available to them, and they have the opportunity to talk to “real” scientists about their work. Teachers receive a stipend for participation plus classroom materials. Work funded by NASA through an E&PO supplement to the Dawn Participating Scientist Program.

515.03 Young Engineers and Scientists (YES) - Engaging Students and Teachers in Research

- Daniel C. Boice¹, P. Reiff²

¹Southwest Research Inst., ²Rice University.

Young Engineers and Scientists (YES) has been a community partnership between local high schools in San Antonio, Texas (USA), and Southwest Research Institute (SwRI) for the past 20 years. The goals of YES are to increase the number of high school students, especially those from underrepresented groups, seeking careers in science and engineering and to enhance their success in entering the college and major of their choice. This is accomplished by expanding career awareness, including information on “hot” career areas through seminars and laboratory tours by SwRI staff, and allowing students to interact on a continuing basis with role models at SwRI in a real-world research experiences in physical sciences (including astronomy), information sciences, and a variety of engineering fields. YES consists of two parts: 1) An intensive three-week summer workshop held at SwRI where students experience the research environment and 2) a collegial mentorship where students complete individual research projects under the guidance of SwRI mentors during the academic year. At the end of the school year, students publicly present and display their work, spreading career awareness to other students and teachers. Twenty-one YES 2012 students developed a website for the Dawn Mission (yesserver.space.swri.edu) and five high school science teachers are developing space-related lessons for classroom presentation. Partnerships between research institutes, local high schools, and community foundations, like the YES Program, positively affect students’ preparation for STEM careers via real-world research experiences with mentorship teams consisting of professional staff and qualified teachers. Acknowledgements. We acknowledge support from the NASA MMS Mission, SwRI, and local charitable foundations.

515.04 The Student Spaceflight Experiments Program: Access to the ISS for K-14 Students

- Timothy A. Livengood¹, J. J. Goldstein⁴, H. A. T. Vanhala⁵, M. Johnson⁶, M. Hulslander³

¹NCESSE, ²NanoRacks, Inc., ³National Air and Space Museum.

The Student Spaceflight Experiments Program (SSEP) has flown 42 experiments to space, on behalf of students from middle school through community college, on 3 missions: each of the last 2 Space Shuttle flights, and the first SpaceX resupply flight to the International Space Station (ISS). SSEP plans 2 missions to the ISS per year for the foreseeable future, and is expanding the program to include 4-year undergraduate college students and homeschool students. SSEP experiments have explored biological, chemical, and physical phenomena within self-contained enclosures developed by NanoRacks, currently in the form of MixStix Fluid Mixing Enclosures. Over 9000 students participated in the initial 3 missions of SSEP, directly experiencing the entire lifecycle of space science experimentation through community-wide participation in SSEP, taking research from a nascent idea through developing competitive research proposals, down-selecting to three proposals from each participating community and further selection of a single proposal for flight, actual space flight, sample recovery, analysis, and reporting. The National Air and Space Museum has hosted 2 National Conferences for SSEP student teams to report results in keeping with the model of professional research. Student teams have unflinchingly reported on success, failure, and groundbased efforts to develop proposals for future flight opportunities. Community participation extends outside the sciences and the immediate proposal efforts to include design competitions for mission patches (that
also fly to space). Student experimenters have rallied around successful proposal teams to support a successful experiment on behalf of the entire community. SSEP is a project of the National Center for Earth and Space Science Education enabled through NanoRacks LLC, working in partnership with NASA under a Space Act Agreement as part of the utilization of the International Space Station as a National Laboratory.

515.05 JunoCam: A Public Endeavor
- Candice Hansen¹, S. Bolton², M. Caplinger³, P. Dyches⁴, E. Jensen³, S. Levin⁴, M. Ravine³
  ¹PSI, ²SWRI, ³Malin Space Science Systems, ⁴JPL.

The camera on the Juno spacecraft is part of the payload specifically for public outreach. Juno’s JunoCam camera team will rely on public participation to accomplish our goals. Our theme is “science in a fishbowl” - execution of camera operation includes several amateur communities playing essential roles, and the public to help make decisions. JunoCam is a push-frame imager with 4 filters, built by Malin Space Science Systems (MSSS). It uses the Juno spacecraft rotation to sweep its field of view across the planet. Its wide field of view (58 deg) is optimized to take advantage of Juno’s polar orbit, yielding images of the poles with 50 km spatial scale. At perijove of Juno’s elliptical orbit images will have 3 km spatial scale. Jupiter is a dynamic planet - timely images of its cloudtops from amateur astronomers will be used to simulate what may be in the camera field of view at a given time. We are developing a website to organize contributions from amateur astronomers and tools to predict ahead where storms will be. Students will lead blog discussions (or the 2016 equivalent) on the merits of imaging any given target and the entire public is invited to weigh in on both the merits and the actual decision of what images to acquire. Images will be available within days for the public to process. The JunoCam team is relying on the amateur image processing community for color products, maps, and movies. When Junocam acquires images of the Earth in October 2013, we will use the opportunity to gain experience operating the instrument with public involvement. Although we will have a professional ops team at MSSS, the tiny size of the team overall means that the public participation is not just an extra - it is essential to our success.

515.06 Sun Earth Day 2012, The Transit of Venus: From Mauna Kea to the World
- Louis Mayo³
  ³NASA’s GSFC.

For 2012, NASA’s Sun Earth Day program (http://sunearthday.nasa.gov/ and http://venustransit.nasa.gov/), now in its 13th year, featured the transit of Venus as well as other close celestial encounters. A NASA sponsored team of scientists, social media experts, telescope technicians, students, and the NASA EDGE webcasting team journeyed to the 14,000 foot summit of Mauna Kea in Hawaii to view and share with the world this wondrous last in a lifetime show. Fifteen NASA missions participated providing educational resources and science content. And when it was all over, it was the biggest education event NASA ever held, bigger than the Super Bowl, the last shuttle flight, or Prince William’s wedding. Over 600 million web hits, 7.7 million web streams, and an estimated 500 million to 1 billion people reached. This presentation will highlight this phenomenal education program, discuss best practices, and show how we are replicating the Sun Earth Day approach and methods for other event based education programs.
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