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Comets: Visitors from the Early Solar System

by Beatrice Mueller

This is a great time to be a cometary scientist. We have had three successful spacecraft encounters in the past few years: Deep Space 1 flew by comet 19P/Borrelly in September 2001; Stardust flew through the dust coma of comet 81P/Wild 2 collecting samples in January, 2004, and delivering them successfully to Earth in January, 2006; and, most recently, Deep Impact (the mission, not the movie) hit comet 9P/Tempel 1 in July, 2005. We have also had two "naked-eye" comets in the middle of the nineties: comets Hale-Bopp and Hyakutake, both discovered by amateurs.

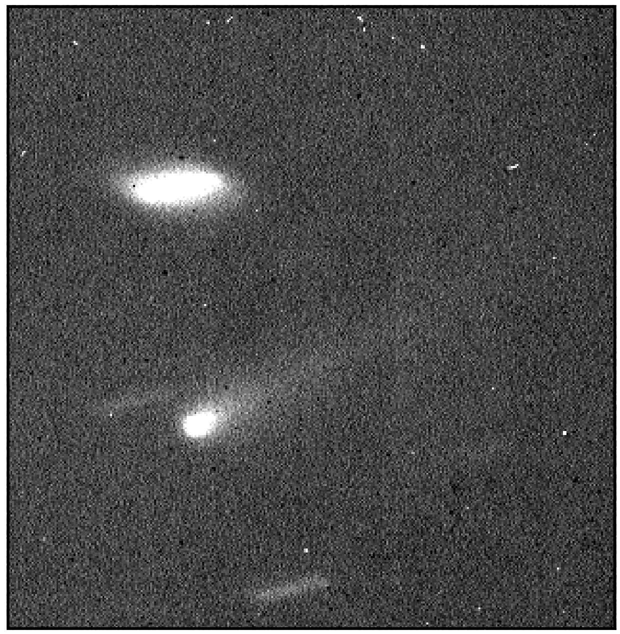
Although I am not on the science teams of these spacecraft missions, I was, and still am, involved with ground-based support observations doing additional scientific research. Only a few specific, but important, science questions can be answered at the time of the actual short-lived spacecraft flybys and much important research is accomplished long after these exciting events.

I am working currently on the rotation state of comet 10P/Tempel 2. Ignacio Ferrin and I (Mueller & Ferrin 1996, Icarus) observed this comet in 1994 and compared the derived rotation period with a previous pass and found a small change in the rotation period. Numerical simulations by Nalin Samarasinha (PSI & the National Optical Astronomy Observatory [NOAO]) show that all comets eventually spin faster. Nalin and I acquired data in 2000, 2001, and 2004 on this comet and are now hoping to confirm the earlier results. We are also investigating if the apparent change in period of rotation is really a spin-up or spin-down or if this period change masks an underlying tumbling motion.

How do comets die? One possibility is they spin-up so fast that they eventually break into small pieces that are no longer observable (there are other scenarios for a comet's demise and/or break up). But if comet Tempel 2 is indeed spinning up due to torques, as predicted by numerical simulations, this would be the first firm observational confirmation!

An observing team from various universities, NOAO, and PSI are preparing for a unique opportunity in May, 2006, when Comet 73P/Schwassmann-Wachmann 3 (SW3) will have a close encounter with the Earth — the closest encounter with a comet in a century. Its closest distance to the Earth will be 0.05 AU, which is only about 20 lunar distances!

(continued on page 2)



Raw CCD R-filter image of the main component of comet 73P/Schwassmann-Wachmann 3 (small white object). Note the extension and fuzziness of the comet and the narrow tail. The telescope was tracking the motion of the comet, thus the stars appear as streaks (the pinpoints are not stars but image defects). The large white object is a random galaxy. Astronomers note: The exposure time is 900 seconds; north is at the top, east is to the left; and the size is approximately 100 x 101 arcseconds.

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Comets *(continued from front page)*

The importance of this close encounter is that, unlike comets Hale-Bopp and Hyakutake, SW3 is a periodic comet, so it returns regularly. And if this were not exciting enough, this comet split into several pieces in 1995. This will be the first time we will be able to observe a split comet up close. We hope to study the different fragments, some which presumably have fresh material not previously exposed to the Sun.

So far, the main component and six other smaller components have been located. Yan Fernández, from the University of Central Florida, and I observed the largest component in early December, 2005. This component was already active and showed a narrow but distinct tail (see front page).

Comets are the least processed remnants of the early solar system formation, and studying them will give us insight into the conditions of the early solar nebula. What we have learned from the spacecraft missions is that comets are very diverse and, except for the Deep Impact mission which excavated a crater and released sub-surface material, we have literally only scratched the surface.

PSI scientist Cathy Weitz and her adorable 6-month-old son, Patrick Tyler Grant-Weitz, were in Tucson (from Virginia) on February 22. Cathy was in town for a HiRISE rehearsal meeting at the University of Arizona, as she is a co-investigator on the science team. The HiRISE camera, actually the High Resolution Imaging Science Experiment, on board the Mars Reconnaissance Orbiter reached Mars' orbit on March 10th. Stay tuned for exciting Mars images to arrive next fall.

Meanwhile, other babies take note of Patrick's superb choice in infant attire. Looking good, Cathy and Patrick!

Bill Feldman Joins PSI

In January, Bill Feldman joined PSI as a Senior Scientist. He has been a staff member at Los Alamos National Laboratory (LANL) for more than 34 years, contributing to a variety of projects under the umbrellas of Nuclear Treaty Verification and Non-Proliferation Technologies.

His formal training is in experimental nuclear physics (Ph.D. in Nuclear Structure from Stanford University), but he has branched into space plasma physics as applied to the solar atmosphere, the interplanetary medium and planetary magnetospheres. He later moved into planetary physics through being responsible for the fast neutron detector on LACE (Low-power Atmospheric Compensation Experiment), an Air Force satellite, in near-Earth orbit between 1990 and 1992; the three spectrometers (Gamma ray, Neutron and Alpha particle) on Lunar Prospector between 1998 and 1999; the Neutron Spectrometer on Mars Odyssey, between 2001 and the present; and the Neutron Spectrometer on Mercury Messenger. This spectrometer was checked out after launch in 2004 and will be turned on permanently after the second flyby of Venus in June, 2007. There will be three Mercury flybys before orbit insertion in 2011. Operation in Mercury orbit is scheduled for one Earth year. He is a co-investigator of the Gamma Ray and Neutron Detector on Dawn, a mission to Vesta and Ceres that will be launched some time in 2007.

He is presently principal experimentalist for the X-ray, Gamma-ray and Relativistic Electron (XGRE) experiment aboard TARANIS, a French mission to study upward lightning at Earth. The scientific objectives of XGRE are to determine and understand the generation mechanisms and consequent phenomenology of atmospheric gamma-ray flash events driven by upward lightning. This mission is currently in a Phase-A study, which will be reviewed for flight on April 6, 2006. If it is selected, launch will be in 2009.

Highlights of his scientific accomplishments include the development of a comprehensive understanding of the internal states of the solar wind and the terrestrial bow shock, the discovery of magnetic reconnection in the geomagnetic tail, the discovery of water near both poles of the Moon, and the mapping of water on Mars. He is a fellow of both the LANL and the American Geophysical Union.

Although he is a full-time employee of PSI, Bill and his wife Margrethe will be dividing their time equally between Tucson and New Mexico, where their grown children reside.

We are very proud to welcome Bill to PSI!

Correction: In our Winter 2005 Newsletter story on HiRISE, we neglected to mention that the HiRISE Operations Center (HiROC) is located at the Lunar and Planetary Laboratory of the University of Arizona, Tucson. The Principle Investigator of HiRISE is University of Arizona Professor Alfred McEwen.

Additional information is at http://hirise.lpl.arizona.edu.

David O'Brien Returns to Tucson

David O'Brien joined PSI as an Associate Research Scientist in March 2005 while he was working at the Observatoire de la Cote d'Azur in Nice, France. In January 2006, he moved to Tucson and was promoted to Research Scientist.

His research interests include the dynamics of asteroids and other small bodies in the solar system, the early evolution of the solar system and the formation of the terrestrial planets, and the geophysical and thermal modeling of planetary and icy satellite surface processes.

David received his Ph.D. in Planetary Science at the University of Arizona (Tucson), working with Professor Richard Greenberg on the collisional and dynamical evolution of the main-belt, near-Earth asteroids, and trans-Neptunian object populations. He also collaborated with PSI scientists Elizabeth Turtle and Elisabetta Pierazzo developing software to model the post-impact thermal evolution of craters on the Earth, which he later applied to craters on Titan. He was awarded a Poincare Fellowship at the Observatoire de la Cote d'Azur in Nice, where he worked with Alessandro Morbidelli to numerically model the primordial evolution of the asteroid belt and the formation of the terrestrial planets.

David is funded through NASA's Planetary Geology and Geophysics (PGG) and Outer Planets Research (OPR) programs to continue that work at PSI, as well as to explore a number of additional topics regarding the influence of the outer planets on the origin and evolution of the solar system.

A great outdoors person and an enthusiastic bicycler, David is seen here enjoying the beauty of the Gorges du Verdon, in south-eastern France, last year. However, he is pleased to be back in sunny, cycling-friendly Tucson, and PSI is very glad to have him on board.

PSI Welcomes Lijie Han

Lijie Han was born and raised in a small town in Hebei Province, northern China. In 1987, she went to Peking University's Geology Department for her undergraduate study. She continued her graduate studies there under the supervision of Professors Xunying Sun and Ren Wang. Lijie's research focused on numerical simulations of mantle convection and plate tectonics on Earth. She received her Ph.D. in Geodynamics from Peking University in 1997.

In summer 1997, Lijie moved to the U.S. to take a postdoctoral research position under the guidance of Professor Michael Gurnis at the California Institute of Technology, where she continued her work in numerical simulations of Earth's mantle convection and plate tectonics. While at Caltech, she met her future husband, Adam Showman, who suggested collaborating on research of Jupiter's icy satellites.

From 2001 to 2004, she took a position in the Earth Sciences Division at Lawrence Berkeley National Laboratory to work on the Yucca Mountain Nuclear Waste Disposal Project while at the same time continuing her research of Jupiter's icy satellites in collaboration with Adam.

In spring 2004, Lijie first learned about the wonderful work environment at PSI, and, recognizing it would be an ideal place for her, she applied for an Associate Research Scientist position and began writing proposals for an Outer Planets Research (OPR) grant. In the meantime, she took a position with the Planetary Sciences Department at the University of Arizona. With the successful funding of her OPR program grant she moved to PSI in 2005.

Now her research includes studying the influence of internal dynamics on Europa's (one of Jupiter's icy satellites) surface tectonics, and physical and chemical conditions for potential life on Europa. She performs numerical simulations to understand how thermo-compositional convection in Europa's icy shell affects geology and geophysics on Europa's icy surface. Lijie and her collaborators will perform numerical simulations to study thermal convection and volcanism in Europa's silicate mantle and their impacts on hydrothermal circulations and chemical conditions at the vicinity of the seafloor. These simulations will help the planetary science field to understand upper-mantle temperature structure, heat flux, and the extent to which partial melting (hence seafloor volcanism) occurs under conditions relevant to Europa. This study will provide strong constraints on chemical sources of energy for potential life on Europa.

PSI extends a warm welcome to Lijie.

(Note: Lijie may be pronounced LEET zee uh or LEE gee uh.)

Ice Crystals in Clouds: Rings Around the Sun and Moon *by Dave Lien*

In my previous article on cloud colors (Spring 2005 Newsletter), I described how small water drops can create concentric circular rings around the sun and moon. Here, I will discuss a much larger ring — the "halo" — seen around both the sun and moon, which is created by ice crystals instead of water drops.

The accompanying photograph shows a halo around the sun taken outside of PSI's west wing in October, 2005. The inner radius of the halo is about 22 degrees, which corresponds to about two palm-widths of my extended hand in this picture (the cloud coronae I described previously would have been completely obscured by my hand in this picture). Notice also the faint reddish tinge along the inside of the halo — the color indicates that the ice crystals are acting like prisms.

The halo is created when sunlight, or moonlight, passes through one face of a hexagonal ice needle, then exits out of another face (see embedded diagram). The ice crystals are very small — about the width of a human hair.

Sunlight is bent as it enters and exits the ice due to the change in the index of refraction between the air and ice. The minimum deviation is around 22 degrees, which is why the inner radius of the halo is 22 degrees. Sunlight can also pass obliquely through the ice needle as it enters one face and leaves the other, in which case the minimum total deviation of the ray of light can be as large as 24 or 25 degrees. This range of deviations is what creates the "width" of the halo.

The thin ice needles act like a prism, dispersing the colors of the sunlight into the colors of the rainbow. Red light is bent the least, which is why we see it on the inside of the halo. The colors that are bent more (green and blue) are mixed with the red from light passing through the ice needle obliquely, and this additive re-mixing of colors gives us the white light we see in the outer part of the halo.

Halos around the sun and moon are fairly common whenever you see high cirrus clouds (about 50% of the time, from personal experience), and I have seen them year round all over the U.S. In the midwest and eastern U.S., high cirrus clouds usually precede a warm front — if you see a halo in the clouds in Iowa, there is a good chance that precipitation will arrive within 12 to 24 hours! (Unfortunately, this does not hold true in Tucson.)

Director's Note: PSI Travels to DC to Fight Research Cuts

With Arizona Congressman Jim Kolbe (center) in DC, l-r, Michael Meyer (UA), Mark Sykes, David Hernandez (UA) and David O'Brien.

NASA space science, particularly solar system exploration, is facing some tough times. Administrator Griffin has redirected funds from space science to human space flight to cover that program's ever-increasing costs, even going as far as retroactively reducing *all* NASA research programs for 2006 by 15% to help pay for the Space Shuttle replacement vehicle and launchers. Research funds could be reduced an additional 15% next year. Even worse, Astrobiology is targeted for a 50% reduction.

It is ironic that these cuts come at a time when the amount of data from missions are skyrocketing, particularly from Mars, and headlines about water geysers discovered on Saturn's moon, Enceladus, are asking whether life might exist at such great distances from the Sun. Cutting these research programs guarantees that much of these data will never be studied and many significant questions never considered. Even funding for the NASA Planetary Data System is being cut, with the result that future data acquired at great expense might not be archived. A generation of young scientists is threatened. NASA is making decisions today that will leave American solar system exploration in permanent retreat unless they are reversed now.

PSI has taken a leadership role in challenging these actions by NASA, alerting the planetary community at large, writing commentary, and communicating with our Congressional delegations across the country. We are not alone. PSI Research Scientist David O'Brien and I traveled to Washington DC as members of an American Astronomical Society delegation to meet with Congressional staff. We supported initiatives by the White House and Congress to increase support for basic science, and pushed for the reversal of cuts to research programs and small competitively-selected missions in this year and next. We also argued for a firewall to be imposed, preventing the transfer of funds from space science to human space flight. The response from Congress has been very positive, but continuing action is required.

If you would like to help, please keep an eye on the PSI website for alerts and directions.

Mark V. Sykes
April 2006

LANDSLIDES GALORE: CLUES TO DATING MARTIAN GEOLOGY

by Bill Hartmann

High resolution orbital imaging of Mars continues to reveal intriguing small landforms, from glacier-like features to apparent water erosion gullies, as discussed in past issues of the PSI Newsletter. An ongoing challenge is to understand the ages of such features.

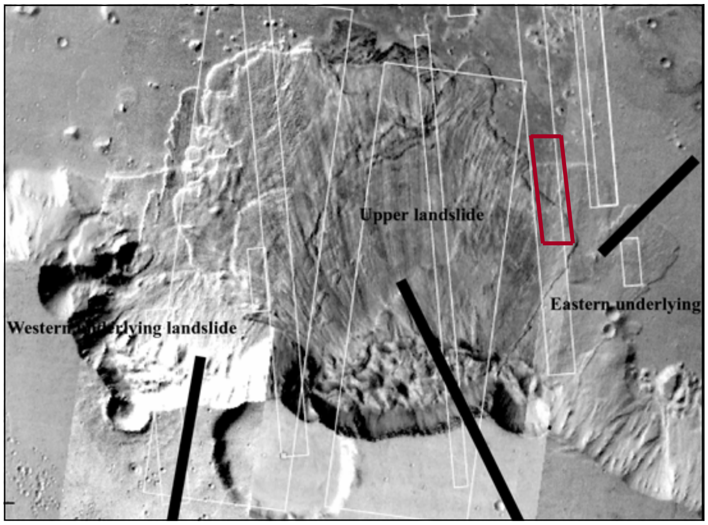
How can we estimate such ages? PSI has helped pioneer dating of Martian surfaces by counting the accumulated number of impact craters. The more craters, the older the surface. This system works well on large, state-sized provinces. But small features, which may cover only a few acres or a few square kilometers, may have accumulated only a few, small craters, (each perhaps only 20 meters across). In the last year or so, the dating problem has become controversial, because no one is sure of the rate of accumulation of such small craters and they are easily obliterated by Martian erosion or blowing sands.

Some investigators have suggested that the small craters mark not so-called "primary" meteorite impacts from space, but rather impacts of "secondary" debris blasted out of larger primaries. They argue that secondaries accumulate in statistical clusters so that different crater densities at small sizes would not reflect age differences, but merely random concentrations of the craters.

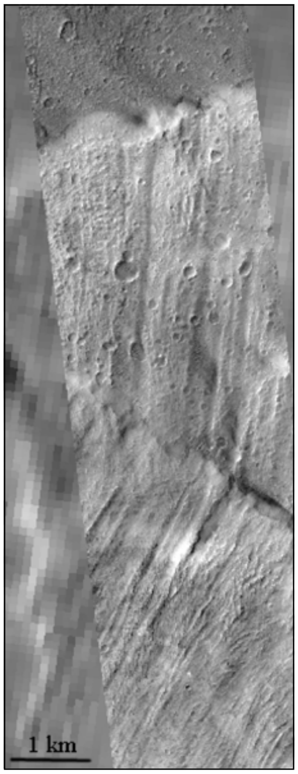
Landslides in Mars giant canyon system, Valles Marineris, may come to the rescue. In each landslide, material broke loose from the wall and extended out onto the canyon floor in a fan-shaped deposit. French researcher Cathy Quantin, who visited PSI in 2005, has used the PSI crater counting system in her Ph.D. dissertation (University of Lyon) to tabulate crater densities on the surfaces of several dozen of these landslides in order to estimate landslide ages and rates of formation.

As shown in these images, a result of her work is that different landslides clearly have different densities of small craters, and the crater densities correlate with the stratigraphic placement (i.e., overlap) of different landslides. This means that small craters apparently do carry information about ages of small features on Mars — the trick is to learn how to read that information. Current studies suggest that a small surface with virtually no visible small craters (10m to 50m sizes) can't be more than a few tens of My (million years) in age — extremely young, geologically speaking. Cathy, French researcher Nicolas Mangold (based in Orsay), and I have just submitted a collaborative publication about these studies.

Among other things, we use the crater statistics to suggest that the number of asteroid fragments scattered through the solar system (therefore crater numbers) has decreased as the asteroid belt grinds itself into dust — hence connecting with asteroid research by PSI dynamicists Don Davis, Steve Kortenkamp, Stu Weidenschilling, and Pasquale Tricarico. Thus, oddly enough, landslides on Mars may help clarify the evolution of the asteroid belt and the system for estimating ages in the solar system. As stated in ads for the recent film *Syriana*, "Everything is connected."



This mosaic of images shows several overlapping landslide deposits at the foot of the wall in the Ganges region of the Valles Marineris canyon complex on Mars. Boxes show locations of detailed images used to study the features; area outlined in red is shown in detail. Image width 92km (58 miles). (Figure courtesy of Cathy Quantin, University of Lyon; Viking mosaic from NASA.)



Closeup of eastern overlapping landslides outlined in red in above image. As found by French researcher Cathy Quantin, the younger (overlying) debris fan has a distinctly lower crater density of small craters than the older (underlying) deposit. This relationship confirms that small crater densities correlate with stratigraphy and ages, and refutes recent suggestions that statistical clustering makes small craters useless for dating. (Figure courtesy of Cathy Quantin, University of Lyon; images from Mars Global Surveyor, JPL, NASA.)

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1700 E. Fort Lowell Road, Suite 106
Tucson, AZ 85719-2395
Phone: 520/622-6300
Fax: 520/622-8060
www.psi.edu

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