Dedicated to Solar System exploration, PSI scientists are involved in NASA and international missions, fieldwork around the world, education, and public outreach.

**PLANETARY SCIENCE INSTITUTE**

The Planetary Science Institute is a private, nonprofit 501(c)(3) corporation dedicated to Solar System exploration. It is headquartered in Tucson, Arizona, where it was founded in 1972.

PSI scientists are involved in numerous NASA and international missions, the study of Mars and other planets, the Moon, asteroids, comets, interplanetary dust, impact physics, the origin of the Solar System, extra-solar planet formation, dynamical evolution of planetary systems, the rise of life, and other areas of research.

They conduct fieldwork on all continents around the world. They also are actively involved in science education and public outreach through school programs, children’s books, popular science books and art.

PSI scientists are based in 25 states and the District of Columbia, and work from various international locations.

**PSI BOARD OF TRUSTEES**

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*ON THE COVER:*

“Erupting plume along a fissure in icy plains near the south pole of Saturn’s satellite, Enceladus”  
Acrylic painting by William K. Hartmann, co-founder and Senior Scientist Emeritus at the Planetary Science Institute.

Even before Enceladus was first seen at close range by Voyager 2 in 1981, its surface was known to be unusual, having the highest reflectivity of any object known in the Solar System. Spectroscopic observations from Earth revealed the surface material is mostly frozen water. The Voyager images revealed a surface heavily cratered in some regions but with smooth, uncratered plains in other regions. Lack of craters in those plains indicated geologically very young ages, with occasional resurfacing by water eruptions. In 1985, the Cassini spacecraft discovered plumes, primarily water vapor, erupting from fissures near Enceladus’s south pole.

This painting shows the possible appearance of the plumes as seen from the surface of Enceladus, with Saturn dominating the sky. The rings are seen edge-on (since Enceladus orbits in the equatorial plane of Saturn), and parallel to the horizon (as required by viewing geometry from the either pole). The foreground landscape was painted outdoors on the floor of Kilauea caldera in Hawaii Volcanoes National Park. Fractured plates of lava were used as a stand-ins for plates of fractured ice that are likely to exist among the fissures and fractures of Enceladus.
We are pleased to announce the opening of a new office on the west side of Denver, Colorado. This office is anchored by the Mars Reconnaissance Orbiter Shallow Radar sounder, SHARAD, led by its U.S. Deputy Team Leader and PSI Senior Scientist Than Putzig, and Postdoctoral Research Scientist Isaac Smith. They are producing spectacular 3-D maps of the interiors of the Martian ice caps in addition to providing insights into other Martian terrains. We are open for business and there is much room for growth!

PSI infrastructure is also expanding with the major donation of a spectroscopy laboratory by the U.S. Geological Survey. This was built over decades by Roger Clark, who recently joined PSI as a Senior Scientist, and has been the source of a large number of research papers ranging from the study of planetary materials at cryogenic temperatures (simulating the surfaces on outer solar system satellites), Martian, lunar, and asteroid analogs, to terrestrial imaging spectroscopy including ecosystems research, mineral mapping and rapid response to disasters. The facility is now being reestablished in Tucson under Clark’s direction. We will seek commercial opportunities for supporting the facility and its maintenance. Otherwise, there are a vast number of planetary materials whose properties need to be measured to compare with detailed observations of planetary surfaces.

In mission news this year, PSI is involved with NASA’s OSIRIS-REx mission, which was successfully launched in September to return a sample from the primitive asteroid Bennu. Research Scientist Eric Palmer leads the effort to provide detailed models of the asteroid’s shape and topography to guide near-surface operations of the spacecraft. Other PSI scientists will be determining the photometric properties and composition of its surface.

Senior Scientist Candy Hansen leads the JunoCam imager on the NASA Juno mission to Jupiter, allowing the public to participate in the planning and selection of points of interest on Jupiter to image and discuss.

PSI scientists produced a lot of interesting science news as well.

Using the Dawn Gamma Ray and Neutron Detector (GRaND), which is led by Senior Scientist Tom Prettyman, evidence was found for water ice at high latitudes beneath the surface of the dwarf planet Ceres. Research Scientist Maria Banks and others found Mercury to be tectonically active as a consequence of the continuing cooling of the planet’s interior, evidenced by cliff-like landforms called fault scarps. Associate Research Scientist Jordan Steckloff was able to reproduce dramatic jets observed outbursting from the comet Churyumov-Gerasimenko by the Rosetta spacecraft with surface avalanches sliding into active areas. These jetting events had been a riddle since there is no internal heat source to explain a geyser-like eruption. Senior Scientist Alexis Rodriguez discovered evidence for mega-tsunamis in the ancient ocean of Mars that left large and characteristic sedimentary deposits.

Finally, Senior Scientist Darby Dyar received the Geological Society of America’s G.K. Gilbert Award for her outstanding contributions to the solution of fundamental problems in planetary geology, and I was honored by the Division for Planetary Sciences of the American Astronomical Society with the Harold Masursky Award for Meritorious Service to Planetary Science.

As an institute, we are always looking forward to improving opportunities for our scientists and educators, and we celebrate their wide ranging accomplishments.

— Mark V. Sykes
CERES REMAINS FOCUS OF PSI RESEARCH

Our scientists continued to play an important role in NASA’s Dawn mission as the spacecraft continued to investigate the dwarf planet Ceres.

Ceres’ surface globally contains materials that were altered by the action of liquid water within the interior of the dwarf planet, nuclear spectroscopy data from the Dawn spacecraft shows.

Dawn’s Gamma Ray and Neutron Detector (GRaND) instrument measured the concentrations of iron, hydrogen and potassium on the surface of Ceres. The elemental data show that materials were processed by liquid water within the interior, said Senior Scientist Thomas H. Prettyman.

Prettyman, Dawn mission Co-Investigator and lead for GRaND, is lead author of the Science paper “Extensive water ice within Ceres’ aqueously altered regolith: Evidence from nuclear spectroscopy” that was the topic of a press conference at the American Geophysical Union Fall Meeting in San Francisco.

Ceres’ uppermost surface is rich in hydrogen, with higher concentrations at mid-to-high latitudes, which is consistent with the presence of vast expanses of near-surface water ice. The ice table is closest to the surface at high latitudes.

“On Ceres, ice is not just localized to a few craters. It’s everywhere, and nearer to the surface with higher latitudes,” said Prettyman.

“These results confirm predictions made nearly three decades ago that ice can survive for billions of years within a meter of the surface of Ceres. The evidence strengthens the case for the presence of near-surface water ice on other main belt asteroids.”

Paper co-authors include PSI scientists Naoyuki Yamashita, William C. Feldman and Hanna G. Sizemore.

Hubble Space Telescope observations of Ceres have discovered the first evidence of sulfur, sulfur dioxide and graphitized carbon found on an asteroid. The sulfur species are likely associated with regions of recent activity, reports Senior Scientist Amanda Hendrix.

The discoveries were made by comparing Ceres’ ultraviolet-visible spectra to laboratory measurements and are presented in the paper “Ceres: Sulfur Deposits and Graphitized Carbon” that appears in the journal Geophysical Research Letters.

Senior Scientists Faith Vilas and Jian-Yang Li are co-authors.

The new HST observations are complementary to observations being made by instruments on the Dawn spacecraft in orbit at Ceres, covering additional wavelengths.

The presence of graphitized carbon is consistent with weathering of carbonaceous material on the asteroid’s surface, caused by processes such as charged particle bombardment.

“For the first time, a carbon-rich asteroid has been observed in the spectral region where graphitized carbons show unique spectral features,” said Hendrix. “Other dark asteroids probably have graphitized carbon on their surfaces as well.”

“This is a window to evidence of the effects caused by direct exposure to space for a primitive asteroid surface,” said Vilas.

“Both sulfur and sulfur dioxide are volatile species at typical Ceres temperatures – they aren’t likely to stick around for long before they sublime and are lost to space. These species could also migrate to cold regions on Ceres, such as some shadowed craters, where they are stable,” said Hendrix. “The presence of these volatile species on the surface suggests that they have recently been emplaced, perhaps by some sort of geothermal activity. Both Dawn observations and Herschel Space Telescope observations have suggested recent activity at Ceres, so it may be that sulfurous materials are involved in the activity.”

“It is remarkable that Ceres has this graphitized carbon covering much of its surface – which tells us that it has been exposed to weathering processes for eons – and yet Ceres also shows evidence of relatively young, fresh materials as well,” said Hendrix.

“With two space probes planning to rendezvous with dark, carbon-rich asteroids in the next few years, these Ceres observations are helping us to build a good foundation for our understanding of these type of bodies,” Vilas said.

A Dawn Science Team meeting in Tucson attracted about 100 researchers from around the world. The event was locally arranged by PSI.

Participants shared information that focused on data from the dwarf planet Ceres, where NASA’s Dawn spacecraft is currently investigating.

Three days of the gathering were spent at the Hilton El Conquistador Resort, and the final day was a mapping meeting held at PSI’s Conference Center.
Dawn Images Reveal Ceres’ Mysterious Mountain Ahuna Mons

Senior Scientist David O’Brien worked on new Dawn images showing Ceres’ mysterious Ahuna Mons. O’Brien has worked on a number of images taken by the Dawn spacecraft since it arrived at Ceres a year ago. These are taken by Dawn during its low-altitude mapping orbit 240 miles, or 385 kilometers, above the surface.

Ceres’ Ahuna Mons

Left above, Ceres’ mysterious mountain Ahuna Mons is seen in this mosaic of images from Dawn in December 2015. The resolution of the component images is 120 feet (35 meters) per pixel. On its steepest side, this mountain is about 3 miles (5 kilometers) high. Its average overall height is 2.5 miles (4 kilometers). These figures are slightly lower than what scientists estimated from Dawn’s higher orbits because researchers now have a better sense of Ceres’ topography. The diameter of the mountain is about 12 miles (20 kilometers). Researchers are exploring the processes that could have led to this feature’s formation.

Left below, a side-perspective view of Ceres’ mysterious mountain Ahuna Mons taken by Dawn in low-altitude mapping orbit.

Credits: NASA/JPL-Caltech/UCLA/MPS/DLR/IDA/PSI

Nuclear spectroscopy data from the Dawn spacecraft shows that Ceres’ surface globally contains materials that were altered by the action of liquid water within the interior of the dwarf planet.
NEW MARS FINDINGS

Our scientists were involved in some exciting research on Mars in 2016, offered the public the opportunity to help point NASA to new Mars findings, and studied ways rovers can more efficiently explore the planet.

The search for life, or evidence that Mars is or was potentially habitable, have been the focus of research for many years.

Work by Senior Scientist J. Alexis Palermo Rodriguez has found an area on Mars that could possibly have harbored life.

Groundwater circulation beneath a massive tectonic rift zone located along the flanks of some the Solar System’s largest volcanic plateaus resulted in the formation more than 3 billion years ago of some the deepest basins on Mars, Rodriguez found.

These basins could have been episodically covered, perhaps during hundreds of millions of years, by water lakes that were discharged from subsurface pressurized sources, Rodriguez writes in “Groundwater flow-induced collapse and flooding in Noctis Labyrinthus, Mars” that appears in Planetary and Space Science.

This shows an area on Mars that could possibly have harbored life.

“The temperature ranges, presence of liquid water, and nutrient availability, which characterize known habitable environments on Earth, have higher chances of forming on Mars in areas of long-lived water and volcanic processes,” Rodriguez said. “Existing salt deposits and sedimentary structures of possible emplacement within Martian paleo-lakes are of particular astrobiological importance when looking for past habitable areas on Mars. This is particularly true if the discharge of early Mars groundwater, perhaps likened to hydrothermal systems that were active for billions of years, contributed to the formation of the paleo-lakes, as it is proposed in this investigation.”

The detection of paleo-lake sites on Mars is particularly challenging because under the planet’s frigidly cold and thin atmosphere, their ponded water would have behaved differently than on Earth, he said.

“In this research we propose a Tibetan region where high mountain lakes show unique sets of landforms that might explain some basin interior features in the studied region of Mars.”

Senior Scientist Cathy Weitz and Senior Research Associate Thomas Platz are co-authors on the paper.

Rodriguez also found evidence of possible mega-tsunami deposits on Mars that revives the hypothesis that ancient oceans existed on the planet.

New geologic mapping in the Martian northern plains reveals vast sedimentary deposits that were likely emplaced by two mega-tsunamis, Rodriguez wrote in a paper in Scientific Reports. The proposed tsunami events had onshore wave heights that likely reached 120 meters and moved several hundred kilometers inland.

“For more than a quarter century, failure to identify shoreline features consistently distributed along a constant elevation has been regarded as inconsistent with the hypothesis that a vast ocean existed on Mars approximately 3.4 billion years ago. Our discovery offers a simple solution to this problem: widespread tsunami deposits distributed within a wide range of elevations likely characterize the shorelines of early Martian oceans,” Rodriguez said.

“The tsunamis could have been triggered by bolide impacts, which about every 3 million years, generated marine impact craters approximately 30 kilometers in diameter. Thus, the proposed tsunami events likely took place a few millions years apart,” said Platz.

Mega-tsunamis also form on Earth, and their deposits, too, show tremendous variability in their topographic distribution and inundation distances. However, these are extremely rare and catastrophic events, and consequentially their deposits are mostly obscured – or removed – by younger resurfacing processes.

“During the time period that separated the two tsunami events the ocean level receded to form a lower shoreline and the climate became significantly colder. Evidence for climate change is reflected in the morphology of the tsunami deposits. The older tsunami
emplaced enormous boulder-rich deposits and as the wave retreated back into the ocean it formed widespread backwash channels,” Rodriguez said.

In contrast, the younger tsunami emplaced lobes that froze in place, he said. Sampling of these materials by future landers is of particular scientific importance because they likely consist of frozen ancient ocean water brines. Furthermore, these materials are in relatively close proximity to the Mars Pathfinder landing site, demonstrating possible accessibility with current and tested technologies.

The vast areas covered by these ice-rich lobes imply that the frozen remnants of early Mars ocean water might be widespread, not just rare and localized occurrences. The fact that many of the lobes have well-defined boundaries and that their flow-related shapes are not significantly modified suggests that they might still retain much of the originally emplaced materials, which could be informative of the ocean’s primary composition.

Senior Scientist Candice Hansen asked the public to help NASA find interesting sites to investigate on Mars. Input from about 10,000 volunteers viewing images from Martian south polar regions has identified targets for closer inspection, yielding new insights about seasonal slabs of frozen carbon dioxide (dry ice) and erosional features called “spiders.”

The volunteers from around the world have been exploring the surface of Mars by examining images from the Context Camera (CTX) on NASA’s Mars Reconnaissance Orbiter (MRO) and identifying certain types of terrain around Mars’ South Pole. The collected information is used by scientists planning observations of Mars by the orbiter’s High Resolution Imaging Science Experiment (HiRISE) camera, which photographs much less ground but in much greater detail, compared to CTX.

“It's heartwarming to see so many citizens of Planet Earth jump in to help study Mars,” said HiRISE Deputy Principal Investigator Hansen. “Thanks to the discovery power of people, we're taking pictures of features of Mars with HiRISE of places we would not have imaged without this assistance.”

“In the spring the dry ice turns to gas and carves unusual features in the Mars surface, resulting in exotic terrains described informally as ‘spiders,’ ‘Swiss cheese’ and ‘channel networks,’ – this is what we asked our citizen scientists to find in the CTX images,” said Hansen.

The terrain type called spiders or araneiform (from the Latin word for spiders) is characterized by multiple channels converging at a point, resembling long legs of a spider. Previous studies concluded this ground texture results from thawing of extensive sheets of ice bottom-side first as the ice is warmed by the ground below; thawed carbon dioxide gas builds up pressure underneath. Wherever it finds a place to escape through the overlying sheet of remaining ice, a rapid flow out through that vent pulls dust with it. Gas flowing under the ice toward the escape point picks up that dust as it carves the channels that resemble spiders’ legs.

Senior Scientists R. Aileen Yingst, Michelle Minitti and Becky Williams were on a team that worked at a site near Green River, Utah, that is the location of an ancient inland sea, designing and testing rover operations to optimize scientific returns for missions on distant planets. The research was part of NASA’s GeoHeuristic Operational Strategies Tests (GHOST) program.

The team tested rover science operations protocols to determine best practices for a future sample cache and return mission to Mars planned for 2020. The testing took place in a Mars analog environment – specifically an environment that may have once been habitable. Lessons learned on Earth can improve efficiency, and scientific results, when rovers are used to explore Mars and other distant worlds.

“It’s heartwarming to see so many citizens of Planet Earth jump in to help study Mars.”

—Candice Hansen, Senior Scientist and HiRISE Deputy Principal Investigator
Even though NASA's MESSENGER spacecraft ended its scientific operations by crashing into Mercury April 30, 2015, PSI scientists remained busy analyzing data collected from the planet closest to the Sun.

Images acquired by the MESSENGER (MErcury Surface, Space ENvironment, GEochemistry, and Ranging) spacecraft show geologic features that indicate Mercury is likely still contracting today, joining Earth as a tectonically active planet in our Solar System.

Previously undetected small fault scarps were observed in images collected during the MESSENGER mission's final 18 months in orbit around Mercury. During these last months of the mission, the spacecraft's altitude was lowered, allowing the surface to be imaged at higher resolutions than ever before possible.

Research Scientist Maria Banks is a co-author on “Recent tectonic activity on Mercury revealed by small thrust fault scarps” that appeared in Nature Geoscience.

“These small-scale thrust fault scarps are orders of magnitude smaller, only a few kilometers in length and tens of meters of relief, than larger scarps previously known to exist on the surface of Mercury,” said Banks, who studied MESSENGER images to find and analyze these small-scale tectonic structures. “Steady meteoroid bombardment quickly degrades and destroys structures this small, indicating that they must have formed relatively recently. They are comparable in size to very young fault scarps identified on the lunar surface attributed to shrinking of the Moon.”

Fault scarps appear as cliff-like landforms. Larger, older scarps were identified in both MESSENGER and Mariner 10 images and are evidence of the global contraction of Mercury as its interior cooled causing the crust to shrink.

The young age of the small scarps means that Mercury joins Earth as a tectonically active planet in our Solar System, with new faults likely forming today as Mercury's interior continues to cool.

Active faulting, paired with evidence for ancient faulting and also the recent discovery by PSI Senior Scientist Catherine Johnson that Mercury's global magnetic field was present billions of years ago, offer consistent support for long-lived slow cooling of Mercury's still hot outer core.

Slip along thrust faults associated with small lunar scarps is possibly connected with shallow moonquakes detected by seismometers deployed during the Apollo missions. Some of these moonquakes reached magnitudes of near 5 on the Richter scale. Seismometers deployed on Mercury in future missions would likely detect Mercury-quakes associated with ongoing slip events on small faults and reactivated older large faults.

Research led by Senior Scientist Deborah Domingue Lorin offers new insights on Mercury's surface materials. She is lead author on an Icarus paper whose results indicate that Mercury's regolith is smoother on micrometer scales and has a narrower particle size distribution with a lower mean particle size than the lunar regolith.

Regolith grain structures are different than those of regolith particles on either the Moon or those asteroids observed to date by...
spacecraft, and suggest that Mercury’s regolith contains a compositionally distinct component as compared to the Moon.

When images are acquired by spacecraft of a planetary surface, they are not all acquired at the same illumination and viewing geometries. Nor are they typically acquired under the standard illumination and viewing geometries as laboratory spectral measurements of minerals, to which they are often compared to derive surface composition.

Photometric models are used to standardize images obtained at a variety of illumination and viewing geometries, thus facilitating the construction of image mosaics and maps in addition to the comparison with laboratory measurements. Application of these photometric models is also used to infer the physical properties of the upper surface, such as porosity and roughness.

Geologic features indicate Mercury is likely still contracting today, joining Earth as a tectonically active planet in our Solar System.

EVIDENCE OF MERCURY’S TECTONICS

Figure A, above: A cluster of small lobate scarp thrust faults on Mercury’s intercrater plains. The longest scarp in the cluster (upper arrows) is ~4.3 km in length.

Figure B, above: Close up view of small scarp shown in A. Inset: A small impact crater ~90m in diameter (lower arrow) is potentially disturbed or crosscut (note the lack of a well-defined rim on the scarp face) by the scarp segment, and another crater ~135m in diameter (upper arrow) may be horizontally shortened. The box in B shows the location of the inset. Figure modified from Watters et al., 2016.
PSI scientists and staff continued to garner prestigious awards during 2016.

Senior Scientist Darby Dyar received the Geological Society of America’s G.K. Gilbert Award for her outstanding contributions to the solution of fundamental problems in planetary geology. Dyar received the award at the GSA Annual Meeting in Denver.

Dyar is a mineralogist and spectroscopist interested in a wide range of problems relating to the evolution of the Solar System. Her research focuses on the signatures of hydrogen and oxygen throughout our Solar System, particularly in terrestrial bodies such as the Earth, the Moon, Mars, and the parent bodies of meteorites. She studies rocks from diverse localities on Earth from the deep oceans to Antarctica, as well as lunar rocks and meteorite samples.

Director and CEO Mark Sykes received the 2016 Harold Masursky Award for Meritorious Service to Planetary Science.

Outbursts of comet nuclei are likely caused by surface avalanches rather than geyser-like eruptions from within, research by Associate Research Scientist Jordan Steckloff shows.

Rapid asymmetric brightening events of comets, observed for decades, have long been thought to be the result of some sort of eruption of materials from deep within the interior of a comet. High-resolution images from Rosetta observations of 67P/Churyumov-Gerasimenko show outbursts that resemble plumes of material from geysers on Earth.

“However, there is a major problem with this model. There is no internal heat source on comets to power geyser-like eruptions,” Steckloff said. “Instead, these outburst plumes are the natural result of avalanches.”

Observations of Comet Pan-STARRS (P/2016 BA14) using the NASA Infrared Telescope Facility (IRTF) on Mauna Kea, Hawaii during a close flyby of the Earth at a distance of 3.6 million kilometers (2.2 million miles), show that it reflects less than 3 percent of the sunlight that falls on its surface. For comparison, fresh asphalt reflects about 4 percent of the light that falls on it.

“We measured the spectral and thermal properties of the comet using the NASA IRTF and found that the comet reflects between 2 to 3 percent of the sunlight that falls on it,” said Research Scientist Vishnu Reddy, who estimates the size of the comet to be between 600 meters and 1.2 kilometers (0.4 mile and 0.75 mile) in diameter.

“It is an extremely rare opportunity to be able to study a pair of comets with historically close flybys. Measuring the physical properties of both comets will help us understand the evolution of comets in general,” said Senior Scientist Jian-Yang Li. Li was observing 252P/LINEAR with the Hubble Space Telescope during its close encounter.

Astronomers using NASA’s Hubble Space Telescope captured images of Comet 252P/LINEAR just after a close encounter with Earth on March 21. The close proximity to the comet offered scientists new insights on the body’s nucleus.

“Because comets are usually only a few kilometers in size, and probably less than 1 kilometer for this comet, reliable measurement of size is best done when they are close to us. That’s why the close approach to Earth of this comet offered us a great opportunity to study it,” said Li, who led this project to observe 252P with HST during its close approach to Earth.

“With the small distance of this comet to us, and the high spatial resolution of HST, we reached 1.6 kilometers per pixel resolution, which is the highest for HST ever on a comet,” Li said. “For comparison, ground-based observations of this comet have more than 10 times lower resolution than HST!”

PSI Senior Scientist Nalin Samarasinha also worked on the project.
The Masursky award was presented by the American Astronomical Society Division for Planetary Sciences at the DPS annual meeting in Pasadena, Calif.

The award was established by DPS to recognize and honor individuals who have rendered outstanding service to planetary science and exploration through engineering, managerial, programmatic or public service activities.

Senior Scientist Michelle Thomsen was honored by being asked to present the Van Allen Lecture at December’s meeting of the American Geophysical Union. Thomsen spoke to a crowd of 500 scientists and guests about how magnetospheres are influenced by the intrinsic properties of the planets they surround.

Thomsen was particularly thrilled by her selection as the annual lecture was established in honor of Dr. James Van Allen, her thesis advisor.

Research Assistant Emily Joseph and Public Information Officer Alan Fischer were honored for their work in publicizing NASA’s Dawn mission to the dwarf planet Ceres.

Joseph and Fischer are members of the Dawn Communications and Outreach Team that received a 2016 NASA Group Achievement Award “for outstanding execution of the Ceres public communications campaign, sharing the excitement of the Dawn mission with the world,” NASA said.

PSI scientists received a NASA Group Achievement Award for their work on NASA’s Dawn Mission.

Thomas H. Prettyman, William C. Feldman, Naoyuki Yamashita, Jeffrey Morgenthaler, Bruce Barraclough and Robert C. Reedy are on the Dawn Gamma-Ray and Neutron Detector team that was cited by NASA for “exceptional achievement in development, building, and operating the Dawn Gamma Ray and Neutron Detector, contributing to mission success at Vesta and Ceres.”

Spectroscopy Lab Arrives At Tucson PSI Facility

Senior Scientist Roger Clark moved a spectroscopy lab into PSI’s Tucson facility. The lab equipment came from Colorado, where it was donated by the U.S. Geologic Survey office in Lakewood.

The equipment, an environment chamber facility, features four different chambers that can study temperatures, pressures and other factors. “This simulates planetary surfaces virtually anywhere in the Solar System, from hot Mercury to almost Pluto,” Clark said.

The facility is being set up in Tucson’s West Wing building under Clark’s direction. Plans call for the lab to offer commercial spectroscopy services to support the facility and its maintenance.

Interns Make Archived NASA Planetary Science Data More Accessible

An internship program offered by NASA’s Planetary Data System’s Small Bodies Subnode hosted at PSI is making archived scientific information more accessible to researchers and the public.

“This is an outstanding opportunity for NASA scientists to connect with the youth of the nation,” said Research Scientist Eric Palmer, who heads the intern program.

Two Pima Community College (PCC) students, Nathan Berg and Ki Huang, kicked off the program, working to improve access to the data archive, said Senior Scientist Beatrice Mueller, Co-Investigator on the program. “Berg and Huang gather and analyze information, engage in creative communications, and increase their knowledge of computer web page design while learning about the NASA’s space science missions and research.”

continued on page 12
Frances Butcher and Katherine de Kleer were named winners of the 2017 Pierazzo International Student Travel Award. The Pierazzo award was established by PSI in memory of Senior Scientist Betty Pierazzo to support and encourage graduate students to build international collaborations and relationships in planetary science.

Butcher, of the Open University in the United Kingdom will receive the award for a non-U.S. based graduate student traveling to a planetary meeting in the U.S. Her research title is “Eskers Associated with Extant Glaciers in Mid-Latitude Graben on Mars: Evidence for Geothermal Controls upon Recent Basal Melting of Glaciers on Mars” and she will be attending the Lunar and Planetary Science Conference in The Woodlands, Texas, March 20-24, 2017.

University of California, Berkeley student de Kleer will receive the award for a U.S.-based graduate student traveling to a planetary meeting outside the U.S. Her research title is “The Impact of Io’s Volcanism on the Jovian Extended Neutral Environment” and she will be attending the joint Japan Geoscience Union – American Geophysical Union meeting in Chiba, Japan, May 20-25, 2017.

A PSI representative will present each awardee with a certificate and check for $2,000 at their respective conferences.

Butcher and de Kleer Named 2017 Pierazzo Award Winners

“This internship will benefit us by improving our archive web sites, which will help our users,” Mueller said. “It will be beneficial for the students to provide them with technical skills they might otherwise not be able to acquire, and will prepare them better for the job market.”

PSI has provided PDS archiving services for more than 20 years and last year received a $4 million, five-year cooperative agreement from NASA to manage the Planetary Data System’s Asteroid and Dust Subnode.

The intern program runs five years, and PSI intends to seek an extension for an additional five years, Mueller said.

The project is funded by a contract to PSI from NASA.

PARTNERING WITH CHINA

PSI Director Mark Sykes, left, is shown signing an agreement in Beijing between PSI and Chemical Industry Press and Beijing Touch Lab to explore education and public outreach opportunities. Dr. Wenhu Zhang, right, is a Deputy Chief Editor at CIP, and an EPO Scientist at the Touch Lab. CIP is the largest publisher in China.
As it has been for more than 40 years, PSI’s strength and advantage continue to be in its people. Our culture of openness and high level of mutual support distinguishes us as an organization.

In 2016 PSI continued to grow, adding 20 new research and administrative staff members.
PSI Education and Public Outreach

Education and public outreach efforts continue with new funding and many ongoing events across the country and the world.

It was a busy year for education and public outreach for numerous PSI scientists, education specialists, staff, and docents who hosted or participated in more than 100 education and public outreach events across the United States and the world during 2016. Events included professional development workshops for K-12 teachers, star parties, youth camps, public science events, public lectures, writing articles for popular magazines, hosting outreach websites, judging science fairs, mentoring students, and classroom visits. PSI personnel active in education and outreach efforts included scientists Elisabeth Adams, Alice Baldridge, Amy Barr, Mark Bishop, Roger Clark, David Crown, Jules Goldspiel, Jennifer Grier, David Grinspoon, Candice Hansen, Bill Hartmann, Amanda Hendrix, Liz Jensen, Steve Kortenkamp, Scott Mest, Jim McElwaine, Beatrice Mueller, Dave O’Brien, Nathaniel Putzig, Nalin Samarasingha, Vishnu Reddy, Isaac Smith, Jordan Steckloff, Karen Stockstill-Cahill, Mark Sykes, Cristina Thomas, Henry Throop, Bryan Travis, Dave Vaniman, Faith Vilas, Ryan Watkins, Linda Welzenbach, Becky Williams, Chuck Wood, Shawn Wright, Zou Xiao-Duan and Aileen Yingst. Education specialists include Andrea Jones, Larry Lebofsky, Sanlyn Buxner and Thea Cañizo, and research assistants Emily Joseph and Maya Bakerman. Additionally, staff member Dianne Janis and docents Al Anzaldua, Bob Gent, David Acklam, Rob Bovill and Nancy Lebofsky also participated.

Professional Development

Workshops were held for teachers in Southern Arizona, California, and Maryland through both grant funded and volunteer efforts by our education specialists. PSI supported workshops through a collaborative program with Cosmoquest that highlighted lunar science and online crater mapping. A workshop series included activities and support to help teachers engage students in astronomy related science fair projects. Additional workshops for teachers and librarians were offered at NASA’s Goddard Space Flight Center related to lunar and planetary science and exploration, supported by the Lunar Reconnaissance Orbiter (LRO) mission and the DREAM2 team in NASA’s Solar System Exploration Research Virtual Institute (SSERVI). Instructors in these education programs included Buxner, Cañizo, Jones, and Lebofsky.

Additionally, Grier, Lebofsky and Buxner provided professional development workshops and opportunities for scientists at professional science conferences including the American Astronomical Society Meeting, the Division for Planetary Science Meeting, the American Geophysical Union Meeting, and the 128th Annual Meeting of the Astronomical Society of the Pacific.

Programs for Students

During 2016, Associate Research Scientist & Senior Education Specialist Mark Bishop mentored four Year 11 students from the Australian Science and Mathematics School in Adelaide who worked on an analogue study of grain size, shape and mineralogy of terrestrial basaltic aeolian sediments and the Bagnold dune field, Mars. The group presented this work as a poster at the Japan International Science Fair and received first place for their efforts. Subsequently, two students have continued with this research using MAHLI data from the MSL, alongside technical guidance from Senior Scientist Aileen Yingst, and have submitted their work as the formal Research Project requirement of the South Australian Certificate of Education.

PSI provided summer science camps for Tucson students in first through third grades at the Children’s Museum Tucson. Students learned about objects in the Solar System and space exploration. PSI also supported an after-school science program, “I am a Scientist,” at the museum for third graders from local downtown Tucson schools through a collaborative grant by way of the Institute of Museums and Library Services.

Public Events in Tucson

PSI co-hosted an overnight event for families at the Children’s Museum Tucson to explore space, look through telescopes, and interact with scientists David Crown, Beatrice Mueller, Nalin Samarasingha and Larry Lebofsky. Activities included making comets, exploring volcanoes and volcanic rocks, and handling meteorites.

Lebofsky and other EPO team members staffed exhibit tables at three major Tucson public events, each drawing hundreds to thousands of adults and children. They presented hands-on experiences with PSI’s Meteorite and Impact Rock Kits. The events were the Future Innovators Night held in conjunction with the SARSEF Regional Fair, the two-day SpaceFest VII, and the two-day Tucson Festival of Books (TFOB). TFOB was a collaboration with the Vatican Observatory Foundation.

In December, PSI partnered with Tucson’s professional hockey team, the Roadrunners, to provide thousands of visitors access to meteorites during a regular season game. Lebofsky, Buxner and Janis provided activities during the game and information about PSI.
PSI Fundraising and Development

PSI is a nonprofit research organization that relies primarily on NASA for its funding. Because the NASA budget is vulnerable to government budget cuts, there is an inherent uncertainty in depending exclusively on NASA funding to support the organization’s growth. Therefore, it is important for PSI to seek additional funding support through the private sector.

We have several mechanisms in place that we employ to attract new sources of private sector funding. First and foremost we strive to raise the visibility of PSI via traditional media (local, national, and international) as well as social media via Facebook, PSI website, and Twitter. All of these efforts contribute to keeping the public and our supporters informed about PSI’s accomplishments. Specific fundraising events and campaigns throughout the year include:

Annual Dinner

The 2016 Annual Fundraising Dinner featured PSI’s own David H. Grinspoon, a nationally recognized speaker (a.k.a. Dr. FunkySpoon), author, and radio host. David is a recipient of the prestigious Carl Sagan Medal for Excellence in Public Communication and was named “Alpha Geek” by Wired Magazine.

The event’s table sponsors included PSI Board members, staff members, and local businesses that support the Institute’s research efforts.

A highlight of the evening event was the raffle drawing that included rare and unique items such as meteorites as well as a telescope, binoculars, photos and custom-made posters of the night sky, one-of-a-kind jewelry, books, and much more.

Challenge Match Campaign

For the second year PSI launched a “Challenge Match Campaign” initiative. A group of generous PSI supporters offered the Institute a $10,000 pledge that PSI would receive if it could raise funds to match the pledge. The 2016 effort was highly successful – we not only matched the pledge, we exceeded it.

“Friends of PSI” Program

The “Friends of PSI” program is our core group of supporters comprised of individuals and businesses who further PSI’s global work through an annual (tax deductible) membership donation. “Friends” receive the PSI Quarterly Newsletter, a discount on tickets to the Annual Dinner, breaking press release announcements, and invitations to special events throughout the year including the popular monthly social hour.

Social Hours

The always popular and lively “Friends” social hour is generally held on the last Friday of the month. This informal gathering of “Friends of PSI,” scientists and staff is an opportunity to engage in friendly discussion and networking. In order to make the event convenient to our group wherever they might work or live in the Tucson area, we vary the location around town and therefore support a variety of local establishments.

Outreach

PSI scientists represent the organization at numerous events throughout the year. Not only do our scientists conduct educational workshops for teachers, but they also volunteer as keynote speakers at venues such as local astronomy clubs and as judges at science fairs.

Grants and Business Sponsorships

We actively pursue funding through submitting grant applications and making presentations to Tucson-area businesses that we have identified as possible donors and/or sponsors of our work.

Other

We have continued our partnership with Amazon through the AmazonSmile program and we maintain a “PSI Gift Shop” on the PSI website.

Other Public Events

Education Specialist Andrea Jones served as Director of International Observe the Moon Night (InOMN), an annual worldwide celebration of lunar and planetary science and exploration. Jones organized an LRO/InOMN outreach event at NASA’s Goddard Space Flight Center in Maryland, attended by several hundred visitors. Almost 600 events were registered worldwide in over 50 countries, attended by an estimated 100,000 visitors.

Additionally, Jones helped organize MarsFest, a planetary analog festival held in Death Valley National Park during the National Park Service’s Centennial. The goal of the event was to celebrate and raise awareness of the rich heritage of planetary science and exploration research conducted in Death Valley National Park, as well as the park’s dark skies.
THANK YOU TO OUR 2016 BENEFACERS

With deep appreciation the Planetary Science Institute acknowledges the following individual and organizational benefactors who made contributions between Jan. 1, 2016 and Dec. 31, 2016.

$25,000 and up
Dr. David P. Brown

$15,000-$24,999
Dr. Mark V. Sykes and Ms. Marilyn Guengerich

$5,000-$14,999
Dr. Jay Melosh
Anonymous

$2,000-$4,999
Dr. Michael Belton and Ms. Anna Don
Dr. and Mrs. Tim and Carol Hunter
Dr. and Mrs. William and Gayle Hartmann
Dr. Thomas H. Prettyman

$1,000-$1,999
Mr. and Mrs. Joe and Diana Alexander
Dr. John L. Mason
Ms. Kathryn Schmoll
Mr. Bruce Barnett and Ms. Tammi Palmer
Dr. and Mrs. William and Margrethe Feldman
Drs. Donald R. Davis and Diana Wheeler
Mr. and Dr. John and Dorothy Oehler
Dr. and Mrs. Robert and Maria Reedy

$500-$999
CODAC Behavioral Health Services
National Bank of Arizona
Keegan, Linscott & Kenon
The Mahoney Group
Wolf & Sultan, P.C.
Echo Construction
Vantage West Credit Union
Mr. Anthony Villari
Ms. Elaine Owens
Dr. and Mrs. Daniel and Janet Kortenkamp
Dr. Robert M. Nelson and Ms. Marguerite Renner
Dr. Faith Vilas and Mr. Larry Smith

$250-$499
Dr. Candace Kohl
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Dr. and Mrs. Bevan and Mary-Hill French
Drs. Robert and Gloria McMillan
Dr. and Mrs. Brent and Joanne Archinal
Lt. Col. Robert Gent and Judge Terrie Gent
Dr. and Mrs. Lee and Donna Rogers
Mr. and Mrs. Otto and Linda Rueger
Mr. and Mrs. Alan and Gina Fischer

$100-$249
Mr. David Fales and Ms. Sara Hammond
Mr. Randy Sooter
Mr. and Mrs. Bruce and Lynne Wood Dusenberry
Dr. Amanda Hendrix and Mr. David Richardson
Drs. Tod Lauer and Beatrice Mueller
Dr. Ian Shivack and Ms. Ina Giller Shivack
Dr. Bryan J. Travis and Mrs. Gayle L. Travis
Dr. Tim Jull
Mr. Alex Berman
Mr. and Mrs. Donald and Darlene Burgess
Ms. Dianne Janis
Dr. Nalin Samarasingha
Mr. and Mrs. Alfred and Maria Anzaldua
Mr. and Mrs. Robert and Judith Breault
Dr. and Mrs. Larry and Nancy Lebofsky
Dr. Alan Stern
Mr. Richard N. Pugh
Ms. Julie Bates
Dr. Rosemary Chang
Ms. Mary Ann Gilman
Mr. Terrence Greenwood
Dr. David Johnson
Dr. C. Darrell Lane
Dr. D. Terence Langendoen and Ms. Nancy Kelly
Ms. Martha Leake
Mr. and Mrs. John and Kathleen O’Brien
Dr. David O’Brien
Dr. Anna Spitz
Mr. Charles Steerman
Dr. Sugata Tan
Ms. Marie Turley
Dr. David Vaniman and Ms. Donna Gary

$1-$99
Mr. Gary Bingham
Dr. and Mrs. Andrew and Anna Nelson
Mr. and Mrs. William and Beth Woodin
Ms. Ann Cleaves
Mr. James Cummings
Mrs. Pudding Lassiter
Dr. and Mrs. Jonathan and Cynthia Lunine
Mr. Kurt Marti
Dr. and Mrs. Robert and Carolyn Milkey
Mr. Claud Smith
Dr. Ann L. Sprague and Mr. Edward D. Hinson
Mr. and Mrs. David and Teresa Acklam
Ms. Greer Barkley
Dr. Kunegunda Belle
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Mr. Stephen D. Hopkins
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Dr. E. Philip Krider
Dr. Dennis L. Matson
Mr. and Mrs. Jerry and Jeannine Neese
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Mrs. Marcia Neugebauer
Ms. Elaine Noel
Mr. James Prettyman
Mrs. Susanna Schippers
Dr. and Mrs. Geert and Renate Schmid-Schoenbein
Ms. Jennifer Shopland
Mr. Peter H. Simpson
Dr. Michael Snowden
Dr. Andrew Wheeler
Mr. and Dr. William and Kathleen Bethel
Mr. Pete Kasper and Ms. Chris Holmberg
Rosa’s Mexican Food

BETTY PIERAZZO MEMORIAL FUND

The following individuals donated to the Betty Pierazzo Memorial Fund, established by the Planetary Science Institute to honor and celebrate the life and achievements of Senior Scientist Betty Pierazzo and to promote science and education.

Anonymous
Mr. and Mrs. Alan and Gina Fischer
Dr. and Mrs. William and Gayle Hartmann

Dr. and Mrs. Tim and Carol Hunter
Dr. Jay Melosh
Drs. Tod Lauer and Beatrice Mueller
Dr. David O’Brien
During 2016, PSI changed its fiscal year end from Jan. 31 to Sept. 30 to correspond with the federal fiscal year. The numbers reported below reflect an eight-month period from Feb. 1, 2016 to Sept. 30, 2016. PSI continues to experience annual revenue growth with revenues totaling approximately $8 million for the eight-month period. Funding from NASA represents approximately 99 percent of billed revenues. During the fiscal year, PSI had 108 active NASA grants with a PSI scientist as principal investigator and 140 active subawards/contracts issued by other institutions with mainly NASA prime awards.

**REVENUES**

<table>
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<th>Source</th>
<th>Amount</th>
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<td>Grants and Contracts</td>
<td>$7,896,155</td>
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<td>Contributions</td>
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<td>Other</td>
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<td><strong>Total Revenues</strong></td>
<td><strong>$7,965,579</strong></td>
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Salaries and related fringe benefits represent 80 percent of PSI’s total expenses of $8 million. Operating expenses include $318,825 paid on subawards to other institutions whose scientists are included on PSI awards. Program services expenses were 88 percent of total expenses.

**EXPENSES (eight-month period ending 9/30/2016)**

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<td><strong>Total Expenses</strong></td>
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**CURRENT ASSETS**

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<th>Category</th>
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<tr>
<td>Current Liabilities</td>
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<td>Long-term Liabilities</td>
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<tr>
<td>Unrestricted Net Assets</td>
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<tr>
<td><strong>Total Liabilities &amp; Net Assets</strong></td>
<td><strong>$3,030,566</strong></td>
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</table>

PSI’s financial records are audited annually by independent auditors. A condensed Statement of Financial Position from PSI’s audit report as of Sept. 30, 2016 is reflected below.
Natasha Artemieva. Extraterrestrial cause for mass extinctions – reassessing the hazard. NASA Exoplanet Exploration program.

Natasha Artemieva. Ejecta and melt interactions during impact ejecta emplacement. NASA Lunar Data Analysis program, University of Arizona subcontract.

Maria Banks. Analysis of Lunar Reconnaissance Orbiter images. NASA Lunar Reconnaissance Orbiter Camera, Smithsonian Institution subcontract.


Amy Barr Mlinar. Radar for Europa Assessment and Sounding: Ocean to Near-Surface (REASON) Science Co-Investigator Phase A. NASA Europa mission, University of Texas at Austin subcontract.


Sanlyn Buxner. Bridging the learning gap out-of-school elementary education program. Institute of Museum and Library Services program, Tucson Children’s Museum subaward.

Sanlyn Buxner. CosmoQuest: Engaging students & the public through a virtual research facility. NASA Science Mission Directorate Science Education program, Southern Illinois University Edwardsville subaward.


Deborah Domingue Lorin. Spectrophotometric modeling of spectrometer and imager observations. NASA Hayabusa 2 Participating Scientist program.

Darby Dyar. Volatile adsorption onto primitive grains for understanding the formation of the early Solar System. NASA Emerging Worlds program, Johns Hopkins University subaward.


Jennifer Grier. CosmoQuest: Engaging students & the public through a virtual research facility. NASA Science Mission Directorate Science Education program, Southern Illinois University Edwardsville subaward.

David Grinspoon. Observational and theoretical constraints on current volcanism from Akatsuki UV and IR imaging. Venus Climate Orbiter Participating Scientist program, Southwest Research Institute subcontract.


Andrea Jones. Sky to Earth 1, NASA Heliophysics Education Consortium.


Jian-Yang Li. Born small or gone small – determining the evolutionary state of Comet 252P/LINEAR during its close approach to Earth. Hubble Space Telescope mission, Space Telescope Science Institute subcontract.

Jian-Yang Li. The smooth areas of the nucleus of Comet 67P/Churyumov-Gerasimenko. NASA Early Career Fellowship.

Jian-Yang Li. Comprehensive analysis of Comet Siding Spring, before, during and after its Mars encounter. NASA Solar System Workings program, University of Maryland subaward.

Michelle Miniti. Participation in cross calibration activities for the scanning habitable environments with Raman and luminescence for organics and chemicals (SHERLOC) investigation for the 2020 mission. NASA Mars 2020 mission, Jet Propulsion Laboratory subcontract.

Jeff Morgenthaler. The mass transfer function of a magnetosphere: Synoptic monitoring of Jupiter’s magnetospheric response to Io’s volcanic activity. National Science Foundation.

Beatrice Mueller. In the eyes of the storm: Inner coma remote sensing of three Jupiter family comets. NASA Solar Systems Observations program, University of Arizona subaward.

Eldar Noe Dobrea. Relaxation of small craters at Phoenix landing site latitudes – testing the thin permafrost layer and rapid relaxation rates hypothesis. NASA Mars Data Analysis program.


Eric Palmer. OSIRIS-REx Phase E. NASA OSIRIS-REx mission, University of Arizona subaward.

Alex Patthoff. A global geologic map of Enceladus. NASA Planetary Geology and Geophysics program, Jet Propulsion Laboratory subaward.


Alex Patthoff. Enhancing SatStressGUI: Simplifying stress calculations for satellites. NASA Planetary Data Archiving Restoration and Tools program, Jet Propulsion Laboratory subaward.

Alex Patthoff. Unraveling the early tectonic history of Enceladus and Dione/ The geophysical and athermal evolution of Dione. NASA Cassini Data Analysis and Participating Scientists program, Smithsonian Institution subaward.

Alex Patthoff. Ocean worlds mobility. Jet Propulsion Laboratory contract.

Thomas Prettyman. LunaH-map preliminary instrument design and modeling support. NASA Radiation Monitoring Devices program.


Nathaniel Putzig. Understanding layered ejecta craters on Mars: Keys to subsurface water. NASA Mars Data Analysis program, Southwest Research Institute subcontract.

Nathaniel Putzig. Advanced 3-D subsurface imaging and analysis of Planum Boreum with SHARAD data. NASA Mars Data Analysis program.

Nathaniel Putzig. Material properties of dune fields in the southern highlands of Mars from thermophysical observations and modeling. NASA Planetary Geology and Geophysics program.

Nathaniel Putzig. 3-D subsurface imaging and analysis of Planum Australe with SHARAD data. Mars Data Analysis program.


Julie Rathbun. Active volcanoes on Io from ground-based observations of
Jupiter and mutual satellite occultations. NASA Planetary Data Archiving, Restoration, and Tools program.

Jim Rice. MER geomorphic and sedimentological investigations. NASA Mars Exploration Rover mission, Jet Propulsion Laboratory subcontract.

Jim Richardson. Ejecta melt interactions during impact emplacement. NASA Lunar Data Analysis program, University of Arizona subcontract.

Jim Richardson. Modeling regolith evolution during the post-basin epoch of lunar history. NASA Solar System Workings program, Purdue University subcontract.


Matthew Siegler. Explaining the Apollo heat flow experiment. NASA Solar System Workings program.


Hanna Sizemore. Experimental investigation of excess shallow ground ice on Mars. NASA Mars Fundamental Research program, Johns Hopkins University subcontract.

Sarah Sonnett. NEOWISE reactivation. NASA NEOWISE mission, Jet Propulsion Laboratory subcontract.

Joseph Spilita. Understanding free normal modes and irregular structures on the edges of Saturn's rings. NASA Cassidy Data Analysis and Participating Scientists program.


Cristina Thomas. OSIRIS-REx Phase E. NASA OSIRIS-REx mission, University of Tennessee subcontract.

Cristina Thomas. A Search for OH/H2O on Near-Earth Objects and nominally anhydrous Main Belt asteroids. NASA Solar System Observations program, University of Tennessee subcontract.


Cathy Weitz. Defining the geologic history and record of potentially habitable environments in Gale Crater. NASA Mars Science Laboratory Participating Scientist program, Smithsonian Institution subcontract.

Rebecca Williams. Reconstructing the aqueous history of Gale Crater from Mars Science Laboratory observations. NASA Mars Science Laboratory mission, Jet Propulsion Laboratory subcontract.

Rebecca Williams. Mapping sinuous ridges and estimating runoff rates in Northwest Hellas, Mars. NASA Mars Data Analysis program, United States Geological Survey cooperative agreement.

Shawn Wright. Assembling evidence of impact at highly deformed impact craters: A workshop with field trips to the Santa Fe impact structure, New Mexico. NASA Topical Workshops, Symposiums and Conferences program.

Yuki Yamashita. High-resolution gamma ray spectra for lunar geochemistry from KAGUYA. NASA Planetary Data Archiving, Restoration, and Tools program.

R. Aileen Yingst. Quantitative clast morphology as a probe to the transport history of sediments at the MER landing sites. NASA Mars Exploration Rover mission, Jet Propulsion Laboratory subcontract.

R. Aileen Yingst. A revised global geologic map of Vesta from Dawn image, elemental and spectral data. NASA Discovery Data Analysis program.


