Painting by William K. Hartmann showing a view from the surface of Europa, a moon of Jupiter.
The rocky profile along the edge of asteroid 25143 Itokawa is a fine example a “rubble pile” structure, a concept developed at the Planetary Science Institute in the 1970s and 1980s as a type of asteroid fragmented and reassembled during large-scale collisions. PSI scientists Paul Abell, Donald Davis and Robert Gaskell have been part of the Hayabusa science team that obtained the image. (Japanese Space Agency; image processed by W. K. Hartmann.)
A Busy Year at PSI

Planetary Science Institute researchers created new maps of the seasonal polar caps of Mars using neutron measurements from orbit, placing new constraints on global circulation models of the atmosphere; raised questions about subsurface ice trapped in Martian dunes, preventing their movement; provided new insights into the large role that water has played in shaping the topography of large Martian craters; and determined that warm weather near the Martian equator may have melted the ice in ice-rich soils as recently as 2 million years ago, indicating that the planet may have been more life-friendly very recently.

In addition, PSI scientists participated in the Dawn flyby of Mars; supported NASA missions to comets Hartley 2, Tempel 1 and Wild 2 using ground-based observations; made the first-ever, up-close look at neutron production from a solar flare; identified and mapped on the lunar surface previously unidentified chemical elements, including uranium; and determined a means by which small gravitational effects on a satellite could be used to constrain the local population of near-Earth objects.

This was a small fraction of research conducted this year at the Institute, and demonstrates its breadth and richness.

PSI Strengthens Science, Education and Support Staff

PSI’s strength and advantage is in its people. Our culture of openness and high level of mutual support sets us apart from other organizations.

In 2009 PSI continued to grow, adding 15 new staff, including 10 researchers. Other new personnel focus on Education and Public Outreach efforts and add to PSI’s science support and administrative efforts.

New PSI staff members for 2009:

Alice Baldrige
Associate Research Scientist

Susan Benecchi
Associate Research Scientist

Jade C. Bond
Postdoctoral Research Assistant

Sanlyn Buxner
Education Specialist

Thea Cañizo
Education Support Specialist

Mary G. Chapman
Senior Scientist

Steven K. Croft
Senior Education Specialist

Deborah Domingue Lorin
Senior Scientist

Rossman Irwin
Research Scientist

Jian-Yang Li
Senior Research Associate

Joseph R. Michalski
Research Scientist

Karly M. Pitman
Associate Research Scientist

Linda Rueger
Human Resources Specialist

Nicholas Tosca
Associate Research Scientist

Michael Wendell
Software Developer
NOTE FROM THE DIRECTOR

At PSI we take pride in being an organization that is run by scientists for the benefit of scientists. We are a community of people that seeks not only to advance our own research, but also to provide support for our colleagues within the Institute through things like internal proposal reviews and strategy workshops.

We also remove subjective barriers to advancement and salary rates and promote an egalitarian work environment – everyone is treated the same whether they are one of the founders who has been around for 37 years or a young scientist submitting his or her first proposals to NASA. Our criteria for promotion are objective (becoming the Principal Investigator of grants and years since Ph.D.). Scientists set their own salaries, guided by national averages for similar positions.

One consequence of PSI’s institutional culture was driven home when I recently attended the Women in Astronomy (WIA) conference in Washington, D.C. to give an invited lecture on PSI’s policies and practices. I was very surprised when an earlier speaker presented statistics showing that women astronomers at universities earned about 20 percent less in salary than their male colleagues of comparable experience and position.

Women make up 33 percent of Ph.D.s at PSI, increasing to 44 percent when considering scientists earning their degrees less than 20 years ago (a time when the profession was far more male-dominated). Comparing salaries at PSI of women and men as a function of years since Ph.D., women’s salaries were on average higher than their male counterparts, bucking the national trend!

Scientist retention was another issue discussed at the Women in Astronomy conference. A common problem in our profession arises when one spouse needs to relocate for work and the other spouse may not have job opportunities in the new location. PSI addresses this issue by allowing scientists to work basically anywhere, supporting people in 16 states and around the world. Nature magazine has highlighted PSI as one of a few such companies that uses the internet to bring together and provide support for geographically distributed scientists.

Interestingly, at PSI this problem of co-location has been an issue for as many husbands following wives as for wives following husbands.

At the same time, joining the PSI science staff is not automatic. We seek scientists who are interested in actively participating in our community and who have demonstrated the capability or show the promise to develop a dynamic, independent research program to advance our understanding of the solar system. Applications are required, as are letters of reference. We bring candidates to Tucson to give a seminar. Finally, the staff has an open discussion of the application and the suitability of the candidate to be a PSI scientist. If a positive consensus is reached, an offer for an appointment to the Institute is made. Eleven new appointments were made in 2009 to Principal Investigator-eligible positions in science and education.

PSI was honored this year by the visit of Congresswoman Gabrielle Giffords, Chair of the House Subcommittee for Space and Aerospace, which oversees NASA, our principal source of funding. PSI brings in millions of federal dollars each year to Giffords’ district, providing well-paying jobs to a highly educated work force and stimulating the local economy. It is always a pleasure to show off the Institute, its people, and the incredible range of science we undertake.

We are on the science teams of 11 missions by the U.S., Europe, Japan and India. We run instruments on four of these missions, and have 130 ongoing contracts and grants with NASA. We are also involved in the future of human exploration. PSI has a long history, going back to the 1980s, of supporting the role of near-Earth asteroids (NEOs) in the future of human exploration. Currently, PSI scientists are generating simulations of human missions to NEOs for NASA. I recently briefed President Obama’s Review of U.S. Human Spaceflight Plans Committee, headed by Norm Augustine, on this subject.

Our work is funded by the public, so we feel a deep commitment to convey what we are doing and its value back to them. Our research is very much comparative planetology – and what we learn about other worlds is important to understanding the history, present and future of our own world. It is also laying the groundwork for any future expansion of humans beyond the Earth.

Mark V. Sykes
PSI received a NASA grant of nearly $2.5 million to archive data relating to asteroids and interplanetary dust. PSI has been part of NASA’s Planetary Data System (PDS) effort to preserve, organize, and make mission data available to the scientific community since the PDS was formed in the early 1990s.

The five-year grant will fund PSI work on the Asteroid/Dust Subnode of the PDS Small Bodies Node. PSI Senior Scientist Donald R. Davis is the Principal Investigator on the project.

“NASA established PDS as a long-term archive for data collected on planetary missions,” Davis said. “NASA’s Planetary Science Division spends more than $1 billion each year to acquire data, and the PDS is the primary way in which this data is made available to the scientific community, both for immediate analysis and for future use.”

There’s a lot more to archiving than simply tossing data into a computer file and noting where it is. Data must be archived in a way that makes it easy to retrieve and scientifically useful.

“We make sure the data is well described so that scientists 10, 15, or even 50 years from now can understand how it was taken, the instrument used, the spacecraft and the mission objectives,” Davis said. “All of this has to be adequately described and documented. Without this background, a bunch of tables, numbers or images is much less useful. We also include published papers that are based on a particular dataset.”

PSI has developed the On-Line Archiving Facility (OLAF) that guides mission scientists and scientists engaged in NASA-funded research in preparing their datasets for inclusion in the PDS.

The data and its accompanying support material are then peer-reviewed and any weaknesses in the dataset or supporting documentation are referred back to the researcher or researchers for further clarification before the data is added to the archive.

PSI also is developing a small bodies Data Ferret that will make it much easier for scientists to sift through the increasingly voluminous holdings in the Asteroid/Dust Subnode to find what they need.

This tool, slated to become operational in 2010, will allow a scientist to query the archive using standard scientific terms, rather than computer-specific terminology.

The Data Ferret will then search through the holdings and return a list of datasets, which the scientist can ask the Data Ferret to further sift and refine.

The Small Bodies Group also includes ground-based observations in the archive to make it even more useful.

“A mission can tell you an awful lot about a single body, but you really want to be able to extrapolate that to the entire population of thousands of comets, millions of asteroids, and endless amounts of space dust,” Davis said. “We’re really interested in populations, not just individuals visited by missions, and the larger datasets in small bodies are taken primarily by ground-based observations.”

The group is also including data gathered by amateur astronomers who have the knowledge and sophisticated equipment — CCDs and half-meter class telescopes, for instance — to do professional-quality work.

Nearly all the data on asteroid light curves, for instance, are now collected by amateur astronomers, Davis said.

All of this effort to preserve data in a scientifically useful archive will be as important in the future as it is now.

“After all, there is no use-by date on scientific data, and researchers frequently want to re-examine old data as new theories and data analysis techniques are developed,” Davis said.

Fifty years from now this data will still form a priceless archive to help future generations in their quest to understand the solar system and their place in it.
PSI Researchers Take the Solar System to the Public

PSI scientists have been featured in several national TV science specials and radio broadcasts where they offered the public information on their solar system research.

PSI Director Mark Sykes again joined Neil deGrasse Tyson, host of NOVA scienceNOW on PBS and director of the New York Hayden Planetarium, on the Nova television program “The Pluto Files.” In that show Tyson investigated the public uproar over Pluto’s demotion from planetary status. Sykes previously sparred with Tyson in “The Great Planet Debate” moderated by NPR’s Ira Flatow.

Sykes has been a vocal critic of the International Astronomical Union’s new classifications for solar system objects that proclaim there are only eight planets in our solar system — excluding Pluto and several others, and effectively slamming the door on future discoveries of planets beyond Neptune. He advocates a definition based on common geophysical characteristics that are applicable throughout our solar system and to worlds around other stars.

PSI Senior Scientist Kim Kuhlman’s research was featured on an NPR StarDate radio program series dealing with space weathering. The first program provided a general overview and the following three programs discussed Kuhlman’s research on how micrometeorite impacts pulverize the moon’s surface. Her research will foster better understanding of the moon’s history and provide data that may help future astronauts discover and extract resources from the lunar surface.

PSI scientists Stephen Metzger, Matt Balme and Asmin Pathare were featured on “Storm Worlds – Earth,” a one-hour program in a three-part series on the National Geographic Channel.

“Storm Worlds – Earth” shows how dust becomes airborne in desert regions and is distributed around the globe, where it is found in deposits such as glaciers and associated with long-distance transmission of sometimes dangerous bacteria.

The program emphasizes the role that dust devils play in this process, and includes a section featuring Metzger, Balme and Pathare chasing dust devils in Nevada. They are studying these terrestrial dust devils as analogs for those on Mars that are believed to contribute to the Red Planet’s dusty atmosphere.

Balme and Metzger were also interviewed for the BBC production, “Seven Wonders of the Solar System,” a multi-part series of hour-long episodes. That interview also related to the Nevada dust devil research.

PSI Senior Scientist Elisabetta Pierazzo was one of several scientists featured in the National Geographic Channel’s “Known Universe.” The three-hour program focused on the biggest, smallest, fastest and most explosive things in the universe.

National Geographic interviewed Pierazzo at Arizona’s Meteor Crater, the most well-preserved impact crater on the planet. The 3,000-foot-diameter, 570-foot-deep crater was formed when a boxcar-sized object crashed in northern Arizona’s desert.

Pierazzo talked about the energy involved and the consequences of large meteor impacts on Earth.

A larger object that hit Yucatan led to the extinction of dinosaurs. Could a similar-sized object slam into Earth, ending life as we know it? That was one of many questions addressed in the series that combines the latest scientific knowledge with interviews of experts, such as Pierazzo, who can explain complex concepts in ways that are easy for non-scientists to understand.
Congresswoman Gabrielle Giffords toured Planetary Science Institute's headquarters in Tucson to learn more about the institute’s research and outreach activities.

Giffords, who chairs the Subcommittee on Space and Aeronautics of the House Committee on Science and Technology, emphasized the importance of adequate funding for space research and praised PSI for providing high-tech jobs in her Arizona Congressional District.

She also said America’s space program is vital to the country because access to space near Earth has important national security implications.

During a presentation given for Giffords, PSI Director Mark Sykes explained that understanding other planets helps us better understand Earth and has already led to a deeper understanding of the effect humans have on Earth’s atmospheric processes.

He also said that the long-term dominance by the United States in space will depend on whether it is the first to address the question of whether humans have a future beyond the Earth.

Sykes noted that PSI participates on the science and instrument teams of a number of missions sponsored by NASA and other agencies.

These include: Mercury MESSENGER, Dawn, Cassini, Mars Odyssey, Mars Reconnaissance Orbiter, Mars Exploration Rovers, Mars Express (European Space Agency), Hayabusa (Japanese Aerospace Exploration Agency), NEO Surveillance and Tracking (Canadian Space Agency) and Chandrayaan1 (Indian Space Research Organization).
PSI Researchers Chase Desert Dust Devils

Riding shotgun in a pickup truck, journalist Tony Reichhardt careened around a dry lakebed this summer with PSI scientists Matt Balme, Asmin Pathare and Steve Metzger as they studied dust devils in Nevada, up close.

In the resulting article entitled “Devils’ Advocates,” which appears in Air & Space/Smithsonian Magazine’s November issue (Sept. 14 online edition), Reichhardt describes the PSI team’s unique research technique: racing around in scorching hot, dry deserts purposefully inserting themselves into huge whirling clouds of choking dust, over and over again.

The team, led by PSI’s Balme, uses a grid of meteorology towers plus several specially equipped trucks to collect data such as dust load, wind speed and direction, atmospheric pressure, and temperature to help gauge the abundance of dust devils and the amount of aerosols they pump into the atmosphere.

Their NASA-funded research studies how similar atmospheric phenomena might have helped shape the Martian surface by using deserts in Nevada and Arizona as hands-on, and much less expensive, research stand-ins.

The PSI-led effort brought together an international team of 12 scientists all focusing on different aspects of dust devils. Do dust devils on Mars cause the giant dust storms often seen there?

Perhaps not, but they might add to the planet’s dust overall. This is just one of the questions the PSI team hopes to answer.

“Tumbleweeds” Offer Novel Way to Explore Mars

PSI Senior Scientist Kim Kuhlman is the Principal Investigator of the Tumbleweed project. She has put together a team of scientists and engineers, including two NASA centers and several academic and private institutions, to design a fleet of instrumented Tumbleweeds for missions of opportunity.

Tumbleweeds are lightweight, inexpensive vehicles that can carry a variety of instruments and cover large swaths of terrain as Martian winds cause them to roll like tumbleweeds across the surface of Mars.

They are designed to bridge the gap between large-scale surveys done by spacecraft in Mars orbit and intensive, small-scale research conducted by Mars rovers.

Fleets of Tumbleweed vehicles could conduct long-range, randomized surveys with simple, low-cost instrumentation that is functionally equivalent to conventional coordinate grid sampling.

These vehicles can be suitably instrumented for surface and near-surface sensing and analysis and released to roam for the duration of a season or longer.

It is anticipated that within just a few years, instruments such as gas chromatograph mass spectrometers (GC-MS) and ground-penetrating radar (GPR) will be deployable on Tumbleweed vehicles. Different Tumbleweed configurations can provide the capability to operate in varying terrains and accommodate a wide range of instrument packages,
making them suitable for autonomous surveys for in situ natural resources.

Tumbleweeds are lightweight, relatively inexpensive and very attractive for multiple deployments or piggybacking on larger missions.

The Tumbleweed vehicles, some of which resemble beach balls on steroids, are based on well-developed and tested technology.

**Vesta and Iceland Share Some Geographic Traits**

The NASA Dawn Mission spacecraft was launched in September 2007 to conduct the first ever double rendezvous. Its destinations are the two largest objects in the asteroid belt, Vesta and Ceres, which orbit the sun between Mars and Jupiter. Dawn will be arriving at Vesta in July 2011 and will acquire science data for about a year. The spacecraft will then depart for Ceres, arriving in February 2015. PSI has three scientists on the Dawn Science Team: William Feldman, Mark Sykes and Thomas Prettyman.

In August 2009, the Dawn Science Team gathered in Iceland, at 66 degrees north latitude. In addition to technical discussions, the team spent two days on geology field trips to locations within driving distance of Reykjavik, guided by geologists from the University of Iceland and Reykjavik University. The meeting was hosted by the Massachusetts Institute of Technology.

Endeavors with the complexity of the Dawn mission require a close-knit, multidisciplinary team. For those team members who are not geologists, the field trips were an opportunity to learn more about volcanism and field geology and to make connections between Iceland and what might be seen when the Dawn spacecraft arrives at Vesta.

Like Vesta, Iceland’s surface was shaped by basaltic magmatism and achieved its present form quickly, within 20 million years. Due to heating by short-lived radioisotopes injected into the solar nebula by a nearby supernova, Vesta formed hot and, like the moon, may have had a magma ocean. As Vesta cooled, the small body differentiated, forming a crust, mantle, and core. Molten silicate rock from the mantle erupted through the crust onto the surface, forming features that might be very similar to those seen on Earth. Volcanism on Vesta ceased nearly 4.5 billion years ago, once gravitational forcing by Jupiter brought accretion of the main asteroid belt to an end. In contrast, Iceland is located in one of Earth’s most active regions and volcanoes have been an important part of Icelandic life since the first settlers arrived in 871 AD.

Volcanism on Vesta ceased nearly 4.5 billion years ago, once gravitational forcing by Jupiter brought accretion of the main asteroid belt to an end. In contrast, Iceland is located in one of Earth’s most active regions and volcanoes have been an important part of Icelandic life since the first settlers arrived in 871 AD.

Iceland offers NASA Dawn Mission researchers a living lab for studying the effects of volcanic activity.

Iceland is a geothermal cauldron, and silicate minerals are rapidly undergoing chemical alteration by hydrothermal processes. Aqueous alteration products, such as clays, are abundant at numerous hot springs and several active geysers. Ceres formed far enough away from the sun that water must have played a role in its formation and thermal evolution. Ceres contains up to 20 percent water and has undergone aqueous differentiation at low temperature, forming minerals similar to those found in Iceland. When Dawn arrives at Ceres in 2015, the surface will likely reveal evidence for complex aqueous processing within the interior of Ceres from materials brought to the surface by gas-driven volcanism.

Will Vesta’s south polar basin reveal the composition of Vesta’s interior? Does Ceres harbor a subterranean ocean in which life may have arisen? These may be among the exciting discoveries of the Dawn mission as it continues its journey in space and time.
PSI experienced a robust 23 percent annual revenue growth in the fiscal year ended Jan. 31, 2010, with revenues totaling $5.6 million. Funding from NASA represents $5.4 million, or 96 percent of total revenues. During the fiscal year, NASA funded 73 grants with a PSI scientist as Principal Investigator and 57 contracts issued by other institutions with NASA prime awards.

### REVENUES

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<td>Grants and Contracts</td>
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<td>Contributions</td>
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<td>Other</td>
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### NASA FUNDING

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Salaries and related fringe benefits represent 77 percent of PSI’s total expenses of $5.6 million. Operating expenses include $293,770 paid on subcontracts to other institutions whose scientists are included on PSI awards. Program services expenses are 84 percent of total expenses.

### EXPENSES

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### EXPENSES BY FUNCTION

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PSI’s financial records are audited annually by independent auditors. A condensed Statement of Financial Position from PSI’s audit report for the fiscal year ended Jan. 31, 2010 is reflected below.

### Current Assets

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### Current Liabilities

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### Property & Equipment

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### Total Liabilities & Net Assets

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</thead>
<tbody>
<tr>
<td>Total Liabilities &amp; Net Assets</td>
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</table>

David O’Brien, Collisional and dynamical processes in the solar system. NASA Planetary Geology and Geophysics Program.


Elisabetta Pierazzo, Impacts and environmental catastrophes: Investigating the effects of impact events on the climate system. NASA Exobiology.

Elisabetta Pierazzo, Direct numerical simulation of comet impacts and low-density atmospheric flow on the moon and the effects of ice deposition in cold traps – Phase 2. University of Texas at Austin.


Tom Prettyman, Fast neutron dosimeter for the space environment, radiation monitoring devices. NASA Small Business Innovative Research, Phase I.


Robert S. Reedy, Collaborative research: A proposal for the cosmic-ray produced nuclide systematics on Earth (CRONUS-Earth) project. National Science Foundation.


J. Alexis Palmero Rodriguez, Formational history of the polar troughs in the north polar plateau on Mars. NASA Mars Data Analysis Program.


Ed Tedesco, Application of an improved asteroid magnitude phase function to real-world data. Jet Propulsion Laboratory.

Rebecca Williams, Mars Odyssey – THEMIS extended mission. Arizona State University.

Rebecca Williams, Environmental implications of highly sinuous channels on Mars. University of Virginia.

R. Aileen Yingst, Optimizing lunar science return from lunar mobile robotic missions by testing rover field methodologies. NASA Moon and Mars Analog Mission Activities.

PSI Publications


Artemieva N. and J. Morgan (2009). Modeling the formation of the K-Pg boundary layer. Icarus 201, 768-780.


