PSI NEWSLETTER

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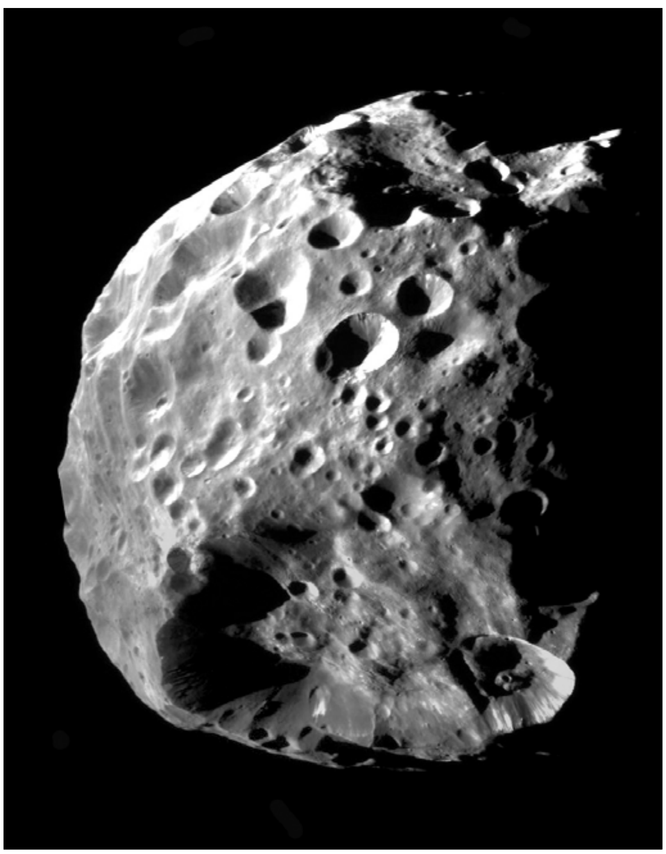
The Importance of Being Phoebe

By William K. Hartmann and Steve Kortenkamp

On June 11, the Cassini spacecraft entered the Saturnian system and zipped by Saturn's outermost large satellite, Phoebe, at a distance of 2068 km (1285 miles), giving us spectacular images of this very irregular moon, as seen below. This is our first close up look at a body that has been a mystery since its discovery in 1898.



A mosaic view of Saturn's outer moon, Phoebe, from the Cassini spacecraft. The craters testify to Phoebe's history of intense collisions. The satellite is about 220 km (135 miles) across, and the giant 88-km crater dominating the lower hemisphere was nearly big enough to shatter the moon. The exposure and printing of the image gives an impression that the surface is bright grey rather than the actual blackish color of the object (NASA/JPL/SSI).

The mystery comes from an odd feature of the solar system: all giant planets have extended families of satellites that all revolve around the planet in one direction, the same *prograde* direction that planets move around the sun — counterclockwise. But most planets also have several moons on the outskirts of their systems that revolve in the wrong direction, i.e., the *retrograde* direction — akin to having one car in the Indy 500 driving the wrong way on the track — and Phoebe is one of these moons. Similar so-called *irregular* satellites are orbiting Jupiter, Uranus, and Neptune. How did these irregular moons get into their backward orbits? The answer could tell us something about how satellite systems formed and evolved, and also could yield clues to the origins of the planets themselves.

The "normal" extended satellite families are thought to have formed in a process similar to planet formation: these moons aggregated from debris orbiting around the newly-formed planet, explaining why they all move in the same direction. The "wrong-way" satellites must have some different process of origin. What was it? It's long been supposed that these satellites must have started out as interplanetary bodies that strayed too close to the planet and were somehow captured into orbit around them.

In the 1980s, PSI astronomer Bill Hartmann worked with University of Hawaii astronomers Dale Cruikshank and Dave Tholen at Mauna Kea observatory, to show that virtually all interplanetary bodies in the outer solar system, whether cataloged as asteroids or comets, are very dark, blackish-brown-colored bodies. Even if they contain ice, which many of them do, they are dark-tinted because of carbonaceous, sooty material mixed in their frosty soil. The data developed at that time also showed that the outermost satellites of the giant planets, both the prograde and retrograde ones, have these same blackish colors. This fits the theory that the outer satellites are indeed captured interplanetary bodies.

(continued on page 2)

Inside this issue:

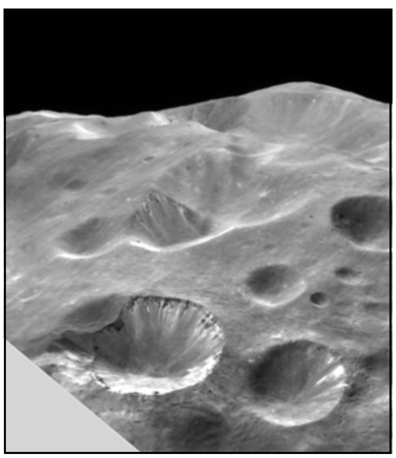
The Importance of Being Phoebe *(continued)*

The problem is the capture process has always seemed difficult to achieve. Usually when an asteroid or comet passes a giant planet, it is moving too fast to be captured and would have to be slowed down (just as a space probe has to fire an engine or pass through a planet's upper atmosphere to slow down enough to go into planetary orbit). How could a hurtling asteroid be slowed down? PSI dynamicist Steve Kortenkamp has been studying a possible solution to this mystery.

New Work on an Old Mystery

The solar system formed in a gaseous, dust-rich nebula around the sun. Thus, small bodies that were aggregating into asteroids, comets, and moons experienced gas drag that slowed them down. The new work by Kortenkamp details what happens as gas drag moves a small body into what is called a co-orbital resonance, i.e., an orbit that has the same orbital period around the sun as the planet itself. Co-orbital resonances (also called 1:1 resonances) are of particular importance in our solar system because there are numerous small bodies known to be trapped in these resonances with several different planets. Jupiter is the king of co-orbitals, hosting over 1600 known objects called Trojan asteroids. Earth, Mars, and Neptune also have populations of Trojan-like resonant companions.

The connection between co-orbital objects and irregular satellites like Phoebe lies in an obscure sub-class of the 1:1 resonance. Most objects trapped in 1:1 resonance spend all of their time far from the planet, avoiding dangerous close encounters with the planet that might kick them out of the resonance. But objects known as quasi-satellites inhabit a region of the 1:1 resonance that keeps them very near the planet. For nearly a century, quasi-satellites had been figments of astronomers' imaginations, existing only on paper or in computer simulations. However, in 2003 the first real quasi-satellite was discovered. Surprisingly, this object is not a faint denizen of the outer solar system; quite the contrary, it is a near-Earth asteroid known as 2003 YN107. In fact, this object is a quasi-satellite of Earth!



Close up of Phoebe shows its cratered surface, with a lumpy and irregular horizon created by overlapping crater rims. Bright, overexposed patches in crater walls (foreground) are thought to mark layers of ice-rich soil exposed by landslips on the crater wall (NASA/JPL/SSI Cassini image).

Computer simulations done at PSI show that small bodies experiencing gas drag in the primordial solar system can become trapped as quasi-satellites. The continuing influence of gas drag can slowly convert quasi-satellites into true satellites like Phoebe. Thus, Trojan-type co-orbitals, quasi-satellite co-orbitals, and Phoebe-like irregular satellites may all be products of the primordial solar system that took shape with the loss of nebular gas 4.5 billion years ago.

To see animations of the computer simulations described above visit: http://www.psi.edu/~kortenka/quasi_satellites/

David Lien Joins PSI Science Staff

Dr. David Lien joined the PSI Tucson staff in mid-July as an Associate Research Scientist. He brings with him an eclectic blend of science and education interests. Dave received his bachelor's degree in Physics and Astronomy from the University of Wisconsin (Madison) in 1977, then went to the University of Illinois (Champaign-Urbana) where he received both a Masters degree (1979) and a Ph.D. (1983) in Astronomy. His dissertation focused on the physical properties of diffuse interstellar clouds derived from multi-wavelength (UV, visible, and radio) observations of the atomic and molecular constituents of the clouds.

Although he's still interested in interstellar astronomy, Dave's current research efforts are directed toward three different areas: comets, meteorological optics, and archeaoastronomy. Dave's interest in comets began in 1984 as a post-doctoral fellow at Lowell Observatory where he spent many months at a variety of telescopes observing Halley's comet (and other comets as well). To better understand the data, Dave began to develop what is now a sophisticated computer program designed to simulate the gas and dust emitted from multiple active areas on the surface of a rotating comet as it moves along its orbit.

Dave's models for comet Hale-Bopp were published in *Sky and Telescope* and featured on their web site during the comet's 1996-1997 apparition. Dave's computer model also simulates the very large slow-moving dust particles ejected by short period comets which ultimately form the "trail" of the comet (originally discovered by Mark Sykes, PSI's new director). Mark and Dave have been collaborating on the study of dust trails for over 15 years.

Dave's interest in how light interacts with small particles has morphed into a study of the colors produced by clouds back here on Earth. Water drops can create more than just beautiful rainbows, and Dave's work has led to new insight into the answers to questions as simple as "why are clouds white?" to identifying previously unrecognized features (not all clouds are white—some are as blue as the sky!). Dave presented the results of his work in mid-September at PSI in a talk entitled "The Color of Clouds."

Dave has a strong interest in science education: Over the past twenty years he has taught astronomy and physics to thousands of students at a variety of institutions ranging from large, land-grant state universities to small, private, liberal arts colleges. He has extensive experience in the development of educational programs specifically targeting undergraduates, and has mentored undergraduate research projects for more than 30 students. He has also written two children's books about science, which have been submitted for publication.

PSI welcomes Dave Lien!

Visitors to PSI—An International Mars Project *By William K. Hartmann*

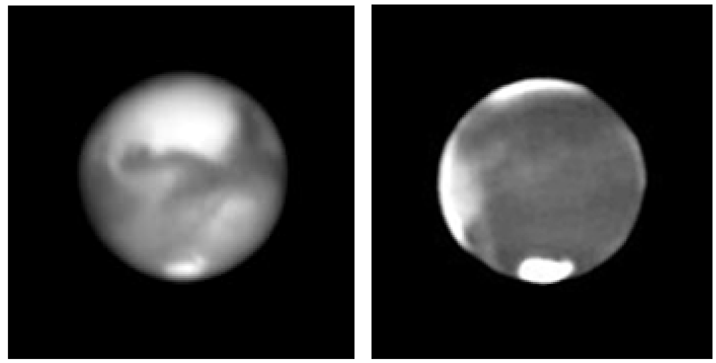
In the PSI conference room, Michael Snowden (left) and Keith Hege work on sharpening Mars images, August 20, 2004.

In August, PSI hosted New Zealand astronomer Michael Snowden, who has been working with well-known Tucson astronomer Keith Hege. In 2003, Snowden made images of Mars in infrared and ultraviolet wavelengths with the 0.6m Hogg telescope at Complejo Astronomico el Leoncita Observatory (CASLEO) in Leoncito, Argentina. The observations were unusual in their attempt to pierce the Earth's ozone layer that blocks most UV light from reaching ground-based telescopes; Snowden was able to do this by observing Mars nearly at the zenith from the southern hemisphere.

The next step was to meet with Keith Hege in Tucson. Hege is known for his work in image processing, in particular, computer algorithms that sharpen images by considering how light from any point in the sky spreads due to effects such as guiding errors or poor seeing (i.e. atmospheric shimmering). The image is then reconstructed into a version sharper than the raw original.

The accompanying figure shows one of the results. The infrared image shows the usual view of features on the surface of Mars. The ultraviolet image essentially shows the atmosphere of Mars, revealing prominent cloud patterns that are hard to see in visual or infrared light.

Snowden and Hege hope to use this material as a demonstration to support a proposal for further observations with larger telescopes in 2005.



Mars as imaged from Argentina in infrared light (left) and ultraviolet light (right). The IR image shows the usual surface markings of Mars; the nearly simultaneous UV image shows clouds, especially at the morning edge of Mars (left edge, where clouds condensed during the cold night are carried around onto the day-lit side at dawn). (North is at the top.)

Undergraduate Research at PSI: 2003-04

By David A. Crown, Mary C. Bourke, and Mark V. Sykes

As part of its mission in space science education and to keep the wheels of research in motion, PSI has long involved undergraduate students in its activities. The past year has been no exception, with a group of hard-working, enthusiastic, and capable students contributing to a variety of important research projects at PSI.

For the 2003-2004 academic year, PSI scientists David Crown and Mark Sykes were selected as mentors for the Arizona/NASA Space Grant Undergraduate Research Internship Program. This program, run by the Arizona Space Grant Consortium at the University of Arizona, selects highly qualified undergraduates to participate in research projects under the supervision of a scientific mentor.

Megan Pitcher, a Computer Science major at the University of Arizona, worked with David Crown on a project entitled “Analyses of Lava Flows on Earth and Mars.” Megan’s project included two main components: 1) reconstructing the history of lava flow activity for 2000-2004 for the Puu Oo flow field at Kilauea Volcano in Hawaii and identification and analysis of Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) satellite images corresponding to this period of eruptive activity; and 2) construction and analysis of a Geographical Information Systems (GIS) database for the Tyrrhena Patera lava flow field, Mars using NASA datasets from the Mars Global Surveyor and Mars Odyssey missions.

Conrad Hutcheson, a junior Physics and Astronomy major at the University of Arizona, worked with Mark Sykes on recently obtained Hubble Space Telescope observations of Ceres. They helped identify previously unknown surface features and albedo structures on its surface. Conrad also worked on detailed modeling of surface scattering properties of Ceres and participated in groundbased observations of Ceres and other asteroids at the Heinrich Hertz Submillimeter Telescope on Mount Graham (AZ).

During the summer of 2004, PSI hosted a group of interns in our Planetary Geosciences Laboratory. Two of these interns, Lida Teneva and Brett Carpenter, were awarded NASA Planetary Geology and Geophysics Undergraduate Research Program internships. This program matches undergraduate students from all over the U.S. with NASA scientists working at universities, research institutions, and NASA centers for an 8-week period in the summer.

Lida Teneva, a junior Geosciences major from Franklin and Marshall College (Lancaster, PA) worked with David Crown on a project entitled “Geologic Analysis of Hellas Basin Interior Deposits.” Lida spent the summer compiling an extensive GIS database of Mars Global Surveyor and Mars Odyssey datasets for the ~2,000-km across Hellas Basin and examining the distribution and characteristics of fine-scale layering along Hellas’ eastern rim that may be related to climate changes on Mars.

Brett Carpenter, a junior at Mansfield University of Pennsylvania majoring in Earth and Space Science Education and

(continued on page 4)

Melissa Lane's Work Discussed in *Science*—A Once-Wetter Mars?

By William K. Hartmann

The August 6, 2004, issue of the journal *Science*, with a beautiful Spirit rover cover photo of the Martian surface, contains a handful of articles from the rover team, reporting that they found no clear evidence that a lake or watery environment ever existed in Spirit's Gusev crater landing site. This result at Gusev crater contrasts with evidence for sulfur-bearing sediments and water alteration at the site of the other Mars rover, Opportunity, in Meridiani Planum. The negative result on water comes in spite of the fact that the Gusev site was chosen as a possible ancient lake, since a huge river channel cuts through its southern rim and empties into it. The tone of the Spirit rover team articles is that any lakebed in the crater was covered by lavas.

Easy to miss in the same issue of *Science*, however, is an article by *Science* journalist Richard Kerr that updates the findings of intense water-caused alteration in soils in the ancient hills recently reached by Spirit — not to mention the sulfur-rich sediments and hematite concretions at the Opportunity site. Kerr speaks of "the emerging picture [of] a salt-laden, often corroded planet that had standing water early in its history."

Kerr's article goes on to cite PSI's Melissa Lane, along with several other researchers, as developing a "counterculture view" of the Gusev crater site, in which it may have been highly watered and weathered after all. Much of the controversy revolves around the role of the mineral olivine in the lava-like rocks. One view, advanced by team spectroscopists Phil Christensen, Dick Morris, and Goestar Klingelhöfer, is that olivine has been detected in the soils, and that because olivine breaks down fairly rapidly when exposed to water, the soils on Gusev's flat floor cannot have been lake-covered.

Melissa Lane (who got her degree working in Christensen's group) proposes an opposing view, along with several other independent workers. Lane and her colleagues suggest that the spectrometer team has not compared the Martian soil spectra with enough comparison minerals in the lab, and that certain hydrous iron sulfate minerals match the spectra (Mini-TES and Mössbauer) of the Gusev crater soils as well as the lava soils proposed by the team. Moreover, hydrous iron sulfate is one of the minerals predicted to have resulted from severe water-based (and acidic) weathering of the soils. In this view, the Gusev rover team claim of olivine is basically a misleading misidentification.

Lane's view would clear up a puzzle. A number of researchers have adopted the conventional view of the spectrometer results — that Mars is dominated by volcanic rocks that have not been much exposed to water, since the presumed olivine has not weathered away. The puzzle is that all the Martian meteorites which have fallen to earth, volcanic or igneous, have been exposed to water and contain residues of water-born salts and carbonates, and/or water-altered minerals. Moreover, one of the Gusev science papers by McSween et al. mentions the presence of alteration rinds on the Gusev rocks that show possible olivine casts (i.e., holes in the shape of olivine crystals), suggesting that olivine has weathered away (McSween et al., 2004) from the surface of the rocks as they are being broken down.

Much of the answer may involve different degrees of water exposure, from brief condensation of transient puffs of water vapor in some rocks, to full-fledged lakebed immersion in other rocks. In any case, Lane's research is fostering an improved look at spacecraft spectra of Martian rocks and soils.

This dramatic Martian vista shows the floor of Gusev crater (middle distance) from a rocky perch in hills climbed by the Spirit rover in August. A current controversy revolves around whether a nearby river once emptied large amounts of water onto this crater floor. In the distance are more hills, and in the far distance on the horizon is the pale rim of Gusev crater. The image was taken on August 5, 2004, the 210th Martian day of Spirit rover operations. (NASA Image, additional processing at PSI by W. Hartmann).

Undergraduate Research at PSI

(continued from page 3)

Physics Education, worked with Dr. Mary Bourke on an aeolian geomorphology project entitled "Comparative Study of Terrestrial Frozen Sand Dunes and the North Polar Sand Seas on Mars." Brett compiled a report on the geomorphic attributes of Arctic and Antarctic sand dunes and examined Mars Orbiter Camera images of sand dunes on Mars for evidence of melting water.

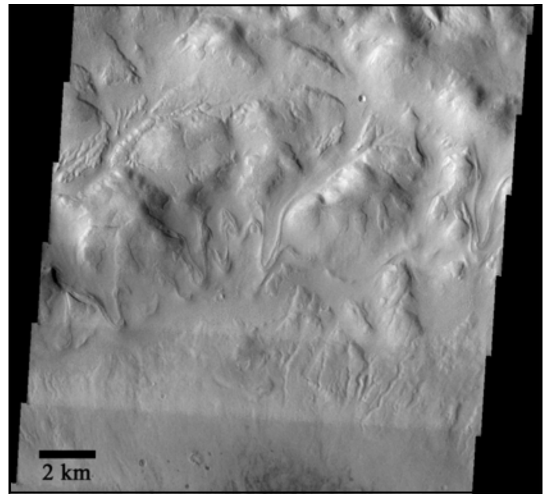
Our third summer intern, Alex Brearley, is a second year Geography student at the University of Oxford. He achieved the highest grade in A-Level Geography in Britian in 2002, and came first in his class at Oxford in 2003. He came to PSI to work with Dr. Mary Bourke on his undergraduate dissertation topic "Rock breakdown processes at the Spirit Landing site, on Mars."

With the increase in PSI science staff and the wealth of new datasets (from such efforts as the Spitzer Space Telescope and NASA's Mars Exploration Program), both the opportunities for students to work with PSI scientists and the impact that they can make should grow significantly in the future.

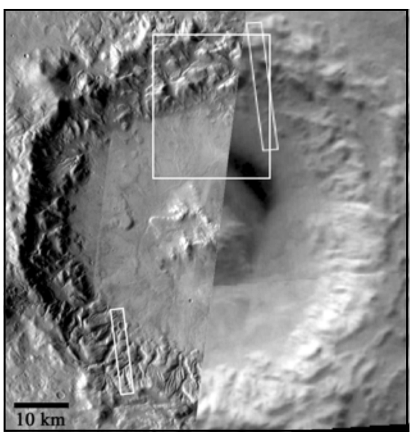
This Month's Mars Images: A Mystery Revisited *By Daniel C. Berman*

One of the exciting recent discoveries on Mars is the presence of distinct tongue-shaped lobes on the sloping walls of large (25-100 km diameter) craters in the mid-latitude regions. These lobes resemble terrestrial glaciers and may be composed of a mixture of water ice and rock. We showed one of the best examples, discovered at PSI, on our Summer 2001 cover (figure [c]). More recently, the Mars Odyssey re-imaged the region of this feature. Figure [a] shows the crater on which this feature was found, at –38°S latitude. The more detailed Mars Odyssey image of the northern wall of this crater is shown in [b], where more of these features can be discerned.

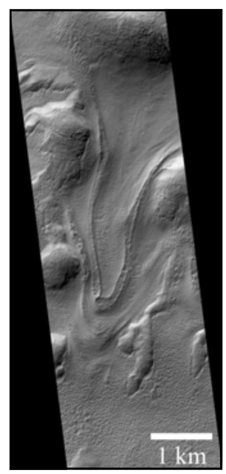
Along with David Crown and William Hartmann, I have been surveying craters on Mars to catalog these types of features in order to better understand the role of ice in the degradation of craters, as well as its overall role on the surface of Mars. We have found many examples of similar lobes on craters throughout the middle latitudes of the southern hemisphere. The lack of fresh craters on the surfaces of these lobes, as seen in Figure [c], suggests they are extremely young in age, and preliminary crater counts have shown model ages on the order of tens of millions of years. We believe that the ice may have been deposited through precipitation during recent periods of high obliquity, when the planet's axis had a much higher tilt, and ice may have been more stable at moderate latitudes. At current atmospheric conditions such water ice is unstable and will sublime directly into gas. Sublimation may now be occurring on the surfaces of these lobes, resulting in the observed pitted texture. We have recently submitted a proposal to NASA, with Dr. David Crown as Principal Investigator, to continue studying these and other ice-related features on Mars.



(b) THEMIS image (V08298002) shows tongue-like flows—possible glaciers—extending downhill in several valleys on the crater (left edge, center, right edge).



(a) North wall of this mid-latitude crater shows several glacier-like features. Large box shows area of (b), narrow strip at its right edge shows area of (c). This image is a mosaic of THEMIS IR (I07961003 and I0643002) and MOC wide-angle (M18-00898) images. The crater is near Reull Vallis in eastern Hellas.



(c) MOC image (M18-00897) of flow lobe; note response to small topographic obstacles on crater rim and change in lobe width.

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