# The PLANETARY REPORT

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Laser "Footprints" on Mars

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## From The Editor

In this issue, we feature two old warhorses of exploration: *Galileo* launched in 1989 and reached the Jovian system in 1995; *Mars Global Surveyor* launched in 1996 and entered Mars orbit in 1997. Long after their primary missions ended, both spacecraft are still returning data, testifying to the imagination, ambition, and skill of the human explorers who stand behind them.

Both spacecraft teams confidently overcame mechanical failures threatening their missions. On *Galileo*, the main antenna refused to open, rendering it useless. Communications had to be routed through a smaller antenna, but thanks to mission engineers, the spacecraft returned still-spectacular amounts of data.

On *Mars Global Suveyor*, a small damper failed, causing a solar panel mount to crack during deployment and forcing a delay in the spacecraft's reaching its mapping orbit. Still, the avalanche of data from the mission buried many old assumptions about Mars, and we now see the Red Planet as a much more vital and dynamic world.

Achieving grand ambitions, overcoming failure, transforming knowledge—these missions have taught us what is possible when we are demonstrably confident, clever, and smart. Planetary exploration is a beacon to humankind of all that we can become.

—*Charlene M. Anderson*

### On the Cover:

This image, produced from Mars Orbiter Laser Altimeter (MOLA) data, reveals abundant evidence for the past flow of liquid water on Mars. Shown here is the Chryse outflow region, located 315 to 330 degrees east and 0 to 20 degrees north. Thanks to MOLA, scientists now know the topography of Mars better than they do the topography of many regions on Earth.

Image: MOLA Science Team (published here for the first time)

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# Members' **Dialogue**

### Honoring *Voyager*

Normally, I finish reading *The Planetary Report* just before the next issue arrives. The special *Voyager* issue (September/October 2002) changed all that. Before even checking the other mail I received that day, I had read the magazine cover to cover! Hats off and thumbs up to all the staff in Pasadena.

Kudos, too, to all those who were part of *Voyager*. Your shoulders are broad and strong. Thank you for the view. It is more beautiful than we could ever have imagined.
—JOE SALVADORE,
*Frisco, Texas*

My copy of the *Voyager* special issue arrived today. The entire magazine is superb—the best retrospective I've seen on *Voyager*. Many thanks!
—BRAD SMITH,
*Santa Fe, New Mexico*

*Editor's note: Brad Smith led the imaging team on the* Voyager *project.*

Your special issue on *Voyager* brought back fond memories. The pictures of *Voyager*'s encounter with Saturn that I first saw as a teenager started my lifelong interest in the solar system. I have followed every *Voyager* encounter after that, and every planetary probe since.

The shattering of our view of planets as simply giant balls of gas and their moons as dead rock should forever inspire exploration of our universe. I hope that *Galileo* and *Cassini* won't be the only outer planet probes we have to look forward to. In a world turning increasingly inward as well as fearful, *Voyager* will always be there to represent hope and to inspire future generations.
—WILLIAM V. STINE,
*Fairfax, Virginia*

In your September/October "From The Editor" column, you posed the question of why the *Voyager* spacecraft were so much more successful in the public imagination than were the *Pioneer*s. I think the answer is very simple: the enormously better pictures that were returned by the *Voyager*s. In contrast to the crude images obtained by the *Pioneer*s, the *Voyager*s supplied us with pictures we might have taken ourselves had we been there.
—PETER H. LLOYD
*Toddington, United Kingdom*

### More on "What to Tell Them"

James Walker's challenge to explain the importance of science and space exploration in twenty-five words or less (see the July/August issue of *The Planetary Report*) set me thinking, and I realized that the practical implications don't really matter.

The human spirit exists to experience joy. Essential to that pursuit are curiosity and exploration.
—ROBERT TARRON,
*Uxbridge, United Kingdom*

I would like to respond to James Walker's letter by paraphrasing David McCullough: Not knowing the story of this ancient and elegant universe that spawned us isn't simply stupid. It's rude.
—CHRIS TODD,
*Shoreline, Washington*

If we ever expect to figure out what we are, we need to know where we are.
—TERRY CHURCHMAN,
*Altadena, California*

Exploration of the unknown and greater understanding of planet Earth, our home, are as nourishing and vital to the human spirit as food and shelter.
—DAVID HUFNAGEL,
*Golden, Colorado*

We may discover that our role in the great scheme of things is perhaps more marginal than we like to imagine.
—SHELAGH BURKE,
*Clonmel, Ireland*

### Mistaken Identity

On page 17 of your September/October issue, one of the photo captions reads: "Astronaut James McDivitt is shown here on a space walk from a *Gemini* orbital flight. His hand is visible . . . "

Indeed, Mr. McDivitt had a hand in this photo, but as the astronaut who took the photograph. The subject of the photograph is Edward H. White II, America's first space walker.
—CARL ALESSI,
*Yorba Linda, California*

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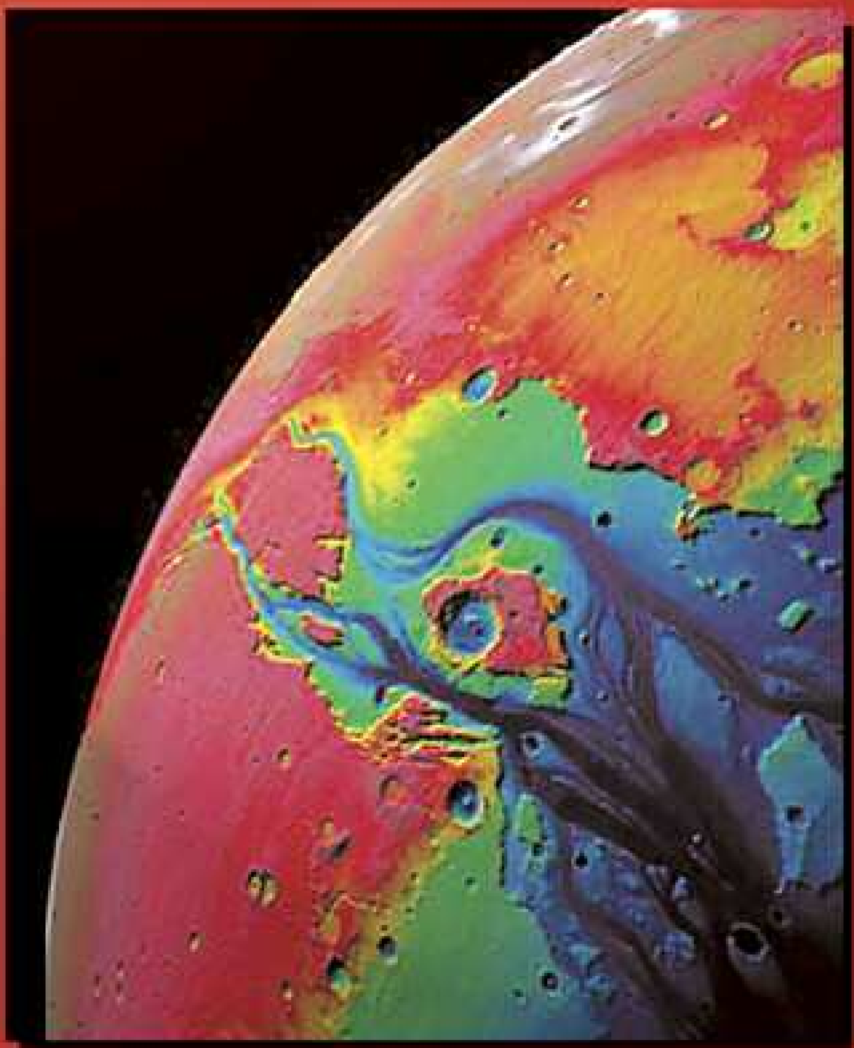
# SHEDDING LIGHT ON THE RED PLANET:

## Science Findings From the Mars Orbiter Laser Altimeter



*The dark blue features seen here mark Kasei Valles, a region on Mars where liquid water once flowed. This view is based on observations by the Mars Orbiter Laser Altimeter (MOLA) on board* Mars Global Surveyor (MGS). *MOLA's views of the Red Planet are giving scientists new insights into Mars' geologic history and into the ways that water has flowed across its surface during the last 4 billion years.*

*Image: MOLA Science Team and Goddard Space Flight Center Scientific Visualization Studio*

**by Maria T. Zuber, David E. Smith, and James B. Abshire**

A planet's topography tells the story of its evolution, as many geologic processes—including tectonics, volcanism, and erosion—are controlled by elevation or surface slope. To better understand Mars' rich geologic history, early spacecraft missions used a variety of methods to try to measure the shape of the Red Planet. *Viking*-era analyses produced models of surface heights on Mars with average errors of about 1 kilometer (0.6 mile), although in some areas, errors were as much as 5 kilometers (3 miles). In addition, early maps failed to determine locations accurately in latitude and longitude. Errors in surface location were typically less than 3 kilometers (2 miles), but some areas were misplaced on maps by more than 15 kilometers (9 miles).

The payload on *Mars Global Surveyor* (*MGS*; see the

July/August 1999 issue of *The Planetary Report*) contained the Mars Orbiter Laser Altimeter (MOLA), a device used to develop the most accurate global topographic model in existence for any planet, including Earth. Taking advantage of technological advances in laser technology, the MOLA experiment applied state-of-the-art techniques to produce highly precise measurements that address a range of questions about the surface, interior, and atmosphere of Mars. Here, we discuss the MOLA experiment and summarize some of its key science findings.

## The Instrument

The MOLA instrument operates by firing infrared laser pulses at Mars, then measuring how long it takes the laser signal to bounce off the planet's surface (or clouds in some cases) and return to the spacecraft. Knowing the speed of light allows scientists to derive the distance to the Martian surface at the time of the laser pulse. Combined with knowledge of the spacecraft's location in space, this information makes it possible to determine the planet's topography (see "Getting Technical," page 6).

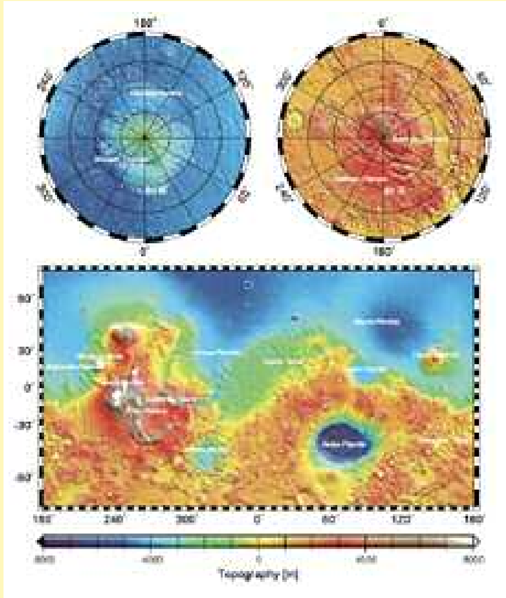
While MOLA's primary function is to measure surface topography, the instrument supplies two additional measurements. First, it measures the roughness of the surface in laser-pulse-size sections (a laser pulse is about 100 meters in diameter by the time it reaches the surface). A flat surface will return the entire pulse at once, whereas a rough surface will spread out the pulse. MOLA also measures the reflectance of the Martian surface in the near infrared in a passive mode (that is, without use of the laser-ranging function described above).

## "Sea Level" on a Planet With No Sea

Topographic models of a planet require a reference point. On Earth, this is typically sea level. But on Mars today, there is no sea.

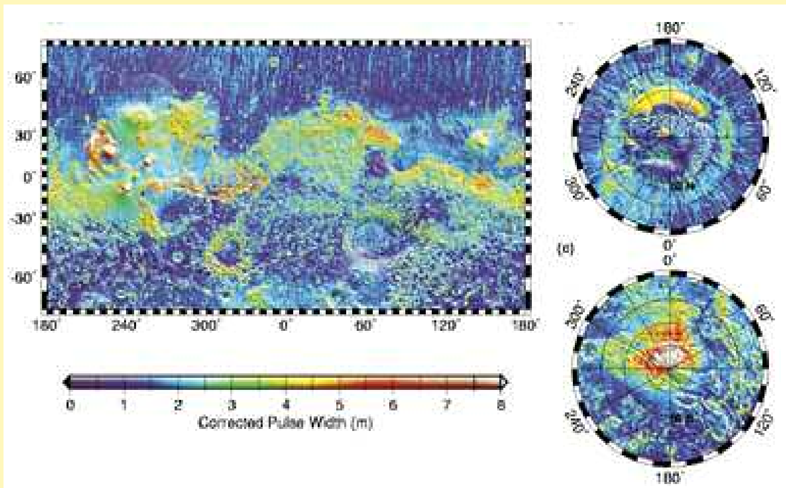
Pre-MOLA topography on Mars was referenced to an imagined surface where the atmospheric pressure was 6.1 millibars. However, using a pressure surface as a topographic reference introduced large errors into estimates of elevation. That is because the height of any given isobar (constant pressure surface) varies by as much as 2.5 kilometers (1.6 miles) over the Martian year due to the seasonal exchange of carbon dioxide between the atmosphere and polar caps and to the dynamic motions in the atmosphere.

To rectify this problem, the MOLA science team chose a static reference surface. Zero elevation on Mars from MOLA is defined as the gravitational equipotential surface (an imaginary surface with the same gravitational geopotential everywhere across it) whose average value at the equator is equal to the mean radius of the planet. The average height of the 6.1-millibar pressure level occurs at approximately –1,600 meters relative to the zero reference of MOLA topography for the first day of spring in the northern hemisphere.



***These global maps of Mars' topography show the striking difference between the planet's smooth northern hemisphere and its heavily cratered southern hemisphere, which sits an average of 5 kilometers (3 miles) higher than the north. Warm colors correspond to topographic highs, and cool colors show topographic lows. The very dark blue oval denotes Hellas, the deepest known topographic depression in our solar system.***

***Maps: MOLA Science Team***




***Although its main task is to measure Mars' topography, MOLA also senses the planet's surface roughness by calculating how the* MGS *spacecraft's laser pulse spreads out on contact with the ground. On a smooth surface, the pulse will bounce back all at once, whereas on rough terrain, the pulse will spread out. Cool colors on these maps show smooth areas and warm colors depict rough zones. The roughness sensed from the spreading pulse is a measure of the variation inside a circular laser footprint about 160 meters in diameter on the planet's surface.*** ***Maps: MOLA Science Team***

MOLA data have been used to redefine the geodetic grid of Mars and have provided up to one hundred times better knowledge of the absolute locations of latitude and longitude and one thousand times better knowledge of the planet's radius over all previous models of Mars. Locations on Mars sampled by MOLA are now known to approximately ±100 meters, and vertical positions are known to approximately 1 meter.

## Global Topography

MOLA's global topographic map of Mars (at the top of this page) has a spatial resolution of 1 kilometer and a radial accuracy of about 1 meter. The map reveals the major physiographic provinces on Mars, showing the striking difference between the southern and northern hemispheres.

Mars' hemispheric dichotomy has been known since early maps of the planet, but MOLA data have clarified significant aspects of this puzzling feature. The dichotomy has two components: a contrast in surface geology and an elevation change.

Regions with differing geologic style are separated by what is known as a *dichotomy boundary.* Mars' southern highlands are more heavily cratered than the northern lowland plains. The difference results from resurfacing of the northern hemisphere by volcanic flows and sediments.

MOLA's topographic map also shows that Mars' south pole is 6 kilometers (4 miles) higher in elevation than the north pole, with a south-to-north slope of 0.036 degree. As we will discuss later, this global longitudinal slope—which predates other geologic features on the surface—means that the northern lowlands represent a sink for water and sediments. Along part of the north-south dichotomy boundary, the elevation increases as much as 3 kilometers (2 miles). The area may represent an erosion boundary providing a source for some of the sediment fill in the northern plains.

The difference in elevation between the north and the south has been attributed either to a large impact or impacts in the northern hemisphere or to intense mantle dynamics. Recent modeling has established the feasibility of the latter origin, and while northern lowlands seem to be inconsistent with the proposed impact origin, evidence for such a process may have been erased by more recent geologic events.

The Red Planet's other major feature examined by MOLA is the Tharsis province. Centered near the equa-

*For scale, the MOLA instrument's receiver telescope has a diameter of a half-meter. The telescope is the circular silver object at the center of the image.*
*Image: JPL/NASA*

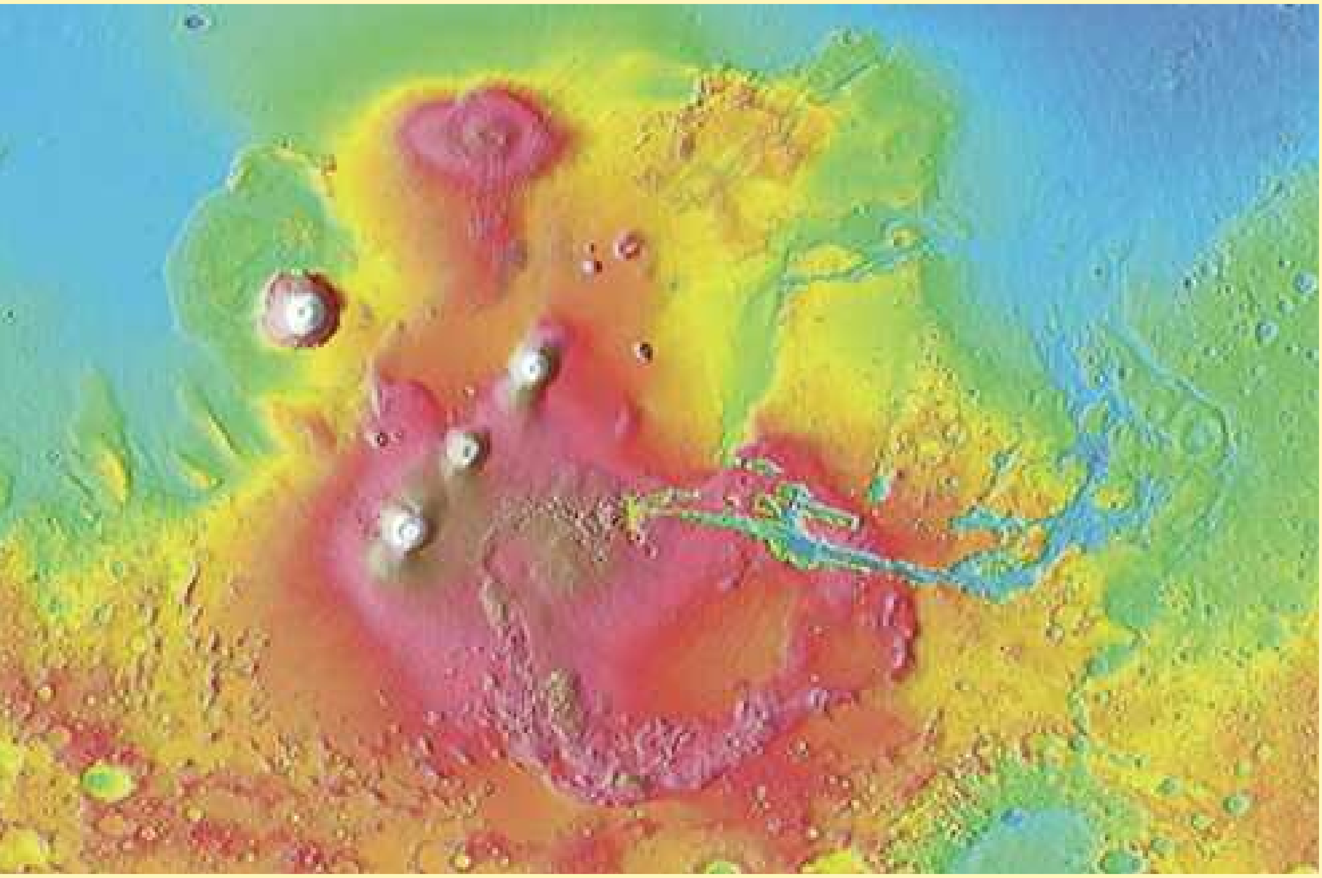
## Getting Technical

The Mars Orbiter Laser Altimeter (MOLA) instrument, which is mounted on the downward-facing deck of the Mars Global Surveyor (MGS) spacecraft, operates by firing infrared laser pulses at Mars and then measuring the round-trip flight time of the laser signal. The laser transmitter consists of a solid-state (chromium- and neodymium-doped yttrium aluminum garnet, aka Cr:Nd:YAG) oscillator excited optically by a 36-bar diode array to produce laser action at 1,064 nanometers (the near infrared). A Q-switch causes the laser to emit approximately 8-nanosecond-long pulses at a rate of 10 Hertz.

MOLA's receiver is a 0.5-meter-diameter, gold-coated beryllium telescope. The receiver optics includes a narrow (2.0-nanometer-wide) bandpass filter that rejects the solar photons near the laser wavelength and a silicon avalanche photodiode detector. The receiver also contains a time interval unit—a binary counter that records the number of clock cycles to measure the time between transmitted and received pulses. In addition, the instrument contains an 80C86 microprocessor that executes the flight software.

MOLA was designed to range continuously to the surface of Mars during the MGS mapping mission. The backscattered laser pulse is detected within a range gate, that is, a period during which the returned pulse is expected. The telescope collects photons from laser pulses scattered by terrain or clouds, which are then focused on a detector that outputs a voltage proportional to the rate of backscattered photons. When this voltage exceeds the detection threshold, the time interval unit is stopped and the round-trip time of flight recorded.

By interpolating the MGS orbital trajectory determined from radio tracking of the spacecraft to the time of the laser measurement, one can determine the distance between the spacecraft and the center of mass of Mars. Subtraction of the range to the surface from the MGS orbit yields measurements of the radius of Mars. In order to determine directions of downhill flow on the surface, one converts radius to topography by subtracting the gravitational geopotential from the radius measurement. —MTZ, DES, JBA



***This topographic map reveals that Mars' Tharsis Montes—the Ascraeus, Pavonis, and Arsia volcanoes—are situated on a main rise (shown in pink) that includes the Chryse outflow region and part of Valles Marineris. The Alba Patera volcano sits above them on a northern rise, and unlike in previous topography models, Olympus Mons is not associated with the main Tharsis bulge. Instead, it sits by itself off Tharsis' western edge.***

*Map: MOLA Science Team (first published by* Sky & Telescope*)*

tor, Tharsis is a locus of volcanism and tectonism (faulting). The complex structure of Tharsis revealed by MOLA indicates that most of the topographic rise was formed by the intrusion and extrusion of volcanic material (as opposed to doming from upward-directed mantle forces).

The topographic map also shows Tharsis to consist of a primary rise that contains the Tharsis volcanoes (Ascraeus, Pavonis, and Arsia) and a secondary rise that comprises the Alba Patera volcanic structure and surroundings. In contrast to previous topography models, here, Mars' largest volcano, Olympus Mons, is not associated with the main Tharsis rise but rather is situated off its western edge.

Prior to *MGS*, it was thought that Tharsis formed over most of the 4.5-billion-year history of Mars. However, geophysical modeling and stratigraphic analysis of ancient valley networks now show that most Tharsis magmas were emplaced during the earliest epoch of Martian history, known as the Noachian. Tharsis magmatism may have caused the release of vast quantities of carbon dioxide and water to the surface and into the atmosphere. Thus, the formation of Tharsis may have played a central role in contributing to early Mars' possible clement climate.

## Surface Roughness

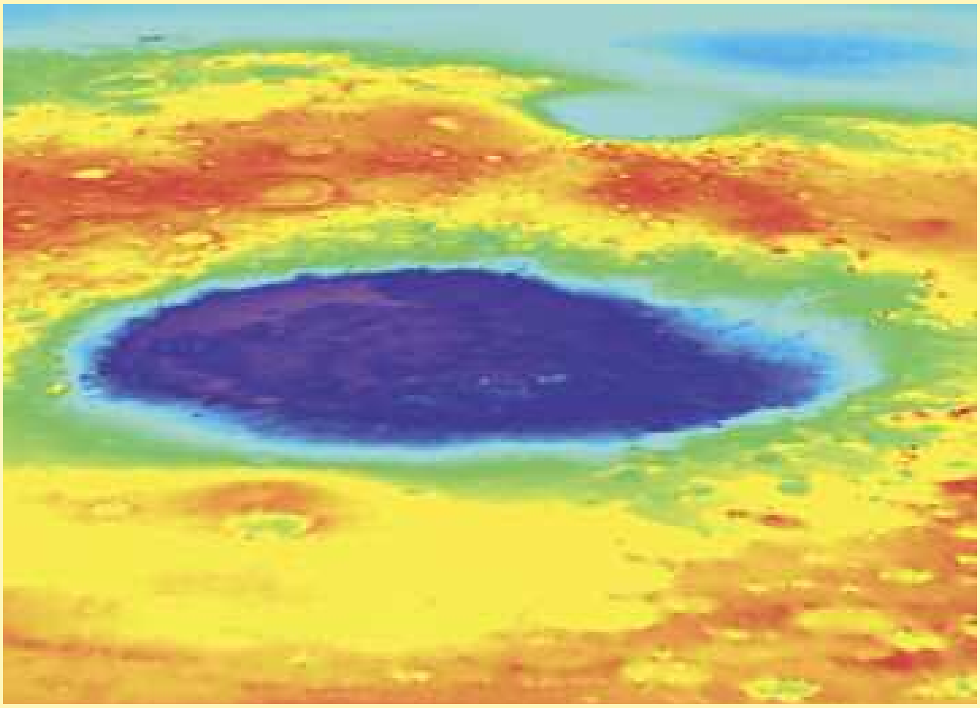
Measurements of the spreading of MOLA's backscattered pulses (see image on page 5) indicate an approximate bimodal roughness distribution, with a contrast across the geologic dichotomy boundary. High-latitude southern highlands, while rougher than the northern lowlands, are considerably less rough than equatorial highland regions.

The northern lowlands of Mars are now known to be the smoothest large-scale surface in the solar system yet measured by altimetry. The smoothness is likely explained by depositional processes (wind, water, and vocanic eruptions), but whether deposition was accomplished by, alternatively, wind-driven deposition or by sedimentation in an ancient ocean remains a subject of debate.

## Impact Craters and Basins

MOLA topography has shown that the massive Hellas impact basin is the deepest known topographic depression in the solar system—more than 9 kilometers (6 miles) deep from the top of the rim to the bottom of the basin. MOLA's global map shows the concentric distribution of cratered highland material around the basin, which rises above its surroundings 2 kilometers (about 1 mile) and accounts for a significant amount of the high-standing topography of the southern hemisphere. Material excavated from Hellas represents a major redistribution of the Martian crust, contributing in part to the features along part of the dichotomy boundary.

MOLA data also verified the existence of the Utopia basin, buried beneath the northern plains. Similar in



*The Hellas impact basin in Mars' southern hemisphere is 9 kilometers (nearly 6 miles) deep and 2,100 kilometers (1,300 miles) across. This massive depression is surrounded by a ring of material (most likely ejected by the impact of an asteroid) that rises 2 kilometers (about 1 mile) above the surrounding terrain and stretches out to 4,000 kilometers (2,500 miles) from the basin's center.*

*Image: MOLA Science Team*

diameter to Hellas but only 2.5 kilometers (1.63 miles) deep, Utopia was, on the basis of geologic mapping, proposed originally as an impact structure, although not resolved as such in pre-MOLA topographic models.

In addition, MOLA's high-resolution global grid has resolved numerous subtle, degraded, and previously unrecognized impact basins. In number and size, these partly buried craters indicate that beneath their resurfacing, Mars' northern lowlands are at least as old as its southern highlands. Thus, the crust in the northern lowlands and the crust in the southern highlands must have formed nearly contemporaneously.

## Past Water

Early on, spacecraft images yielded abundant evidence for flowing water on the surface of Mars during the planet's youth, but many questions remain regarding the amount, duration, and possible episodicity of the flow of liquid water on the surface. Such questions bear significantly on the nature of Mars' early climate.

It is now known that the basic shape of the planet formed relatively early, so present-day topography can be used to infer approximate past pathways of water. For example, MOLA data reveal a continuous flow route from the Argyre basin to the Chryse outflow region, illustrating the south-to-north transport noted previously. Depending on the amount of water on the surface in the past, as much as 90 percent of the surface area may have drained into the northern plains. High-resolution topographic images, such as shown in the image of the Chryse outflow region (on the cover of this issue), have provided evidence for sustained flow and multiple floods.

## Polar Regions

MOLA models of the polar regions have yielded the best available estimates of the volume of present-day water on Mars. The southern ice cap is much smaller in extent than the northern, although layered deposits in the south extend much farther from the ice cap and exhibit a more asymmetric distribution than in the north. The relief of the southern polar cap is comparable to that of the northern cap.

The total amount of surface ice is roughly 3.2 to 4.7 million cubic kilometers. If you spread all this ice evenly over the entire planet, it would be 22 to 33 meters thick. Even accepting that both caps are composed of pure water-ice (in reality, there is also carbon dioxide ice, but specific relative quantities are unknown), this range is at the low end of previous estimates of the amount of water believed to have been present early in Mars' history. At high latitudes, MOLA coverage is so dense that the surface is oversampled. Nevertheless, the high resolution shaded relief images produced (above right) show the complex surface structure in the vicinity of the Chasma Australe feature in the southern cap's layered terrains.

*Mars' north polar cap sits at the center of this shaded relief image, which extends from the pole to 54 degrees north. The polar stereographic projection shows ubiquitous rampart craters (with fluidized ejecta blankets), as well as partially buried craters in the plains surrounding the cap. These provide insight into the resurfacing of the planet's northern hemisphere and into the past presence of subsurface water and carbon dioxide.*

*Image: MOLA Science Team*

*At high latitudes, MOLA has gathered so much data that scientists have been able to produce extremely detailed relief images, such as this view of the Chasma Australe region of Mars' layered south polar terrains. The 400-by-300-kilometer (about 249-by-186-mile) image shows the complex surface structure of layered terrains overlying cratered uplands.*

*Image: MOLA Science Team and G. Shirah, Goddard Spaceflight Center Scientific Visualization Studio*

## Clouds and Snow

MOLA also has functioned as an atmospheric lidar (a visible- or near-visible-light analog to radar), providing the first measurements of the three-dimensional distribution of cloud fronts on Mars. MOLA detects clouds in two ways: by either reflection or absorption of the outgoing pulse. Unusually strong, clustered atmospheric reflections suggest precipitation of carbon dioxide snow under supercooled atmospheric conditions. Clouds are most commonly viewed at night over the winter pole, but weaker cloud reflections have been observed at all latitudes, mainly during twilight and also at night.

The absorptive clouds—defined by an absence of range returns due to atmospheric absorption of the outgoing pulse—are mostly associated with the advance and recession of the edges of Mars' seasonal polar caps. Biweekly averaging of MOLA data has yielded the first direct measurements of carbon dioxide snow depth, with both polar regions accumulating a maximum of 2 meters near the winter poles.

## Radiometry Mode

After successful operation for the duration of the *MGS* mapping mission, MOLA ceased active ranging to Mars on June 30, 2001, during the extended mission. The ranging function was lost after an oscillator in the receiver electronics failed. At the time, MOLA had been in space for 1,696 days, and the laser had fired more than 671 million times in space; the instrument had made approximately 640 million measurements of Mars' surface and atmosphere.

MOLA continues to operate in passive mode, measuring the brightness of the Martian surface. For example, MOLA observed the reflectivity of seasonal changes in the southern hemisphere's polar frost. The signal varies noticeably through the seasons due to the pattern of deposition and sublimation, and subtle reflectivity changes may indicate the crystal grain or particle size of the frost. Such observations will contribute to the understanding of volatiles and dust cycling on Mars.

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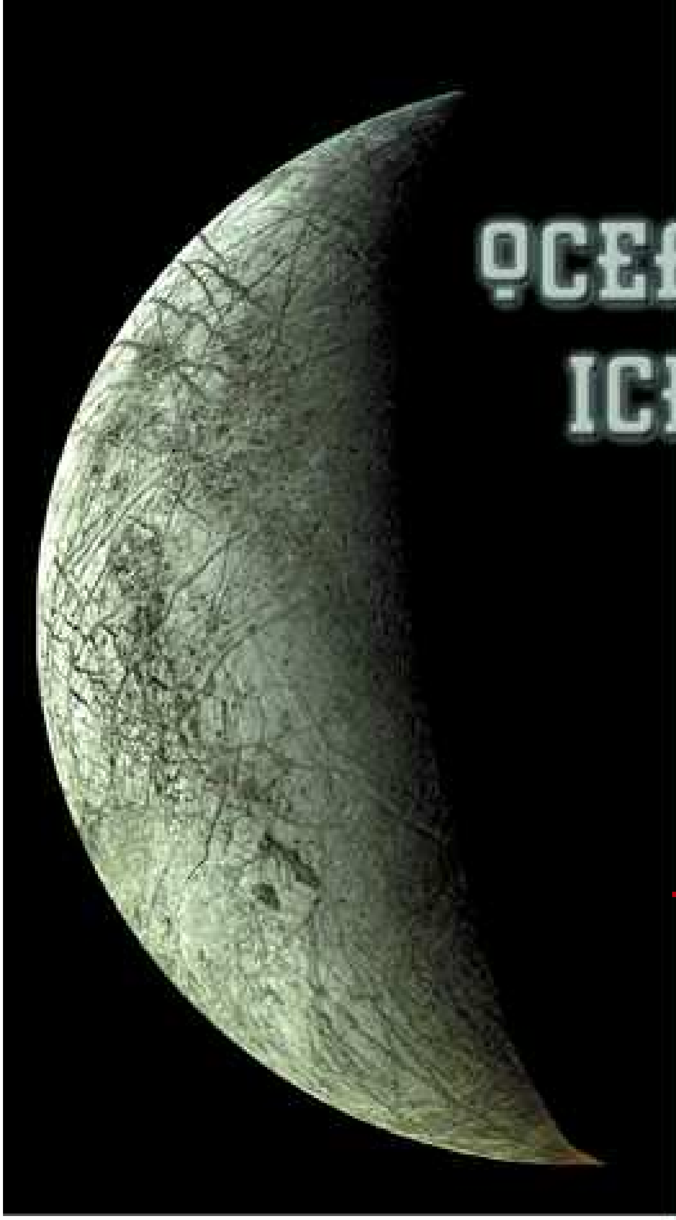
*Maria T. Zuber, a member of The Planetary Society's Board of Directors, is a professor of geophysics and planetary science at the Massachusetts Institute of Technology and a senior research scientist at the Laboratory for Terrestrial Physics at NASA's Goddard Space Flight Center. David E. Smith and James B. Abshire are scientists at the Laboratory for Terrestrial Physics.*

**More information about the MOLA investigation can be found at**

***http://www.gsfc.nasa.gov/tharsis/mola.html***



*Europa's dark, linear features resemble a crackle glaze on the moon's bright, icy surface. This view was created by merging lower-resolution natural color with the highest-resolution mosiac of Europa images taken by Voyager 2.* *Image: JPL/NASA and Paul Schenk, Lunar and Planetary Institute (LPI)*

# Oceans, Ice Shells, and Life on Europa

**by Paul Schenk**

***Scientists are hotly debating whether they prefer Europa with a thick or thin crust—hence, The Great Europan Pizza Debate. The answer may well determine what life-forms could develop in the subsurface ocean of the Jovian satellite and how we humans might explore this amazing body.***

The four large satellites of Jupiter are famous for their planetlike diversity and complexity, but none more so than ice-covered Europa. Since the provocative *Voyager* images of Europa in 1979, evidence has been mounting that a vast liquid water ocean may lurk beneath the moon's icy surface. Europa has since been the target of increasing and sometimes reckless speculation regarding the possibility that giant squid and other creatures may be swimming its purported cold, dark ocean. No wonder Europa tops everyone's list for future exploration in the outer solar system (after the very first reconnaissance of Pluto and the Kuiper belt, of course).

Europa may be the smallest of the Galilean moons (so-called because they were discovered by Galileo Galilei in the early 17th century) but more than makes up for its diminutive size with a crazed, alien landscape. The surface is covered with ridges hundreds of meters high, domes tens of kilometers across, and large areas of broken and disrupted crust called *chaos.*

Some of the geologic features seen on Europa resemble ice rafts floating in polar seas here on Earth—reinforcing the idea that an ice shell is floating over an ocean on this Moon-size satellite. However, such features do not prove that an ocean exists or ever did. Warm ice is unusually soft and will flow under its own weight. If the ice shell is thick enough, the warm bottom of the shell will flow, as do terrestrial glaciers. This could produce all the observed surface features on Europa through a variety of processes, the most important of which is convection. (Convection is the vertical overturn of a layer due to heating or density differences—think of porridge or sauce boiling on the stove.) Rising blobs from the base of the crust would then create the oval domes dotting Europa's surface.

The strongest evidence for a hidden ocean beneath Europa's surface comes from the *Galileo* spacecraft's onboard magnetometer, which detected fluctuations in Jupiter's magnetic field consistent with a conductor inside Europa. The most likely conductor: a somewhat salty ocean.

## THE GREAT EUROPAN PIZZA DEBATE

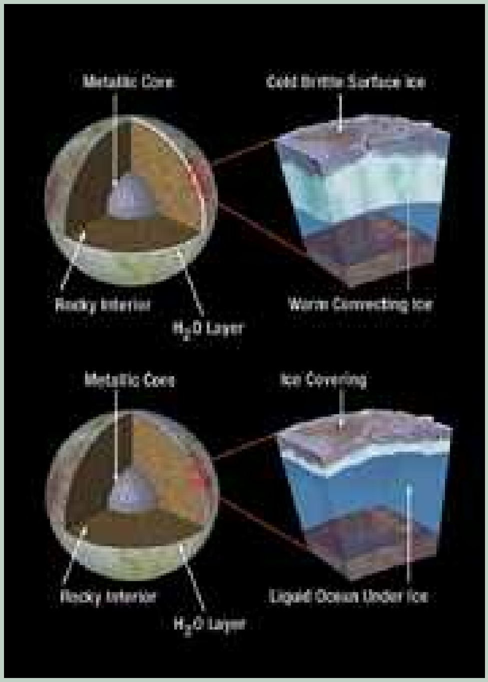
Although we cannot prove the existence of a subsurface ocean on Europa until we return with more sophisticated robots, most planetary geologists consider such an ocean likely. In fact, considerable effort has been devoted to determining the thickness of the floating ice shell. The shell could be only a few kilometers thick (the thin shell, or "thin crust," model), or it could be 15 or more kilometers (9 or more miles) thick (the thick shell, or "thick crust," model). Io may have been the original "Pizza Moon" (the first *Voyager* images made Io look like a pizza), but Europa may prove the ultimate pizza lover's delight (or nightmare), with the thin-crust vs. thick-crust debate sometimes reaching fever pitch. Nevertheless, no conclusive case can be made from either model based on geologic evidence alone.

The thickness of Europa's ice shell has dual significance. First, it could influence the chemistry of the ocean underneath and the form that biological materials or organisms there might take. Second, it will determine the strategies best used to explore the underlying ocean, assuming we wish to sample it directly. Before looking at new evidence regarding the thickness of the ice shell, let's examine these issues.

The debate over life on Europa has focused on chemistry and sunlight. The chemistry of the ocean is unknown, but dark reddish materials on Europa's surface may have emerged from ocean depths. Unfortunately, we are uncertain as to the composition of these materials. They could be hydrated salts or sulfates or possibly something we haven't thought of yet. Organic hydrocarbon compounds could also be present on Europa, but none have been unambiguously identified on the surface in *Galileo* orbiter data.

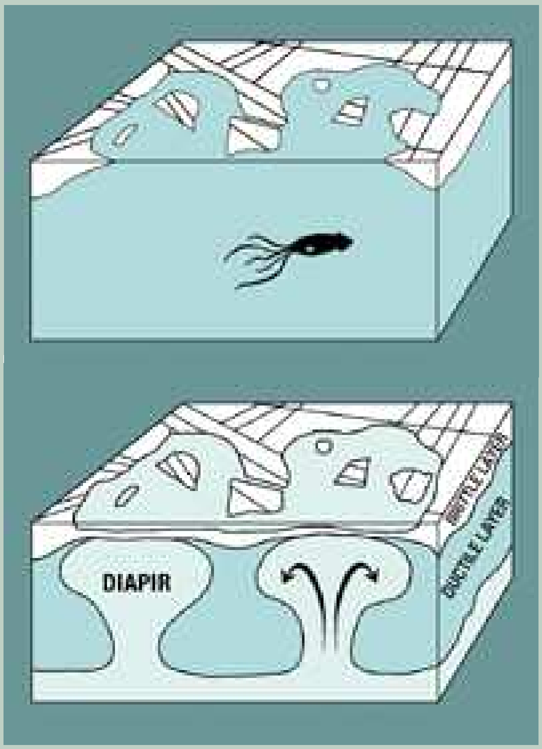
Many terrestrial organisms depend on sunlight for energy to process food. Any ice shell more than a kilometer (0.6 mile) thick will not allow sunlight through. Yet, a thin shell might be disrupted, fractured, or melted locally, allowing ocean water and anything floating or dissolved in it temporary access to the weak sunlight at Jupiter. This could promote the development of photosynthetic organisms, the severe radiation dosage at the surface notwithstanding.

Given a thick ice shell, however, these processes would not happen or would happen so slowly as to limit their effectiveness at giving life a boost. Other, much slower geologic processes, such as convective overturn (also known as *diapirism*) become important in the case of a thick shell.




***The mysterious features on Europa's surface might be explained either by a warm, convecting ice layer—located tens of kilometers below a cold, brittle ice crust such as that depicted in the top model—or by a much thinner layer of ice only a few kilometers thick, shown in the bottom model. A liquid water ocean is believed to lie beneath Europa's ice crust for a total water and ice layer thickness of around 100 kilometers (60 miles).***

*Illustration: NASA*




***These diagrams show how the thickness of Europa's ice shell is critical to what takes place underneath. In a thin-shell model (top), the liquid ocean beneath can easily melt through the ice or seep up through cracks to the surface. These breaches in the ice shell might allow enough weak sunlight through for photosynthetic sea life to evolve.***

***A thick ice crust (bottom) would allow the shell to convect (a process known as*** **diapirism*****, meaning to turn itself inside-out). In this model, large blobs of ice could rise upward from the lower part of the ice shell, potentially bringing bits of the ocean to the surface.***

*Diagrams: Paul Schenk, LPI*

Some Earth organisms do not in fact depend on sunlight but, rather, utilize chemical energy. The most famous are the organisms found at the black smokers along the volcanic midocean ridges and also the bacteria discovered inside rocks deep within Earth's crust. The central question relating to Europa is whether these unusual life-forms originated in such extreme environments on their own or whether they evolved from species on Earth's sunny surface and then migrated to the ocean bottom or deep crust. If organisms can evolve

Right: This *Galileo* image of ice "rafts" in a region of Europa called Conamara Chaos could be evidence of a thin ice shell floating over liquid water. But these broken plates—the largest of them about 10 kilometers (6 miles) across—could also have formed over a large plume of soft ice rising from the lower part of a thick icy crust. In either case, the jumbled, hummocky material called matrix could contain frozen bits of Europa's subsurface ocean.

Image: JPL/NASA

*The setting Sun, reflected off Jupiter, lights this Europan night. A constantly moving subsurface ocean is probably responsible for the "jigsaw puzzle" look of the Galilean moon's cracked, icy crust.*

*Painting: Mark A. Garlick*

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In Europa's cold ocean, the mo
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In this thin-crust scenario, Europa's icy shell has broken, allowing water to seep up to the surface. The dim light from Jupiter illuminates Europan sea life swimming around a hot vent similar to the black smokers found near Earth's ocean trenches.

Painting: David Hardy

ckness of the ice shell on Europa is
of the existence of life there, except
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uropa as a body is much denser than
must be composed of rocks. The total
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2002 issue of *The Planetary Report*),
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crust aside, plans are afoot (or "afin"!)
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ot submarine on the surface—which,
meters long, would melt its way down
ce in the ocean, it could swim some
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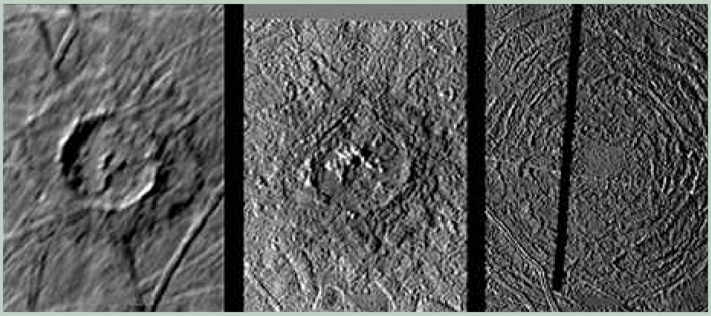
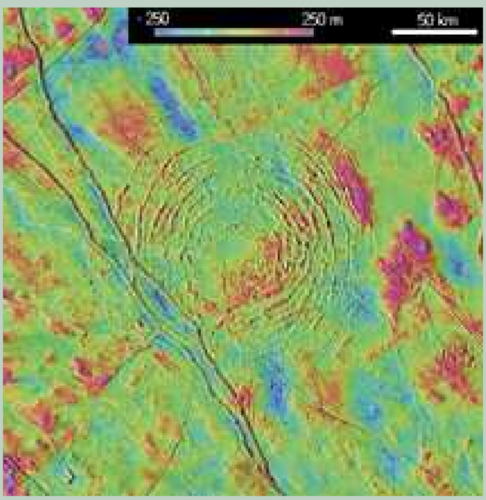


***As Europa's craters increase in size, they also become more complex. These craters (from left to right) are Grainne, Pwyll, and Tyre. Their respective diameters are 14 , 27, and 41 kilometers (about 9, 17, and 25 miles). These images have been scaled to make the craters appear the same size, thus helping us compare crater shape and morphology. The difference between Pwyll's and Tyre's morphologies is abrupt and radical. This indicates that at depths of roughly 20 kilometers (about 12 miles), there is a sudden transition, possibly to liquid water, within Europa's icy shell.*** *Images: JPL/NASA*

***This perspective view of Europa, constructed from long-range*** **Galileo** ***images and digital topographic maps produced by the author, shows an area roughly 100 kilometers (60 miles) across and illustrates just how rugged the surface of the Jovian moon is. Such steep-sided linear ridges are ubiquitous on Europa, but its surface is also characterized by rolling topography. For easy viewing, the apparent relief in this image has been exaggerated about 20 times.*** *Image: JPL/NASA and Paul Schenk, LPI*




***The original*** **Galileo** ***mosaic of the impact crater Tyre was combined with color-coded digital topography to produce this view, in which reddish tones represent high areas and blues depict lows. Tyre consists of numerous concentric ridges and troughs extending up to 75 kilometers (47 miles) from its center. Although only 41 kilometers (25 miles) across, the actual crater is highly flattened and is located just inside the innermost rings seen here. These unusual rings indicate that the crater may have penetrated deep into Europa's icy shell, almost to the depth of the water ocean beneath.***

*Mosaic: JPL/NASA and Paul Schenk, LPI*

We might not need to melt our way through to the ocean to sample it, however. Geologic processes may bring bits of the ocean up to the surface for us. Several geologic processes are candidates, depending on how thick the ice shell is. As mentioned earlier, heating could melt through parts of the ice shell, locally exposing ocean material (now frozen). Large linear cracks could do the same. Europa's surface is covered with cracks, though the interpretation of their origin is highly controversial.

By contrast, if the ice shell is thick, it will convect, as described earlier. Convection allows parts of the lower crust to rise up near the surface. Any pockets or bubbles of the ocean that might be interspersed or trapped within the lower crust would then be brought up to the surface, where we could sample them directly. Many of the chaos regions and oval spots scattered across Europa's surface may be evidence of such convection.

Finally, if a large enough impact crater forms on the surface, it might penetrate through the ice shell and blast bits of ocean directly onto the surface.

## THE CASE FOR A THICK ICE SHELL

How thick is Europa's icy shell? Drill cores through it—similar to those taken from the Greenland ice sheet for climate studies—would ideally answer this question, but setting up drilling operations on radiation-soaked Europa is prohibitively expensive. Nature provides a convenient drill-coring system for us, however, in the form of impact craters.

Impact craters form when comets or asteroids strike Europa's surface. These explosive events excavate material from near the surface of the satellite. The depth of excavated material is related to crater size; larger craters excavate more deeply.

In the same way, the morphology of larger impact craters depends on the strength of the ice shell at greater depths. All rocks (and water-ice is technically a rock) have inherent strength, and this is what helps planetary impact craters remain deep over the eons. If the crust immediately beneath an impact crater is unusually soft, it will not have the strength to maintain the crater's original depth and will collapse very rapidly, forming shallower craters. If the crater is large and deep enough, it will "sense" a liquid ocean beneath it. Since liquid water has negligible strength, we might expect craters that penetrate near the ocean to totally collapse and have no topographic expression. (The crater does not have to actually reach the ocean for this to occur.) To apply this method, we must survey and measure craters of all sizes on Europa and search for such changes in morphology that reflect changes in the satellite's ice shell and potentially its thickness.

For the past two years, my work has focused on mapping as much of the topography of Europa (and the other Galilean satellites) as possible from the *Galileo* images. I have used three techniques to measure crater shapes and depths on Europa. The first is stereo image mapping, which utilizes parallax shifts between exposures to measure heights and depths. The second is called *photoclinometry*, which employs the apparent brightness of slopes on mountains and valleys to estimate the steepness of the slopes. Finally, by measuring the length of shadows cast by a few individual objects on the surface, we can determine the heights of those objects.

By surveying and measuring all available craters on Europa, of which we have identified more than 100 larger than 1 kilometer across, we can begin to use impact crater morphology to probe Europa's icy shell. It is immediately evident from comparison of crater shape and morphology that large craters on Europa are not as deep as on sister satellite Ganymede. Further, the shapes of Europa's craters change at two specific and well-defined diameters. Craters smaller than 8 kilometers (5 miles) appear normal—that is, similar in depth and appearance to those on Ganymede. Yet, craters larger than 8 kilometers across are less deep than they should be. The big change, however, occurs at 30 kilometers (19 miles): craters larger than this are flat but are surrounded by 10 or more concentric rings. The abrupt shift from regular craters to these multiring structures indicates a profound change taking place within Europa to which only the larger craters are sensitive. It turns out that the depth of this change is approximately 75 percent of the crater diameter. Hence, the depth of Europa's ocean must be on the order of 20 kilometers (12 miles). It could be even deeper.

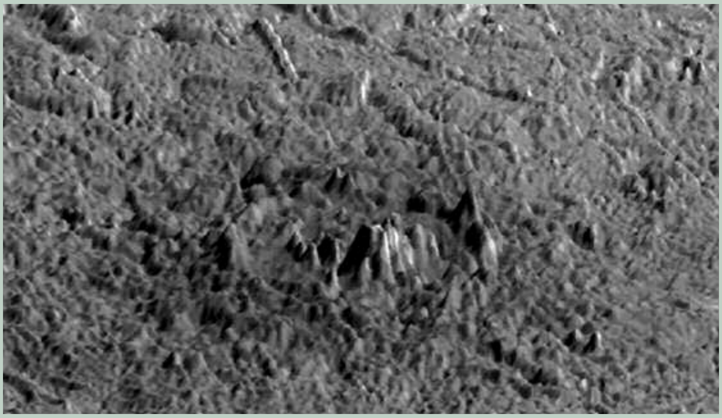
Evidence is mounting in support of the thick-ice view. Topographic maps I have made of roughly 15 percent of the surface of Europa reveal that chaos regions have a warped uplifted surface inconsistent with the thin-ice model. Also, the Europan surface in general has considerably more relief than was previously thought possible. Plateaus up to 1 kilometer (0.6 mile) high and depressions and troughs 500 meters and a few kilometers deep are highly unlikely to survive in an ice shell only a few kilometers thick. Much like oceanic ice on Earth, such topography would either melt away or disappear as the ice flowed laterally under its own weight. Although it is difficult to be precise with such data, they do support the conclusion that Europa's ice shell is thick rather than thin.

## WHAT'S NEXT FOR EUROPA?

Do tiny algae (or giant squid!) swim in Europa's ocean? The answer depends on the origins of life itself as well as on the conditions on Europa over the past billion years or so. Do any volcanoes rise from the ocean bottom? Is the ocean salty or acidic? Has the ice shell ever been thin? Have organic molecules ever existed in Europa's ocean? Can life originate without sunlight? We can't begin to answer these questions without going back to Europa.

Scientists and engineers are looking at new exploration options, including searching for a clever way to determine the ice shell thickness and sample the ocean. One approach would be to land a seismometer and chemical analyzer on a geologically interesting spot. Seismic waves could then be used to precisely map the depth to the bottom of the ice shell, and possibly to the bottom of the ocean. Onboard chemical analyzers could search for organic molecules and potentially determine the chemistry of the ocean, one of the basic indicators of Europa's prospects as an "inhabited" planet.

Our first task, however, is to complete the global geologic, geochemical, and geophysical map of Europa so that we can pinpoint potentially interesting landing sites. Priorities include confirming that the ice shell is in fact as thick as suggested by the crater analyses. Regardless of our ultimate exploration strategy, Europa remains one of the most compelling objects in our solar system.



***By combining new topographic maps with original* Galileo *images, we can simulate the way we'd see Europa's surface from a low-altitude aircraft. This view of Pwyll includes its rim and prominent central-peak complex. (The apparent relief in this image has also been exaggerated about 20 times.) Pwyll is the largest impact crater on Europa formed entirely within the moon's icy crust. Larger craters, such as Tyre, are flat and may nearly penetrate through the crust to the water ocean below.*** Image: JPL/NASA and Paul Schenk, LPI

***Scientists and engineers are developing new strategies to explore Europa. But plans to go ice diving there in search of life will have to be abandoned because the ice is probably too thick, much to the disappointment of the author. Paul Schenk is shown here training for ice diving in the Sierra Nevada.*** Photo: Courtesy of Paul Schenk

*Paul Schenk is a staff scientist at Houston's Lunar and Planetary Institute. He specializes in studying the satellites of the giant outer planets, including Jupiter, and in developing topographic mapping techniques. On weekends, he is also a SCUBA and deep sea diver.*

# Breaking New Ground: Red Rover Goes to Mars

by Bruce Betts

*In January 2004, the first* Mars Exploration Rover (MER) *is set to land on the Red Planet and begin its mission of exploration. The Planetary Society's Red Rover Goes to Mars project has been accepted as an official part of the* MER *mission—providing unprecedented opportunities for students and the general public to be involved in Mars exploration.*

*Painting: JPL/NASA*

**Since 1999, we've been updating you on the twists and turns that our Red Rover Goes to Mars project has taken. Now, after reporting on a mission cancellation as well as three successful interim opportunities, we're excited to announce that Red Rover Goes to Mars will join NASA's *Mars Exploration Rover* (*MER*) mission, set to explore Mars in early 2004.**

Red Rover Goes to Mars began as a project associated with NASA's planned 2001 Mars lander. Through a formal arrangement with NASA, The Planetary Society would be conducting the first-ever education experiment on a NASA planetary mission. This experiment grew out of the Society's Red Rover, Red Rover project. Red Rover, Red Rover developed a LEGO educational product of the same name that allows students to build and drive simulated Mars rovers.

While participants will not actually drive rovers on the Red Planet, Red Rover Goes to Mars involves students and the general public in Mars exploration as never before. Like Red Rover, Red Rover, its sponsors include the LEGO Company in partnership with the Society and with Visionary Products Inc.

The failures of NASA's *Mars Climate Orbiter* and *Mars Polar Lander* in 1999 eventually led to the cancellation of the Mars 2001 lander. This left Red Rover Goes to Mars without a home.

Then, after a period of uncertainty, NASA agreed to incorporate Red Rover Goes to Mars formally into the *Mars Exploration Rovers* (*MER*) mission. The mission will land two identical mobile rovers on the Martian surface in January 2004.

## Interim Opportunities

Even before NASA's incorporation of our project into *MER*, the Society invited the public's participation in Mars exploration. In February 2001, nine international students became the first members of the public ever to target planetary spacecraft imaging. At Malin Space Science Systems in San Diego, California, they targeted the Mars Orbiter Camera aboard *Mars Global Surveyor*. One area they chose to image revealed a cluster of boulders that continues to perplex scientists (see the May/June 2001 issue of *The Planetary Report*).

A year later, in February 2002, a group of eight Student Navigators (see the May/June 2002 issue of *The Planetary Report*) worked at the Jet Propulsion Laboratory (JPL) with the Field Integrated Design and Operations rover—the same vehicle that scientists are training with in preparation for the *MER* mission.

## The Next Generation

On October 15, 2002, after years of preparation and behind-the-scenes effort, The Planetary Society, in partnership with the LEGO Company, announced the latest Red Rover Goes to Mars opportunity: official participation in the *MER* mission.

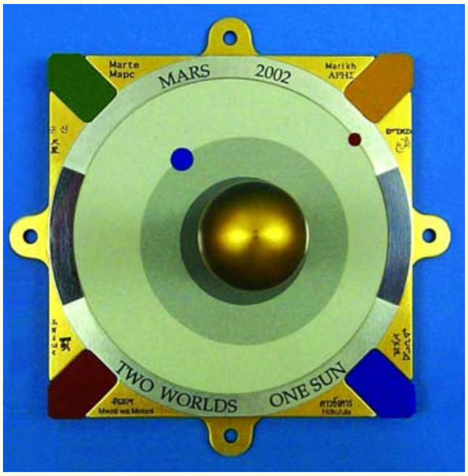
An essay contest is now in full swing with the goal of selecting an international set of students—designated Student Astronauts—to participate in mission operations at JPL. Never before have members of the general public been selected to participate directly in a NASA planetary mission. The essay contest is open to all students ages 13 to 17. Rules as well as application forms can be found at *www.redrovergoestomars.org*.

The selected Student Astronauts will rotate through mission operations at JPL in teams of two, with each team spending approximately one week at the facility. The students will receive specialized training prior to their participation in mission operations. This training will prepare them to be fully involved in two particular activities for each *Mars Exploration Rover*: working with the sundial and assisting the magnet team.

Calibration targets for the *MER* cameras will serve as sundials for educational purposes. Generally, sundials on Earth are stationary; in contrast, the *MER* sundials will be on moving rovers. Therefore, these sundials will lack hour marks. The Student Astronauts will process engineering data from the rovers that will allow them to place hour marks on images of the sundials based on the rovers' orientation. They will also produce captions for these images.

The Student Astronauts will participate in each rover's magnet team as well. Several magnets on the spacecraft will be collecting dust over the course of the mission. The students will assist team members in studying images of the dust on the magnets.


*A DVD assembly similar to this one will travel on each* Mars Exploration Rover*. Each DVD will transport to the Red Planet the names of millions of Mars enthusiasts. The assembly's base is made of machined and anodized aluminum, as are the simulated LEGO bricks. The DVD itself is made of silica glass to increase its archival nature and survivability. The entire assembly weighs 69 grams, or 2.4 ounces. (Note that the label design is not yet finalized, and "passwords" encoded around the outside will vary for each disk).* Photo: The Planetary Society




*The camera calibration target on each* Mars Exploration Rover *will also function as a sundial. On a sundial, the shadow cast onto the face indicates the solar time of day. Because the sundial is on a moving platform, no hour marks appear on it. These will be added later for each image by Red Rover Goes to Mars Student Astronauts. Ellipses around the* gnomon *(the "stick" in the middle) represent the relative orbits of Earth and Mars.* Photo: Cornell University

In addition, Student Astronauts will attend key science meetings that determine the commands sent to each *MER* spacecraft for its next day of activity.

Finally, these exceptional students will serve as ambassadors for the mission, much as actual astronauts do. Through a variety of media, including the Web, they will be communicating to the public what they observe.

## DVDs on Each Spacecraft

Each of the two *MER* spacecraft will carry a DVD produced by The Planetary Society in conjunction with Visionary Products Inc., along with hardware and labor donations from Plasmon OMS. Each spacecraft will also carry the names of millions of people, through

## Name the Rovers Contest

**The Planetary Society has a long history of conducting contests to name planetary spacecraft and planetary objects—including the naming of the *Sojourner* rover and the *Magellan* spacecraft, as well as a few asteroids, including Braille. Just recently, the LEGO Company and The Planetary Society won a NASA competition to jointly run the naming contest for the *Mars Exploration Rovers*. The Name the Rovers essay contest is now open to K-12 students enrolled in US schools (a NASA restriction). For detailed contest entry rules and to enter the contest, visit *nametherovers.org*.**
**—BB**

NASA's Send Your Name to Mars opportunity. (See *www.redrovergoestomars.org* for information and links; but hurry, the deadline is November 15, 2002!)

Each of the DVDs features a number of elements to better involve the public and especially children. These include colors and shades of gray that can be examined for how they look different under Martian lighting conditions. Also included will be a representation of a mini-robot that kids can relate to and that will facilitate creative child-related activities.

Additionally, the DVDs will contain passwords encoded using two-dimensional barcodes. Once deciphered from study of the first images transmitted from Mars, the passwords can be used to access additional activities.

### Stay Tuned

Over the next year and a half, *The Planetary Report* will be informing you of still more opportunities for participation in Red Rover Goes to Mars. You can also keep up-to-date and check out detailed information on the project and the *MER* mission by logging on to our website, *planetary.org*.

Red Rover Goes to Mars is breaking new ground in many ways. It represents only the second privately contributed hardware on a planetary mission. (The first was The Planetary Society's Mars Microphone on the failed *Mars Polar Lander*.) Also, it is the first educational experiment on a planetary mission. After a tough journey that saw a mission cancellation, Red Rover Goes to Mars now stands poised to reach out to the world as part of an even more exciting mission: NASA's *Mars Exploration Rover* mission.

Through Red Rover Goes to Mars, the level of public and student participation in a NASA mission is also unprecedented. The international scope of the participation is significant as well. Plus, The Planetary Society has successfully engaged a large, child- and learning-focused company in an educational project—yet another precedent in planetary exploration.

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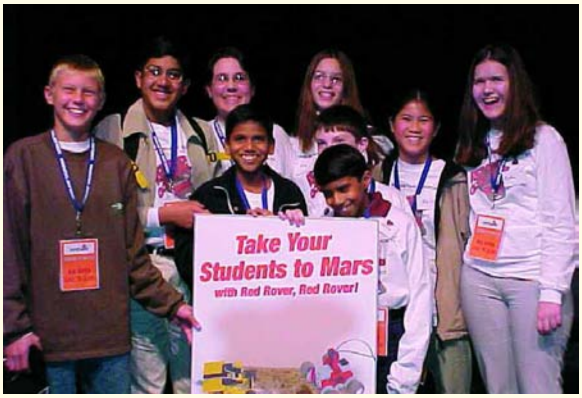
*Bruce Betts is director of projects for The Planetary Society and project manager for Red Rover Goes to Mars. He is also a planetary scientist.*

***The Student Navigators are guests of The Planetary Society in February 2002. From left: Paul Bonato, Kimberly DeRose, Charles Lindgren (teacher), Witold Sokolowski (translator), Daniel Hermanowicz, Avinash Chandrashekar, Bhushan Mahadik, Shaleen Harlalka, Kevin Hou, and Jacqueline Hayes.*** *Photo: The Planetary Society*




***The Student Scientists visit LEGOland in February 2001. From left: Iuri Jasper, Shaleen Harlalka, Bernadett Gaal, Vikas Sarangadhara, Kimberly DeRose, Wojciech Lukasik, Tanmay Khirwadkar, Hsin-Liu Kao, and Zsofia Bodo.***

*Photo: The Planetary Society*

# World Watch

**by Louis D. Friedman**

**Earth Orbit**—Another shipwreck in the ocean of space: the *CONTOUR* (Comet Nucleus Tour) spacecraft, launched on July 3, was lost in mid-August. Bound for two comets, Encke and Schwassmann-Wachmann 3, the spacecraft had spent six weeks in Earth orbit, increasing energy and aligning its orbit geometry for the desired interplanetary trajectory.

Injection to the interplanetary trajectory required a rocket burn—and that, apparently, caused the spacecraft to break apart. Mission controllers received no telemetry after the solid-rocket burn. Earth-based telescopes were able to pick out three objects traveling near where the spacecraft was supposed to be, which leads engineers to suspect that the spacecraft broke up, or something broke off it, as a result of the solid rocket motor firing.

NASA has appointed a special accident investigation commission to determine the cause of the failure. The Johns Hopkins University Applied Physics Laboratory (APL), which was responsible for the mission, will conduct its own internal review.

The loss of *CONTOUR* is a big setback for planetary exploration. *CONTOUR* is the first Discovery mission to be lost in the "faster, better, cheaper" program instituted in the 1990s by then–NASA Administrator Dan Goldin. The *Mars Climate Orbiter* and *Polar Lander* were also "faster, better, cheaper" projects, although part of a different program, and some pundits claim these failures prove that achieving all three goals in a single mission is impossible. But there have been successes, too. We are still getting results from *Mars Global Surveyor* and *Mars Odyssey* and have enjoyed success with *Mars Pathfinder* and *NEAR Shoemaker*. Generalizations are not easy to make.

The loss of *CONTOUR* is also a blow to planetary science. Comets are remnants of solar system formation and can tell us much about the system's origin. We owe much of our oceans—and perhaps even ourselves—to comets. Yet, information about them is hard to get, and although they come our way frequently, missions to them are rare due to political and programmatic complexities. Future comet missions are planned—the European *Rosetta* will launch in 2003, and the US's *Deep Impact* is planned for 2004—but these missions won't reach their targets for many years.

The *CONTOUR* science team, led by Joe Veverka of Cornell University, has proposed building *CONTOUR 2*—a replacement craft to launch in 2006. Considerable money will be saved if identical copies of the spacecraft and instruments can be built. Whether or not a credible case can be made for rebuilding the spacecraft and recovering the lost science will depend, in part, on the reasons for failure.

The *New Horizons* mission to Pluto and the Kuiper belt, planned for launch in 2006, might also be affected by the *CONTOUR* loss. Built and managed at APL, the *New Horizons* spacecraft uses components inherited from *CONTOUR*. Its future hinges on the action Congress will soon take. If it is to fly, *New Horizons* must be added to the NASA budget over the Bush administration's objections (see next item).

Through all this, we must remember that space exploration is an adventure—replete with both accidents and triumphs. We are disappointed but not downcast about the loss of *CONTOUR*. We extend sympathy to the team that labored long and hard to make it happen, but we remember that the losses of *Mars Observer* and other missions were followed by the riches we are now receiving from *Global Surveyor* and *Odyssey*.

**Washington, DC**—The Appropriations Committee of the US House of Representatives joined its Senate colleagues in providing funds for the Pluto–Kuiper belt mission, then went one step further by adding money to reinstate the development of the Europa orbiter. If passed by the full Congress, we will have been completely successful in our effort to overturn the Bush administration's plan to cancel both missions in fiscal year 2003.

We are now sending a copy of our petition in support of the Pluto and Europa missions, signed by more than 10,000 people, to every member of Congress. To accommodate all the signatories to the petition, we had to use very small type. Using normal-size type for all of Congress' copies would have taken about 18,000 pages!

The timing of congressional action is uncertain. As we go to press, congressional staff are indicating that the appropriations bill will probably not be considered until after the November elections.

The new fiscal year started on October 1 without a budget. During the interim period, Congress provided a temporary bill to fund government operations. The Pluto–Kuiper belt mission has sufficient funding only through November, so its fate may depend on a bigger political battle between the White House and Congress after the November elections.

For the latest information on the continuing fight to save the Pluto and Europa missions, see our website, *planetary.org.*

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*Louis D. Friedman is executive director of The Planetary Society.*

# Questions and Answers

***Do solar sails reflect light (visible and infrared) from both sides? Also, can the light reflected from Earth be measured, and is this amount of light significant for* Cosmos 1*?***
**—M.B. Melcon,**
**Durham, California**

Solar sails do reflect light from both sides, but for The Planetary Society's *Cosmos 1* solar sail, the amounts are very different. A deposit of aluminum on one side of the solar sail film creates a highly reflective surface (see photos below). This side reflects 80 to 90 percent of the light that hits it, which makes it efficient in producing thrust. The other side of the solar sail, which is not coated with aluminum, is much less reflective and, therefore, would produce much less thrust. Infrared light also reflects from both sides of the sail material, but the amount of light reflected depends on its wavelength. Most of the Sun's energy is in the visible and very near infrared parts of the spectrum.

It is possible to measure the light reflected off Earth from space, although *Cosmos 1* will not do so. The amount of sunlight reflected from our planet will not be a major factor in the thrust of the solar sail, because rarely will the sail be pointed in a direction to receive much light from Earth. If the sail were pointed that way, the light reflected from Earth would produce a thrust that would move *Cosmos 1* at an angle inclined to the sail's orbit. It would not produce much change to the orbital energy of the spacecraft.
—LOUIS D. FRIEDMAN,
Cosmos 1 *Project Director*

***These close-ups show the difference in reflectivity of both sides of the* Cosmos 1 *solar sail film. The shinier side (top photograph) is coated with aluminum and will reflect 80 to 90 percent of the light that hits it, producing thrust for the spacecraft.***

***Photos: Babakin Space Center***

***Most extrasolar planets found at large distances from their stars appear to have eccentric orbits. What implications might there be for the long-term stability of these systems? Can planets with stable orbits within the "habitable zone" exist within them?***
**—Tom Koleszar,**
**Calgary, Canada**

The stability of a planetary orbit is a complicated function of the planet's period, eccentricity, mass, and the orbits and properties of the other planets in the planetary system. Many eccentric orbits are so unstable, the planet is rapidly flung into an orbit close enough to its parent star that its temperature rises considerably, or it gets tossed out to orbital distances where its temperature is never above freezing. There are also possible combinations of planetary masses and orbital properties in which highly eccentric orbits can be stable for billions of years.

However, life might not develop on planets with stable but highly eccentric orbits. On such planets, the temperature goes from boiling to freezing as the planet rapidly approaches the star and then recedes. For life as we know it to evolve, liquid water is needed, and the temperature must not be so hot that biomolecules are destroyed, nor so cold that chemical reactions needed for metabolism stop. Still, if there are habitats on these planets that avoid severe temperature swings, it's conceivable that life could start there.

We know from the study of living things on Earth that life is found across many different habitats and in a very large temperature range. Life exists in the depths of the sea, buried many kilometers deep in rock, and on the surface where temperatures fluctuate from hot to cold and back again. Some bacteria thrive at temperatures well above boiling in the hydrogen-sulfide-laced waters at the bottom of Earth's oceans, where no light ever penetrates. But life is also found below the ice layer in Antarctic lakes, whose surfaces have been frozen for thousands of years. When environmental conditions become too extreme, then bacterial spores, plant seeds, and simple animals become dormant, and they revive once conditions again become favorable.

Higher-level animals can also adapt to the extreme temperatures that range from winter in Minnesota to summer in Arizona, as well as to the smog-laced atmosphere of Los Angeles. Clearly, we find life on Earch where we wouldn't expect to. Hence, it is reasonable to expect life to exist on planets where extreme temperature ranges accompany highly eccentric orbits—if those planets also harbor pockets of liquid water.

—WILLIAM BORUKI,
*NASA Ames Research Center*

# Factinos

**S**cientists have developed an atmospheric model that lends insight into decades-old mysteries surrounding Saturn's moon Titan. This research could shed light on the chemical processes that may have jump-started life on Earth.

Titan has long puzzled scientists because of several unexplained features in its thick, hazy atmosphere, which is composed mainly of solid organic materials. But even more baffling is a layer of Titan's haze detached from its atmosphere, thus resembling a ghostly shell floating in space.

"Titan is an interesting world. Its organic haze may be an example of the prebiotic organic chemistry that led to life on Earth," says Chris McKay of NASA's Ames Research Center. McKay is coauthor of "A Wind Origin for Titan's Haze," which appeared in the August 22, 2002 issue of *Nature*.

In the *Nature* article, McKay (who is also on The Planetary Society's Board of Directors), Pascal Rannou of the Universities of Paris and Versailles-St. Quentin, and Frederic Hourdin of the University of Paris provide the first "coupled" model of Titan, linking the moon's organic haze with atmospheric winds and with the sunlight that heats the haze.

"We found that the main features of Titan's organic haze arise from a strong feedback loop between the haze, the sunlight, and the wind," says McKay. "This is a critical new factor in understanding Titan."

—from NASA Ames Research Center

**O**n July 4, 2002, Konrad Dennerl of the Max Planck Institute for Extraterrestrial Physics in Garching, Germany captured the first-ever X-ray image of Mars. He used the Chandra X-Ray Observatory to obtain the picture at right. Dennerl's accomplishment is not unexpected since Venus, Jupiter, Earth, and even comets shine (although faintly) in X-rays.

Dennerl's computer simulations even predicted that our rusty neighbor would look about 25 percent brighter in X-rays along its sunlit limb—something Chandra did indeed observe. "There was a remarkably good match between expectation and observation," he concludes.

—from *Sky & Telescope*

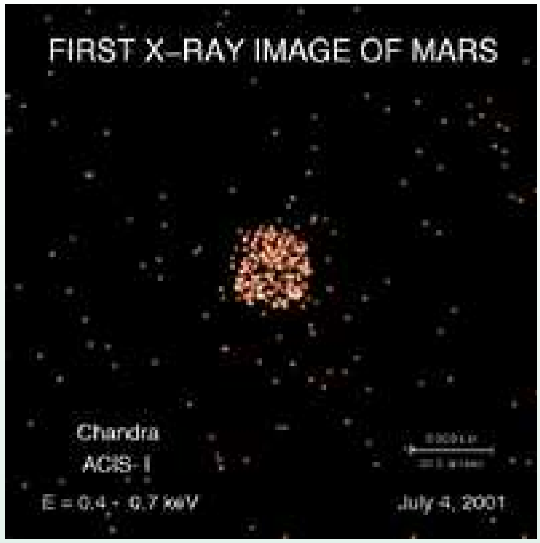
**U**sing a unique device called the Andromeda Chamber to simulate conditions found on Mars, a team of scientists from the University of Arkansas in Fayetteville have discovered that certain microorganisms called *methanogens* can grow at low pressures. Their findings imply that life may have existed on the Red Planet in the past and that it might now or in the future. Tim Kral, an associate professor of biological sciences, presented the team's preliminary findings at a bioastronomy conference in Australia in July 2002.

"Our goal is first to get the organisms to grow well, then to systematically experiment with conditions found on Mars," says Kral. He and his team first grew test tube cultures of various methanogens in a Mars soil simulant called JSC-Mars1. Derived from volcanic ash, JSC-Mars1 approximates the composition, grain size, density, and magnetic properties of Martian soil.

After growing three different types of methanogens successfully on the simulated soil, Kral subjected them to various Martian conditions in the Andromeda Chamber, a stainless-steel vacuum container believed to be the largest instrument dedicated to space simulation research on a North American campus.

So far, the Andromeda Chamber studies indicate low levels of methane production, which means the organisms are metabolizing under low pressures. These results suggest that Martian life would be able to survive at such pressures, since Mars' atmosphere is much less dense than Earth's. To read more about these experiments, visit *http://advancement.uark.edu/news/2002/AUG02/LIfe_on_Mars.html*.

—from the University of Arkansas




***The first-ever X-ray view of Mars was taken by the Chandra X-Ray Observatory on July 4, 2001. The planet's day-night terminator is located near the left edge of this slightly gibbous disk.***

***Image: Courtesy of Konrad Dennerl, Max Planck Institute for Extraterrestrial Physics***

# Society News

### Announcing Red Rover Goes to Mars

On October 15, The Planetary Society announced its participation in NASA's *Mars Exploration Rover* mission with a Red Rover Goes to Mars Student Astronaut Contest and a spacecraft DVD assembly (see "Breaking New Ground: Red Rover Goes to Mars," on page 16). The announcement took place at the World Space Congress—the joint gathering of the International Astronautical Federation, with associates the International Academy of Astronautics and the International Institute of Space Law, and the Committee on Space Research. The gathering, held at the George R. Brown Convention Center in Houston, Texas on October 10–19, was attended by 13,000 scientific, technical, business, and government leaders representing every facet of the international space community.

The Red Rover Goes to Mars Student Astronaut Contest will build on precedents set by Planetary Society programs Red Rover Goes to Mars Student Scientists and Student Navigators (see the May/June 2001 and 2002 issues of *The Planetary Report*). An international essay contest will help select a group of talented young people to participate in operations of the *Mars Exploration Rover* mission in early 2004. (For more information, visit *www.redrovergoestomars.org*.)

With the support of the LEGO Company, The Planetary Society is providing two spacecraft DVD assemblies to the *Mars Exploration Rover* mission. These DVDs will carry to the surface of the Red Planet the names of millions of Mars enthusiasts from around the world. Until November 15, 2002, names are being gathered by NASA at *http://spacekids.hq.nasa.gov/2003/*.

NASA's twin *Mars Exploration Rovers* are designed to study the history of water on Mars. The identical rovers, which are scheduled for two separate launches between May 30 and July 12, 2003, will land in two different locations on the Red Planet in January 2004.

The Planetary Society and the LEGO Company jointly hosted a large booth in the World Space Congress Exhibit Hall. This booth featured an engineering model of the spacecraft DVD, a full-scale model of a *Mars Exploration Rover* built entirely of LEGO bricks, and a remote-controlled LEGO MINDSTORMS rover, which visitors were invited to try their hands at navigating.

*—Emily Stewart Lakdawalla, Science and Technology Coordinator*

### Expedition to Argentina

We are still planning an expedition to Argentina to study some interesting outcrops in Patagonia. At this writing, we are expecting to depart sometime after February 2003. If you're interested in the expedition—even if you're just curious and want to know more—please call Lu Coffing at (626) 795-5100, extension 234, or e-mail her at *lu.coffing@planetary.org*.

*—Lu Coffing, Financial Manager*

### The Society at European Mars Society Convention

Society Executive Director Louis Friedman gave the plenary closing talk to the European Mars Society convention in Rotterdam, Netherlands on September 30, 2002. Friedman spoke about the pioneering *Cosmos 1* solar sail project, which the Society is conducting with the sponsorship of Cosmos Studios and the A&E network. Convention organizers cited *Cosmos 1* —the first space mission ever attempted with private funding by a space interest organization—as an inspiration to the goals of the European Mars Society, which seeks citizen involvement in space exploration missions.

Friedman also gave a presentation at the European Space Agency's European Space Technology Center in the Netherlands. Next year's launches of the *Mars Express* and *Rosetta* missions make Europe a major player in planetary exploration—a welcome and important step for the Society's worldwide membership.

*—Susan Lendroth, Manager of Events and Communications*

### Members-Only Discounts on Planetariums

The Planetary Society has been working with planetariums around the world to establish discounts ranging from 15 to 100 percent off admission prices for our members. For a complete list and more specific information, visit *http://planetary.org/html/member/planetariums.html*, or call Linda Wong at (626) 793-5100, extension 236.

If a planetarium near you is not on our list, please let us know at *tps@planetary.org*.

*—Linda Kelly, Program Development Manager*

### Thank You

We would like to gratefully acknowledge a recent bequest by Michael Sosnowski, a member since 1998. The gift in his name supports the Society's Near Earth Objects programs.

Over the years, bequests have allowed The Planetary Society to fund special projects and to pay for much-needed equipment. If you would like information about making a bequest to the Society, call Lu Coffing at (626) 793-5100, extension 234, or e-mail her at *lu.coffing@planetary.org*.

*—LC*

# Unique Holiday Gift Ideas!

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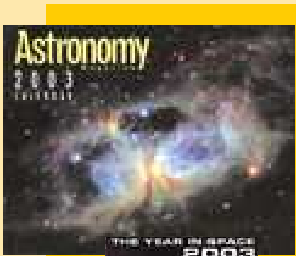


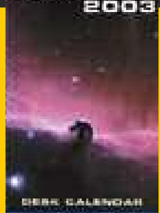


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**Pale Blue Dot Poster**
In February 1990, *Voyager 1* looked back at its home planet for the last time. The image of Earth as a tiny bluish dot inspired Carl Sagan to write one of his best-known essays, which starts off his book *The Pale Blue Dot*. The poster features Carl's timeless words and the full frame of the profound image captured by *Voyager 1*.
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On a list of Mars' topographical charms, its huge volcanoes rank high—and none more so than Olympus Mons. About 100 times larger than Hawaii's Mauna Loa, Olympus Mons covers an area the size of Arizona. Kees Veenenbos' computer-generated portrait of Olympus Mons is based on topographical data from the Mars Orbiter Laser Altimeter (MOLA) on board *Mars Global Surveyor.*

Kees Veenenbos uses MOLA data to produce a variety of still images and animations of Mars. His views of the Red Planet range from realistic renderings of how it looks today to visualizations of it as a much warmer and wetter place—how it may have existed about 3.5 billion years ago. Veenenbos' work has been published in scientific magazines, papers, and other media all over the world.

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