The
# PLANETARY REPORT

Volume XVIII Number 2 March/April 1998

To Sample the Sun

### On the Cover:

Even though humans have watched the Sun throughout our existence, we still don't know exactly what it's made of. The *Genesis* mission, to launch in 2001, will attempt to find out. In this image from the Extreme Ultraviolet Imaging Telescope (EIT) aboard the Solar and Heliospheric Observatory (SOHO), we see features a few thousand kilometers above the visible surface, at temperatures between 900,000 and 1 million kelvins (1.6 to 1.8 million degrees Fahrenheit). SOHO is watching the Sun from Earth orbit, while *Genesis* will collect samples nearer to the Sun and return them to Earth.

Image: SOHO EIT Consortium, NASA/ESA

# Table of Contents

Volume XVIII

Number 2

March/April 1998

## Features

**4 *Mars Global Surveyor:* The Saga of the Solar Array**

No interplanetary mission is flawless. Some are destroyed by minor mistakes. Some are overcome by major disasters. And some achieve their goal despite the problems. It looks like *Mars Global Surveyor* is going to fall into the last category, for last year a serious problem with its solar array threatened to cripple the mission. But a combination of knowledge, skill, and ingenuity enabled the mission team to find a way to deliver the spacecraft into an orbit to map Mars.

**11 *Mars Global Surveyor* Science Update**

Even though *Mars Global Surveyor* has not yet achieved its final mapping orbit, the spacecraft has already made major discoveries and is returning valuable scientific data to Earth. Here's a quick summary of its findings by the project scientist.

**12 The *Genesis* Mission: Catching Pieces of the Sun**

NASA's new Discovery program has challenged the solar system exploration community to come up with quick and inexpensive yet scientifically valuable missions. The American space agency recently selected two proposals for funding. *Genesis* will sample the solar wind and bring pieces of the Sun back to Earth for study.

**12 The *Contour* Mission: Seeking Clues to Our Origin**

Another recently selected Discovery proposal is this mission to visit some of Earth's closest neighbors: short-period comets whose orbits swing them around the Sun every few years. These comets retain memories of when the solar system was young, and by studying them close-up and in detail, mission scientists hope to tease out the story of our own origin.

## Departments

**3** Members' Dialogue

**16** The Stuff of Life

**18** News & Reviews

**19** World Watch

**20** Questions and Answers

**22** Society News

## From The Editor

In a field of endeavor as young as planetary exploration, it's amazing that we can look back over only 40 years and speak of a "golden age" and a "renaissance" all packed into a few decades. The 1960s and 1970s are often called the golden age of planetary exploration, when the stream of spacecraft flying to the planets seemed continuous. Then came the 1980s, which many regard as a sort of dark age.

In 1980 the Planetary Society came into being and grew into the largest space-interest group in the world—despite the dearth of missions. Spacecraft launched only every few years, rather than months, and we longed for the time when the space-faring nations would find renewed vigor and become bold explorers once more.

Now, we hear of a renaissance in planetary exploration, with cheaper, faster, better missions planned to launch to other worlds. Just last year we had *Mars Pathfinder* and *Mars Global Surveyor*, plus *Galileo* in the Jupiter system and the Near-Earth Asteroid Rendezvous at Mathilde, with the launch of *Cassini* to Saturn, and more. We are rich in discoveries. But *terra incognita* still dominates our maps of the solar system.

The original Renaissance, which began in the 1300s, grew into the Scientific Revolution and spawned an age of exploration. The Space Age renaissance has the potential to be just as significant to humanity. Let's work to see what's possible.

*—Charlene M. Anderson*

## Contact Us

Mailing Address: The Planetary Society, 65 North Catalina Avenue, Pasadena, CA 91106-2301

General Calls: 626-793-5100 Sales Calls Only: 626-793-1675

E-mail: tps@mars.planetary.org World Wide Web Home Page: http://planetary.org

*The Planetary Report* (ISSN 0736-3680) is published bimonthly at the editorial offices of the Planetary Society, 65 North Catalina Avenue, Pasadena, CA 91106-2301, 626-793-5100. It is available to members of the Planetary Society. Annual dues in the US are $25 (US dollars); in Canada, $35 (Canadian dollars). Dues in other countries are $40 (US dollars). Printed in USA. Third-class postage at Pasadena, California, and at an additional mailing office. Canada Post Agreement Number 87424.



A Publication of THE PLANETARY SOCIETY

# Members' Dialogue

### To Convert or Not to Convert

I totally disagree with D.T. Bath's statement that lay persons do not relate to extreme temperatures in either Fahrenheit or Celsius scales (see the January/February issue of *The Planetary Report*). That is a put-down. I also disagree that double references, such as kilometers to miles, interrupt the flow of reading.

You are doing the right thing with immediate conversions in the sentence. Please, no footnotes! Let "those readers with a deeper interest" have their flow interrupted.

—LLOYD RUST,
*Lemont, Illinois*

While I can understand D.T. Bath's concern regarding running into a set of parenthesis while reading along at high speed, I cannot fathom his problem with Fahrenheit. While I can do the math to convert the different temperature scales, it is far less distracting for me to find the conversion in parenthesis than to stop and figure it out.

A Fahrenheit scale of temperature measurement is no more or less "scientific" than any other scale. Perhaps some day we will contact a species that measures temperature on a scale based on the freezing and boiling point of ammonia or methane. Should we try to convert them to our Celsius scale or would parenthesis, perhaps, be more appropriate?

—MICHAEL HUGHES,
*Melbourne, Florida*

I agree with D.T. Bath. Use the SI version and use footnotes for conversions. Try it for 6 months or so and see what comments are generated.

—SANDY POLLACK,
*Tucson, Arizona*

### Martian Rocks

I just received the November/December 1997 issue of *The Planetary Report*. Thanks for an entertaining article about Planetfest '97 and the *Pathfinder* mission! As one of the "rover drivers," I did not have a chance to sample the public's excitement about the mission until a couple of weeks had passed after landing. Thus, I enjoyed reading about the thrilling reaction of the Planetfest visitors to the same events I had watched tucked away in Mission Operations.

I do have one minor correction to make, however. On page 9, on the Mars panorama, you have the rightmost rock name listed as "Little Matterhorn." Actually, it is called "Mini Matterhorn." I was the one who named it. And, just to keep the record straight, I wasn't thinking of Disneyland when I gave the rock its moniker.

—SHARON LAUBACH,
*Pasadena, California*

### The Public View

I agree with both Clark R. Chapman and Timothy Ferris (see the November/ December 1997 issue) that the public has been more interested in the robotic accomplishments of *Voyager*, *Hubble*, and *Mars Pathfinder* than it has with the "boring exploits of each successive shuttle launch." Both gentlemen misinterpret the public's enthusiastic response to *Pathfinder*, et al., and relative indifference to shuttle and *Mir* operations, as an endorsement that robotic, not human, missions are the way that space exploration should be done.

Space *exploration* piques the public interest, space *operations* do not. It is the images sent back that engender the enthusiasm, not the means of obtaining them. They show us something many people, including me, would like to see in person, if that were only possible.

Robotic probes are our proxies, and will be until humans can be sent to "boldly go where no one has gone before." But to provide a foundation of knowledge and experience necessary for advanced missions to the Moon, Mars, and beyond, we must gain much more experience in long-duration space operations, such as the shuttle, *Mir*, and International Space Station. Unfortunately, these are operations. But that does not mean such human operations aren't vitally necessary to our continued reach for the stars. They are part of the Dream.

Kill the Dream by reducing human spaceflight operations, which will provide the foundation for human exploration, and whatever support there is for *robotic* missions will evaporate within one or two political election cycles! Why send robots out to scout landing sites if we aren't planning to follow someday?

—JAMES W. BARNARD,
*Littleton, Colorado*

### Members on Mars

What a nice feeling it was for this grizzled, sometimes cynical veteran of the Space Age (I took what I thought was going to be a short-time job as Executive Secretary of the American Rocket Society in 1953) to learn from your article on the Carl Sagan Memorial Station (see the September/October 1997 issue of *The Planetary Report*) that I and 100,000 other members of the Society are on Mars via the "documentation chip." I've been bragging about it ever since.

—JIM HARFORD,
*Princeton, New Jersey*

I was very much excited to read your November/December 1997 issue of *The Planetary Report* with the clear photos of Mars' surface. It gives me immense pride that my name made it to Mars along with thousands of other space enthusiasts. Thank you for bestowing the honor on me.

—T.P. RAMACHANDRAN,
*Kuala Lumpur, Malaysia*

---

Please send your letters to
Members' Dialogue,
The Planetary Society,
65 North Catalina Ave.,
Pasadena, CA 91106-2301
or e-mail:
tps.des@mars.planetary.org.

# Mars Global Surveyor: The Saga of the Solar Array

by Glenn E. Cunningham

*Mars Global Surveyor* is now orbiting the planet Mars, making a global assessment of that planet with detail and coverage many times better than we have for any planet in our solar system other than Earth.

But it has not been an easy journey to reach this point. At times, we thought we might lose the mission. We've had to scramble, stretch the limits of our endurance, and use all our skill and ingenuity to save the mission—all because we depended on a relatively new technique called aerobraking.

The spacecraft carries only a minimal amount of rocket fuel for trajectory adjustments, so we must aerobrake through the planet's atmosphere to reduce our initial elliptical orbit to a circular mapping orbit. Aerobraking uses the drag on the spacecraft created by the Martian atmosphere. As the spacecraft flies through the atmosphere, reaching the low point in its orbit, the atmosphere's resistance slows the spacecraft down. This slowing drops the highest point of the orbit slightly. After hundreds of these drag passes, the orbit will shorten and change from elliptical to circular.

The spacecraft's solar panels absorb the most force from the atmospheric drag. To assure that the solar panels provide a stable drag surface, the spacecraft design holds the panels in place with electrical actuators and a rigid structure. The panel is made of a dense, aluminum honeycomb with graphite-epoxy facesheets bonded to both sides. This material is much lighter than solid metal.

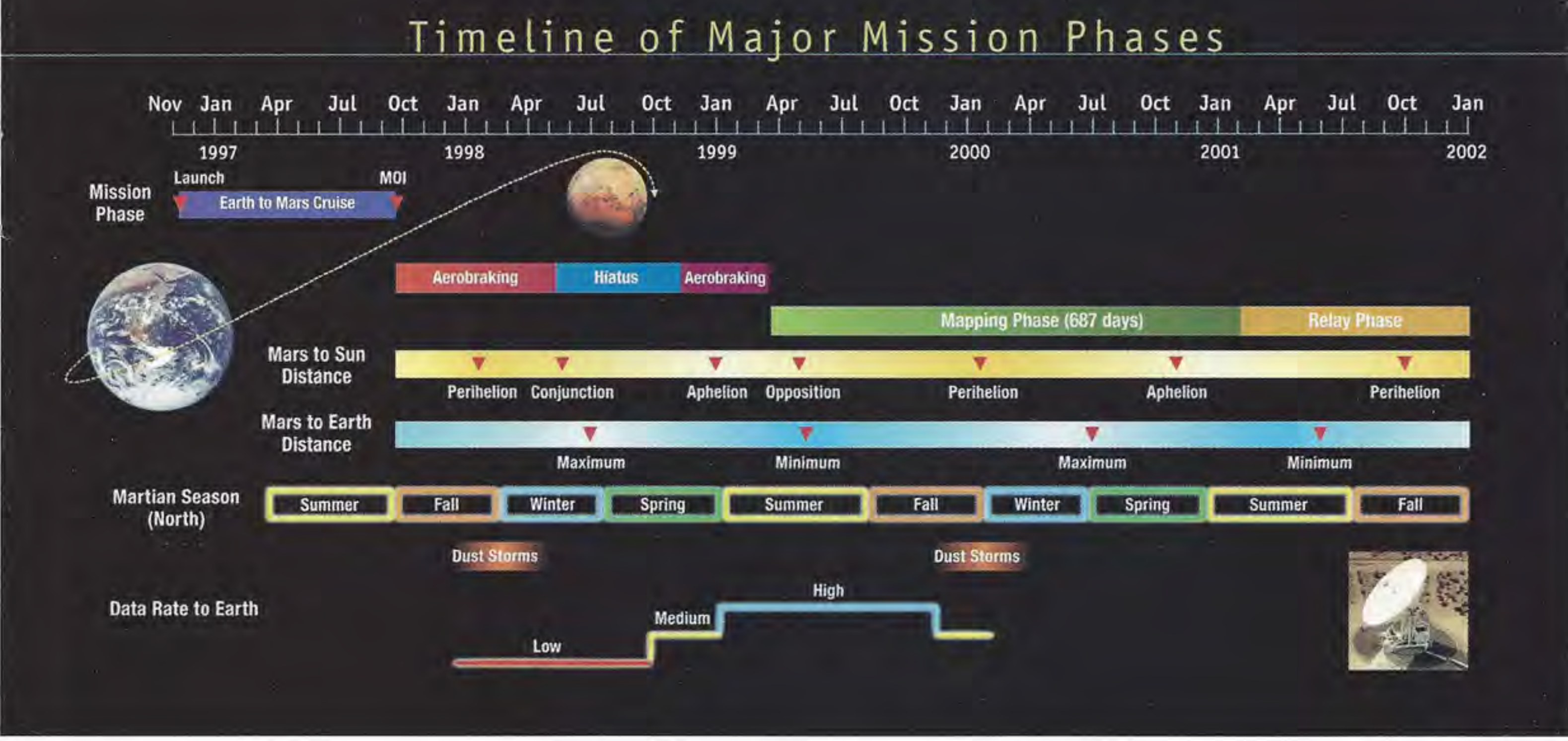
As Martian atmospheric density changes with weather patterns, the drag force on the solar panels changes and so does their temperature, increasing with friction. We closely manage aerobraking to keep the pressure and temperature on the solar panels within the range that the spacecraft design can withstand. To provide a margin for unexpected atmospheric changes, the spacecraft is designed to accommodate a 90 percent variation in these parameters from orbit to orbit.

With this much as background, our saga begins . . .

***In this wide-angle MOC view of Mars, the seasonal, carbon-dioxide frost cap covers the south polar region while a portion of Valles Marineris stretches across the upper quarter of the picture. Taken three weeks after a large regional dust storm had developed, the image has a hazy appearance, especially toward the edges of the planet, resulting from atmospheric dust. The color fringe along the right side of the image and the slightly non-circular outline of the edge of the planet result from unprocessed data and lens distortion.*** *Images: JPL/NASA*

## THURSDAY, NOVEMBER 7, 1996

Launch day for *Mars Global Surveyor*. The spacecraft separated flawlessly from the Delta II launch vehicle, and the solar panels unfolded from their stowed position on either side of the spacecraft's main electronics module. Springs in the hinges forced the panels open. Telemetry showed that one of the panels, the one on the -Y side, ended up about 20 degrees from being folded out flat.




At the post-launch press conference, I announced that this incomplete deployment was our only observed problem and that it was probably because the damper that controlled the rate of unfolding was a little cold. Warming up in the sunlight would likely allow the panel to move to its fully open position.

This slight deformation in the solar panel's geometry was not a problem for electricity production. We used the actuators that connect the panel to the spacecraft to orient the panel to catch sunlight.

## WEDNESDAY, JANUARY 22, 1997

Wiggle tests. Unfortunately, in the two and a half months since launch, the -Y solar panel had not moved to the fully open position. Further analysis of the early telemetry showed that the -Y panel's unfolding had been damper-controlled only for the first 43 degrees of motion. After that, the panel had swung out very rapidly, hard enough to disturb the spacecraft's attitude in flight.

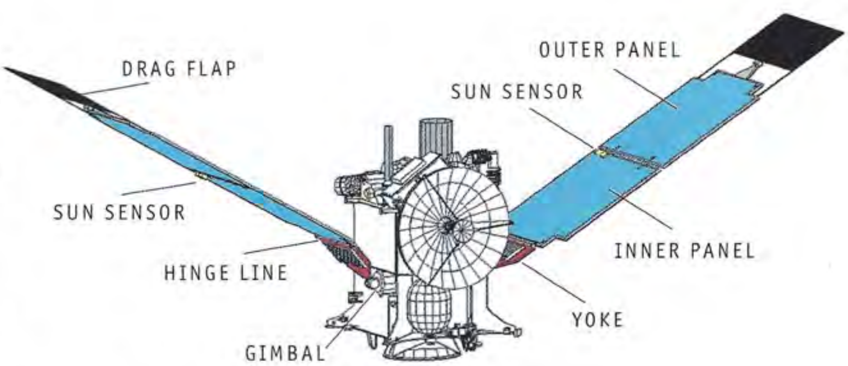
The spacecraft engineers at Lockheed Martin Astronautics and at the Jet Propulsion Laboratory concluded that a component must have broken during the deployment. Their investigation homed in on the shaft of the deployment-rate damper, which must have snapped after that first 43 degrees of travel, right where a two-inch-long lever arm connected the damper shaft to the edge of the solar panel. To make matters worse, the broken-off lever arm must have gotten stuck between the inboard edge of the solar panel and the solar panel yoke, to which the panel is hinged. This piece of metal, jammed in the hinge joint, prevented the solar panel from moving all the way open and latching.

We decided to test this hypothesis by wiggling the panel. The electrical actuators had the ability to move the panel rapidly, and we could interpret the resulting motion of the panel from the spacecraft's attitude telemetry. If the hypothesis was correct, the panel would move stiffly in the outward direction, pushing against the trapped damper arm. Conversely, the motion would be floppy in the opposite direction because the panel was not latched and nothing was holding it except the springs in its hinges, which allow rotation.

Everyone was elated! Telemetry after the first test showed the panel was stiff in one direction but moved several degrees in the opposite direction, returning to its original position under the torque of the hinge springs.

Over the course of several weeks, we conducted 11 wiggle tests with different deflections of the panel. Yes! The hypothesis appeared to be correct.

Some even dared to hope that when the panel wiggled and the hinge opened, the trapped damper arm would move out of the way and allow the panel to open fully and latch. But alas, without gravity or any other force acting on the damper arm, it remained in the hinge joint. ➝




*This figure depicting the structural components of the* Mars Global Surveyor *shows the incomplete deployment of the -Y panel (left side), with a 20° bend at the hinge line. Team members surmised a broken-off lever arm was stuck in the hinge joint, preventing the solar panel from fully deploying and latching into place.* *Illustration: Lockheed Martin Astronautics*

## THURSDAY, JUNE 12, 1997

We faced a dilemma. The solar panels were to have been the major drag surfaces for aerobraking. To provide a rigid drag surface, the panels had to be latched, not floppy as the -Y panel was. If *Mars Global Surveyor* began aerobraking as planned, the force of the wind would push the -Y panel back into the side of the spacecraft's electronic module, upsetting aerodynamic stability and greatly reducing the amount of drag surface.

The spacecraft engineers worked on a procedure to do aerobraking with the -Y panel turned around. Without its latches and mechanical stops in place, the panel would have to be held in position by the electrical actuator. Would the actuator be powerful enough to hold the panel against the wind pressure? Yes, the manufacturer assured us.

But there was another potential problem to consider. With the -Y panel turned around, its solar cells would be facing the wind and exposed to friction as the spacecraft plowed through the Martian atmosphere. Would the resulting heat damage the solar cells, the glue that holds them on, or the panel structure?

We conducted a special test on a spare solar panel. We cooked it in a chamber far above the expected aerodynamic heating. At the highest temperature the chamber could reach, the panel survived without degradation.

At a special review meeting, we evaluated all of the processes and criteria required to support aerobraking. We would start aerobraking on the third orbit. From all indications, it looked as though we understood the reason for the not-quite-full deployment and we had a method for reversed-panel aerobraking that would work without much risk.

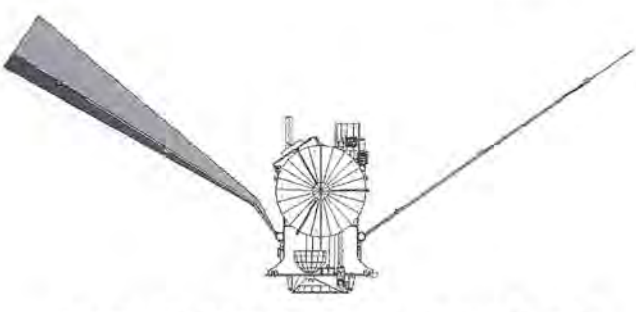
Dilemma solved, everyone was confident.

## THURSDAY, SEPTEMBER 11, 1997

Orbiting Mars! After a 23-minute firing of its main rocket engine, slowing it down by 2,183 mph, *Mars Global Surveyor* was captured by the planet's gravity and became a satellite of Mars.

## TUESDAY, SEPTEMBER 16, 1997

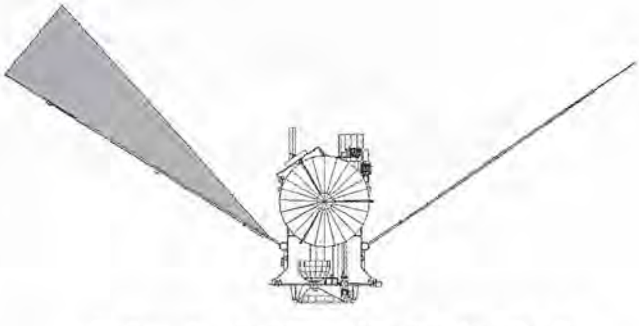
Aerobraking under way. *Mars Global Surveyor* took a first small step down into the Martian atmosphere. It completed 12 aerobraking drag passes without incident. During two passes, at the point where the aerodynamic forces were greatest, the -Y panel moved to its fully deployed position. We suspected that the trapped damper arm must have been squeezed into the honeycomb substrate of the panel.



***In this view, the spacecraft is moving toward the bottom of the page. The 20 degree, incomplete deployment of the -Y panel (left side) is clearly visible, when compared with the opposite panel. Note the hinge between the solar panel and its yoke. The dark gray area represents motion of the panel as the damper arm was crushed into the panel substrate, and the light gray area indicates the deflection of the panel under aerodynamic pressure.***

## SUNDAY, OCTOBER 5, 1997

Aerobraking was proceeding well. The orbital period had already been reduced from 45 hours to 38 hours, and the flight team was doing a good job of navigating the spacecraft within the aerodynamic-pressure corridor to avoid overheating the panels. All the careful design and planning seemed to be working just fine.



***This figure shows the deflection of the -Y panel past the fully deployed position because of strong aerodynamic pressure.***

## MONDAY, OCTOBER 6, 1997

Weather changing. Just as on Earth, atmospheric density and pressure change on Mars as weather features move across the planet. Today, at closest pass at the beginning of the 15th orbit, the atmospheric pressure increased significantly—to a level above our acceptable range. Our atmospheric scientists —the Martian weathermen—advised that the pressure might continue to be high on the next orbit.

But this wasn't the only problem emerging today. Telemetry was telling us that during the last pass the -Y panel had moved past its latched position and returned nearly to the position it was in before the drag pass. This overextension and rebound didn't make sense but was definitely there. So, using predefined procedures, we fired the spacecraft's small thrusters and moved up to an altitude where the pressure on the panel would be quite low.

We didn't understand how the panel could be moving past the fully opened position. The motion was not around the hinge axis. Maybe the hinges were being torn out of the yoke? This motion told us that something more was going on than just the trapped damper arm.

The aerobraking schedule was fairly rigid because we had to reduce the spacecraft's orbital period to two hours by mid-January 1998. By that time the spacecraft was to be locked in a Sun-synchronous condition so it would cross the Martian equator every orbit with the Sun at an angle equivalent to 2 p.m. We had only seven days of margin in the timetable.

By now we were quite concerned. The movement of the -Y panel no longer matched our hypothesis, and our confidence in continued aerobraking was undermined. I gave the flight team four of the precious seven days to figure out what was going on.

We performed more drag passes at high altitude. The -Y panel continued to deflect past the latched position, though in a lesser amount because of the lower pressure.

## SATURDAY, OCTOBER 11, 1997

Decision day. It had become clear that we did not properly understand the situation. Reactions varied. Some members

***This small impact crater near Orcus Patera, imaged by the MOC on October 17, 1997, is one of three adjacent features (shown in the* Viking *image at top), representing one type of "splosh" crater. The patterns seen here are considered to be evidence of the fluidized movement of materials ejected during crater formation. Scientists believe these features indicate the presence of subsurface ice or liquid water.***

***Notice the long, linear features of different brightness on the steep slopes inside and outside the crater rim. These features strongly suggest that small land or dirt slides, started by seismic or wind action, have flowed down the steep slopes. Initially dark, these features have become lighter over time as the ubiquitous, fine, bright dust settles from the Martian atmosphere. From estimates of the dust fall-out rate, it appears that many of these features are probably only a few hundreds of years old.***

***Images: JPL/NASA***

of the team advised against any further aerobraking. It was too risky. "Stay where we are," they said. "A spacecraft in an elliptical orbit at Mars taking science data is better than no spacecraft."

Others said we should continue aerobraking and taking the science readings, which were already revealing a new picture of the Red Planet. These people said we had everything to lose if we stopped. A third group argued for continued aerobraking to get more information on the panel's anomalous behavior, perhaps risking more damage in the process.

I called a meeting, a telephone conference involving the whole *Mars Global Surveyor* team—scientists, engineers, and managers, all across the country. It dragged on through the late afternoon. Everyone had their turn to speak. We all knew that the result of this meeting would have a profound effect on the mission, which many had been working on for over a decade. The potential for an even partially successful mission seemed to be slipping through our fingers.

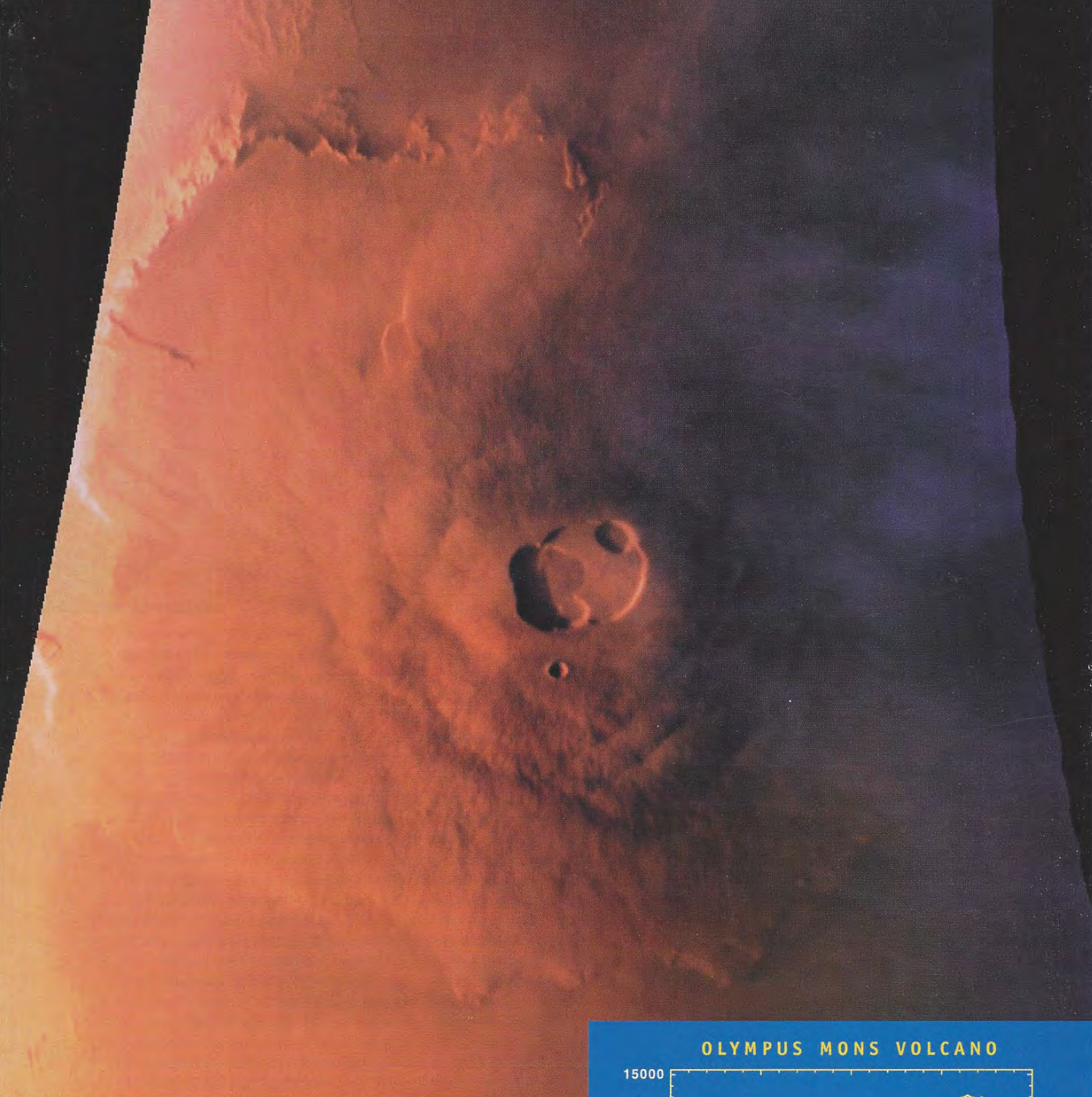
In addition to its own mission goals, *Mars Global Surveyor* also had commitments to provide radio-relay communication for the *Mars Surveyor '98* lander and microprobes, scheduled to arrive at Mars late in 1999. Our spacecraft had to be in the correct orbit when those craft arrived.

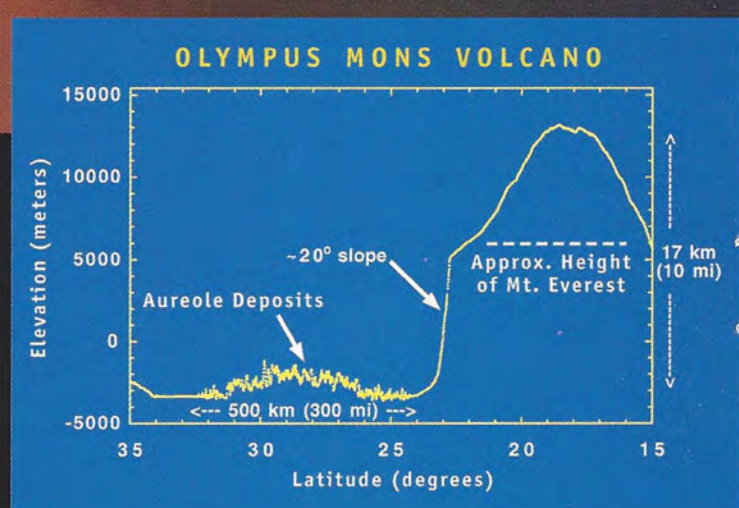
The decision that had to be made was made. I directed that we take a hiatus, at least two weeks, from aerobraking.

I charged the flight team to study the motion of the solar panel and modify our hypothesis of the deployment failure to account for the new motion of the -Y panel. With that information, they were to plan how to resume aerobraking in a way that would not over-stress the panel.

Given new limits on aerobraking intensity, the flight team, with the *Mars Global Surveyor* science investigators, was to determine the best mapping mission still possible. Above all, they were to keep the spacecraft safe and not risk its future ability to acquire science data.

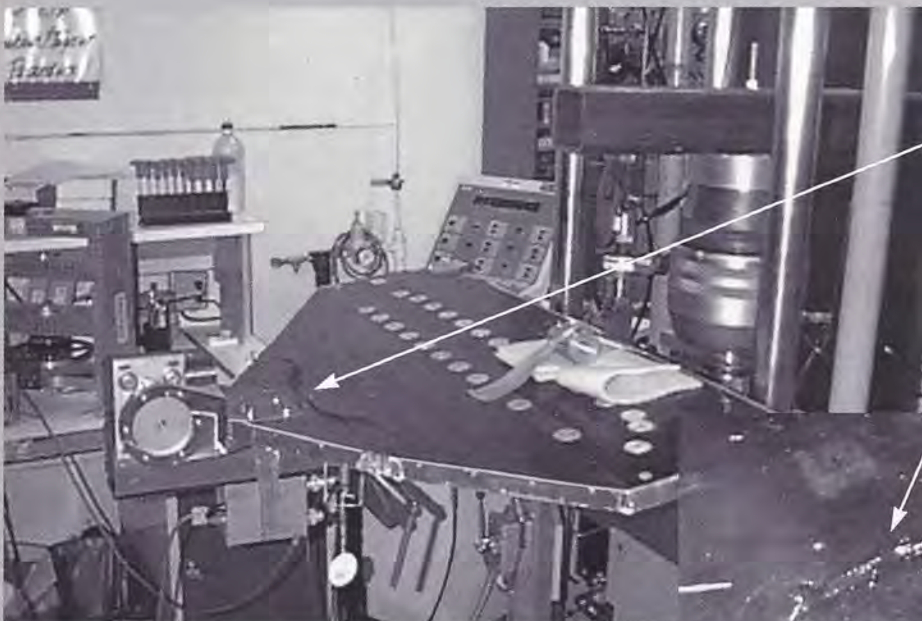
*(continued on page 9)*






*Above: This MOC composite image of the largest known volcano in the solar system, Olympus Mons, was acquired on October 20, 1997 at the beginning of Mars Global Surveyor's 24th orbit around the Red Planet. With a diameter of approximately 600 kilometers (400 miles), Olympus Mons is clearly visible in the center of the image. The summit caldera, a composite of as many as seven, circular collapse-depressions, is 66 by 83 kilometers (41 by 52 miles) across. Also seen in this image are bluish, water ice-clouds that accumulate around and above the volcano during the late afternoon.*

*Right: This figure shows the cross-sectional relief of the Olympus Mons shield volcano as measured by the Mars Orbiter Laser Altimeter (MOLA). By comparison, Mount Everest, the highest mountain on Earth, is less than half the height of Olympus Mons. The profile shows the north flank of the volcano, which has collapsed and formed a rugged aureole nearly 500 kilometers (300 miles) across. The detailed topography provided by MOLA will be used to understand the mechanism for the collapse.* *Image and chart: JPL/NASA*



*Left: A spare solar panel and yoke assembly were subjected to stress analyses in the laboratory in an effort to understand what had happened to* Mars Global Surveyor. *The arrows point to a crack (close-up below) that developed in the facesheet of the yoke. A similar crack most likely occurred on the spacecraft, explaining the anomalous motion around the panel.*

*Photos: Lockheed Martin Astronautics*

*(continued from page 7)*

Later in the evening, we moved the spacecraft up and out of the Martian atmosphere. This stopped aerobraking and effectively eliminated any hope of reaching the 2 p.m. orbit that we had planned the mission around. The science teams were devastated. NASA management was unhappy because we had assured them—as we had ourselves believed—that there would be no problem with the -Y panel during aerobraking.

Would *Mars Global Surveyor* be labeled a failure like its predecessor, *Mars Observer?* Would Mars withhold its secrets once again? Would we be able to keep our radio-relay commitments to the other missions?

I had faith that the flight team and the science investigators would find a solution.

## WEDNESDAY, NOVEMBER 5, 1997

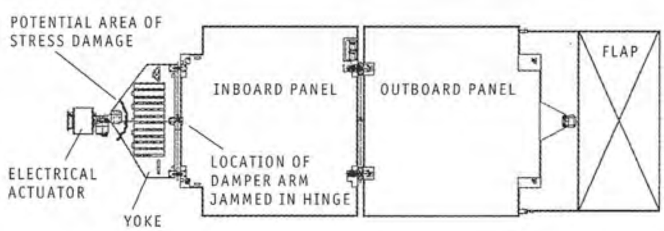
Victory from the jaws of defeat. After four weeks of probably the most intense effort the *Mars Global Surveyor* team had ever seen, it was time to decide what to do with the rest of the mission. Again we assembled the whole project team, this time with special advisors on aerodynamics and composite structures.

A group of mission-design and trajectory experts had looked at all of the possible missions that could have been flown from that time forward. What was the best elliptical orbit? What if we let the spacecraft stay where it was? Could we use the remaining rocket-engine fuel to achieve a circular orbit? Could we aerobrake some more?

The science teams worked on identifying options that would allow the best data return for each of the science investigations.

The Lockheed Martin mechanical team took the spare solar panel and its yoke assembly and analyzed and tested every aspect. They did stress analyses. They subjected the spare hardware to new tests to simulate the forces that the spacecraft would have endured when the damper arm broke and the -Y panel sprang out unrestrained. Their analysis pinpointed an area at the inboard end of the yoke where stresses exceeded design limits. Testing then showed that one graphite-epoxy facesheet of the yoke would probably have cracked and become less rigid. We had our answer, explaining the motion of the panel past its latched position. The panel was flexing, but only a few degrees around this crack.

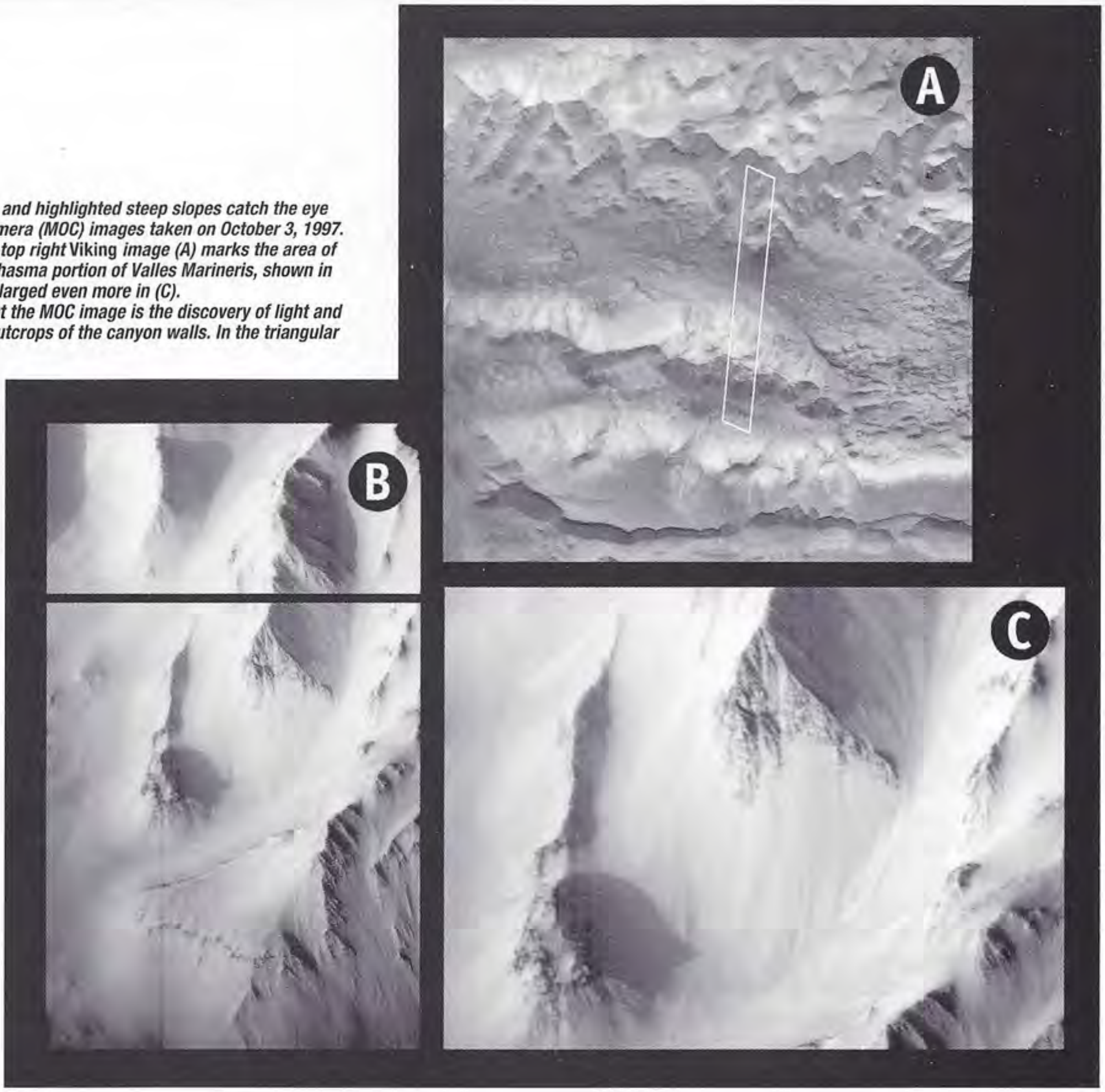
So, two failures had occurred during deployment. One we had observed immediately, when the panel failed to latch, and the second we couldn't observe until aerobraking applied force to the panel.




***This view of the -Y solar array shows the broken damper arm in the hinge joint and the facesheet that likely cracked at a stress "hot spot" on the yoke.***

The engineers subjected the facesheet in the lab to thousands of deflection cycles, simulating how aerobraking would affect the part aboard *Mars Global Surveyor*. Results were very good. The yoke demonstrated the needed ability to endure continued aerobraking at a low pressure.

The mission planners, in turn, had a contingency plan that would allow the spacecraft to continue aerobraking with one-third the previous pressure on the panel. Unfortunately, our



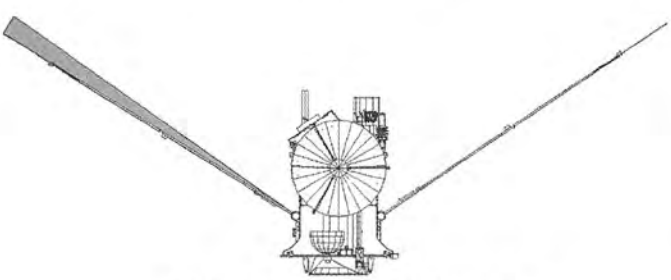

*Shadowed canyon floors and highlighted steep slopes catch the eye in these Mars Orbiter Camera (MOC) images taken on October 3, 1997. The parallelogram in the top right* Viking *image (A) marks the area of the western Tithonium Chasma portion of Valles Marineris, shown in great detail in (B) and enlarged even more in (C).*

*Most remarkable about the MOC image is the discovery of light and dark layers in the rock outcrops of the canyon walls. In the triangular mountain face [center of (B) and at the top of (C)], you can see some 80 layers, typically alternating in brightness and varying in thickness from 5 to 50 meters. This type of bedrock layering has never been seen before in Valles Marineris. It calls into question common views about the upper crust of Mars—for example, that there is a deep layer of rubble underlying most of the Martian surface—and suggests a much more complex early history for the planet.*

*Images: JPL/NASA*

original circular orbit was irretrievably blown—we couldn't get the spacecraft into position to move from north to south and cross the equator on the sunlit side of the planet at 2 p.m. But by waiting for half a Martian year (a whole Earth year), the mission planners could get us to an orbit where the spacecraft would cross the sunlit equator at 2 p.m., moving south to north. This new orbit offered all the same lighting and geometry that the spacecraft and its science instruments had been designed for.

Everyone agreed that this was the right course to pursue.



*This figure shows the minimal deflection caused by the new, low-pressure aerobraking scheme.*
*Illustrations: Lockheed Martin Astronautics*

I announced that we now had a good enough understanding of our situation to return to aerobraking with reduced pressure on the solar panel. We would begin on Friday, November 7, the anniversary of the *Mars Global Surveyor* launch.

We had found a solution that allowed a complete recovery of the mission objectives. We would just wait a year before starting the detailed mapping operations.

## SATURDAY, NOVEMBER 8, 1997

Aerobraking again. We had established a set of action limits to further reduce the pressure on the panel in case it did not behave as predicted. But aerobraking was working fine! Operations continued, with a feeling throughout the project that we had faced and overcome the most difficult kind of challenge—incomplete information about a potentially fatal problem. And our spacecraft had survived, thanks to the Mars Surveyor Operations Project team, men and women whose resourcefulness and dedication define NASA and its industrial partners at their best.

After 13 more drag passes, we all breathed a sigh of relief, more than ready for a stretch of quiet routine. The Martian atmosphere then became quite unstable with the development of a large storm in the southern hemisphere.

But that is *another* story . . .

---

*Glenn E. Cunningham of the Jet Propulsion Laboratory and the California Institute of Technology is the Project Manager for Mars Surveyor Operations.*

# *Mars Global Surveyor* Science Update

by Arden Albee

*Even as* Mars Global Surveyor *is settling into its mapping orbit, the spacecraft has begun collecting data that will sharpen and eventually change our understanding of Mars. The discovery that has so far garnered the most media attention is that the Red Planet possesses, instead of the usual global magnetic field, several small and distinctive magnetic features within its crust. But* Mars Global Surveyor *has observed much more on the planet, including the origin of a dust storm and vistas reminiscent of the Rockies.*

## Atmospheric Observations

For the first time, a spacecraft has captured the start of a major dust storm on Mars and has followed it from development to demise. The storm started around Thanksgiving (1997) with small dust storms along the edge of the southern polar cap and grew to cover an area about the size of the South Atlantic Ocean. *Mars Global Surveyor* studied this weather system in detail with its thermal emission spectrometer (TES) mapping the temperature and opacity of the atmosphere and its Mars Orbital Camera (MOC) recording the visible effects.

The effects of the storm extended to great heights, reaching through the aerobraking altitude of about 130 kilometers (80 miles). As the storm began to abate in mid-December, small local storms again formed along the edge of the polar cap, and ice clouds again formed in depressions. The effects of the storm linger in the form of dust in the atmosphere and large variations in pressure at the aerobraking altitude from orbit to orbit. We wait to see if a truly global storm will occur during this storm season.

## Surface Observations

In addition to taking wide-angle images of the storm, MOC acquired many image strips using its narrow-angle, high-resolution mode. We see dunes and other wind-shaped features almost everywhere. Some images bear a strange resemblance to the Colorado Rockies viewed from an airliner in winter—a landscape with rocky ridges poking through the dry powder snow (the Martian equivalent is dust) and with the sides of the ridges marked by lobe-shaped masses and streaks of powder sliding down the slope. One almost expects to see ski tracks crisscrossing the area.

TES has begun to obtain a few infrared spectra of the Martian surface, although it is still too cold on the surface for the best results. The best spectra taken so far clearly indicate the presence of the mineral pyroxene, apparently in a mixture of pyroxene, plagioclase, and magnesium sulfate (Epsom salt).

## Topographic Observations

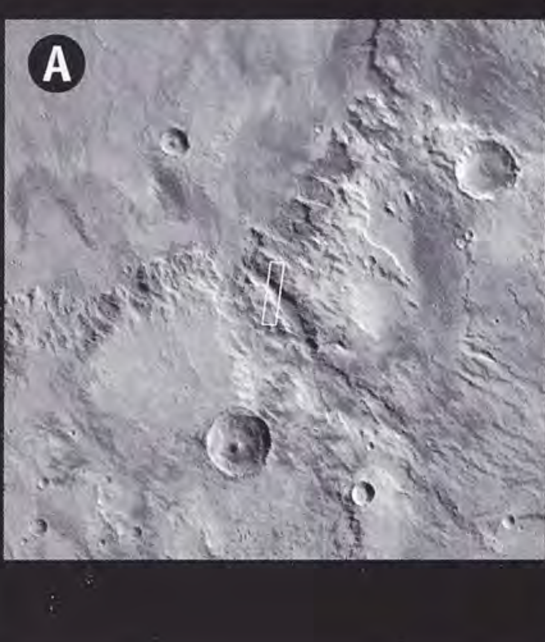
The Mars Orbiting Laser Altimeter (MOLA) has acquired 18 nearly equally spaced altitude profiles with very high resolution, covering most of the northern hemisphere of Mars. Much of the northern hemisphere is exceedingly flat. However, we have acquired detailed topographic profiles across complex features such as volcanic formations, canyons, ridges, craters, and the edge of the northern polar cap. Characterization of the morphology of these features is leading to new understanding of the surface processes on Mars. Ultimately, we hope to discern some of the internal processes hidden beneath the surface.

## Magnetic Observations

The magnetometer (MAG) and the electron reflectometer (ER) have shown that Mars is characterized by a large number of small, highly magnetic features within the crust rather than by a global field similar to those we've found at most planets. Their small size (on the order of 50 kilometers/30 miles) and highly magnetic nature, much stronger than such small magnetic features on Earth, suggest that these are crustal features formed at a time when Mars possessed a global magnetic field. Supporting this hypothesis is the finding that most of the features seem to be within the ancient cratered area of Mars rather than in the younger volcanic areas.

---

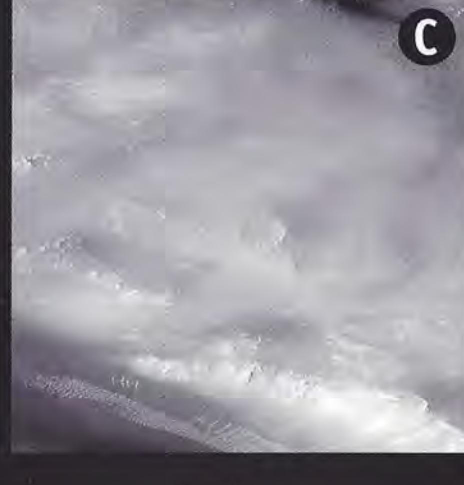
*Arden Albee is Project Scientist for* Mars Global Surveyor.





*Two exciting finds by* **Mars Global Surveyor** *appear in these views of a small area immediately south of the large crater Schiaparelli. (A) is the best available image of the area from the* **Viking** *orbiters. (B) is an October 18, 1997 MOC image, a portion of which is enlarged in (C).*

*The first find is the small dunes sweeping from left to right (north to south) along the canyon floor—apparently derived from bright deposits within Schiaparelli crater. The shape of the dunes, and their relationships to one another, strongly suggest that these dunes have been active recently.*




*The second discovery concerns the small depressions with faint lines crossing lighter floors [best seen at center in (C)]. These depressions and the pattern of lines are similar to dry lake beds seen throughout the southwestern US. The light material may be salts or other minerals deposited as a lake evaporated, and the dark lines may be cracks created as the material dried out.*

*Images: JPL/NASA*

The pace of solar system exploration is picking up. The faster, cheaper, better philosophy has revolutionized NASA, and one concrete example of change is the Discovery program, which selects missions that are tightly focused on crucial scientific investigations and can be conducted for much lower costs than past missions.

*Mars Pathfinder* was the first Discovery mission to complete its objectives; several others, including the Near-Earth Asteroid Rendezvous, are now under way. NASA recently queued up two more missions in the Discovery series: *Contour* to explore comet nuclei and *Genesis* to sample solar materials. Here are brief introductions to these upcoming missions.

*—Charlene M. Anderson, Director of Publications*

# The *Genesis* Mission: Catching Pieces of the

What is the Sun made of? This question has intrigued humanity for centuries, and people have tried out many kinds of answers—in the form of folk beliefs, mythological tales, and scientific hypotheses. With the *Genesis* mission, we will attempt to provide quantitative answers that will meet the needs of solar system science in the 21st century. Specifically, *Genesis* will provide precise measurements of the various elements (and their isotopes) that make up the Sun.

Planetary scientists are interested in the Sun because solar composition can tell us much about the origin of the solar system and our world. We have a widely accepted "standard model" for the origin of solar system materials. According to this model, all the widely diverse planetary objects—including moons, asteroids, and comets—and the Sun formed from a homogeneous cloud of dust and gas called the solar nebula. The composition of this primordial cloud is now preserved for us in the surface layers of the Sun.

We have found the standard n
correct to be useful, but it is uns
questions—which makes things
over, the standard model is clear
aspects, which is even more inte
for volatile elements, such as ox
the homogeneous distribution of
be expected from the standard m
of solar system materials has bee
piece together the real story on h
formed, we need to study a samp

## Riddle of the Isotop

Isotopes of an element differ fro
number of neutrons in their nucl
most abundant form of oxygen, 1
than oxygen-18. In any oxygen-b
water, or rock, there are both for
occurring in a measurable ratio t

(co

# The *Contour* Mission:

Comets retain clear memories of the formation of the solar system 4.5 billion years ago. Locked up in each comet's nucleus there are clues to the chemical and physical processes that led to the production of complex organic molecules, molecules that may have been the sources of organics from which life on Earth arose. Comet nuclei—agglomerations of ice and dust, typically several thousand meters in diameter—are too small to be studied in detail from telescopes on Earth. However, they are within reach of a comet-touring spacecraft to be built by the Applied Physics Laboratory of the Johns Hopkins University for Cornell University.

Our goal with the Comet Nucleus Tour (*Contour*) is to improve fundamentally the knowledge of comet nuclei and assess their diversity. Accumulating evidence shows

us that not all comets are alike
understand the differences. W
comets are indeed primordial
unchanged since the solar syst
they evolved from their origin
we can tell for sure is to study
nuclei up close.

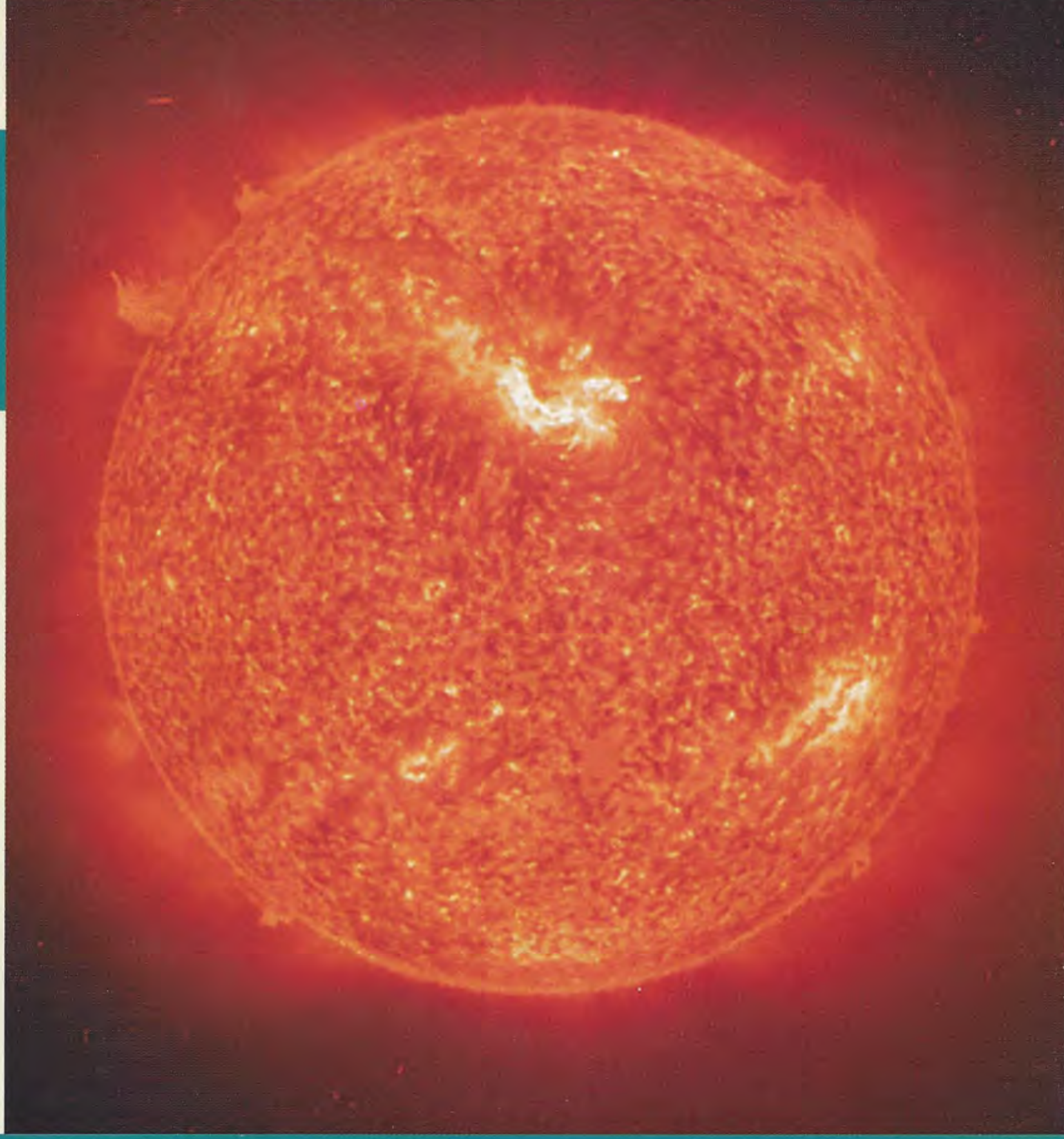
With *Contour* we will inves
Encke, Schwassmann-Wachm
Comet Encke swings by the S
and these frequent heatings h
of the ice and dust that make
a very evolved object that dis
level of activity—an object th
eventually turn into something

Sun by Don Burnett

odel sufficiently
pecific on many
nteresting. More-
y wrong in some
esting. For example,
gen, we don't find
isotopes that should
odel. Our sampling
n limited to date. To
ow the solar system
le from the Sun.

## es

n one another by the
us. Oxygen-16, the
s two fewer neutrons
earing sample of air,
s, with oxygen-18
oxygen-16. The
*tinued at top of page 14)*



***The Sun is not an easy subject to sample. It's far too hot for spacecraft, so* Genesis *will instead collect samples of the solar wind, the ionized particles streaming from the Sun. Here we see our local star through the Extreme Ultraviolet Imaging Telescope (EIT) of the Solar and Heliospheric Observatory (SOHO). The image reveals the region just above the visible surface with a temperature of 60,000 to 80,000 kelvins (108,000 to 144,000 degrees Fahrenheit). We can see a network pattern in which the Sun's magnetic field congregates.***

*Image: SOHO EIT Consortium. NASA/ESA*

# Seeking Clues to Our Origin by Joseph Veverka

, and it is important to
e also need to know if
bjects, substantially
em formed. Or have
l state? The only way
a variety of comet

tigate three comets:
ann 3, and d'Arrest.
n every 3.3 years,
ve cost Encke much
up its mass. It is now
lays a relatively low
t some believe might
hardly distinguish-

able from an asteroid. Comet d'Arrest, with a period of 6.4 years, is a more active comet with a surface that has been less changed by its passages by the Sun. Schwassmann-Wachmann 3 dramatically split into three pieces in 1995. The fragments should still be relatively fresh, exposing deep nucleus materials that we hope to study in detail.

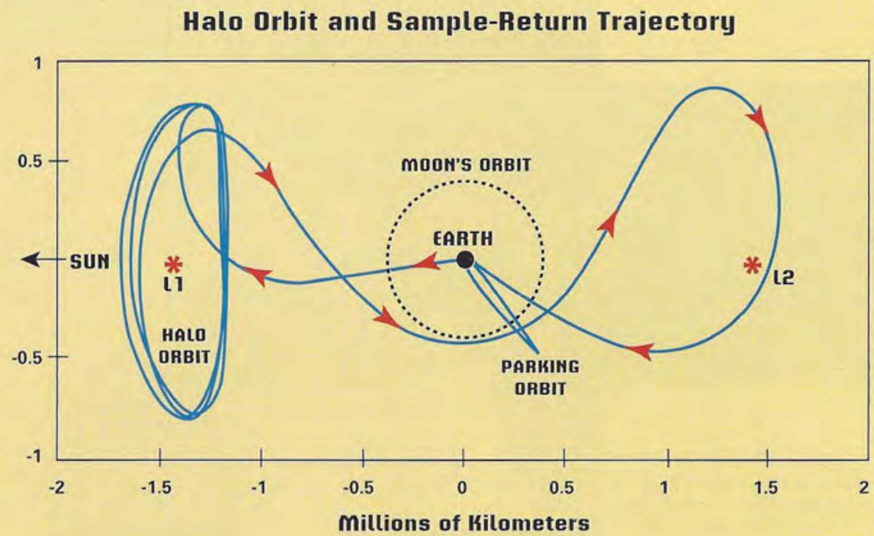
## Comets on the Economy Plan

The *Contour* spacecraft, a compact design with no elaborate mechanisms, will weigh just under 900 kilograms (2,000 pounds). About 40 kilograms (90 pounds) will be devoted to a four-instrument payload comprising a high-resolution imager/spectral mapper, a wide-angle camera, a dust analyzer, and a mass spectrometer.

With these instruments we will see each comet nucleus with resolution as fine as 4 meters per pixel, about 25 times better than the best views of Halley obtained by the *Giotto* spacecraft in 1986. At each comet encounter, we will map the nucleus to determine what its surface is made of and how its composition varies from place to place We will analyze the emitted gas and dust directly, using the mass spectrometer and dust analyzer. *Contour* will fly by at distances ranging from 100 to 200 kilometers (60 to 120 miles).

We have chosen encounter times that will allow us to see the comets when they are most active and

*(continued at bottom of page 14)*




*Genesis will leave Earth in January 2001 and then in April will enter its halo orbit around Lagrangian point 1. There it will collect data and samples for two years. In April 2003, Genesis will begin its return to Earth, swinging by Lagrangian point 2 and entering a parking orbit for Earth reentry in August or September.*

Chart: JPL/NASA; redrawn by B. S. Smith

*(continued from top of page 13)*
relative abundance of isotopes in a sample can be an important clue in tracing its chemical history.

In the study of solar system origins, we have focused our attention on oxygen isotopes because samples of terrestrial, lunar, and meteoritic materials reveal systematic, and relatively large, variations in oxygen-isotope ratios. We don't know why. We do know that these oxygen-isotopic variations are fossilized clues to the events, processes, and materials that formed planetary objects from the solar nebula.

However, we are missing a major piece of the puzzle: the isotopic composition of solar oxygen. To determine this ratio with sufficient precision, we must return a sample of the Sun to Earth. This measurement is the highest-priority science objective of the *Genesis* mission.

So where do we go to get solar matter? Fortunately, we don't have to go to the Sun. It's an understatement to say that a sample return from the Sun would be technically difficult. However, the Sun continuously emits a solar wind, a stream of ionized particles that permeates our solar system. This stream makes solar matter available for the taking, but to take it we have to get out beyond the Earth's magnetosphere, which diverts the flow of the solar wind.

Lockheed Martin Aerospace is building a relatively simple

*These are the targets of the Contour mission: Comet d'Arrest (image at near right) is an active, short-period comet with an orbital period of 6.4 to 6.7 years. Comet Encke (far right, this page) has the shortest known period, traveling from near Mercury's orbit to the outer edge of the asteroid belt every 3.3 years.*

Images: d'Arrest, Steward Observatory, University of Arizona; Encke, Spacewatch Telescope

*(continued from bottom of page 13)*
ideally placed for observations from Earth. We plan to link the detailed observations by *Contour* with data obtained at broader scales by ground-based and Earth-orbital telescopes.

To get by with a small and inexpensive launcher, and to make the mission as flexible as possible, *Contour* will use a series of Earth swingbys to redirect the spacecraft toward its comet intercepts. After launch in late June 2002 aboard a Delta 7425, the spacecraft will encounter comet Encke in November 2003. Two Earth swingbys will retarget *Contour* to fly by comet Schwassmann-Wachmann 3 in June 2006, and two more will send it to comet d'Arrest in August 2008.

## Eyes Peeled for "New" Comets

The mission design is highly flexible, which lets us keep options open in case opportunities develop to increase our science return. For example, we can replace the d'Arrest encounter with a February 2008 flyby of comet Wirtanen. In this scenario, *Contour* would be a pathfinder for the European Space Agency's ambitious *Rosetta* mission, which is scheduled to reach that comet in 2011.

An even more exciting possibility is to retarget *Contour* to some bright comet that has yet to be discovered—perhaps another one like Hale-Bopp. Such objects come to us from spacecraft that will park at a spot in nearby space known as L1, one of five Lagrangian points where the gravitational pulls of the Earth and Sun are balanced. Because of the balance, it takes little energy to maintain a stable position there. L1 is a good place to hang for two years, catching pieces of the Sun.

## Solar Flypaper

During the *Apollo* missions, our science co-investigators from the University of Bern showed that the solar wind, containing all the elements of the periodic table, sticks to things in its path. The fluxes of many elements in the solar wind are very low, so *Genesis* will have to use collector materials that are very pure so we can be certain that the atoms measured are solar in origin and not terrestrial impurities. Ultrapure materials, such as wafers of single-crystal silicon manufactured by the semiconductor industry for electronics applications, are available.

Oxygen isotopes, our highest-priority measurement, provide the biggest challenge in terms of ensuring purity of collector materials and getting enough atoms for a high-precision isotopic analysis. The Los Alamos National Laboratory is designing an electrostatic mirror, or "concentrator," that will enhance the measurement of oxygen and similar lightweight elements by 20 times.

Besides being pure, the collector materials must be kept clean. We'll deploy the collector materials from an ultraclean "science canister," designed and built by the Jet Propulsion Laboratory. The collector materials will be loaded inside the canister in state-of-the-art clean rooms in the NASA Curatorial Facility at the Johnson Space Center. The canister will remain sealed until the spacecraft arrives at L1.

The science canister is integrated inside a sample return capsule (SRC). After about two years of exposure at L1, the collector materials will be retracted into the SRC, and the spacecraft will return to Earth. The spacecraft and SRC will separate, and as the SRC enters the atmosphere, it will be slowed by ablation of material from the re-entry nose cone. At low altitude, a parachute will open and the dangling SRC will be snagged by helicopters over the Utah Test and Training Range.

The canister, with its abundant yet precious cargo, will be delivered to laboratories for isotopic analyses by advanced instruments, and we will have our answer: a measurement of solar oxygen isotopes, as well as important measurements of other elements. We will then understand how the solar isotopic ratios fit with the ratios observed in other parts of the solar system, and how all these data relate to the standard model. The measurement from the Sun will bring us closer to understanding the evolving phases of the solar nebula. And after centuries of inquiry, we'll know much better what the Sun is made of.

*Don Burnett is Professor of Geochemistry at the California Institute of Technology.*

***Comet Schwassmann-Wachmann 3, with a period of 5.3 years, split into at least three pieces in 1995. Two pieces of the nucleus (image at far left, this page) are seen here a few months after the comet split. The split produced a complex structure (near left) in the coma (atmosphere) and tail of the comet.***

***Images: Spacewatch Telescope***

the distant reaches of the Oort cloud of comets surrounding our planetary system, 50,000 times farther than Earth from the Sun.

Given the rate of discovery of such comets, we may well see a suitable target appear during the five years between the Encke flyby and the end of the mission in 2008. Had *Contour* been in space at the time of Hale-Bopp's recent visit to Earth's neighborhood, the spacecraft could have been retargeted to reach this spectacular comet.

We plan to involve the public in the *Contour* mission. We'll publicize the goal of intercepting a new comet fresh from the outer reaches of the solar system and encourage a worldwide search for a suitable target. If NASA chooses a new comet as a target for *Contour*, we will invite the discoverer (or discoverers) to participate in the science team activities for the encounter.

On its completion, the *Contour* mission will have provided important insights into the chemistry of the early solar system, memories of our origins stored in the cores of comets.

*Joseph Veverka is a Professor of Astronomy and Space Sciences at Cornell University and is the Principal Investigator for the* Contour *mission.*

# The STUFF of LIFE: Must Life Be Carbon-Based?

**by Gene McDonald**

For generations, scientists, philosophers, naturalists, writers, and artists have been exploring the chemistry of the origin and evolution of life. When their explorations are not bound by the scientific need for data, they can wander freely through a range of conceivable biologies.

One of the favorite speculations about extraterrestrial life, particularly among science fiction writers, is that biochemistry elsewhere in the universe might be based on some element other than carbon. Stories about strange beasts made of silicon or other elements entertain us, but they also lead us to ask an interesting scientific question: must life be based on carbon?

The elements that can be used as a basis for life depend greatly on our definition of life. Arriving at a satisfying general definition of life is not easy, and we usually end up settling for the somewhat vague operational definition that "life is life as we know it on Earth." This definition immediately answers the carbon question in the affirmative, by defining life as a system based on carbon chemistry.

For people interested in the possibilities for extraterrestrial life, however, this Earth-based definition is too narrow. Plasma entities, radiation beings, self-replicating computer programs, and clay minerals are all examples of phenomena that some brave souls have suggested could be "living." None of these phenomena is based on the carbon chemistry that is at the heart of life on Earth.

For the question "Must life be based on carbon?" to be meaningful, we have to restrict our definition of life. Most biologists, for the sake of continued discussion, would recognize and assent to a definition like the following:

***Living organisms are systems of chain-like molecules that can***

*1)* organize into three-dimensional structures,
*2)* carry out chemical reactions (metabolism),
*3)* store the instructions for their own reproduction,
*4)* use that information to reproduce themselves, and
*5)* evolve through mutation and natural selection.

A system that can form linear polymeric molecules that serve as information carriers or catalysts needs to be based on an element that has several important characteristics, which we will now examine.

## Abundance

The element should be abundant in the universe and in planetary environments, so that the odds will favor prebiotic chemistry's chances of beginning. In our solar system, carbon is the fourth most abundant element behind hydrogen, helium, and oxygen. Considering the elements used in known biologic processes, we observe that oxygen is about 5 times more abundant than carbon, nitrogen 5 times less abundant, sulfur about 20 times less abundant, and phosphorus nearly 1,000 times less abundant.

Silicon, the leading science fiction candidate to replace carbon in biochemistry, is ten times less abundant than carbon in the solar system. Boron, another candidate to replace carbon, is almost one million times less abundant than carbon in the solar system.

In Earth's crust, silicon is ten times more abundant than carbon. Most rocks are in fact made of silicates, combinations of silicon, oxygen, and metals such as aluminum, iron, calcium, and magnesium. Boron is ten times less abundant than carbon in the Earth's crust.

Since our Sun appears to be a fairly average star, we can assume that other solar systems will have similar compositions (though we have no hard data to support this assumption). But planetary crust and bulk solar system material are not the only sources of compounds that make up the chemistry necessary to start life. Primitive meteorites contain prebiotic, carbon-bearing compounds, which tells us that many of these molecules were synthesized in clouds of gas and dust between the stars. Radio astronomers have detected more than 80 molecules in interstellar space. Carbon is found in more than 70 of these molecules, while silicon is present in fewer than 10.

## Cycling

A life-forming element should be able to participate in biogeochemical cycles. Biologists and geochemists have come to realize that the cycling of biological elements among the atmosphere, oceans, crust, and biosphere is crucial to the development of ecosystems.

Nitrogen participates in biogeochemical cycles on Earth through four gases: molecular nitrogen ($N_2$), nitric oxide (NO), nitrous oxide ($NO_2$), and ammonia ($NH_3$). Carbon can be carried through such cycles by methane ($CH_4$) and carbon dioxide ($CO_2$), the major carbon carrier on the terrestrial planets. Carbon dioxide is a gas at planetary surface temperatures and soluble in water, so it is a very mobile compound in the environment.

Silicon dioxide ($SiO_2$), familiar to most of us as sand, is insoluble in water and is a solid at planetary temperatures. Silicon dioxide is also chemically unreactive compared to its carbon analog. Any kind of silicon cycle similar to the carbon cycle operating today on Earth would thus be practically impossible.

## Bonding

A life-forming element's atoms should be capable of forming at least three bonds. In our system of linear biopolymers, in which atoms link together to form the "backbone" of a molecule, each link needs two bonds to connect to the rest of the backbone. At least one more bond from each backbone atom is necessary to connect to atoms forming a side group, which performs a function such as genetic information storage or chemical catalysis. Hydrogen and oxygen, and any other elements that can form only one or two bonds, are thus eliminated from use as the backbone atom.

The element's atoms should form no more than four bonds. Two side groups on each backbone atom is probably the maximum number allowable. Three or more side groups would crowd the space around each backbone atom, preventing formation of bonds with other backbone atoms and inhibiting chain formation. The extra chemical groups sticking out from the sides of the backbone would also make cross-linking between chains more likely, resulting in a structure that would be more like a lattice than a linear polymer. A lattice would be unsuitable as an information-carrying molecule. A linear structure works well because it gives obvious direction and sequence to a genetic code.

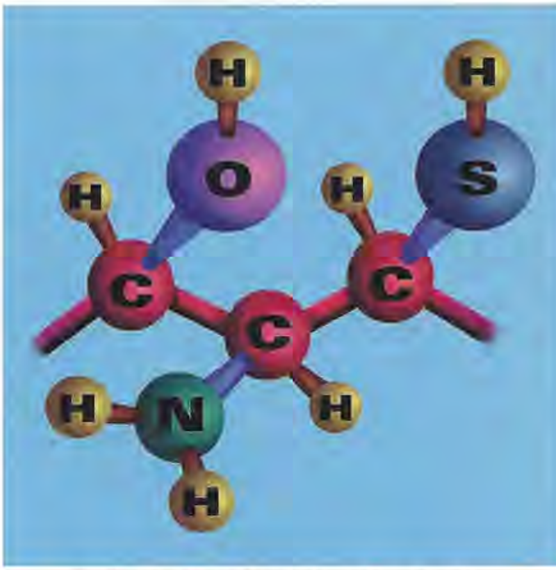
Nitrogen, phosphorus, and boron usually form three bonds, but sometimes four. Sulfur generally forms two bonds, and silicon usually four, but both can participate in up to six bonds. Carbon, on the other hand, forms four and only four bonds in neutral molecules. This consistent bonding pattern makes it much easier to form polymers from carbon than from most other elements.

## Stability

The atoms of a life-forming element should form stable chemical bonds with each other. Biological molecules need to be stable enough so that the chemical bonds holding them together do not randomly break apart when exposed to small increases in temperature. A silicon-silicon bond is only about half as strong as a carbon-carbon bond, so under changing temperature conditions a polymer with a silicon backbone would be much less stable than one with a carbon backbone.

To make matters worse, the silicon-oxygen bond is more than twice as strong as a silicon-silicon bond. Since oxygen is abundant in terrestrial planet environments, silicon-oxygen chains would be more likely to form than silicon-silicon chains. While silicon-oxygen polymers are much more stable than carbon compounds, even at high temperatures, they are so unreactive that their ability to catalyze chemical reactions, essential to life processes, is very limited.

Other alternatives to carbon also have stability problems. Boron and nitrogen can combine to form molecules such as borazine ($B_3N_3H_6$), a ring-shaped molecule that has chemical properties in common with the well-known organic molecule benzene ($C_6H_6$). Benzene is quite stable under most planetary conditions; however, borazine is explosively light-sensitive.



***The linear carbon-carbon backbone keeps the side groups (OH, NH2, and SH in this figure) pointed out into the surrounding environment, where they can interact with other molecules to catalyze reactions or transfer information.*** *Illustration: B.S. Smith*

## Diversity

A life-forming element should be capable of enough chemical diversity to form both a molecular backbone and the functional side groups. An element that can do both allows for the simplest possible metabolism, by which an organism synthesizes biomolecules needed to sustain its life. There are thousands of different molecules that consist of just carbon and hydrogen. When you include oxygen, nitrogen, sulfur, and phosphorus, the number of known carbon-containing molecules becomes several million, and chemists synthesize new ones every year. Molecules formed from these elements have shapes and chemistries that can carry information and serve a wide range of catalytic functions. No other element comes close to carbon in potential for structural and chemical diversity.

Moreover, carbon can form double bonds. As an alternative to making a single bond with each of four other atoms, a carbon atom can form a double bond with one atom and single bonds with two other atoms.

Double bonds between carbon atoms are important. If there are several double-bonded carbon atoms near each other in a molecule, they can share electrons by a phenomenon known as resonance. A molecule with a resonant electron structure can absorb ultraviolet or visible light. Chlorophyll, which absorbs light for plants to use in photosynthesis, and retinol, which allows our eyes to detect visible light, are examples of biomolecules that contain such structures. A few compounds containing silicon-silicon double bonds have been synthesized in the laboratory, but they are much less stable than carbon-carbon double bonds.

## Simply the Best

The combination of properties found in carbon makes it the best element to serve as a basis for life as we know it, life that is similar in chemical organization to terrestrial life and inhabits a similar planetary environment. As we look for extraterrestrial life in the solar system and beyond, we should keep in mind that our instruments are designed to detect life based on carbon. This is the type of life we know. If radically different biochemistries are out there somewhere, it may be very difficult for us to recognize them as life. However, the search for carbon-based life in the universe should keep scientists busy for years to come.

---

*Gene McDonald is a Research Scientist with the Astrobiology Group at the Jet Propulsion Laboratory.*

# News and Reviews

**by Clark R. Chapman**

Science is an element of modern culture, although its manifestation in *popular* culture can be distorted. Brief photo-ops and sound bites are inimical to the thoroughness, precision, and careful qualification in the wording of good science. Nevertheless, science has made a lot of news lately, and as 1997 ended, the news editors of the weekly journal *Science* listed their "top ten" stories of the year. Predictably, Dolly the cloned sheep topped the list. Fully a third of the remaining stories dealt with space science, two with the planets (*Mars Pathfinder* and *Galileo*'s intriguing evidence for a sub-surface ocean on Europa). According to *Science,* space science provided the most grist for the mill of pop culture, thanks to the brilliance of comet Hale-Bopp, the travails of *Mir*, and the meanderings of *Sojourner*.

A reporter for *People* magazine, which epitomizes pop culture, recently asked me to compare the chance of a woman giving birth to surviving septuplets with her chance of being struck dead by a meteorite. The new fertility drugs might actually make it more likely to have septuplets! So I helped the *People* reporter realize that being killed by an *asteroid* and its aftermath, if a big one were to cause a global eco-catastrophe, was far more likely than either having septuplets or being hit on the head by a cosmic rock.

### Instant Ice Ages

Reading through the January 1998 issue of the more urbane *Atlantic Monthly*, I was struck by the pervasiveness of space science issues. The topic of asteroid impacts crops up in the *Atlantic*'s cover story, about another would-be eco-catastrophe: an instant ice age, triggered (author William H. Calvin claims) by global warming. Instant ice ages, like the fictional one in Thornton Wilder's play, "The Skin of Our Teeth," are hardly the most feared consequences of global warming, as I read the literature. But the Earth's complex atmospheric/oceanic interactions (like the current El Niño) are poorly understood, and scientific opinion is divided about whether nature preserves the environmental status quo by checks and balances or, instead, nature is inherently unstable, inducing climate flip-flops, as Calvin warns.

I've never believed that global warming is a horrendous problem. I suspect it will happen; indeed, it probably already is happening. But the prospect of millions being forced to move during the next half-century if Florida is submerged is hardly worse than the migration of millions *to* Florida during the *last* half-century. The severity of a calamity, it seems to me, depends on its *rate.* Nearly all of the 6 billion people now alive will be dead a century from now, which is life-and-death-as-usual, but the death of "just" a billion in the next few years would be an unprecedented catastrophe.

Calvin raises the asteroid impact scenario as a less-threatening counterpoint to his instant ice ages. He writes, "A meteor strike that killed most of the [world's] population in a month would not be as serious as an abrupt cooling that eventually killed just as many. With the population crash spread out over a decade, there would be ample opportunity for civilization's institutions to be torn apart . . . ." Calvin entirely misses the point that a cosmic impact is a guaranteed mechanism for producing just the sort of instant global cooling that he surmises would doom civilization. It makes me wonder how much else is missing or scientifically suspect in this rather rambling article.

The cover story is only one place in this issue of the *Atlantic* where meteor impacts and other cosmic topics intrude. A letter writer says that America has "the best space program." The almanac section lists a meteor shower and other astronomical events for the coming month. The puzzler has a couple of NASA and Russian space program clues. The short story about young lovers invokes not only the Moon but also telescopes and sky watching. The all-about-words column decries the use of "impact" as a transitive verb but allows its use in the context of "meteorites impacting the Moon."

### Meteors, Meteorology, and Monasteries

I thought I found an unusual reference indeed in the travel article about central Greece, which describes the monasteries perched atop huge rocks and pinnacles, hundreds to 2,000 feet high. They are "aptly named," according to the author, "Meteora." The biggest is the "Great Meteoron." A photograph immediately brought to my mind Magritte's surrealistic paintings of rocky ovoids suspended in the air (some with castles perched on top), which I have imagined as enormous meteorites. In fact, "meteor" is derived from the ancient Greek word for "atmospheric" or "suspended in the air," as the Greek monasteries certainly seem to be.

So, other than their "heavenly" religious significance, the Meteora have no truly cosmic meaning. Yet they remind us of something that meteoriticists (who are often confused with meteorologists) know well: human beings have long been fascinated with events and things in the skies and the heavens, and only in recent centuries have we learned to distinguish the merely "atmospheric" from the "astronomical," far beyond our atmosphere. So long as the cosmic objects *stay* above the atmosphere, we can all safely go about our mundane activities, letting astronomical metaphors hang as a cultural backdrop.

---

*Clark R. Chapman helps sky watchers locate the position of the asteroid Eros as part of a Planetary Society project: go to "Star Charts" at the Near-Earth Asteroid Rendezvous Mission site on the World Wide Web: sd-www.jhuapl.edu/NEAR/.*

# World Watch

by Louis D. Friedman

This year promises to be a big one for space exploration—with several planetary missions set to launch and the International Space Station program awaiting the launch of its first component. The confluence of the human spaceflight program and the robotic planetary program presages the day when humans will again leave Earth orbit and explore new worlds.

## Space Station

The Functional Cargo Block, the first element of the space station, will be launched on a Russian Proton booster in June. This component will provide power and propulsion for the early phases of station construction. Soon afterward, a US shuttle will deliver two pressurized mating adapters—one to link the cargo block to node 1 of the modular space station, the other to serve as a shuttle docking port.

## Budget Politics

Cost overruns from US contractors and delays from Russian contractors have afflicted the space station program, causing problems for the NASA budget. Space station funding is supposed to stay at or below $2.1 billion per year. If there are cost overruns, NASA has to either stretch out the schedule or transfer funds from other programs. Congress has usually inhibited transfers, protecting programs in space science, launch vehicles, advanced technology, and, of course, shuttle operations. In 1998, cost overruns in the space station program will be a critical budget issue. As I write this, the proposed fiscal year 1999 budget (for funding that begins October 1, 1998) has not been revealed.

The Planetary Society has been active during the budget deliberations leading to the 1999 US budget. We wrote to key administration members (including Vice President Al Gore) and provided input to NASA, the Office of Management and Budget, Congress, and other policy makers. We will keep our members informed through the budget process.

## The World

In other spacefaring nations, as in the United States, we have demonstrated to government officials and policy leaders that there *is* popular support for space exploration. This past year we have been particularly active in Russia, Europe, and Australia. In Japan, we are trying to build a branch of the Planetary Society.

Among the spacefaring countries, Russia's planetary program is in the worst shape—stopped almost dead by budget woes, economic problems, and infighting among scientific institutes in the Academy of Sciences.

Conversely, Europe is developing a new mission for the year 2003—*Mars Express*—as well as continuing work on the *Rosetta* mission to a comet. France is proposing new ideas for planetary exploration using the newly proven Ariane 5 rocket. Japan's *Lunar A* mission, to drop three penetrators into the surface of the Moon, was delayed from 1997 to 1999 due to technical problems with the penetrator system, not because of the budget. However, Japan is not immune to budget difficulties, and a follow-up lunar mission for 2002 will probably fly a few years later.

## Exploration in 1998

The pace of planetary exploration picked up dramatically in 1997. Sometimes I feel as if I were living in a port town in 16th century England, Portugal, or Holland, hanging around the waterfront taverns, being regaled with sailors' stories of discovery. This year we look forward to more discoveries:

- *Galileo* Europa Mission (GEM)—*Galileo* has completed its initial tour of Jupiter's moons, but Europa proved to be so fascinating, with a liquid water ocean possibly hidden under its icy crust, that the mission has been extended to study Europa in greater detail.
- Near-Earth Asteroid Rendezvous (NEAR)—After its successful flyby of the main-belt asteroid Mathilde, this spacecraft is heading to its primary destination: the near-Earth object, Eros.
- *Cassini/Huygens*—This spacecraft continues on its interplanetary cruise to the Saturnian system. It will fly by Earth in 1999 to pick up a gravity assist that will sling it onto its trajectory to Saturn.
- *Deep Space 1*—This will be the first US spacecraft to use solar-electric propulsion. Its destinations are comet West-Kohoutek-Ikemura and the asteroid McAuliffe.
- *Mars Surveyor*—The orbiter will launch in December, with a lander following in January 1999. The lander will carry the Planetary Society Mars Microphone.
- *Planet B*—Japan's first mission to Mars is scheduled for launch this August.

## An Earth-Based Report

The balloon flight of Steve Fosset—one of several balloonists to attempt an around the world flight—involved an experiment close to the Planetary Society's heart. He carried an instrument payload from the Jet Propulsion Laboratory (JPL) to gather data on high-altitude balloon flight relevant to Mars and Venus balloon missions. The Planetary Society balloon test program lives on in JPL's ballon work and will lead, we hope, to a Mars balloon mission, perhaps by 2003.

---

*Louis D. Friedman is the Executive Director of the Planetary Society.*

# Questions and Answers

***The discovery of possible early Martian life makes me wonder if there could be a source of biologically-derived hydrocarbons under the planet's surface. If the concentration of putative organisms reached a high enough concentration, as they did in Earth's oceans, could there be oil on Mars?***
**—Charles Cockell,**
**Mountain View, California**

We think that crude oil or petroleum on Earth results from the burial of organic matter derived from living things. (Remember that organic molecules are molecules based on carbon, and can be produced either by biology or by simple chemistry. However, virtually all complex organics on Earth today are byproducts of terrestrial biology.) We see evidence for a biological origin of terrestrial petroleum in the presence of small amounts of biological signature molecules in the petroleum. For example, a variety of plant products are present, such as molecules related to chlorophyll. The bulk of the petroleum consists of hydrocarbons, organic molecules containing only carbon and hydrogen.

The first step in making petroleum is for biological organisms—such as plankton, plants, or fish—to die and have their remains accumulate at the bottom of underwater basins. Some of the hydrocarbons in petroleum come straight from hydrocarbons that already exist in these organisms. But most of the petroleum is formed by the conversion of other organics these organisms contain. (These will include, in addition to carbon and hydrogen, elements such as nitrogen, oxygen, sulfur, and phosphorous.)

As these organics are deposited and gradually buried deeper and deeper by the accumulation of more sediments above them, chemical changes called "cracking" occur, converting the organics into hydrocarbons and driving off most of the other elements. This process begins after the organics are buried only a few meters in depth, but becomes commercially useful after burial to depths of half a kilometer or more.

For there to be useful Martian petroleum, then, we would need a source of Martian organics subjected to such sedimentation and burial to substantial depths. The organics could come from an early Martian biota, providing an analogy to petroleum formation on Earth. In the case of Mars, however, it seems likely that the time period over which life could have existed in abundance at the surface—if such a time ever existed—was short, ending around 3.5 billion years ago. The terrestrial organisms mentioned earlier—plankton, plants, and fish—are all examples of eukaryotes, organisms whose cells have nuclei and other sophisticated components. The origin of eukaryotes on Earth appears to have required a couple of billion years of evolution, so it seems unlikely they would have had time to get started on Mars.

Admittedly, these sorts of analogies to the history of life on Earth are very dangerous. But if this is correct, early Martian life, if it existed, may never have gotten beyond the level of single-celled prokaryotes (cells without nuclei) such as bacteria. The high concentrations of organic matter represented by decaying plants and animals on Earth were probably never achieved on Mars.

Nonetheless, we are free to imagine extensive mats of bacteria covering the early Martian surface. Nor is it impossible that large quantities of organics could be produced without biology and subsequently buried. One picture of Earth's early atmosphere suggests that large quantities of hydrocarbons and other organics could have formed and accumulated into what amounted to "oil slicks" on Earth's surface. The kind of methane-rich early atmosphere needed for this picture has not been in favor with most planetary scientists for the past few decades, but had it really existed, ancient Earth (or Mars) might have had these "oil slicks" even in the absence of biology!

But petroleum might prove much less valuable on Mars than on Earth. To burn petroleum to generate energy, it must be combusted with oxygen. Free oxygen exists in large quantities in Earth's atmosphere—the product of billions of years of photosynthesis. But free oxygen is virtually absent on Mars. To get energy from some future Martian gusher, you would therefore also either have to carry your oxygen to the Red Planet with you or, better yet, produce it there. Presumably, you would spend the energy to do this only if you had need of some portable fuel-oxidant mixture.

But if you were generating your oxygen to begin with by breaking Martian water down into its components, hydrogen and oxygen, then your best choice for liberating energy later would probably be just to recombine the oxygen with the hydrogen, rather than combining the oxygen with hydrocarbons that you would have to extract separately from the Martian subsurface.
—CHRISTOPHER CHYBA,
*University of Arizona*

***What would happen to a human body if it were ejected into space without a space suit?***
**—Carol Haynes,**
**Baltimore, Maryland**

On Earth, in the realm of human habitation, water is present in its liquid form due, in part, to the air (or barometric) pressure exerted upon it. If this air pressure is reduced to the point where the water can no longer remain in liquid form, the water will become a vapor. This phenomenon is known as ebullism and results in the water violently "boiling off." That leads to bubbling and expansion of the water vapor.

An astronaut ejected into the vacuum of space without the protection of a pressurized space suit, or one whose suit developed a significant leak, would quickly experience this ebullism, which would affect all the water in his or her body. (Remember that the human body is made up mostly of water!) The astronaut would lose consciousness within about 10 seconds, due to lack of oxygen to the brain. Next, in rapid sequence, paralysis would be followed by generalized convulsions and then more paralysis.

During this time water vapor would form quickly in the body's soft tissue and somewhat more slowly in the venous blood. The water vapor would cause a marked swelling of the body, possibly up to twice its normal size if it were not restrained by a pressure suit. Initially, the astronaut's heart rate might rise, but it would fall rapidly thereafter. The arterial blood pressure would also plummet over a period of 30 to 60 seconds, while the venous pressure would rise due to distention of the veins by gas and vapor.

After an initial rush of gas from the lungs during decompression, gas and water vapor would continue to flow out through the person's airways. This continuous evaporation of water would cool the mouth and nose to near-freezing temperatures. The rest of the body would cool as well, but more slowly. The circulation of blood would have ceased by this time.

It is very unlikely that human beings suddenly exposed to the vacuum of space would have more than 5 to 10 seconds to help themselves. However, some animal studies from the mid-1960s suggest that if immediate help is at hand, though the victim's appearance and condition would be grave, recompression within 60 to 90 seconds might save his or her life. One of the most memorable scenes in the movie "2001, A Space Odyssey" is Dave Bowman's emergency entry into an air lock —sans helmet. The sequence is considered to be technically correct, though it's worth noting that Dave seemed to suffer no noticeable aftereffects from spending several seconds in vacuum.

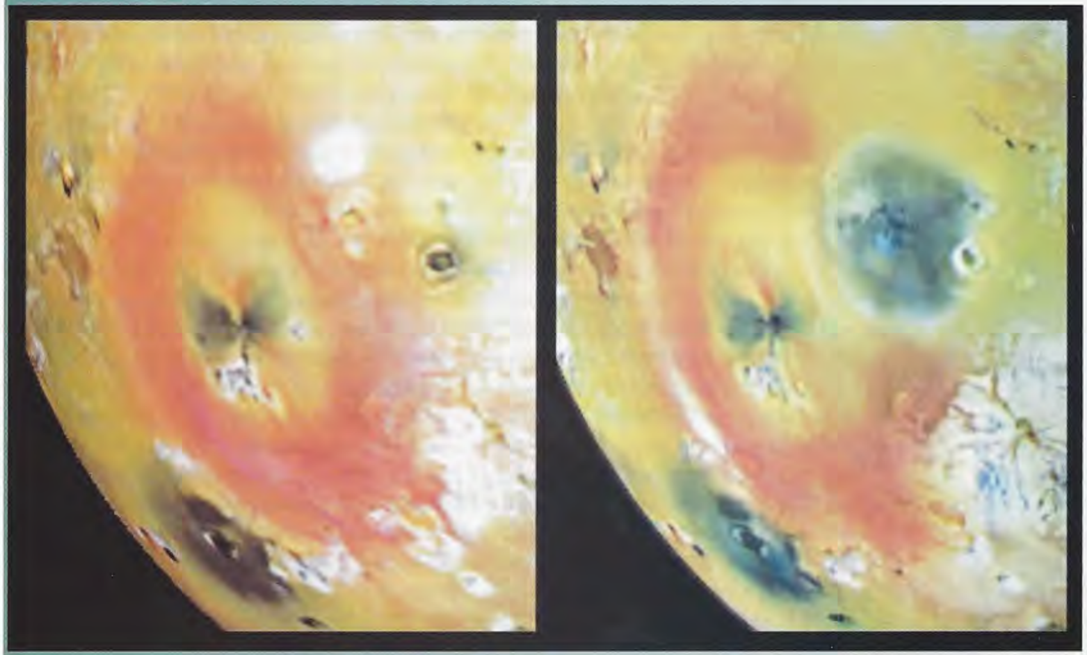
—ROGER D. BILLICA, MD,
*Johnson Space Center*

# Factinos

A new dark spot the size of Arizona has appeared on Io. *Galileo* images (below) captured five months apart indicate that dramatic volcanic activity has taken place on the Jovian moon during that time. "This is the largest surface change on Io observed by *Galileo* during its entire two-year tour of the Jovian system," said Alfred McEwen, an imaging team member from the University of Arizona.

Between *Galileo*'s seventh and tenth orbits of Jupiter, a dark spot 400 kilometers (about 250 miles) in diameter appeared around a volcanic area named Pillan Patera. Dark features at the center of the deposits may be new lava flows.

"Most of the volcanic plume deposits on Io show up as white, yellow, or red due to sulfur compounds. However, this new deposit is gray, which tells us it has a different composition, possibly richer in silicates, than the other regions," McEwen explained. "While scientists knew that silicate volcanism existed on Io from high temperatures, this may provide clues as to the composition of the silicates, which in turn tells us about Io's evolution." —from NASA Headquarters



***These* Galileo *images of Jupiter's moon Io show the results of a volcanic eruption on the fiery satellite between April 4 (left) and September 19, 1997. The new dark spot, roughly the size of Arizona, grew around a volcanic center named Pillan Patera. In June 1997* Galileo *and the Hubble Space Telescope observed an active plume over Pillan. These images also reveal changes in the plume deposit of the volcano Pele, the large red oval southwest of Pillan. It's possible that both plumes were active at the same time and that they interacted with one another.*** *Images: JPL/NASA*

Until recently, Uranus was the only outer planet with no known distant satellites. But a team of scientists has now discovered the planet's 16th and 17th moons. The objects were first detected in early October 1997 by Brett J. Gladman from the University of Toronto in images taken with the 5-meter Hale telescope at Palomar Observatory. The fainter moon is designated S/1997 U 1, and its diameter is estimated to be 80 kilometers (50 miles), while the brighter body, S/1997 U 2, is about 160 kilometers (100 miles) in size.

Brian G. Marsden and Gareth V. Williams from the Harvard-Smithsonian Center for Astrophysics calculate that the objects have inclined, eccentric, retrograde orbits that take them 6 and 8 million kilometers (3.7 and 4.9 million miles) from Uranus. They also say that the orbit of the fainter satellite appears to be significantly less eccentric than that of the brighter moon.

—from the Harvard-Smithsonian Center for Astrophysics

# Society News

### Society to Develop Volunteer Network

The Planetary Society will be updating its volunteer network during 1998, with a new list of volunteers from around the world. We are sending a survey to current volunteers to get information about your interest in assisting in upcoming space and Planetary Society-sponsored events and activities. Our goal is to establish a network of regional coordinators, develop a volunteer newsletter with regional contacts and information, and support our volunteer network with information posted regularly in a volunteer area on the Planetary Society's site on the World Wide Web.

Members interested in getting involved in Society projects and events should telephone Alice Wakelin at Society headquarters or send e-mail to: tps.aw@mars.planetary.org.
*—Alice Wakelin, Volunteer Coordinator*

### Belize and *Surveyor '98* Highlight Web Site

Two new exciting and informative pages are up at the Planetary Society's Web site. Adriana Ocampo and her team of scientists and volunteers sent reports from Belize during their recent 20-day excavations of ejecta from the Chicxulub impact. Ocampo has led previous Society-sponsored expeditions to Central America to uncover rock samples and data about the impact suspected of causing the extinction of the dinosaurs 65 million years ago. Information and images from the expedition are posted; follow-up articles about the 1998 expeditions will appear in upcoming issues of *The Planetary Report* and *The NEO News.*

In addition, our electronic publications department has developed a *Mars Surveyor '98* page at our Web site with information about the upcoming launches of the orbiter and lander in December 1998 and January 1999, respectively. The payload in this next series of Mars missions will include the Society-sponsored Mars Microphone, which will record sounds on Mars. Information about the mission, the microphone, and all the instruments aboard *Mars Surveyor '98* are posted at our site: http://planetary.org.
*—Michael Haggerty,*
*Electronic Publications Manager*

**More News**

*Mars Underground News:*
The latest news and images from *Mars Global Surveyor.*

*Bioastronomy News:*
Life, the evolution of intelligence, and creating the language of SETI.

*The NEO News:*
Gene Shoemaker NEO grants, small-comet debate, *Contour*'s cometary course.

**For more information on the Society's programs, call (626) 793-5100.**

### LA Students Become Mars Mission Planners

A new Red Rover, Red Rover middle-school program has begun in Los Angeles, with 31 Red Rover, Red Rover sites established in the Los Angeles Unified School District. These new sites join a network of more than 100 Red Rover, Red Rover sites at schools, science centers, and educational institutions around the world.

The Society's Red Rover, Red Rover project offers students the chance to experience robotic exploration first-hand. Using computers linked through the Internet, students teleoperate rovers that they build using LEGO Dacta components. The rovers explore model terrains that students create from NASA images of Red Planet surface features.

LA Unified's Mars Rover Project is a joint venture funded by the school district, the Los Angeles Systemic Initiative, and the Planetary Society. Contact Susan Lendroth at Society headquarters by telephone or by e-mail: tps.sl@mars.planetary.org, for additional information about this program,
*—Susan Lendroth,*
*Manager of Communications and Events*

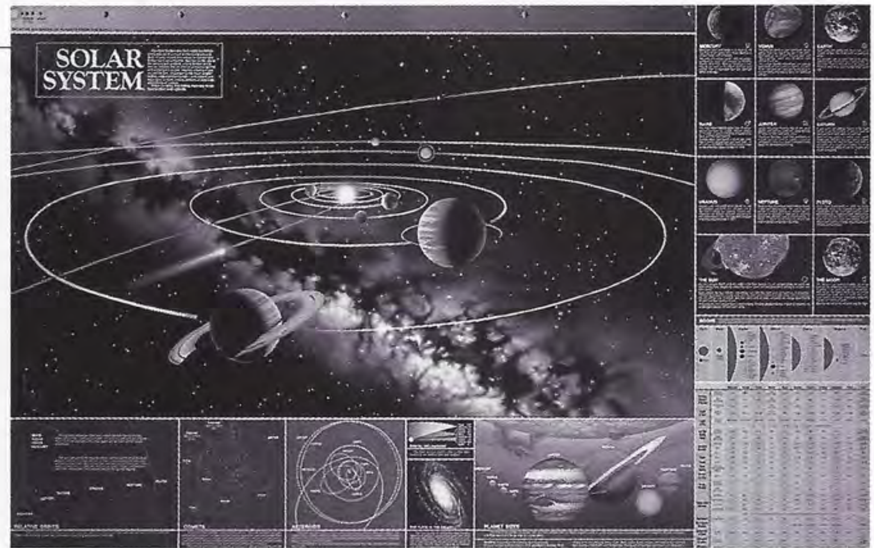
### Plans for Next Thomas Paine Award Underway

Plans are well underway for the next annual Thomas O. Paine Memorial Award and dinner, tentatively scheduled for May 1998 in Pasadena. The Planetary Society award, named in honor of the NASA administrator during the *Apollo* era, is given to leaders who have contributed significantly to progress in Mars exploration. We're developing a gala evening in conjunction with Ray Bradbury. Celebrities will read selections from Bradbury's collected works of science fiction. For more information about the dinner, contact Linda Wong at Society headquarters.
*—SL*

### Planned Gifts Support Society Projects

December 1997 and January 1998 have been marked by exceptionally generous planned-gift donations to the Planetary Society by two long-standing members. The estate of Jean Douglas of San Diego, California made a generous contribution in late 1997, in accordance with her estate trust directives. In January 1998, the Society received the first planned gift from the estate of Gertrude Pick Borchardt of Sarasota, Florida, who died in June 1997 and donated a percentage of her estate to the Society. Planned giving is a great way to support the missions and projects of the Planetary Society.
*—Lu Coffing, Financial Manager*

# Discover the Solar System!






**The Planetary Society T-Shirt**
Adults' M, L, XL, XXL. 1 lb. **#583 $16.00**



**Future Martian T-Shirt**
Children's S, M, L. 1 lb. **#565 $16.00**

**Dive Europa T-Shirt**
Adults' M, L, XL, XXL.
1 lb. **#557 $18.00**

**Future Martian Romper**
Size: 24 months. 1 lb. **#566 $16.00**

## Posters

**Solar System Chart**
39" x 25" poster (shown above).
1 lb. **#338 $6.00**

**Explore the Planets**
22" x 34" poster (shown at right).
1 lb. **#310 $5.00**

**Portrait of the Milky Way**
40" x 27" poster.
1 lb. **#330 $15.00**

**An Explorer's Guide to Mars**
40" x 26" poster.
1 lb. **#505 $6.00**

**Earth and Its Moon**
18" x 24" poster.
1 lb. **#318 $8.50**


## Planetary Miscellany


**Spacecraft Science Kits**
1 lb. **$14.00 each**
**#531** *Mars Global Surveyor* (shown above)
**#525** Hubble Space Telescope
**#538** *Magellan*
**#560** *Voyager*
**#524** *Galileo*
**#529** Keck Telescope

**Images of the Planets**
These large, attractive prints are 20" x 16" 1 lb.
**#305** Earth
**#315** Earthrise
**#319** Jupiter
**#323** Mars (Atmosphere)
**#325** Mars (Full Disk)
**#332** Saturn
**#333** Eight-Planet Montage
**#337** Uranus
**#340** Venus

***Special Sale—Any Combination!***
**1 $7.00** ***each***
**2-3 6.00** ***each***
**4+ 5.00** ***each***

**Craters! A Multi-Science Approach to Cratering and Impacts**
By William K. Hartmann with Joe Cain.
224 pages (soft cover)
2 lb. **#109 $24.95**

**Solar System in Pictures**
Nine 8" x 10" mini-posters.
1 lb. **#336 $10.00**

**Planetary Society Note Cards**
Set of 16 cards.
Envelopes included.
1 lb. **#544 $10.00**

**Planetary Society Mug**
2 lb. **#580 $7.00**

**Planetary Society Key Ring**
1 lb. **#677 $4.75**

**Planetary Society Pin**
1 lb. **#670 $3.00**

***Planetary Report*** **Binder**
2 lb. **#545 $13.00**
***Special Value—Order Two Binders for $23.00***

## Slide Sets

**Images of Mars**
20 slides with 12-page booklet.
1 lb. **#213 $12.00**

**Impact Craters**
20 slides with 12-page booklet.
1 lb. **#212 $17.00**

Attention Teachers: Submit your order on your school letterhead and receive a 20% discount!

**Check out the Planetary Store on the World Wide Web at http: //planetary.org**


At first glance, *The Red Planet* (1934) appears to be a simple still life. Yet careful observation reveals the elliptical table top to be the path of the tiny planet's orbit, and the doorknob becomes a source of cosmic light, casting long shadows from the table legs and stacked books. Spatial ambiguities emerge as the solid door is transformed into infinite space, evoking multiple levels of reality.

---

Helen Lundeberg, whose distinguished career began in the early 1930s, is responsible, with Lorser Feitelson, for founding "Post-Surrealism." Unlike European Surrealism, which promoted the role of accident and the unconscious in the creation of art, the Post-Surrealist aesthetic infused Lundeberg's work with a sense of order and rationality.

**THE PLANETARY SOCIETY**
**65 North Catalina Avenue**
**Pasadena, CA 91106-2301**

PRINTED ON RECYCLED PAPER
Printed in USA