

The PLANETARY REPORT

Volume XVIII Number 4 July/August 1998

A grayscale photograph of a Martian rock formation, possibly the 'Face on Mars'. The image shows a dark, irregularly shaped rock with some internal features that resemble a face, set against a lighter, textured background of the Martian surface. The rock is the central focus of the cover.

**The Face on Mars:
Gone With the Wind?**

On the Cover:

Do you still see the "face on Mars"? For many viewers who have seen the new images from *Mars Global Surveyor*, the face is (with apologies to Margaret Mitchell fans) gone with the wind. This particular view of the feature in the Cydonia region has been processed to replicate as closely as possible the lighting effects of the original image taken by the *Viking* orbiter some 20 years ago. The resolution of today's Mars Orbiter Camera is 10 times better than that of the *Viking* system.

Image: MSSS/NASA

From The Editor

Editing a magazine is a little like running a laboratory—hypothesis must be tested by experiment. Drawing on your experience and knowledge, you have some idea of what will please and provoke your readers, but you don't know for certain until you print it.

We've been running a couple of experiments in the last few issues of *The Planetary Report*. The Stuff of Life is the first, a replacement for our hugely successful Basics of Spaceflight. What we did for aerospace engineering we're hoping to do for biology and planetary science: break complex processes down into small, digestible parts in hope of making these fascinating—but often arcane—subjects understandable to the non-Ph.D. reader.

And we're trying an Opinion section. With this feature, we're veering into controversial waters and approaching topics that incite argument more than didactic exposition.

From the letters and e-mail we've received so far, it seems that our members are enjoying these new features. But we'd like to hear from more of you. What topics should we address in these columns? What else would you like to see in *The Planetary Report*? We need data to design our experiments; let us know what you want.

—Charlene M. Anderson

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Deep Space 1 Delayed by Development Problems

The launch of the *Deep Space 1 (DS1)* mission to test new spacecraft technology has been delayed to October. Late delivery of the high-voltage power converter unit and changes in software forced the delay. As we reported in our last issue, *DS1* was originally set to launch in July and fly by an asteroid, a comet, and the planet Mars. Mission planners are now looking for new target asteroids and comets and must eliminate Mars from their plans. We will report on the new targets when they are chosen.

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Members' Dialogue

Green Space

I enjoyed Kim Stanley Robinson's article, "The Green Space Project," in the May/June 1998 issue of *The Planetary Report*, but there is a point he missed. In 1984 I wrote a book in collaboration with James Lovelock called *The Greening of Mars*. It was a fictional account of how Mars might be terraformed, but a large part of our reason for writing it was to explore what really constitutes a habitable environment. This is surprisingly difficult to study on Earth, simply because Earth is habitable, extremely complex, and all around us. On Mars, which is uninhabitable but could be rendered habitable, we could describe the development of an environment, explaining what is essential and why. In this way space research provides us with opportunities to study Earth indirectly, by comparison, and thus to learn more about our own environment. In the book we dealt with the human urge to explore, showing that opposing this urge runs counter to what it is that makes us human.

A few years ago, I took part in a debate about the desirability of terraforming Mars—assuming it to have no life forms of its own. Sadly, environmentalists in the audience opposed this idea bitterly on the grounds that we should not risk harming the Martian environment, even if that means no living being ever gets to see it and even if the word "environment" is a trifle difficult to define in the absence of any kind of life.

—MICHAEL ALLABY,
Wadebridge, Cornwall,
United Kingdom

International View

I have always been pleased with the quality and scientific accuracy of the articles in *The Planetary Report*. And yet I have one remark about the way the magazine, and the Society as a whole, is expressing itself towards members in other countries. I observe a certain chauvinistic, or nationalistic, state of

mind—contrary to what has been repeatedly said by the president of the Society himself.

The controversy about using the metric system is a small example of that, but not the only one. Most articles in *The Planetary Report* are written by American writers, about American projects, et cetera. I find the same thing when I look at the list of the board of directors and the advisory council. The European Space Agency is certainly the third largest space agency in the world, but this is not reflected in the council, which consists of less than 15 percent Europeans. And it is certainly not reflected in the board—there is not one European among them.

I realize, of course, that most of your members live in the United States, but if you only write for them it leads to a self-fulfilling prophesy: not much is written for European members because there aren't many, and there aren't many because nothing is written for (by) them. If you would change that, there would be an increase in members outside the United States.

—SVEN VAN DER POORTEN,
Zottegem, Belgium

We are trying to serve our non-US members better, and we appreciate your comments. As to the controversy over metric measurements, it is one we have struggled with for years. Metric is our preferred way, but, as you have seen, our US members don't like it—and 80 percent of our membership lives in the US, so we can't ignore them. However, we express our preference for metric by using that form of measurement first and putting the English conversion in parentheses.

About American writers, you are right—most of the flying planetary missions at the moment are American. Even so, we try to seek out European and Japanese partners whenever we can. Over the years, we have featured many articles by authors from ESA, including Roger Bonnet. Jacques Blamont of Centre

National d'Études Spatiales has been a frequent contributor, and we have often featured Russian authors.

We are investigating ways to broaden our reach, including translation of The Planetary Report into Spanish, French, and Japanese. A Russian version is already in the works, and we are in the first stages of setting up relationships with French and Japanese organizations.

—Charlene M. Anderson,
Director of Publications

ISS Worth It?

A recent newspaper article reports yet another delay and greater expenses for the International Space Station (ISS). But the primary reason, for once, is not the anti-space budget busters in Congress. It's the Russians. The article states that there have been hundreds of millions of dollars in Russian shortfalls, which have stalled production on the space station, because the Russians are producing a crucial component—the service module. Doubts have also been raised about their ability to fulfill their initial pledge to launch a steady stream of supply rockets.

It's time we dropped any partners that are this incapable of meeting their initial obligations, thus severely hindering our progress in space. If we cannot build the space station on our own, then perhaps the entire project should be dropped, in favor of focusing our space exploration goals on a human return to the Moon and a dedication to send a human crew to Mars by the first half of the 21st century.

—THOMAS WHEELER,
Tucson, Arizona

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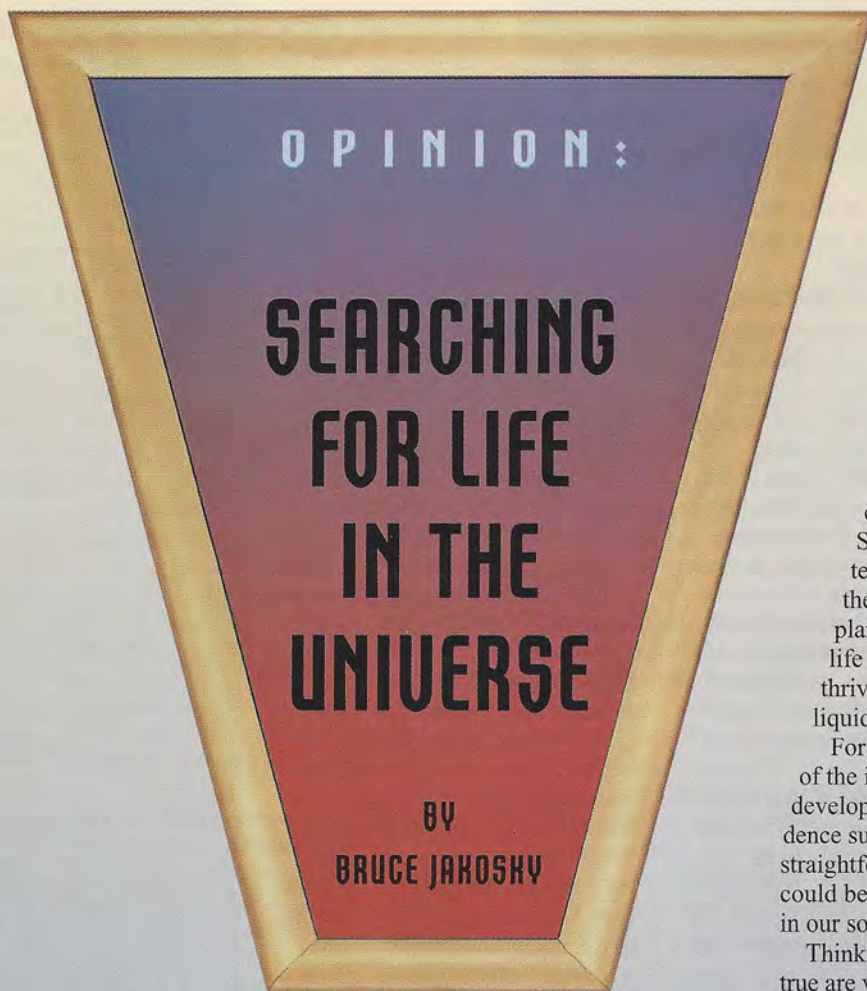
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What would it mean to us, as individuals or as a society, to find extraterrestrial life? Finding even simple microbes on another planet would tell us that life has originated somewhere independently of life on Earth. My own view has been that the occurrence of even a single example of another life-bearing planet would be as significant as the discovery of intelligent beings elsewhere in the galaxy.

Others see the question a little differently. For example, I asked my undergraduate "extraterrestrial life" class last semester what they felt the significance of finding life elsewhere would be. Although this was not a scientific poll, especially coming at the end of the semester, the results are enlightening. The types of answers spanned a broad range of views, including:

▲ Finding bacteria elsewhere would be scientifically interesting, but only finding extraterrestrial intelligence would be truly profound (this was the most common theme).

▲ It won't really make any difference or have much meaning to most people; their lives will go on pretty much as before.

▲ We should solve our own problems on Earth before we even go looking for life elsewhere.

▲ Extraterrestrial intelligence will help us to save the world by solving all of our current problems.

▲ Extraterrestrial intelligence will destroy our civilization, either by intent or by accident.

▲ The existence of extraterrestrial life or intelligence would be inconsistent with the views espoused by modern religions.

▲ Modern religions will adapt to deal with the discovery of life or intelligence elsewhere, as they have with other discoveries and societal changes in the past.

▲ We've already discovered extraterrestrial life and the government is hiding it, probably in a hangar in New Mexico (another common theme).

▲ We may not have discovered it yet, but the government is covering up anyway.

Clearly, the imagined impact of finding life depends on the individual and is a reflection of his or her outlook and beliefs. Is there a difference in outlook between scientists and non-scientists?

From the scientific perspective, a very reasonable case can be made that life might be widespread.

Scientific advances relevant to the search for extraterrestrial life have made front-page headlines during the last year or two. These include discoveries of planets around other stars, evidence of possible fossil life within a Martian meteorite, life forms on Earth that thrive in extremely harsh environments, and a potential liquid-water habitat for life on Jupiter's satellite Europa.

For scientists, these headlines represent only the tip of the iceberg. Over the past two decades, we have been developing the details behind these discoveries. The evidence suggests that the origin of life was both rapid and straightforward on the early Earth and that similar processes could be expected to have occurred on other planets, either in our solar system or around other stars.

Thinking it plausible, though, and discovering that it is true are very different things. Finding proof that life is not unique to the Earth would crystallize our view of humanity's place in the galaxy: it would mean we are just another result of especially interesting chemistry.

This is where I would have expected views to diverge. I would have thought scientists working in the field of exobiology (the study of life and the potential for life elsewhere) would tend to treat any extraterrestrial life forms similarly in terms of their philosophical significance. It would not matter, to an exobiologist, whether the life was microbial or intelligent. In contrast, my survey suggests that most non-scientists think that the discovery of extraterrestrial bacteria would be interesting but not terribly exciting. It would take the discovery of intelligent beings to get the world's attention.

WHAT WE'RE LIKELY TO FIND OUT THERE

We ought to recognize that if there is life elsewhere, it is most likely to be bacteria-like. Microbes were the first organisms to evolve on the Earth and were its sole inhabitants for billions of years. Only in the last one-sixth or so of Earth's history did organisms that were substantially more complicated evolve, and only during the last 0.01 percent of Earth history have humans been around. Although it is not yet widely recognized, bacteria may still dominate our biosphere today in number of species, number of organisms, or total mass.

I believe that we have the highest probability of finding extraterrestrial life in our lifetime on Mars. Mars seems to have (or to have had) all of the ingredients necessary for an origin of life. It is even possible that life continues to exist on Mars today, and we can send spacecraft there relatively

easily. Of course, searching for life on Mars but finding no evidence of it would also have significant implications. If there has never been Martian life, we would have to question seriously our current views of the origin of life on Earth and the possibility of widespread life in the universe.

What about the possibility of extraterrestrial intelligence? Regular viewers of *Star Trek* or *X-Files* may suspect that intelligent beings populate the entire galaxy. However, intelligence is an elusive quality. It is our brain size in comparison to our overall body size that sets humans apart from other terrestrial species, rather than, say, our ability to use tools or recognize contingencies in our actions.

Carl Sagan argued that increased intelligence is so advantageous to any species that it is likely to evolve wherever there is life. On the other hand, consider the multitudes of species that have existed on Earth without developing either large brains or enhanced self-awareness associated with intelligence. There does not seem to be an automatic imperative toward intelligence. Rather there seems to be an imperative toward species' developing brains that are no bigger than necessary to operate their bodies. And even if large brains were to evolve in a species on another planet, it does not automatically follow that intelligence would result.

Even as we debate the many possibilities, exploration continues. We are sending spacecraft to Mars to look for life. The *Cassini* spacecraft is en route to Saturn, where it will explore the moon Titan so that we may understand the nature of its surface and atmosphere and its "pre-biological" chemistry. We are continuing to search for, discover, and understand the nature of planets that orbit other stars, and we are beginning to develop technology that will allow us to look for and observe Earth-like planets.

WHY THE SEARCH FOR INTELLIGENT LIFE MATTERS

In the course of completing this essay, and working through some of the debates on extraterrestrial life, it has become clear to me that the search for extraterrestrial intelligence is just as important as the search for microbial life. Although microbial life may be more widespread and easier to find, the discovery of intelligent life elsewhere would have its own profound implications: such life, if we find it, would help us understand the nature of life, thought, intelligence, and the universe.

The real significance of the search for life, intelligent or microbial, is the search itself and what it means for us here on Earth. Searching for life implies that we as a society want to do more than just get by, more than just survive our day-to-day existence. It means that we want to understand how we fit into the world around us, to understand what it is to be human. As one of my students put it, with several layers of meaning, "We are looking for ourselves." The fact that these questions resonate so strongly with so many people, both non-scientists and scientists, underscores our need to find and understand our place in the universe, whatever the implications might be.

It is humbling to realize that we are

only at the beginning of our exploration of the universe. The 5,000-year written record of human civilization spans only about 250 generations! It is impossible to predict what will happen on Earth in the next hundred years, let alone the next thousand, million, or billion years. Likewise, it is impossible to predict what else might be out there—we have to search in order to find out.

As someone once said while discussing extraterrestrial life, "Either there is life elsewhere or there isn't. Both possibilities are equally frightening."

Bruce Jakosky is a Professor of Geology at the University of Colorado at Boulder and a member of the Mars Global Surveyor science team. His book The Search for Life on Other Planets will be published this summer by Cambridge University Press.



Cosmicide by Helen Lundeberg is an oil painting on masonite. One meter tall and 60 centimeters wide at the base (40 x 24 inches), this work was completed in 1935.

Courtesy of Sheldon Memorial Art Gallery, University of Nebraska, Lincoln. Gift of Peter Kiewit Foundation

THE HUNT FOR LUNAR ICE

BY JAMES D. BURKE

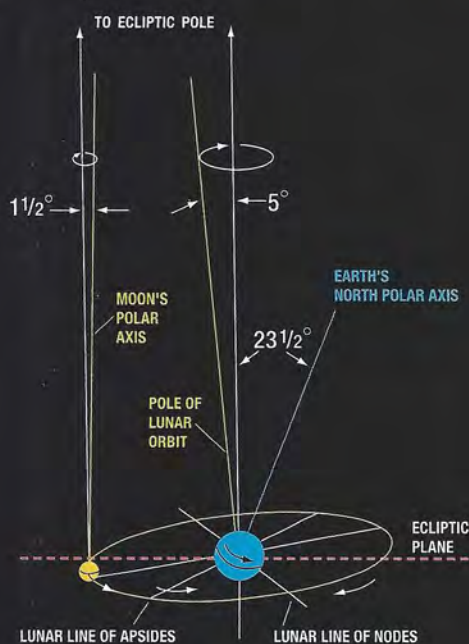


Figure 1. The motions of the Moon's spin axis and the alignment of its orbit were described by the 17th century astronomer J. D. Cassini. Because the polar axis is so nearly perpendicular to the ecliptic (an imagined plane bisecting the Sun and planets), there are no seasons on the Moon.

Diagram by B.S. Smith
based on a drawing by J.D. Burke

Early in the 17th century Johannes Kepler wrote a novella called *Somnium (Dream)* about an imagined civilization on the Moon. It was published after his death in 1630. Kepler realized that the Moon should get very hot during its two-week day, and his lunar beings led a strange, torpid life under the blazing sun. Other natural philosophers, during centuries of human wondering about the Moon, sometimes put forward the idea that it might be a wet and muddy body, perhaps even a giant snowball, but as telescopic observation improved it became clear that the Moon lacked an atmosphere and was likely to be very dry.

In 1692 J. D. Cassini, the first director of the Paris Observatory, with careful observation derived the laws of the Moon's motion as illustrated in Figure 1. Because the lunar polar axis is nearly perpendicular to the Sun's rays, sunlight is always horizontal at the poles. The balance between incoming and outgoing radiation results in low temperatures there. How low, no one knew at the time, for there was then no way to measure lunar temperatures.

In 1667 Robert Hooke, attempting to understand the origin of lunar craters, watched bursting bubbles in boiling plaster and dropped balls into mud to compare volcanic and impact craters. The impact view did not prevail until nearly 300 years later, when scientists finally agreed that most lunar craters are impact scars rather than volcanic

edifices. There remained the question of the great dark lunar plains, the features that we see as the face of the man in the Moon. In 1610 Galileo called them maria (seas), as had ancient Greek observers, and subsequent authors toyed with the idea that they might be oceans, perhaps with ships sailing on them. However, Galileo had presented two observations showing that this speculation could not be true. First, an ocean would have a bright spot reflecting sunlight. Second, a world with oceans and an atmosphere, as seen from here, would be indistinct toward its edges, called limbs, but features of the Moon are clearly seen all the way to the limbs.

EARTH SCIENCE, SPACE SCIENCE

Notwithstanding these hints as to the Moon's real character, the debate on a wet versus a dry Moon continued into the mid-20th century. Some scientists were skeptical about a dry Moon because the Moon does have volcanic features, such as the mysterious sinuous rilles. Volcanoes on Earth emit copious quantities of steam, and the composition of most lavas reveals association with water. The arguments for and against water on the Moon came to a head in the work of three of the world's leading lunar scientists: Harold Urey, Gerard Kuiper, and Eugene Shoemaker.

Urey, the chemist who won the Nobel Prize for discovering deuterium, the heavy isotope of hydrogen, late in his

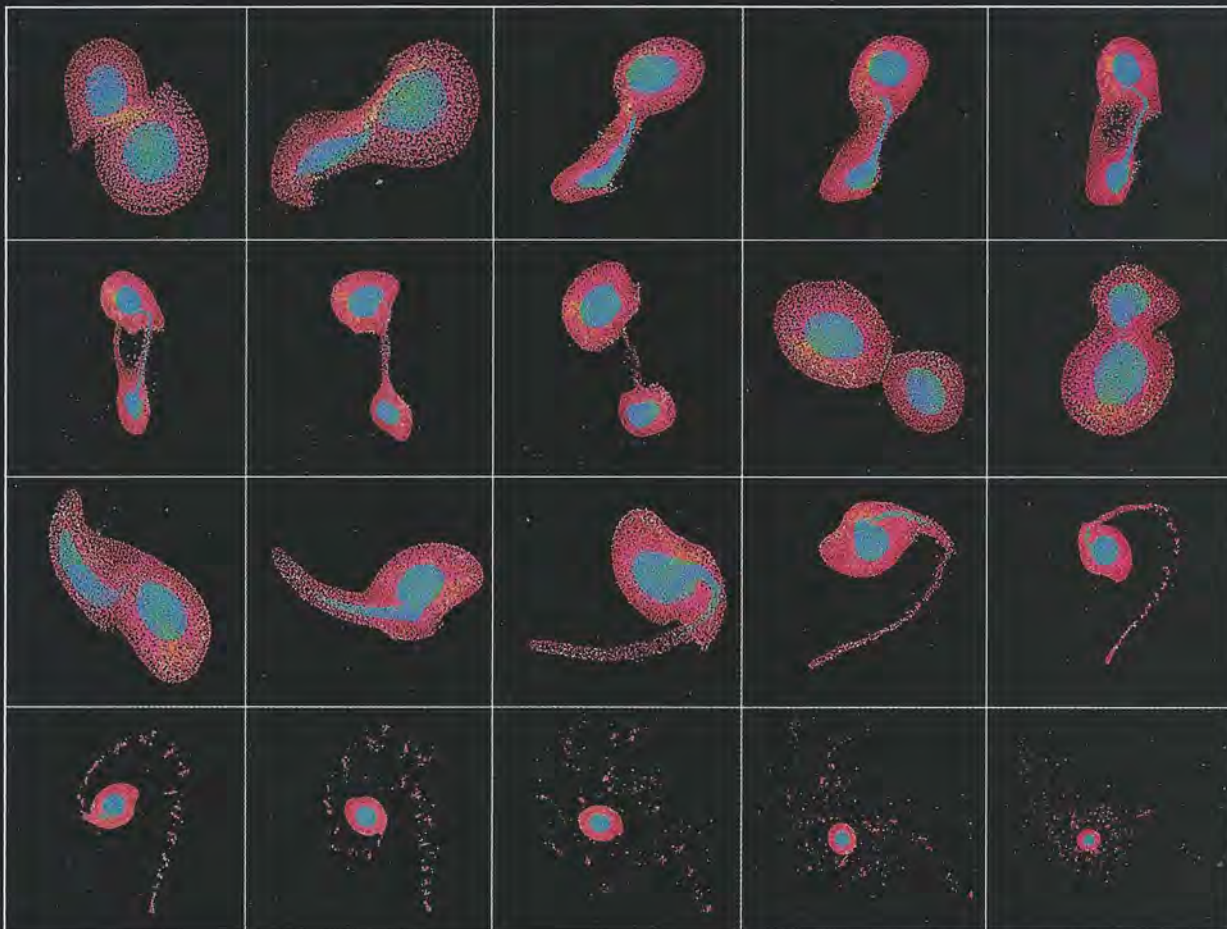


Figure 2. This computer-generated picture shows events just after the colossal impact of a Mars-size body on the early Earth, as analyzed by A. G. W. Cameron and colleagues. The first impact is followed in a few minutes by a second collision, which sprays out a cloud of debris. Part of this orbiting mess of ejecta will later coalesce to form the proto-Moon.

Illustration:
A.G.W. Cameron,
Harvard-Smithsonian
Astrophysical
Observatory

life became passionately devoted to the Moon as a possible key to the early evolution of the solar system.

Kuiper, an astronomer of world renown, spent some of his energies investigating the nearby Moon while most of his colleagues were concerned with galaxies out in the immensity of the expanding universe.

Shoemaker, a skilled geologist, had the seminal idea of using stratigraphy to study surface features of the Moon and planets, thus founding a new field of science for investigating the history of other worlds.

In the 1950s and early 1960s, Urey and Shoemaker engaged in a great debate, using Kuiper's observations and lunar photographic maps, prepared in his University of Arizona laboratory with sponsorship by the US Air Force. Was the Moon, like some meteorites, an ancient, unaltered relic bearing organic substances, water, and traces of the solar system's birth, or was it a highly evolved body like Earth, whose primordial character has been mostly

erased by later events?

Shoemaker won the debate. Even before any spacecraft went to the Moon, he presented convincing telescopic evidence that the lunar maria were formed by vast floods of very fluid lava, while the lighter, more heavily cratered highlands were extremely ancient. The evidence also showed that both maria and highlands had, at one stage in their development, possibly been molten. This history made it very unlikely that water or other volatiles would be found in the Moon; they would all have been baked out during the heating. And indeed, when samples of lunar material were returned by *Apollo* astronauts and the robotic Soviet *Luna* spacecraft, the rocks and soils were found not only to be totally dry but also to have never been exposed to any water during their entire multibillion-year existence.

The hot-Moon hypothesis was correct, and eventually scientists came to agree on how the Moon could have been so thoroughly heated. William Hartmann and colleagues developed a persuasive

scenario as follows: early in solar system history, as planetesimals were building up from the dust and gas of the solar nebula, the proto-Earth became differentiated—that is, heavy materials such as iron sank toward the center, forming a core, while lighter rocks floated up to form a mantle and crust. At the same time, another body about the size of Mars had reached the same stage of development. Then the two bodies collided! Twice! (Figure 2.) And one result of this monstrous catastrophe was an Earth-orbiting cloud that consisted mostly of the lighter mantle material, some of which accreted into the Moon.

SQUEEZING WATER FROM STONES

Once these scientific findings became generally accepted, people who wanted humanity to settle the Moon had to deal with the concept of a harsh world totally devoid of water, the most important substance of life. Realizing that to haul water up from Earth would

be prohibitively costly, lunar base planners turned to other ways of obtaining water for use on the Moon. Some meteorites contain 10 to 20 percent water, and since they are thought to be fragments of asteroids, studies focused on how to mine appropriate asteroids and deliver their water to the Moon.

The most comprehensive examination of this possibility was a design project by a multidisciplinary team of graduate students and young professionals at the 10-week summer session of the International Space University in 1990 at Toronto. The scientists and engineers on the project team showed that by using nuclear heat, power, and propulsion it would be technically possible to deliver asteroid water to the Moon. But their economic and business colleagues concluded that, given reasonable calculations of costs and payback, the process could not show a profit.

Another way to get water on the Moon is to make it there by combining solar-wind hydrogen with the oxygen that is abundant in lunar rocks and soils. The solar wind, bombarding the Moon for aeons with particles from the Sun, has implanted lunar soils with small amounts of hydrogen and other vola-

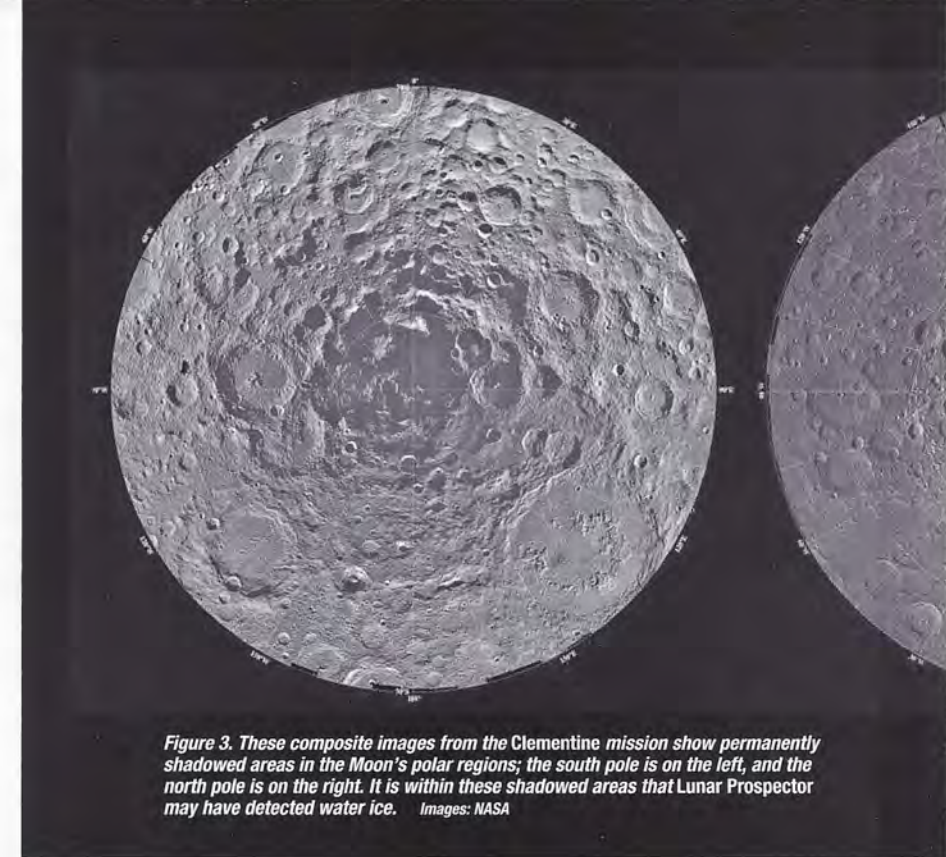


Figure 3. These composite images from the Clementine mission show permanently shadowed areas in the Moon's polar regions; the south pole is on the left, and the north pole is on the right. It is within these shadowed areas that Lunar Prospector may have detected water ice. Images: NASA

tiles (including helium-3, a possible fuel for fusion reactors if they ever come to exist). The volatiles are easily released from lunar soil by moderate heating, but the process must treat huge amounts of raw material to obtain useful quantities of the gases. Nevertheless, various

analyses have shown that even this laborious approach may be preferable to hauling needed hydrogen from Earth.

WHY DIDN'T THE ASTRONAUTS FIND WATER?

Clearly a discovery of economically recoverable water in the Moon would be an enormous bonanza. Is there another possible source? In theory, yes. In 1961 Kenneth Watson, Bruce Murray (a founder and now president of the Planetary Society), and Harrison Brown showed that volatiles, perhaps delivered by comets, might survive indefinitely as buried ices in permanently shadowed lunar polar craters. In 1979 James R. Arnold more thoroughly analyzed this prospect, studying sources and removal mechanisms for lunar volatiles. He concluded that ices could indeed exist at the lunar poles, in regions where it is always dark and surface temperatures may be as low as 40 kelvins (about -405 degrees Fahrenheit). Our knowledge of temperatures on the Moon came from Earth-based measurements, beginning in 1927 with infrared detection by E. Pettit and S. Nicholson at the Mt. Wilson Observatory and culminating in the early 1960s with infrared scans from the Kottamia Observatory in Egypt and a microwave survey at the 3-millimeter wavelength by B. Gary and colleagues

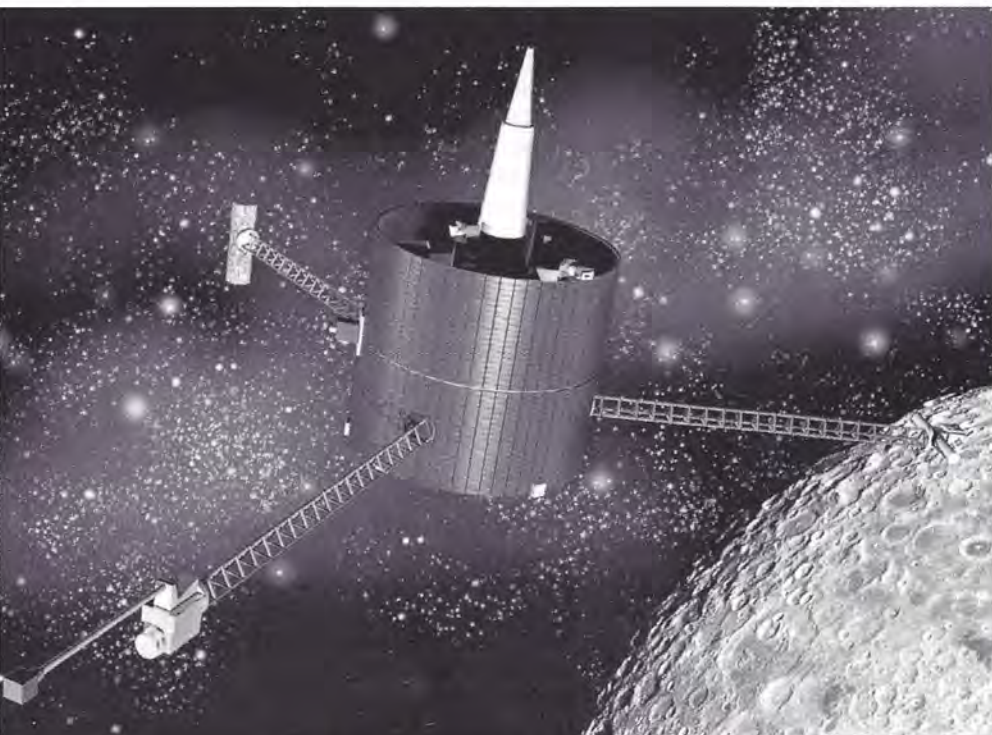


Figure 4. The slowly spinning Lunar Prospector orbits the Moon, with scientific instruments mounted on the extended booms. Image: NASA/AMES Research Center



at the Aerospace Corporation in California.

What remained then was to devise observational ways of proving whether or not ice existed in the polar cold traps. The most direct means, sampling by instrumented vehicles on the surface, was ruled out as too risky and costly. The landings of Soviet and American robotic spacecraft and of the *Apollo* expeditions all occurred at latitudes relatively near the equator for engineering and safety reasons, so the only way to search for polar ice was by remote sensing.

Unfortunately, just at the time when a test of the ice possibility became feasible, the world's lunar exploration programs collapsed. *Apollo's* Cold War victory for the US over its huge Soviet competitor caused the USSR to abandon lunar missions, and both nations then moved on to other space initiatives. For decades a viewpoint of "been there, done that" dominated space exploration planning. Lunar scientists had to get along with what they could glean from Earth-based observation, *Apollo* and *Luna* rock and soil samples, and meteorites that have come to Earth from the Moon. Observation, analysis, and modeling techniques improved greatly during this time so some progress continued, but the question of polar ice remained unanswered.

CLUES FROM CLEMENTINE

For many years after the end of *Apollo*, lunar enthusiasts labored without success to obtain approval for missions to continue the scientific exploration of the Moon. In 1989 President George Bush announced an initiative for permanent habitation of the Moon and human exploration of Mars, but that plan died when Congress refused to fund it. Lunar missions were studied in Europe and Japan (now working on a seismic-penetrator mission called *Lunar A*), but in America even robotic-mission studies stopped.

The lunar renaissance arrived suddenly and unexpectedly with the *Clementine* mission, launched in 1994. Designed as a low-cost, quick test of sensors for the Strategic Defense Initiative ("Star Wars"), *Clementine* placed in lunar polar orbit a highly capable suite of remote-sensing instruments that gave multispectral images and topographic maps of the entire Moon. The science team for the mission included Shoemaker and a leading member of the next generation of lunar scientists, Paul Spudis. His book, *The Once and Future Moon* (Smithsonian Press, 1996), gives a comprehensive summary of lunar science as well as a history of lunar exploration, including the *Clementine* findings.

The *Clementine* project was characterized by a fast pace, a small team, and imaginative solutions to problems. In that atmosphere, it was possible to carry out radical, unplanned experiments. With the spacecraft already in lunar orbit, S. Nozette and colleagues took up the idea of looking for polar ice by bouncing the spacecraft's radio beam off the Moon and analyzing the properties of the scattered signal. Using ground-based radar, D. Muhlemann and colleagues at the California Institute of Technology had already observed a signature of ice in the polar regions of the torrid planet Mercury; a similar experiment beamed at the Moon by a Cornell University team using the Arecibo radar yielded negative results.

However, the *Clementine* radar data hinted strongly at the presence of ice near the south lunar pole, fueling interest in the flight of instruments that could give a more definite answer.

For a decade or more, Alan Binder and his colleagues had been developing

(continued on page 10)

LUNAR PROSPECTOR CARRIES EUGENE SHOEMAKER'S ASHES TO THE MOON

In an unprecedented tribute, cremated remains of Gene Shoemaker, who was killed in a car accident last July, were launched aboard the *Lunar Prospector* spacecraft—destined to crash onto the Moon after completing a year-long search for water, minerals, and gases.

"This is so important to us," said Gene's widow Carolyn Shoemaker. "It brings a little closure, in a way, to our feelings. We will always know when we look at the Moon that Gene is there."

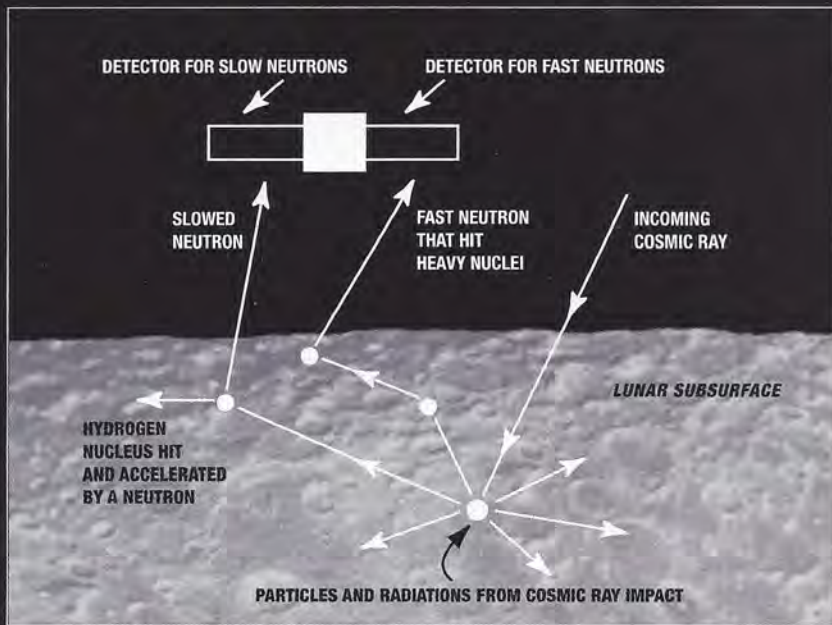
The ashes, encased in a polycarbonate capsule, are stored safely in a vacuum-sealed, flight-tested aluminum sleeve mounted deep inside the spacecraft. Wrapped around the capsule is a piece of brass foil inscribed with an image of comet Hale-Bopp, an image of Meteor Crater in northern Arizona, and a passage from William Shakespeare's *Romeo and Juliet*:

*And, when he shall die,
Take him and cut him out in little stars,
And he will make the face of heaven so fine
That all the world will be in love with night,
And pay no worship to the garish sun.*

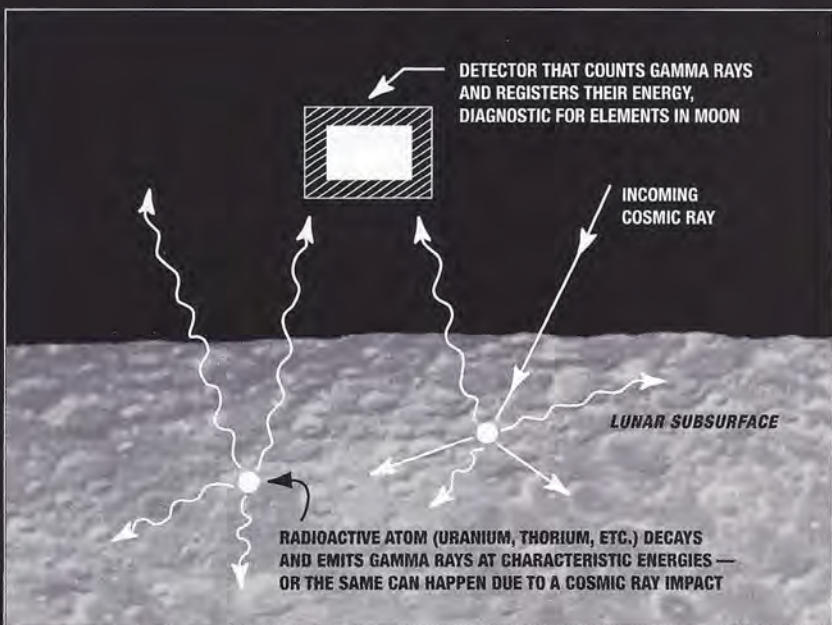
A former student of Shoemaker's, Carolyn Porco, coordinated preparations for the special payload with the Shoemaker family and NASA. "It was legend in the planetary science community that Gene had always wanted to go to the Moon as an *Apollo* astronaut and study its geology firsthand," Porco said.

A health problem prevented Shoemaker from becoming the first geologist on the Moon. Instead, he helped select and train the *Apollo* astronauts in lunar geology and impact cratering. Later he served as science-team leader for the *Clementine* mission.

In a conflict of cultural values, the Navajo Nation has denounced sending Shoemaker's ashes to the Moon as "a gross insensitivity to the beliefs of many Native Americans." NASA issued a formal apology and promised to "consult more widely" if a similar occasion should arise in the future. —Jennifer Vaughn, Assistant Editor



This sketch shows the principle of neutron detection of near-surface hydrogen. An incoming cosmic ray (a massive, high-energy particle) interacts with nuclei of atoms in the lunar regolith—releasing a shower of neutrons. If a neutron hits the nucleus of a heavy element such as silicon or oxygen, it will bounce off with much of its energy intact. But if it hits a light nucleus such as that of hydrogen, it will impart speed to the target and so itself be slowed. A spectrometer, detecting neutrons of high and low energies as they come up out of the Moon, can show if there is an excess of low-energy neutrons and a deficit of higher-energy ones, thus revealing the presence of light elements in the regolith, typically within tens of centimeters of the surface.



This sketch shows the principle of gamma-ray detection to determine both natural and induced radioactivity of the lunar regolith. Again, cosmic rays are the primary exciting agent, but in this instance the spectrometer is designed to measure the flux and energy of gamma rays (high-energy light) coming up from the lunar surface. Each element, either naturally radioactive or excited by cosmic rays, will release gamma rays of specific energies. After we have repeated observations to overcome background noise, eventually the gamma-ray spectrum can reveal the elemental content of the regolith—including deuterium, which emits a characteristic gamma ray at an energy of 2.2 million electron volts and, if present, is an indicator of hydrogen within a meter or so of the surface.

Diagrams by B.S. Smith based on drawings by J.D. Burke

(continued from page 9)

plans for a low-cost, highly focused lunar orbiter with non-visual instruments for determining the Moon's magnetism, gravity, and surface chemistry. Now at last it appeared that the mission had a chance of approval by NASA. Binder's team (by then comprising people from NASA Ames and Lockheed Martin) submitted a proposal to the new Discovery program, and *Lunar Prospector* became the third mission in the Discovery series, after the Near-Earth Asteroid Rendezvous (NEAR), managed by the Applied Physics Laboratory of Johns Hopkins University, and *Mars Pathfinder*, managed by the Jet Propulsion Laboratory.

"SEEING" WATER IN THE DARK

On January 6, 1998, *Lunar Prospector* (Figure 4) was launched by the new Lockheed Martin Athena II, a multi-stage solid-fuel rocket based on Minuteman ICBM technology, from the new commercial spaceport at Cape Canaveral, Florida. Flight to the Moon was perfect, and after some intermediate orbital maneuvers the craft was placed in a circular, pole-to-pole mapping orbit at an altitude near 100 kilometers (62 miles).

Prospector's instrumentation includes a gamma-ray spectrometer, a neutron spectrometer, two kinds of electromagnetic detectors, an alpha-particle detector to observe radioactive gas emissions from the Moon, and the spacecraft's radio signal for Doppler gravity measurement. The neutron spectrometer and the gamma-ray spectrometer (built under the direction of W. Feldman at Los Alamos National Laboratory) are capable of detecting the signatures of hydrogen and deuterium, respectively, signaling the presence of water ice within a meter of the lunar surface. (These instruments also have other uses: the neutron spectrum is diagnostic for lunar temperatures and the gamma-ray spectrum is diagnostic for many chemical elements in lunar soils and rocks.)

At a NASA-sponsored press conference in February 1998, Feldman and Binder announced that the neutron spectra collected up to then gave unequivocal evidence of water ice at both lunar poles. (The gamma-ray observations were still being collected and analyzed, but it was already known that the instrument was working properly.)



Above: In an imagined future, lunar explorers are elated when they find a little ice brought up by drilling in the floor of a cold, dark crater near a lunar pole.

Illustration: Mike Stovall for Eagle Engineering

Left: at a lunar polar base, cryogenic infrared and millimeter-wave telescopes view the visible half of the sky. Nearby, a solar power tower collects eternal sunlight to provide electricity, warmth, and high-temperature process heat. In reality the underground habitats would be more distant from the telescopes, so as not to disturb their quiet, cold environment.

Painting: Marilyn Flynn

A few weeks later, at the 29th Lunar and Planetary Science Conference in Houston, Binder presented his and Feldman's results to a scientific audience. Dips occurred in the higher-energy part of the neutron flux near the poles, just as expected if the observed neutrons have interacted with the nuclei of some light element in the lunar regolith, the impact-gardened lunar surface. There is every reason to believe that this light element is hydrogen. Not everyone agrees that the hydrogen

resides in water ice. Geologist and *Apollo 17* astronaut Harrison Schmitt suggests that it may be just solar-wind hydrogen, concentrated to a few percent due to the unique environment at the lunar poles.

Final confirmation of water ice on the Moon will have to await direct sampling by instruments aboard a surface rover (as in the recently rejected proposal for a European Space Agency mission to be called *Euromoon*), and lunar ice will then enter the realm of

policy decisions. If recoverable in useful quantities at acceptable cost, it will transform the future of human efforts to live away from Earth. Water on the Moon will have to be regarded as a priceless resource, to be used and recycled with care and diligence so that nature's bounty can continue to give us humans the good life, not only here but also on the Moon.

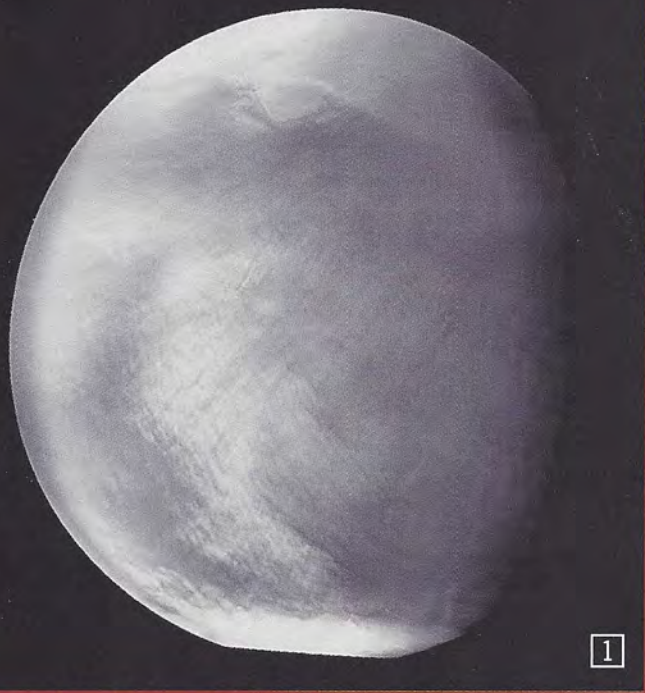
James D. Burke is Technical Editor for The Planetary Report.

Mars Global Surveyor

Observes Dust Storms and

Since last September, when Mars Global Surveyor (MGS) began aerobraking into a close circular orbit about Mars, the Mars Orbiter Camera (MOC) has kept a close eye on the planet surface, recording seasonal changes. The dust-storm season, which begins in Mars' late autumn, was well under way by November, when MGS observed a regional storm that steadily disseminated during orbits 50 and 51 to a general dustiness lasting for many weeks (image 1).

Before the storm began, the MOC recorded condensate clouds (formed as gas changes into ice) and hazes in many places, especially near volcano summits. Image 2, a color composite from the MOC, came from orbit 48, shortly before the outbreak of the dust storm. In this view, condensate



1

clouds hover over the Tharsis region, around the northwest edge of the Tharsis Bulge, where many of the largest and youngest volcanoes on Mars are located. The bluish-gray haze is thick enough to obscure the volcano summits.

Interestingly, within four days of the onset of the dust storm, condensate clouds no longer appeared anywhere on the planet. Yet within a month after the storm subsided, the condensate clouds returned to the same summit areas.

The MOC observed a well developed, local dust storm this spring while attempting to capture the Viking 1 lander site. Image 3, from orbit 235, shows an area 310 by 290 kilometers (190 by 180 miles). The thick dust in the Martian atmosphere obscured the Viking 1 lander site, which is on a relatively smooth plain in Chryse Planitia, indicated in this image by the white parallelogram. Plumes from the storm suggest that the wind is blowing from southwest to northeast. The subtle dark zone around the dust cloud appears to be surface area that has been swept clean of a layer of the dust.

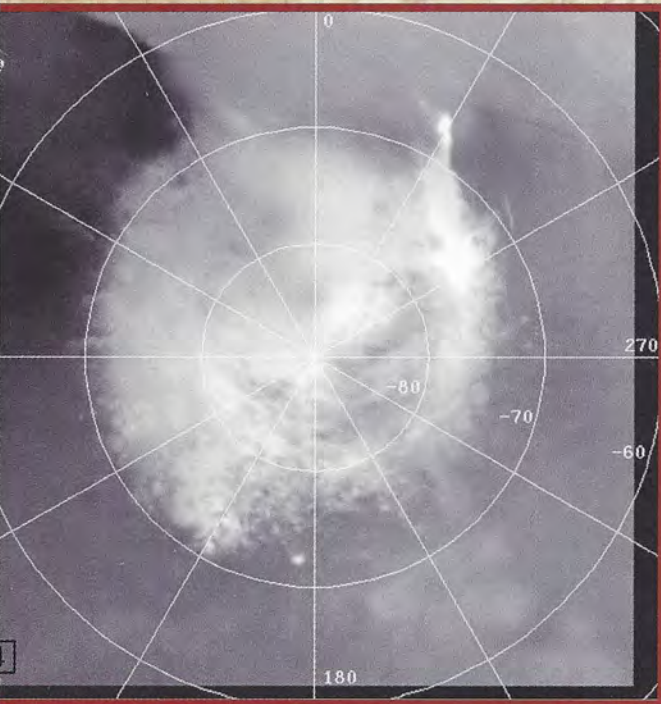
2



3



and Polar Cap Recession



The seasonal formation and dissipation of polar ice caps have been the target of scientific study since early telescopic observations. MGS turned its camera toward the Martian south pole, recording diverse textures and the annual recession of the polar cap—the first recession documented by spacecraft since the *Viking* observations in 1977. The mostly carbon dioxide ice cap recedes by sublimation—the transition of a solid to a vapor without passing through a liquid state.

The stereographic mosaic (image 4) from orbits 67 through 73 shows seasonal change in the south polar region. The bright peninsula of frost extending from the cap is called the Mountains of Mitchel. Although dust-storm conditions (timing and intensity) differed significantly in 1997 from 1977, the position and definite edge of the frost cap were found to be similar in *Viking* and MGS images, suggesting that annual polar sublimation is, for the most part, unaffected by dust-storm activity.

A more detailed look at the south polar cap revealed complex layers of deposits varying in texture. Image 5 shows slopes and scalloped textures, whereas the landscape in image 6 is smooth and nearly featureless. The texture differences suggest that the strength and character of the layers within the deposits are variable and may reflect the thickness of water or carbon dioxide ice above the deposits.

Image 7 reveals a complex pattern of intersecting rectangular ridges, possibly remnants of an ancient deposit resting below the surface layers. However, some of the features resemble dunes, indicating there may have been more than one process involved in the formation of this terrain. — Jennifer Vaughn, Assistant Editor

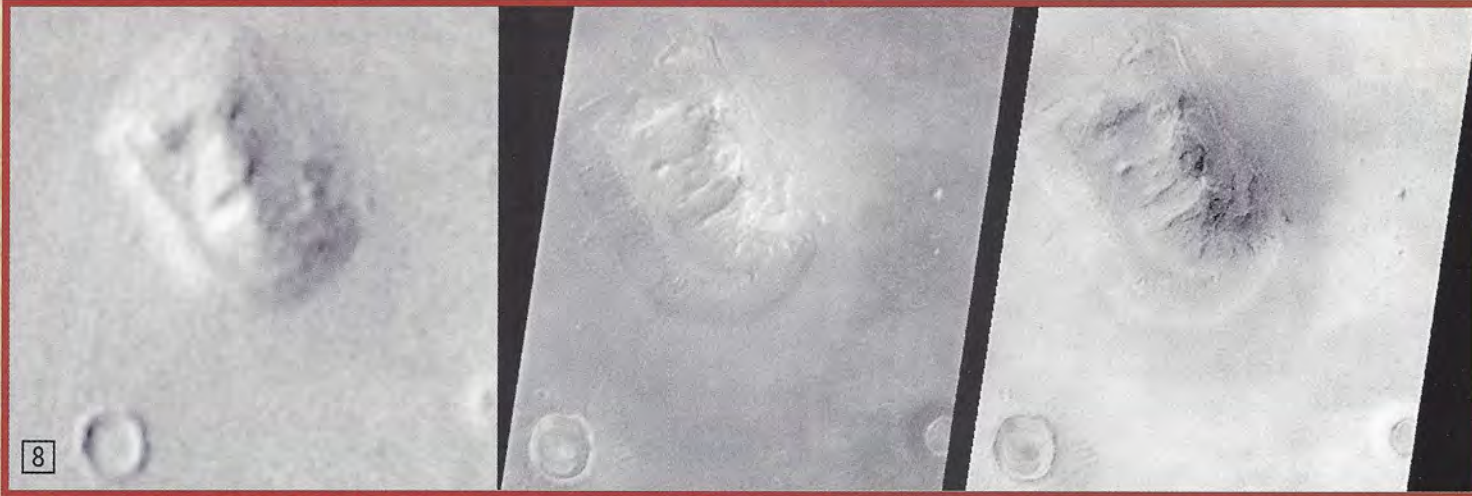


Images: MSSS/NASA

ANITIA



Mars Face Off



Early last April, *Mars Global Surveyor* (MGS) turned the Mars Orbiter Camera (MOC) toward the popular and controversial Cydonia Plain in an attempt to see the “face on Mars,” first imaged by *Viking*, with greater detail and with different lighting conditions.

More than 10 years ago, scientists enhanced *Viking* images of the Cydonia region and found a surface feature looking roughly like a face, which led some to believe the structure was a signal created by intelligent beings. The new MOC pictures are 10 times better than the ones taken by *Viking*, and the resolution with computer enhancement is excellent.

NASA will not comment on or interpret the new images, preferring instead to let the new pictures speak for themselves. However, in an interview with CNN, MGS Project Scientist Arden Albee commented, “Individual scientists, like myself, might make conclusions, and just looking at the preliminary ones, it looks like natural features. It has been interpreted for a long time by the people who map that region of Mars as an area where extensive erosion of a soft unit had occurred. For example, there are craters that are perched up on pedestals because they compacted and made that soft material harder. Then it eroded all around them, leaving these perched craters. So there are features like that which we have known for a long time. That’s the nature of it.”

In the triptych (image 8, above), a portion of the *Viking 1* orbiter’s image of the Cydonia region appears on the left. In the middle is a portion of a recent MOC image shown normally, and on the right is the same MOC frame but with the contrast reversed (light features are dark, dark features are light) to mimic the lighting in the *Viking* image. The best *Viking* image has been enlarged to 3.3 times its original size, and the MOC image has been decreased by a similar 3.3 times, creating images of roughly the same size. In addition, the MOC images have been geometrically transformed to an overhead projection for ease of comparison with the *Viking* image.

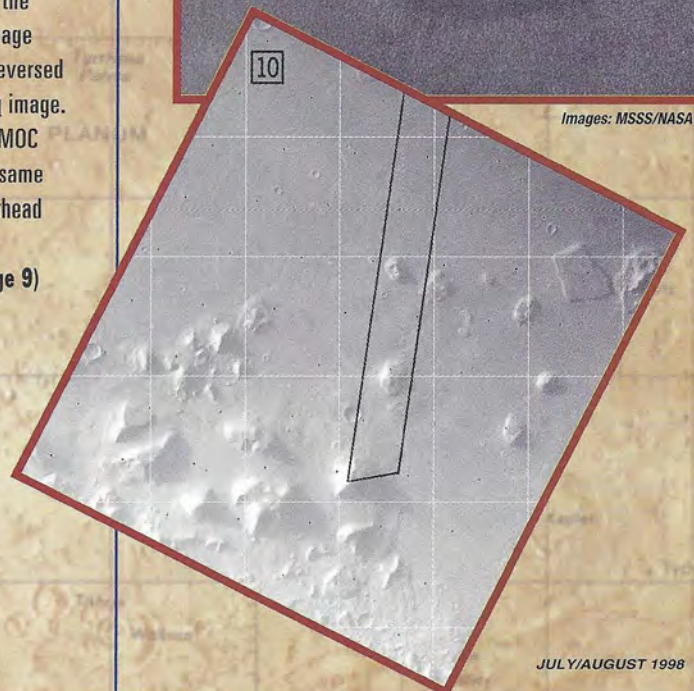
The MOC acquired a high-resolution image of the “face on Mars” feature (image 9) in the Cydonia region on April 5, 1998 during MGS orbit 220. The picture has a resolution of 4.3 meters per pixel, making it 10 times sharper than the best *Viking* image.

Image 10 is a *Viking* orbiter image from 1976 of the Cydonia region. The black inset indicates where the MOC took a closer look at the “face,” located nearly in the center.

—Jennifer Vaughn, Assistant Editor



Images: MSSS/NASA



THE MARS MICROPHONE:

by Greg Delory

Ever wonder what it sounds like on Mars? When the next lander in NASA's program to explore the Red Planet touches down in 1999, we will all have the chance to find out. On board the *Mars Polar Lander* will be a small recording device, the Mars Microphone, whose job is to sample sound while the rest of the probe studies the soil, weather, and atmospheric dust.

The idea for the Mars Microphone started with Janet Luhman of the University of California, Berkeley and David Juergens of the Jet Propulsion Laboratory, who proposed to the Planetary Society that a sound-recording device would be easy to include on a Mars mission. Society Executive Director Louis Friedman investigated the possibility of incorporating a microphone in the *Mars Polar Lander* mission.

At that time, mission planners had just selected a Russian instrument to be put aboard the spacecraft (the first Russian instrument included on a US planetary mission). Under the direction of Viacheslav Linkin of the Space Research Institute in Moscow, the lidar will use a laser to study the distribution of dust in the Martian atmosphere. Linkin offered a place on the lidar for the microphone, which could operate without requiring any mass, power, volume, or data-rate adjustments on the lander.

In August 1996, Friedman and Society President Carl Sagan requested NASA approval to include the microphone in the *Mars Polar Lander* payload, stipulating that there would be no cost to NASA. NASA Associate Administrator for Space Science Wes Huntress agreed.

The Planetary Society formed a team with the Space Sciences Laboratory at Berkeley, and together we developed a low-cost implementation plan that enabled us to build the instrument with funding solely by the Planetary Society.

The Mars Microphone will be the first instrument funded by a membership organization to fly to another world. It was designed, constructed, and tested under Luhmann's direction at the Space Sciences Laboratory.

Are There Sounds on Mars?

Given that sound waves need an atmospheric medium through which to travel, many people are surprised to learn that

any sounds at all can be heard on Mars. The atmospheric pressure on the surface of the Red Planet is small, amounting to less than one percent of the Earth's sea-level pressure. But even at Mars' low pressure, acoustic signals within the frequency range of the human ear can be detected. And while the atmosphere of Mars is very different from Earth's, consisting mostly of carbon dioxide, there are similarities between these environments that should make the sound data worthwhile.

For example, there is weather on Mars, including winds, sandstorms, and dust devils, which are little tornadoes caused by local weather patterns. The Mars Microphone may be able to hear these winds and perhaps even a type of lightning within sandstorms. The microphone will also record noises made by the lander, such as the sound of the robotic arm digging for soil samples.

However, the most exciting sounds are likely to be ones that we don't even know about yet. Experience has demonstrated that whenever a new instrument is developed and flown in space, we learn something new about extraterrestrial environments, and therein lies the true spirit of the Mars Microphone concept.

Building and Testing on a Shoestring

The Mars Microphone is a small device, roughly 5 centimeters on a side and one centimeter thick (2 x 2 x 0.5 inches), weighing less than 50 grams (1.8 ounces) and using a small amount of power, less than 0.1 watt during its most active times. In addition to the microphone, the instrument contains digital electronics to acquire and store sound samples. Because the rate at which we can acquire data will be limited, it will take several days, maybe even a week, to retrieve one 10-second sound clip. The device has internal memory, similar to the RAM in your home computer, which will store sounds for transmission to Earth along with other lander data.

In the construction of the Mars Microphone, we relied on commercial, off-the-shelf technology, meaning that very few of the components were developed specifically for this mission. Most are readily available commercially. Our sound processor chip, for example, is also used in

READY TO GO!



The entire Mars Microphone, including the equipment for acquiring and storing sound samples, fits easily in the palm of a hand. The Planetary Society is the first membership organization to fund a science instrument that will fly to another world.

Photo: Robin Weiner of the Associated Press

talking toys and educational computers that listen and respond to spoken words. The microphone itself is typically used in hearing aids. The entire program, including design, construction, and testing, cost roughly \$50,000, a bargain for an instrument on a planetary probe.

The Mars Microphone has since passed several tests to show it can withstand the rigors of a planetary mission. Radiation levels in space and on Mars are higher than what we are used to on Earth, and, like humans, the electronic components in the microphone are sensitive to radiation damage. We exposed the microphone and the sound processor chip to levels of radiation that they would receive during the mission, and there were no failures or degradation of performance. We also conducted thermal tests with temperature ranges of -100 to +20 degrees Celsius (about -150 to +70 degrees Fahrenheit) and detected no malfunctions.

The microphone was integrated onto the *Mars Polar Lander* last October at Lockheed Martin in Denver, Colorado. We verified that the microphone worked properly on the lander and even listened to the technicians conversing as they tended to the craft.

Visit the Mars Microphone home page at <http://sprg.ssl.berkeley.edu/marsmic> for the latest on the Mars Microphone project and more details about the experiment.

Greg Delory is a Postdoctoral Physicist at the Space Sciences Laboratory of the University of California, Berkeley.

The STUFF of LIFE: What Was Life's First Energy Source?

by Robert M. Hazen

For centuries, the source of energy for life has been as certain as anything in biology. Every high-school textbook proclaims what we all have accepted as intuitively obvious—that all life depends ultimately on the Sun's radiant energy. And, until recently, there has been little reason to doubt those claims. But new discoveries of deep life—life forms at ocean depths or buried in rock, far beyond the Sun's influence—have upset this comfortable certainty.

If there is one thing that science has taught us, it's that cherished notions about our place in the natural world often turn out to be dead wrong. We observe that the Sun rises in the morning and sets at night; an obvious conclusion, reached by almost all observers until relatively recently in human history, is that the Sun circles the Earth. Yet we now know that it is the Earth that orbits the Sun, and we are not at the center of the universe. We observe that mountains and oceans are unchanging attributes of the globe; surely these features are permanent. Yet we have learned that through the mechanisms of plate tectonics every topographic feature on Earth is transient over geological time and that our war-contested political boundaries are doomed to disappear.

The great power of science as a way of knowing is that it leads us—haltingly but inevitably, by means of observation, experiment, and reasoning—to conclusions about the physical universe that are not self-evident. The history of science has been repeatedly punctuated by the overthrow of the obvious. Could our intuitive view of life's original energy source also be in error?

Life and Energy

All living things require a continuous source of energy. Without energy, organisms cannot seek out and consume food, manufacture their cellular structures, or send nerve impulses from one place to another. They cannot grow, move, or reproduce. A steady energy input is also essential to maintain cells, which are constantly subjected to damage by radiation, chemicals, and other environmental hazards.

Metabolism, the mechanism by which organisms obtain and use energy, is a chemical process that takes place in every living cell, including all of the tens of trillions of cells in your body. Until recently, we believed that almost all life forms relied directly or indirectly on photosynthesis—the conversion by plants and a variety of one-celled organisms of the Sun's light

energy into the chemical energy of sugars, or carbohydrates. (A few unusual microbes that obtain their energy from minerals have been known for more than a century, but they were viewed as little more than biological footnotes.) Carbohydrates can be used to build physical structures such as leaves, stems, and roots, or they can be further processed to provide a source of chemical energy for each cell's machinery.

While plants manufacture their own carbohydrates, animals and other non-photosynthetic life must find another source of sugar. Thus, we eat plants (or we eat animals that eat plants). There is an elegant symmetry to this story; the biological world seemed much simpler when the Sun was life's only important energy source.

Deep Life

Our view of life on Earth was changed forever in the late 1970s, when oceanographer Jack Corliss guided the submersible *Alvin* to the deep ocean's volcanic terrain of the East Pacific Rise. There, in the vicinity of "black smoker" vents that belch out hot, mineral-laden water into the cold ocean water, Corliss discovered astonishing ecosystems, with new species of crabs, clams, and bizarre six-foot-long tube worms. One-celled organisms also abounded, coating rock surfaces and clouding the water. These communities, cut off from the Sun, thrive on geothermal energy supplied by Earth's inner heat.

Microbes are the primary energy producers in these deep zones; they play the same ecological role as plants at the Earth's surface. These one-celled organisms exploit the fact that the cold ocean water, the hot volcanic water, and the sulfur-rich mineral surfaces over which these mixing fluids flow are not in chemical equilibrium. This situation is similar to the disequilibrium between a piece of coal and air. Just as you can heat your house or power machinery by burning coal (thus combining carbon and oxygen to make carbon dioxide), so too can these deep microbes obtain energy by "burning" sulfide minerals or by initiating any of a number of other energy-liberating, oxidation-reduction reactions.

Following on Corliss' revelations, dozens of other scientists are examining a wide variety of deep, wet environments. It seems that everywhere they look—in deeply buried sediments, in oil wells, even in porous volcanic rocks more than a mile down—microbes abound. These organisms seem to thrive on



Scalding, mineral-clouded water shoots from a black smoker, a hot spring lying 2.5 kilometers (1.6 miles) beneath the ocean's surface. Such a locale, forbidding to us surface-dwellers, may have nurtured Earth's first life forms.

Photo: Dudley B. Foster, courtesy of Wood's Hole Oceanographic Institute

mineral surfaces, where water-rock interactions provide the chemical energy for life. Such one-celled creatures account for only a tiny fraction of the rock mass, but the volume of Earth's wet crust is vast—a few billion cubic kilometers. By some estimates, therefore, deep life may account for half of Earth's total biomass. Inevitably, our view of life has been skewed because these life forms are completely hidden from our everyday view.

Solar Versus Geothermal

If so many organisms exist beyond the Sun's radiant reach, then geothermal energy, and the chemically active mineral surfaces that are synthesized in geothermal domains, must be considered as a possible first power source for life. To be sure, sunlight remains the leading contender for life's original energy source. The vast majority of known life forms do rely, directly or indirectly, on photosynthesis. What's more, in a series of groundbreaking experiments in the 1950s, University of Chicago graduate student Stanley Miller and his followers demonstrated that sunlight (as well as lightning and cometary impacts) can energize the conversion of simple gas molecules into carbon-based molecules and thus provide the molecular building blocks of life. Thousands of studies have amplified these results, and a surface origin of life under a bright Sun has become the seemingly unassailable conventional wisdom.

But nagging problems remain. Most known species depend on the Sun, but solar energy can be harsh (as you know if you've ever forgotten sunblock on a bright day at the beach). Sunlight can trigger the synthesis of smaller molecular building blocks of life, but it tends to inhibit the assembly of larger structures called polymers, on which all organisms depend. Furthermore, if the earliest life of almost 4 billion years ago was confined to the surface, how did it escape the brutal, sterilizing final stages of bombardment by planet-forming asteroids and comets?

The hypothesis of a deep, hydrothermal origin of life, far from the insults of asteroid bombardments and harsh solar radiation, is supported by two recent types of experimental evidence. First, in studies of genetic mechanisms common to all life on Earth, University of Illinois biologist Carl Woese and others have revealed that microbes from extreme environments appear to be among the most primitive on Earth. Organisms that obtain energy from the interaction of water and rock may

thus be closer to the first cell than photosynthetic microbes.

Experimental studies of organic synthesis in hot, high-pressure water provide additional insights. Results from several laboratories suggest that vital organic molecules, including amino acids (the building blocks of proteins) and lipids (which form cell membranes), may be synthesized in the presence of sulfide minerals. In addition, the formation of larger molecular structures—the polymers essential to all known life—also seems to occur more easily in the presence of mineral surfaces. The Earth's crust may thus provide an ideal chemical environment for the synthesis of life.

And there is another reason why we should look closely at the possibility of hydrothermal origins. If life is constrained to form in a sun-drenched pond or ocean, then Earth, and perhaps ancient Mars, are the only possible places where life could have begun in our solar system. If, however, life can originate in deep, wet zones, then life may be much more widespread. The possibility of deep origins raises the stakes in our exploration of other planets and moons.

Heaven Versus Hell

The idea that life may have arisen in a deep, dark zone of volcanic heat and sulfurous minerals flies in the face of deeply ingrained religious metaphors. To many people, the Sun represents the life-giving warmth of heaven, while sulfurous volcanoes are the closest terrestrial analog to hell. How could life have come from such a dark, hostile environment?

Nature is not governed by our metaphors, however cherished they may be. Life as we know it demands carbon-based chemicals, a water-rich environment, and energy with which to assemble those ingredients into a self-replicating entity. We are many years from knowing how life began, but ongoing laboratory experiments under both surface and deep conditions, coupled with observations of life on Earth and, perhaps, elsewhere in the solar system, will be the ultimate arbiters of truth.

Robert M. Hazen is Staff Scientist at the Carnegie Institution of Washington's Geophysical Laboratory, where he investigates hydrothermal organic synthesis. He is also Clarence Robinson Professor of Earth Science at George Mason University in Fairfax, Virginia, where he teaches courses in scientific literacy.

News and Reviews

by Clark R. Chapman

Scientists, who often blame the media for inaccurate stories, have a duty to inform the public of reliable facts amid the babble. Centuries ago, procedures evolved within professional societies to reduce error and bias in scientific reporting; for instance, peer review of articles before publication helps to minimize crackpot ideas and errors due to haste.

With the Internet, the cacophony has grown into a roar. As society increasingly depends on technology, we must resist pressures to relax standards. In an open society, anyone can publish in unrefereed publications or on the World Wide Web. Opinion leaders and policy makers rely on media like *The New York Times*, rather than supermarket tabloids, for credible reports. So scientists and their institutions bear an obligation to help the *Times*, and similar media, learn what's fit to print.

As food for thought about how well we are doing, consider the following recent cases in which planetary science institutions inadvertently helped to promulgate borderline science—unbalanced, speculative, or plain wrong. Admittedly, there are other cases of straight-arrow reporting of solid, mainstream results. On balance, is the public getting a credible picture of planetary science?

The Face on Mars

Recently, the reputable *All Things Considered* on National Public Radio (NPR) aired a segment on the supposed "face." For two decades, planetary geologists have known that this feature in a *Viking* photo was as likely to be an artificial monument as yonder cloud is an actual floating camel. Yet NPR featured a non-geologist, with a supposedly "balanced" view about whether the sharp new photos by *Mars Global Surveyor* had debunked the "face." He felt not, and eagerly awaited photos of the nearby supposed "city" (those images are now back: on the Web, see www.msss.com). NPR came off like an audio *National Enquirer*. But NASA itself lent credibility to the "face" issue.

The designer of the *Global Surveyor* camera, Mike Malin, never opposed snapping a portrait of the "face." But NASA insisted on a higher-profile campaign; Malin was told to give the same priority to the pseudo-scientific icons of Cydonia, like the "face," the "city," and the "fortress," as to scientific targets like the *Viking* and *Pathfinder* landing sites. NASA's laudable goal was to educate the public about science and to respond to public concerns about governmental secrecy. While many outlets played the story as NASA hoped, NPR probably wouldn't have given a platform to the crazies without NASA's stamp of approval, the implication that the "face" was worth a bit of the resources of a \$250 million spacecraft mission.

The Rain of Mini-Comets

For a dozen years, Iowa space physicist Lou Frank—an otherwise respectable researcher—has promulgated a discredited hypothesis that the Earth is being bombarded by countless house-sized mini-comets. So cleverly has he adjusted his model for the mini-comets (to explain their invisibility to everyone and every instrument, except himself) that his colleagues have dubbed them "stealth comets." Yet NASA, in coordination with a May 1997 American Geophysical Union (AGU) talk by Frank, issued an official press release claiming that new spacecraft data had proved Frank's theory correct. The story was reported uncritically by some of the nation's most trusted newspapers and networks. Frank's resuscitation was soon undermined by a flood of technical articles, which again proved him wrong from every angle. The news media backtracked to varying degrees, but less prominently than they played the original accounts. Are the media to blame? Probably the soul-searching should begin within the AGU and NASA about how to avoid lending credibility to bad science.

Life on Europa

I plead guilty to participating in what was,

in hindsight, a well intentioned but misleading press conference a year ago at the Jet Propulsion Laboratory. The *Galileo* imaging team was releasing new, sharp pictures of apparent "ice rafts" floating in a recently frozen ocean. Some non-*Galileo* scientists—with a decided bias toward extraterrestrial life—were invited to the rostrum. Unintentionally, we all contributed to banner-headline-producing stories about the likelihood of life in a sub-surface European ocean. While possibly true, it was speculation that hardly represented a consensus of *Galileo* scientists, a few of whom inadvertently contributed to the imbalance by opting out of the press conference.

No Asteroid Impact in 2028

Both the International Astronomical Union and the American Astronomical Society lent their good names to a story that dominated headlines worldwide for two days in March, about a mile-wide asteroid that just might strike the Earth, with horrible consequences, on October 26, 2028. The story was retracted the next day, ostensibly because new data were obtained, and the world's press breathed a collective (and prominent) "Whew!" In fact, the potential impact never should have been announced in the first place; it was another failure of peer review in the Information Age. Had the astronomer who made the announcement checked with his colleagues before shouting (with an exclamation mark) to the world, he would have realized that data in hand months earlier already proved this to be a certifiably safe asteroid rather than a potentially dangerous one (see www.boulder.swri.edu/clark/ncar.html).

Planetary scientists should stop using journalists as scapegoats for all bad science reporting and rethink our own responsibilities to "get it right."

Clark R. Chapman, a planetary researcher, published a neighborhood newspaper and studied journalism as a teenager.



World Watch

by Louis D. Friedman

Washington, DC—The dominant political issue for NASA is the delay and increased costs of the International Space Station. As we go to press, NASA has not announced when the first launch date will be rescheduled, but a postponement to the end of 1998 is being discussed. The first element, built by the Russian Space Agency (RKA), is the Functional Cargo Block (FCB), which is to provide initial power and propulsion for assembly of the space station. The second element, built by NASA, is node 1, the connecting passageway to the FCB and, later, to the US laboratory module. Node 1, named *Unity*, will be launched as soon as the FCB is launched.

An independent review board has projected increased costs and delays for the station. It does not appear, however, that the program is in jeopardy. Contingency plans exist in case Russian elements cannot be finished, and the basic plan for the station, including the Russian elements, remains intact.

The problem in Russia has been long delays in government funding for the contractors.

In the US Congress' consideration of the NASA budget, the focus of Planetary Society efforts has been restoration of funding for the Human Exploration and Development of Space (HEDS) component of the Mars program. The Mars 2001 mission has been reduced in scope because of cuts to the HEDS budget and because of growth in the rover that was planned for that mission. The revised 2001 mission will not include a rover (which will be delayed until the 2003 launch opportunity) but will include both an orbiter and a lander. The lander will carry out the first experiment on in-situ propellant production—a technology to enable human exploration of Mars.

The Planetary Society has been lobbying for an increased budget in the Mars program, but no action has been taken to date by the appropriations committees in Congress.

Hollywood—Blockbuster movies (*Deep Impact* and *Armageddon*), an erroneous prediction of an asteroid hitting the Earth, and discoveries of more impact craters on Earth are all helping to focus attention on the need for observations of near-Earth objects (NEOs). The Society has been campaigning vigorously for increased search programs and has supported NEO observations for nearly two decades.

The US House of Representatives' Science Committee held a hearing on this subject and invited testimony from Clark Chapman, our News and Reviews columnist, who is an expert on NEOs and the probabilities of impact.

In April, NASA's Office of Space Science announced the formation of a program office and an increased budget to deal with the subject of near-Earth objects. The new office will support NEO observations as well as data analysis and studies stemming from exploratory missions, such as the Near-Earth Asteroid Rendezvous, which will reach the asteroid Eros next February. The new NASA office is also charged with coordinating public release of information about NEOs.

Even with the increased attention from NASA, observation programs are still below levels recommended by various advisory committees in recent years. Earth-based observations, especially international programs, are still lacking adequate financial support.

Paris—The European Space Agency (ESA) has withdrawn from *Euromoon*,

a lunar orbiter and lander mission proposed by a group headed by astronaut Wubbo Ockels. The spacecraft would have launched in 2001 as a celebration of the new millennium.

Euromoon was intended to be only partially supported by government funds through ESA. Most of the funding was to have been privately raised. Whether the private funds would have been forthcoming is problematical, but ESA's withdrawal makes it highly unlikely the mission will go ahead.

The only lunar missions now scheduled for launch are both from Japan: *Lunar A*, which will deploy penetrators to the Moon's surface in 1999, and *Selene*, an orbiter and lander scheduled for launch in 2003.

London—The United Kingdom is reducing its already meager support for space science. Matters have reached the point where adequate funding for *Mars Express* is now in doubt.

The reduction in British support delivered a double whammy to *Mars Express*. First came the ESA decrease of its overall space science budget. Then came the lack of support for a proposal from the Open University for a lander to be put aboard *Mars Express*.

Mars Express will now be an orbiter mission with no lander. We hope to see confirmation in early November of the mission's inclusion in the ESA budget.

In the United Kingdom, we've observed a great dichotomy between public and scientific interest in planetary exploration on the one hand and the continuing lack of government support on the other.

Louis D. Friedman is Executive Director of The Planetary Society.

Questions and Answers

"A Brief History of the Moon" (see the September/October 1997 issue of The Planetary Report) was a great article, but I didn't understand the reason for the Moon's orbital growth. William Hartmann said that moons gradually increase their orbital heights over the millennia because of tidal forces.

How do tidal forces transfer energy to the orbiting planet?

—Dan LeMay,
Blanchardville, Wisconsin

Several readers wrote to ask for more information about how tidal forces act to make the Moon spiral outward. At any moment in time (see step 1 in the illustration below), the gravity of a satellite acts to stretch the body of the planet, causing tidal bulges A and B. (Similar

Tidal forces are very complicated and have many effects that are not obvious. For example, if you study the second illustration, you can see that if the Moon were moving in the opposite direction (retrograde orbit), the force would pull against the orbital motion, causing the Moon to spiral *inward* instead of outward!

Tidal effects are much stronger when the planet-satellite distance is small. Therefore, the outward movement of the Moon was much faster in its early history. The Moon moved most of the way toward its present position in the first few hundred million years. Due to this tidal effect, the Moon is still moving outward, though very slowly, over geological time.

—WILLIAM K. HARTMANN,
Planetary Science Institute

along with all other low-velocity stars and interstellar clouds in the galactic disk, moves up and down through the plane of the disk with a best-estimated cycle time of about 60 to 70 million years (meaning we cross the mid-plane every 30 to 35 million years or so).

This oscillation perpendicular to the galaxy's disk is caused by the gravitational forces associated with the stars and clouds that are concentrated around the mid-plane. The cycle time depends upon the total density of matter in the disk (including any so-called dark matter). The motion is a simple harmonic oscillation: if the Sun starts above the plane, then gravitational force would pull it down toward the plane. Since there is nothing to stop its motion, the solar system overshoots the mid-plane, only to be pulled back again by the mass concentration in the galactic plane.

The Sun reaches a maximum distance above and below the plane of about 80 parsecs (one parsec equals about 206,265 times the distance between the Earth and Sun). At present, we are less than 15 parsecs above the plane, having just passed through it in the past few million years. Interestingly, we are also at a position in our galactic revolution closest to the Milky Way's center, in an epicyclic motion that repeats every 170 to 180 million years.

Such cycles of stellar motion exist in all spiral galaxies and are not the result of collisions or mergers. The galactic oscillation hypothesis for comet showers, if correct, suggests that all solar systems that exist in our galaxy's disk, and in other galaxies as well, might suffer such periodic cometary cataclysms.

—MICHAEL R. RAMPINO,
New York University

I see many references to the chemistry, composition, and structure of the atmospheres of Earth, Mars, and Venus, but I can find no information on the comparative depths of these three planets' atmospheres.

—Malcolm Drobig,
Farham, Surrey, England

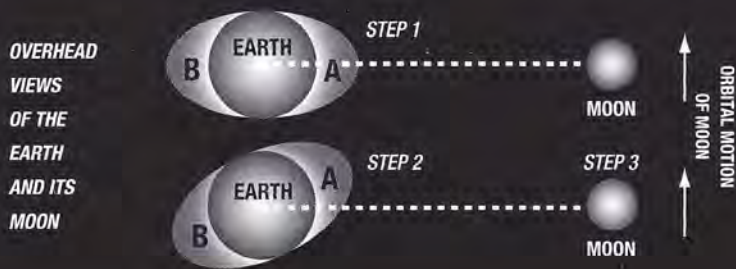


Diagram by B.S. Smith based on a drawing by William K. Hartmann

but smaller bulges are raised on the moon by the planet, but we can ignore them in discussing this effect.) The first diagram shows the situation that would exist if Earth did not rotate. However, because Earth *is* rotating, the tidal bulges are dragged around off the Earth-Moon line (step 2).

Each bulge (A or B) has a mass and thus a gravitational attraction to the Moon. But mass A is closer to the Moon and it dominates. Therefore, mass A (or, more accurately, the net pull of masses A and B) pulls forward on the Moon (step 3). This is an extra force pulling the Moon forward in its orbit. With this extra force acting on it, the Moon moves outward toward a higher orbit.

In "The Shiva Hypothesis" (see the January/February 1998 issue of The Planetary Report), Michael Rampino referred to the motion of our solar system up and down through the plane of the Milky Way. Do we know the cause of this? How many other stars behave this way? Could such cycles be the residual effect of galactic collisions or mergers?

—James L. Snyder,
Carmichael, California

The solar system is involved in several cyclic motions as it travels through the Milky Way. The Sun and planets revolve around the center of the disk-shaped galaxy about once every 240 million years. At the same time, the solar system,

The answer depends on how you define “depths.” The three definitions below give three different answers to the question “Which planet has the deepest atmosphere?”

One useful definition is the scale height, a value that varies proportionally with absolute temperature and the universal gas constant and is inversely proportional to the planet’s gravity and the molecular mass of the gas. Let’s consider these four factors on the three planets. Mars has a lower gravity than Earth and Venus. Venus is the warmest near the surface, but Earth is warmest at high altitudes. Also, Mars’ and Venus’ atmospheres are mostly carbon dioxide, which has a higher molecular mass than nitrogen, which is the principal constituent of Earth’s atmosphere. When all these factors are taken into account, the scale heights are not all that different. In the middle atmospheres, away from the extremes of temperature, the scale heights

are 5, 8, and 10 kilometers (about 3, 5, and 6 miles) for Venus, Earth, and Mars, respectively.

A definition that works for Earth and Venus is the altitude of the tropopause. This is the place where the atmosphere becomes transparent to infrared radiation, and it marks the base of the stratosphere, where temperature is constant or increases with altitude. The tropopause is also the altitude of the cloud tops. On both Earth and Venus this altitude occurs where the pressure is about 0.1 bar, which is one-tenth the Earth’s sea-level pressure. But the surface pressure on Venus is 90 bars, so the tropopause there is much higher than on Earth—70 versus 10 kilometers (43 versus 6 miles). The surface pressure on Mars is only 0.007 bar, so the atmosphere is infrared-transparent at the surface.

A third way is to define the top of the atmosphere as the altitude where the molecules no longer collide with one

another but follow ballistic trajectories that mostly lead back into the denser gas below. This transition, which marks the base of the exosphere, is gradual and varies with latitude and time. Carbon dioxide keeps the upper atmospheres of Mars and Venus much cooler than that of Earth, so their scale height is less and their exospheres are much closer to the ground. The exosphere begins at an altitude around 150 to 200 kilometers (90 to 125 miles) for Venus, 200 to 250 kilometers (125 to 155 miles) for Mars, and 500 to 800 kilometers (310 to 500 miles) for Earth. By this definition, Earth has the “deepest” atmosphere.

—ANDREW P. INGERSOLL,
California Institute of Technology

If the reader is baffled, he or she can join the community of people who have to take on faith the proposition that atmospheric scientists know what they are talking about.
—James D. Burke, Technical Editor

Factinos

Scientists have detected a large concentration of water vapor in a cloud of interstellar gas near the Orion nebula. This discovery of a large “chemical factory” in interstellar space provides important evidence on the possible origin of water in our solar system.

Michael Kaufman of NASA’s Ames Research Center and his team measured water concentrations of roughly one part in 200 by volume, using data gleaned by the European Space Agency’s Infrared Space Observatory Satellite. The team attributed the high concentration of water to the nebula’s fast-moving shock waves, which made the gas cloud abnormally warm. Scientists have long predicted that when the temperature exceeds 93 degrees Celsius (200 degrees Fahrenheit), chemical reactions will cause most oxygen atoms in the interstellar gas to combine with hydrogen atoms to form water.

The team reports that enough water molecules are generated in a single day to fill 60 Earth oceans. Eventually, the water vapor turns into ice particles, similar to those believed to be present within the gas cloud from which our solar system formed.

—from NASA Ames Research Center

A new class of dust ring has been detected around Jupiter. A team led by researchers at the University of Colorado reported on their discovery in the April 3, 1998 issue of *Science*.

Evidence for this new ring comes from computer simulations that correlate with data from *Galileo*’s dust detector. Surprisingly, the researchers say, most of the interstellar and interplanetary particles that make up the ring appear to be orbiting backwards—that is, in the direction opposite the rotation of the planet and its moons.

In 1979 *Voyager 2* detected an uneven dust ring around Jupiter that scientists think formed from collisions of small bodies in the Jovian system. But the newly found ring, made of smoke-sized particles originating beyond the solar system, is much larger and sparser and may be unique in our planetary neighborhood.

—from the Jet Propulsion Laboratory



This image of the Orion nebula shows the region of space where scientists have detected a large concentration of water vapor. This discovery provides important evidence on the possible origin of water in our solar system.

Image: Space Telescope Science Institute/NASA

Society News

Society Hosts Capitol Hill Breakfast

On May 8, 1998, Planetary Society Executive Director Louis Friedman and Cornell University professor Steve Squyres met with members of Congress and their staffs at a well attended, Society-sponsored Capitol Hill breakfast to discuss NASA's Mars program. Friedman and Squyres reported on exciting *Pathfinder* and early *Mars Global Surveyor* results as well as plans for upcoming Mars missions through 2005. The Society advocated strong congressional support for the Mars program, particularly urging that additional funds be allocated for upcoming Mars Surveyor experiments related to human exploration of the planet. —*Charlene M. Anderson, Director of Publications*

Next Shoemaker Grant Selection Planned

The selection committee for the Planetary Society's Gene Shoemaker Near-Earth Object (NEO) Grant is collecting proposals for grant money. An announcement of the next grant recipients will be made sometime this fall. The seven-member selection committee will re-evaluate proposals that were submitted but not selected for the

first Shoemaker grant, as well as new or revised proposals submitted by August 15, 1998.

The first Shoemaker grant, totaling more than \$35,000, was divided among two US programs, a Russian program, and an Australian program. The grant supports professional and amateur observing programs with equipment-upgrade and other operational funding. For information about the grant, contact Society headquarters.

—*Louis D. Friedman, Executive Director*

Assembly Program Inspires Tomorrow's Explorers Today

The Planetary Society's newest educational project, "Worlds to Discover," enables educators and community volunteers to share the wonders of space exploration with schools in their communities. The special assembly package, targeted at students in grades kindergarten through 8, is designed for easy use by teachers or adult volunteers with limited science backgrounds. The program contains a slide set, a complete script, and a follow-up packet for teachers to share with classes.

"Worlds to Discover" provides information on how discoveries are made in

space and takes students on a tour of the solar system. "The assembly program is the perfect opportunity to change students' lives by inspiring them to envision what they might themselves discover if they make planetary exploration their goal," says program creator Linda Morabito Hyder, the Society's Manager of Program Development and former Jet Propulsion Laboratory scientist who discovered active volcanoes on Jupiter's moon Io.

"Worlds to Discover" costs \$34.95 plus a \$7.24 shipping charge for the complete package: slide set, script, and sample follow-up packet. Additional teacher packets can be ordered as needed free-of-charge from the Planetary Society by anyone who purchases the program. —*Susan Lendroth, Manager of Communications and Events*

Find Your Name on Stardust

The names of Planetary Society members as of November 1997 are now aboard *Stardust*, set for launch in February 1999. NASA has posted current names at the *Stardust* site on the World Wide Web: <http://stardust.jpl.nasa.gov/microchip/names.html>. —*Michael Haggerty, Electronic Publications Manager*

SEE THE LAST SOLAR ECLIPSE OF THIS CENTURY!



Photo of total solar eclipse, February 26, 1998, by Vivian Zee

View the Total Solar Eclipse From the Mediterranean in August 1999!

Stunning locations through the Mediterranean and Black Sea region will be the backdrop for an extraordinary adventure to see the last solar eclipse of the millennium. Two limited tours are available:

■ A land-based tour through Turkey will take you to exotic locales like Istanbul and Diyarbakir. Center-line viewing of the eclipse will be near the town of Batman.

■ A two-week cruise tour departs from romantic Venice, Italy aboard the luxurious Cunard liner *Vistafjord*. You'll dock in picturesque Greek, Turkish, and Ukrainian ports (Istanbul, Yalta, Odessa, and the island of Mikonos).

For brochures and information, contact Susan Lendroth at The Planetary Society, 65 N. Catalina Avenue, Pasadena, CA 91106. E-mail (include your postal address): tps.sl@mars.planetary.org

Space is limited! Make your reservations early for the best cabin selection.



Scientists using the Hubble Space Telescope have captured what may be our first direct view of a planet outside our solar system. Taken on August 4, 1997, this near-infrared image of newborn binary stars (center) reveals a long, thin nebula that leads to a faint companion object (bottom left).

Located 450 light-years from Earth within a star-forming region in the constellation Taurus, the mysterious object, called TMR-1C, appears to have been flung away from its young parent stars. TMR-1C is now 209 billion kilometers (130 billion miles) from the parent stars and is thought to be hurtling into interstellar space, destined to drift forever through the Milky Way.

Image: Susan Terebey, Extrasolar Research Corporation, and NASA

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