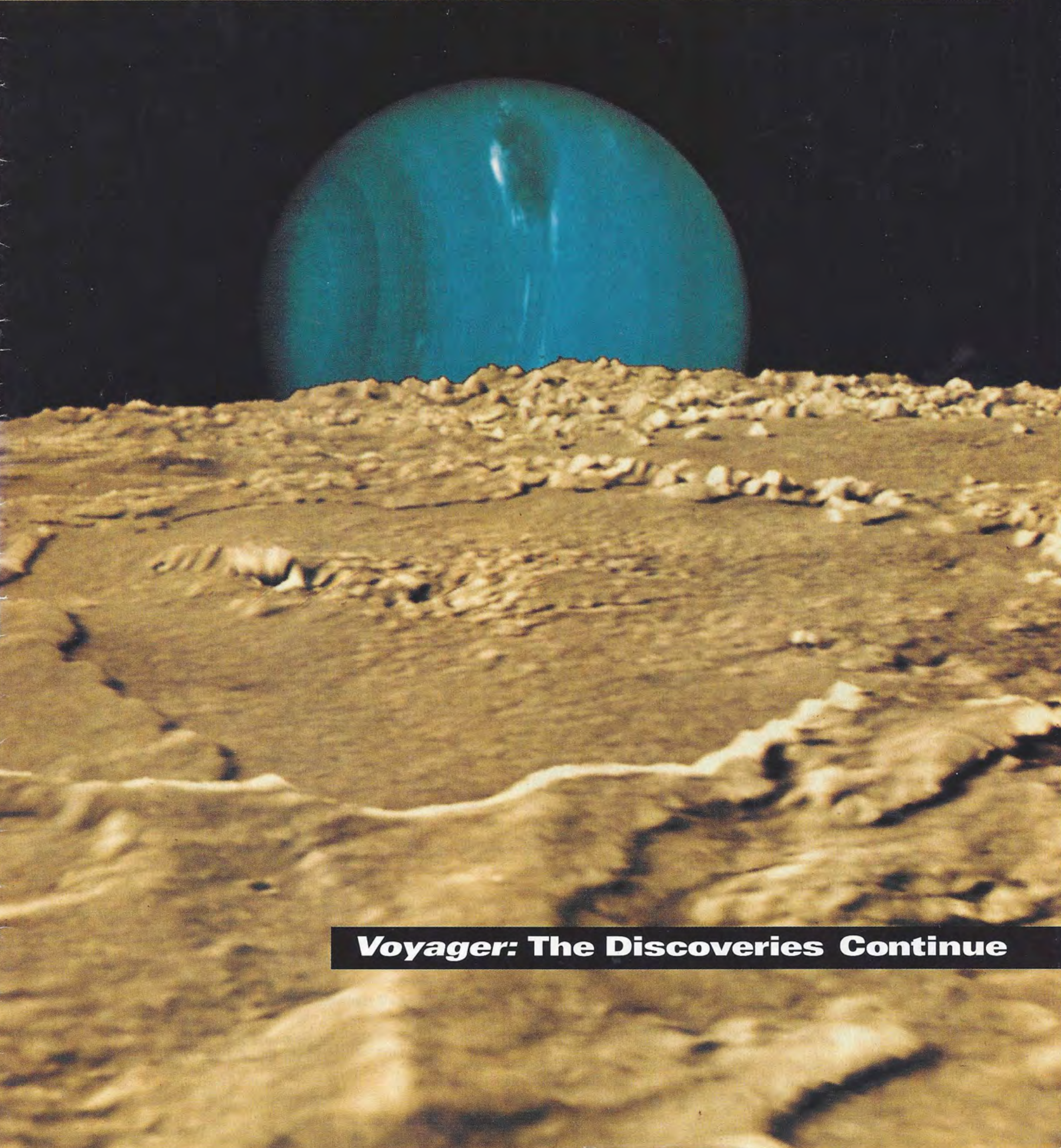
# The PLANETARY REPORT

Volume XV Number 4 July/August 1995



**_Voyager:_ The Discoveries Continue**

**On the Cover:**

Neptune hangs on Triton's horizon in this three-dimensional view created from *Voyager* images. While this view is dramatic, it isn't what an explorer would actually see while flying over Triton: The relief has been exaggerated about 30 times. In the foreground are Triton's maria ("seas"), with terraces testifying to several episodes of volcanic flooding—only the floods were of molten ice, not rock. *Voyager*'s greatest legacy is that the spacecraft revealed strange worlds such as this to us for the first time.

Image: United States Geological Survey, Flagstaff

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While others critique the new information technology, the Society is using it: We're holding an on-line conference with the leaders of our Belize expedition. We're also forging ahead with our Red Rover, Red Rover project, holding a space science workshop with the United Nations and the European Space Agency, preparing to celebrate *Galileo*'s arrival at Jupiter and publishing another newsletter. Plus, our members have met the Micron challenge!

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Radiation belts surround many of the worlds in our solar system, affecting their interactions with the pervasive solar wind. We explore those regions and revisit the collision of comet Shoemaker-Levy 9 with Jupiter.

## From The Editor

As we go to press, NASA is facing what could be the greatest crisis in its existence. As you'll read in World Watch, the agency is threatened with budget cuts that could destroy its vitality. If the budget proposed by the United States House of Representatives becomes reality, what survives as NASA may be a pale shadow of the agency that took us to the planets.

Another agency of explorers is in even more danger: Some in Congress are threatening to eliminate the US Geological Survey. Through its branch of astrogeology, the USGS is a major force in planetary exploration, and its loss would be a body blow to those endeavors supported by The Planetary Society.

Things are worse in Russia. Mars Together, the program supported by the Society, appears to be in trouble. The Russian Space Agency just doesn't have enough money for all its projects.

This year could mark a downward turn in planetary exploration. What can you do to stop it? First, let your government know that you support planetary exploration. Then reaffirm your support of the Society. Our voices joined will be more effective in the fight to preserve Earth's ability to explore the planets.

*—Charlene M. Anderson*

*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, 818-793-5100. It is available to members of The Planetary Society. Annual dues in the US or Canada are $25 US dollars or $30 Canadian. Dues outside the US or Canada are $35 (US). Printed in USA. Third-class postage at Pasadena, California, and at an additional mailing office. Canada Post Agreement Number 87424.

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A Publication of
THE PLANETARY SOCIETY

# Members' **Dialogue**

### Jason

Recently I had the pleasure of attending an interactive session sponsored by the Jason Foundation and The Planetary Society at a PIN (Primary Interactive Network site) near my home. (See the May/June 1995 issue of *The Planetary Report*.) Not only was the presentation interesting and informative, but the student displays of data on Hawaii, volcanism and plate tectonics were well done and indicated a lively interest in scientific subjects.

The final three minutes of the presentation were devoted to the Mars Rover. A 14-year-old student got the chance to drive the rover, and she did very well. I want to take this opportunity to thank the Society for enabling me to take part. It certainly was time well spent.
—EDWARD J. WARD, *Hicksville, New York*

### Pluto's Pals

Viva Louis Friedman for his legwork in lobbying NASA since 1993 to accept a joint Russian-United States Pluto probe, using each side's strengths—a Russian *Proton* and a lightweight US space probe. The Planetary Society deserves our congratulations for seeing this through to the Gore-Chernomyrdin text. (See the September/October 1994 issue of *The Planetary Report.*)

The Pluto/Charon probe is still under threat from financial squeeze on both the US and Russian sides. Planetary Society members need to organize something like the Mars Underground—maybe the Friends of Pluto and Charon. We need to petition NASA to give this mission priority over less time-constrained space science projects.
—KEITH GOTTSCHALK,
*Claremont, South Africa*

*This is a good idea, and I invite Society members to share their views on the Friends of Pluto and Charon concept. I would also like to point out that in 1991 we published a letter by Keith in Members' Dialogue in which he suggested a Pluto/Charon mission using a US-built spacecraft and a Russian launch vehicle.*
*—Louis D. Friedman,*
*Executive Director*

### Moon Mining

I read with interest the letters in the March/April 1995 issue of *The Planetary Report.* While I agree with the spirit, if not the entire content, of Marge Currie's letter, I take issue with that of D. Downs.

While the Moon belongs to no one in particular, it belongs to the human race in general, by virtue of the fact that Earth is its primary. If Downs is concerned that we will turn the Moon into a slag heap, I say that it is *already* a slag heap by its very nature. It has no ecology or fragile environment.

Downs, as a member of the Society, should know better than anyone that mining the Moon for terrestrial benefit will never be an economical proposition due to transportation costs, engineering difficulty, and so forth. If the Moon were made of solid gold and studded with diamonds, it would not make sense to mine the ore and bring it back, since even the lowest grade terrestrial ore would be more economical to process. Rather, when we do mine the Moon, the material harvested will be used *there* to build a new society and construct the infrastructure that will ultimately set us on the path to the planets.

Downs spoke of destroying the "poetic inspiration for humankind," as if these activities would be visible to the unaided eyes of the poetic dreamers. Aside from possible minor changes in albedo, there would be no visible manifestation over the quarter of a million miles that separate us.

The Moon is a pristine wilderness, to be sure. By the very fact of its low gravity, it will never be able to hold an atmosphere for any length of time, so terraforming it will never be a viable option. Therefore, humans must always live underground or in small surface establishments. Even with these and the mining efforts to support them, on the large scale the "magnificent desolation" will prevail for all time.
—JEFFREY E. HOYLE,
*San Jose, California*

I was disappointed at D. Downs' letter in the March/April Members' Dialogue. If the Moon's resources belong to no one, then like all other resources throughout history they will eventually belong to whoever puts them to use or seizes them by force. The rain forests are being burned down for farmland by people who have no wish to see their children starve and who are receiving little consideration from the "planetary community."

If we were to go after the Moon with everything we've got, from mining equipment to nuclear warheads, it would look exactly like—the Moon. The difference would only be whether its vast material, territorial and gravitational resources would go to feed those starving children (and save the rain forests) or continue to sit, untouched and useless. I find little poetic inspiration in moonlight when it shines on poverty, suffering and environmental destruction.
—E. WEBER JONES,
*Cincinnati, Ohio*

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

# What's New, *Voyager*: The Discoveries Continue

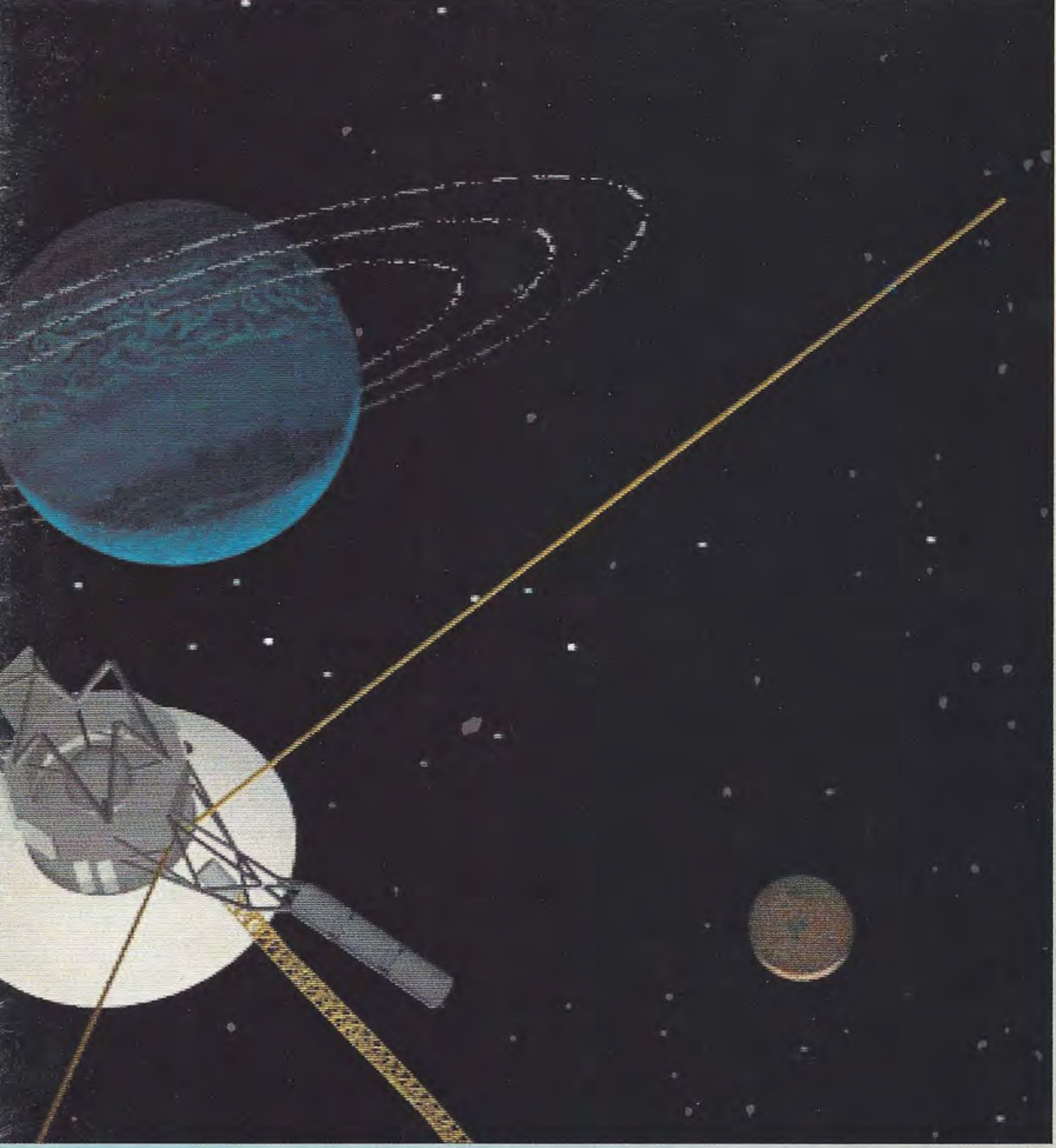
**by Ellis D. Miner**

Nearly six years have elapsed since *Voyager 2* flew by Neptune, and we will soon celebrate the 15th anniversary of *Voyager 1*'s final planetary encounter (Saturn). Yet it is far more than nostalgia that keeps these hardy space robots on our minds.

This most successful of all planetary missions is still very much alive. NASA's Deep Space Network—a system of three tracking complexes, one near Canberra, Australia; one near Madrid, Spain; and one at Goldstone, California—continues to receive transmissions from *Voyager 1* at the rate of about 120 hours of science and engineering data per week. *Voyager 2*, which shares the DSN's southern hemisphere coverage with *Galileo,* nevertheless provides about 90 hours of data per week. It is anticipated that these data collection rates will continue well past the turn of the century.

Some of the new data are intriguing in their implications for the nature of the magnetic bubble blown by the Sun (the heliosphere) and of the interstellar medium beyond the heliosphere. Perhaps just as interesting and important are discoveries being made from continued analysis of data taken during *Voyager*'s six giant-planet flybys (two at Jupiter, two at Saturn and one each at Uranus and Neptune). When *Galileo* begins its detailed atmospheric probe and orbital mission this December, its data will begin to supplant *Voyager*'s as the premier source of jovian information. The arrival of *Cassini* at Saturn in 2004 will cause a similar evolution for Saturn data. There are no plans now to send orbiters to Uranus or Neptune, so, for these distant neighbors, *Voyager* data are likely to remain the definitive data set for the foreseeable future.

*Voyager*'s voice has been heard in many places. Theoretical analyses built around boundary conditions provided by the *Voyager* data continue to provide unprecedented insights into the nature of the Jupiter, Saturn, Uranus and Neptune systems. Any theories that predict results inconsistent with the *Voyager* observations are either discarded or revised. Ground-based and Earth-orbital observations



**Voyager 2** ***completed its reconnaissance of the giant-planet systems in August 1989 with its flyby of Neptune and Triton. It thus accomplished the most ambitious planetary mission yet flown from Earth. As they now follow paths leading out of our solar system, the two*** **Voyager** ***spacecraft continue to explore and to relay data back to their home world.***

*Computer graphic courtesy of Charles Kohlhase, JPL/NASA*

of the gas giants and their systems, although of poorer resolution than *Voyager* observations, nevertheless are stimulated by and benefit greatly from the understanding provided by *Voyager* data. Studies of the satellites of the giant planets by the Hubble Space Telescope and ground-based instruments are good examples of this aspect of *Voyager* influence.

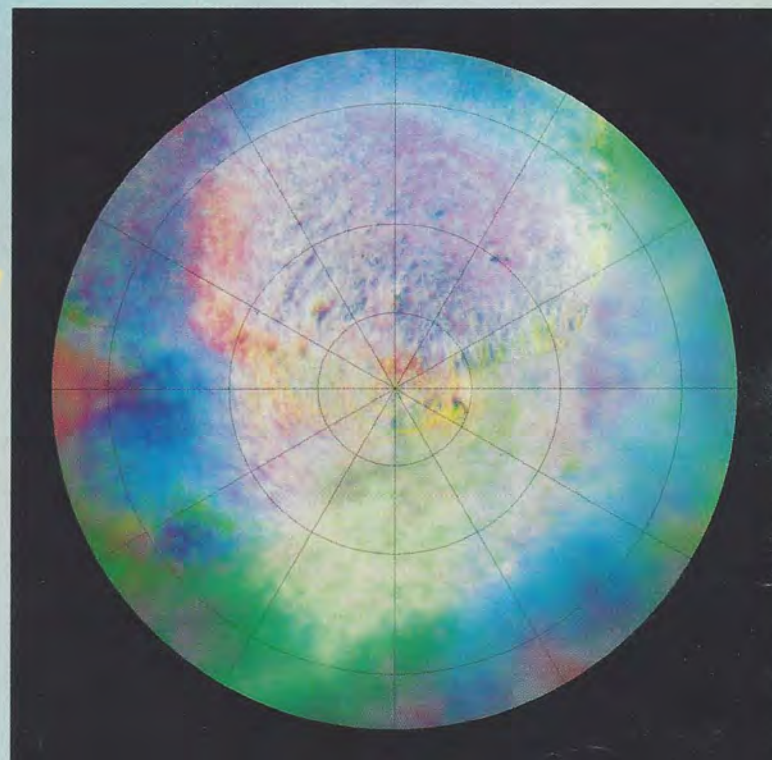
Finally, the great success of the *Voyager* mission has positively influenced the scientific objectives and observation designs of the *Galileo* and *Cassini* missions. While some of their objectives are general enough to have been generated before the *Voyager* encounters of Jupiter and Saturn, the majority are based either on questions raised or on questions left unanswered by the *Voyager* observations.

I have chosen to concentrate on only two aspects of *Voyager*'s legacy here—new data on the heliosphere and new conclusions drawn from *Voyager*'s giant-planet flybys. I will also limit the discussion to those items of information that have been discovered within the past five years.

## Edging Toward the Heliopause

An early 1995 mission status report from NASA's Jet Propulsion Laboratory said that the *Voyager* spacecraft "are using their ultraviolet spectrometers to map the heliosphere and study the incoming interstellar wind [a stream of electrons and protons blowing in from nearby hot stars]. The cosmic ray detectors are seeing the energy spectra of interstellar cosmic rays in the outer heliosphere. The magnetometer sensors are still measuring the strength and direction of the solar magnetic field. The plasma detectors looking back at the Sun record the solar wind parameters. The low-energy charged particle experiment studies the energy spectra of particles coming from the Sun. The plasma wave instrument is studying the incoming signals from the direction of the heliosphere."

***Right:** Four spacecraft are now searching for the edge of our solar system, a boundary called the heliopause where the solar wind blowing from the Sun gives way to the stream of protons and electrons blowing in from the stars. The plasma wave instruments on the* Voyager *spacecraft have detected intense low-frequency radio emissions that may signal the spacecraft's approach to the heliopause. The fastest moving craft,* Voyager 1, *may reach this boundary early in the coming century.* Chart: JPL/NASA



***Above:** The Galilean moon Io has proven to be the most volcanically active body in our solar system. Since its 1979 discovery, Io has become a prime target for theoreticians and observational astronomers. Pele, the first discovered and largest ionian volcano, sits in the middle of the horseshoe-shaped feature in this image. The feature has been formed by material erupted from the caldera in the center. The moon's colors, ranging from white and yellow to orange, red and black, are all derived from compounds of sulfur erupted from beneath the surface.*

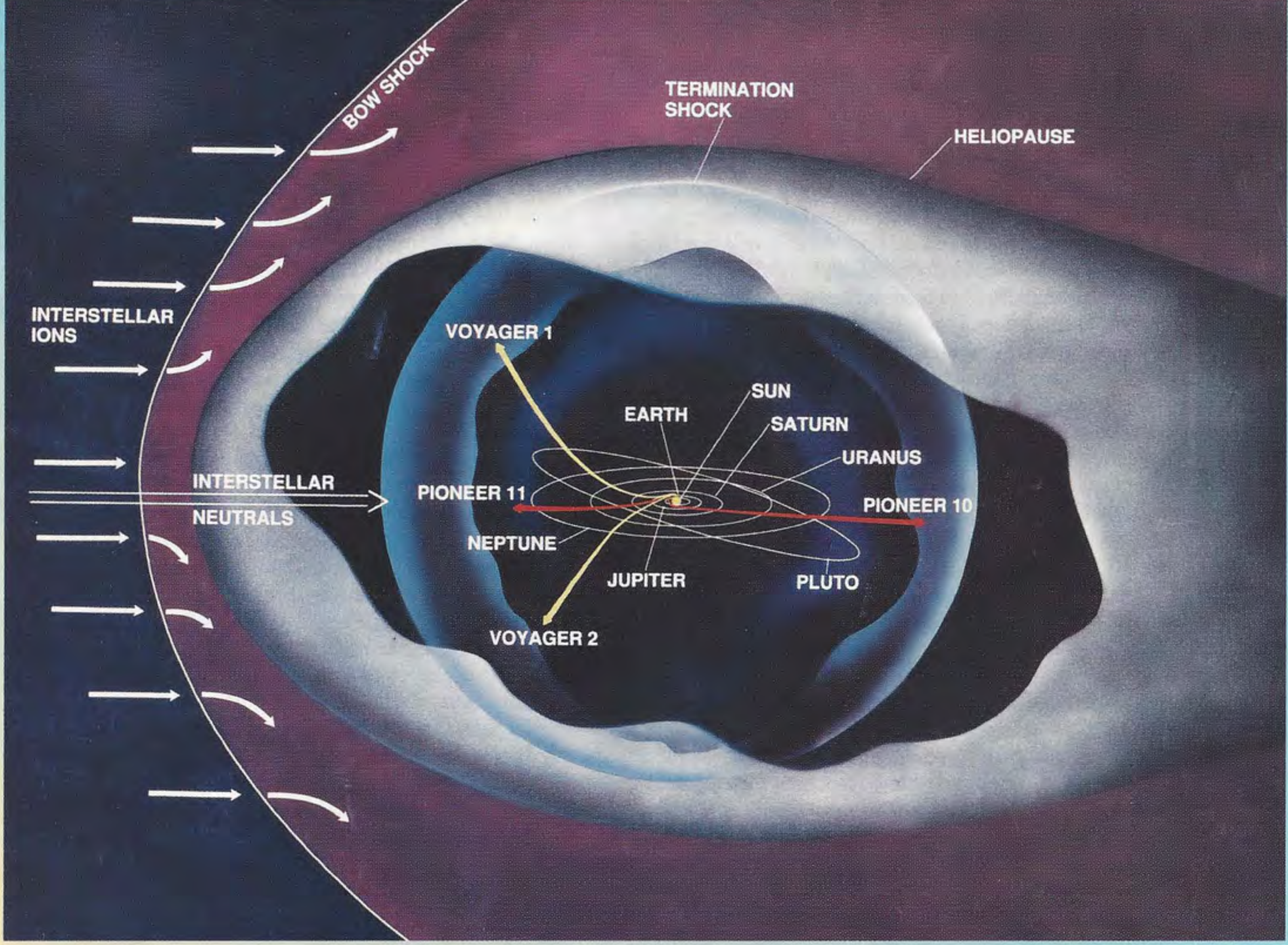
***Right:** In the years since* Voyager 2 *completed its Neptune flyby, scientists have continued to process, analyze and, in this case, "stretch" the data collected by the spacecraft. This stereographic projection of the moon Triton shows the south polar cap as a human eye would never see it. A bright fringe around the cap becomes very apparent in this stretch; it's probably composed of fresh nitrogen frost or snow. The rays pointing out from the fringe are frozen nitrogen blown out by winds from the south.* Images: United States Geological Survey, Flagstaff

As indicated in this status report, six of *Voyager*'s 11 investigations are continuing to collect data about the structure of the heliosphere. Each of the six provides a different piece of the puzzle. When one assembles that puzzle, the message is clear: Both spacecraft are edging ever closer to the outer boundary of the Sun's magnetic influence. Some data even lead to estimates of where the boundaries are.

Two successive boundaries are relevant. The first, called the termination shock, marks the distance from the Sun where the electrons and protons streaming outward in the solar wind slow abruptly from supersonic to subsonic speeds. The second, called the heliopause, occurs where the outward flow of the solar wind is stopped altogether. The heliopause also defines the outermost extent of the Sun's magnetic field. Beyond the heliopause, the particle environment is that of interstellar space. Inside the heliopause, it is primarily the Sun that controls the environment.

Measurements of radio bursts in the 2,000- to 3,000-hertz frequency range are of particular significance in distance estimates. In May and September 1991, *Voyagers 1* and *2* and *Pioneers 10* and *11* (launched about five years earlier but now at comparable distances from the Sun) detected massive solar bursts. Beginning in 1992 and continuing until the present, *Voyager*'s plasma wave instruments saw enhanced (stronger and more spread out in frequency) radio emissions. We now believe that interaction of the solar material with incoming interstellar material at the heliopause generates these emissions. By combining estimates of the outward velocity of the solar wind and the returning speed-of-light radio bursts with the time delays involved, one can estimate the distance to the heliopause.

The distances to the termination shock and the heliopause are not fixed, but vary both with time and with direction in the sky. *Voyager 1* and *Pioneer 10* are each




***Below: During the 1986 encounter, Uranus' moon Miranda stole the show with its strangely contorted face. In this image, two of its puzzling coronae are seen (top right and bottom). To explain such features, scientists once suggested that the moon had been blasted apart by impacts and reassembled by gravity. Now they believe a more mundane explanation of melting ice and upwelling may account for Miranda's appearance.***
***Image: United States Geological Survey, Flagstaff***

between 60 and 65 astronomical units (1 AU equals 149,597,900 kilometers, or about 93 million miles) from the Sun. However, *Voyager 1* and *Pioneer 10* are traveling in roughly opposite directions in the sky. *Pioneer 10* sees no evidence of the approaching boundaries, whereas such evidence is plentiful on *Voyager 1*. Even *Voyager 2,* at a distance of about 48 AU, appears closer to the heliopause than *Pioneer 10*.

The heliosphere is compressed and smaller in the direction of the Sun's motion relative to nearby hot stars. That direction is in the constellation Hercules near its boundary with the constellation Lyra. Both *Voyager* spacecraft are leaving the solar system in that same general direction; *Pioneer 10* may be traveling down the "tail" of the Sun's magnetic field.

Solar sunspot activity waxes and wanes on an 11-year cycle. When the solar activity is high, the

heliosphere expands; when solar activity is low, it shrinks. Estimates based on *Voyager* measurements place the heliopause distance (in the *Voyager 1* direction) at between 110 and 160 AU; termination shock distances vary from about 70 to 115 AU. *Voyager 1* will reach 70 AU in 1998 and 110 AU in 2009, but will not reach 160 AU until 2023. Using the declining output of their nuclear power sources, the two spacecraft will continue to transmit useful scientific data until 2015 to 2020.

*Voyager* data also suggest that the termination shock and heliopause boundaries may not be very sharp. At distances beyond the orbit of Neptune (30 AU), electrically neutral particles from interstellar space are electrically charged by interaction with sunlight and become a part of the solar wind. This process slows the solar wind perceptibly and increases its density. It is the increase in density that results in "smearing" of the boundaries.

Another interesting discovery is the observation of dust impacts with the spacecraft every few thousand seconds. These imply a density of about one dust particle per cubic kilometer in the outer solar system. Plasma wave scientists will continue to monitor these dust impacts. The two spacecraft progressively depart farther and farther from the ecliptic plane in which the planets orbit the Sun. The distribution of dust density with respect to the ecliptic plane may help determine the source of the dust.

## The Jovian System

*Voyager 1* encountered Jupiter in March 1979; *Voyager 2* followed only a few months later, in July. Among their more famous discoveries were a ring around the planet and the erupting volcanoes of Io, the innermost Galilean satellite. Since then Io has been recognized as the most volcanically active body in the solar system, and research since the encounters has understandably focused on that unusual moon.

Shortly after the Jupiter encounters of *Voyagers 1* and *2*, the infrared interferometer spectrometer (IRIS) team published evidence that one of the dark "lava lakes" on Io was warmer than its surroundings, perhaps by as much as a few hundred degrees Kelvin (about 500 to 1,000 Fahrenheit degrees). A more extensive analysis by the team shows 11 more hot spots identified from IRIS data.

Over the years, ground-based measurements of Io occasionally have indicated that Io is brighter than normal for about 10 minutes following its exit from Jupiter's shadow. One interpretation of this phenomenon is that sulfur dioxide ($SO_2$) condenses as a thin layer of ice on the surface during the cooling caused by the shadow of Jupiter. Recent analysis of images of the dark face of Io (illuminated by reflected sunlight from Jupiter) has shown that it is bluer than the sunlit side. This is what would be expected if the surface were coated with sulfur dioxide frost. The findings therefore provide evidence for condensing sulfur dioxide frost on the non-sunlit face of Io.

It has long been known that Io influences dekametric (having wavelengths of about 10 meters) radio emissions from Jupiter. Studies of changes in the Jupiter aurora (northern lights) now show that those changes also are influenced by the position of Io in its orbit. In both cases, the connection is probably through the Io flux tube (a flow of electrons between Io and Jupiter). More than a million amperes of current flow in this flux tube.

## The Saturnian System

Saturn was *Voyager 1*'s last planetary encounter; it flew through the system in November 1980. *Voyager 2* made its flyby in August 1981. Saturn's tantalizing moon Titan, with its thick, nitrogen-rich atmosphere, was a primary target for investigation, but the spectacular ring system stole the show. Since *Voyager*, we have discovered that all the giant outer planets possess rings. Once distinguished from the other planets because of its rings, Saturn has become the paradigm for the study of ringed planets.

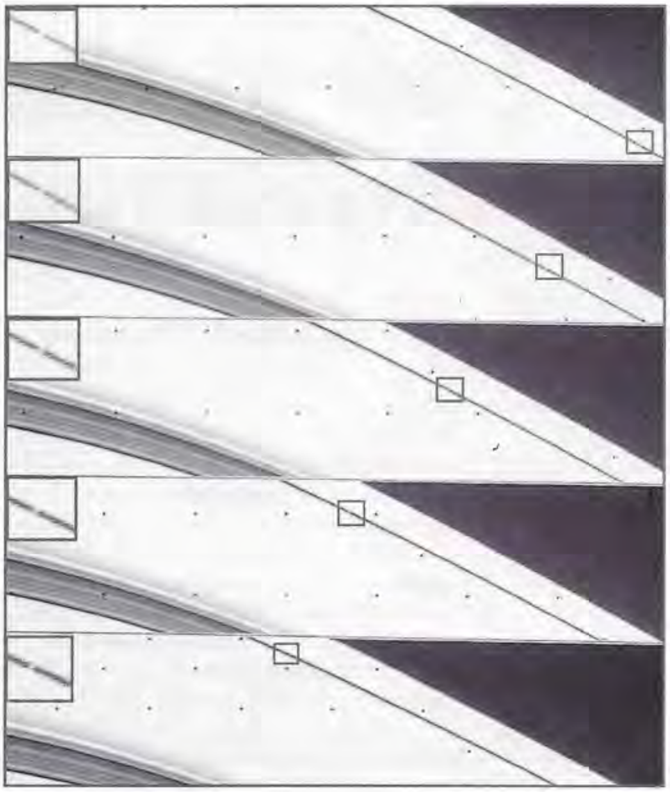
Following the discovery of ring arcs (partial rings) around Neptune in the mid-1980s, searches began for such arcs in the other ring systems. Similar arcs were found in the Encke gap of Saturn's A ring. Because the same arcs were identified in both *Voyager 1* and *Voyager 2* images, these unusual ring features must be stable over a period of at least nine months. Detailed study of images of the edges of the Encke gap and spiral density waves near those edges led to a prediction that they were caused by a small moonlet at a determinable position. Other images were then searched, resulting in the discovery of tiny Pan in the Encke gap. Pan's diameter is estimated to be 15 to 25 kilometers (9 to 16 miles). With the discovery of Pan, Saturn's known satellite count is now 18.

Careful study of *Voyager* and ground-based images of Saturn's extensive E ring has led to the conclusion that E-ring particles have a very narrow size range of 1 plus or minus 0.3 micrometers in radius. This is an important conclusion for the *Cassini* Saturn orbiter, which must pass through the E ring more than a hundred times during its four-year orbital tour. Particles of such small size present no hazard to the spacecraft.

Saturn's E ring is known to be densest near the orbit of the moon Enceladus. This has led to the speculation that the tiny ice or dust particles that make up the E ring may originate from "water volcanoes" on the moon. Analysis of the *Voyager* imaging data and theoretical considerations now suggest another possibility. Dust particles in the E ring collide with eight of Saturn's satellites: Mimas, Enceladus, Tethys, Telesto, Calypso, Dione, Helene and Rhea. Some of these impacts are of high enough velocity that many new dust particles are launched into Saturn orbit. The theory also accounts for the density peak near Enceladus. The E ring may thus be self-sustaining.

Ring systems of the four major planets appear to be much younger than their planets, according to *Voyager* data and theoretical considerations. While the planets may have had ring systems since shortly after their formation, the present ring systems must be regenerated by ongoing processes. The primary source of ring material is likely the collisional breakup of small moons, which themselves may be the product of the breakup of larger moons.

Continued analysis of *Voyager* data now confirms that there is a 99 percent probability that the amount of argon in Titan's atmosphere is less than 6 percent. This has important implications for the design of the *Huygens* probe's descent to Titan's surface in 2004. The probe, built by the European Space Agency, will be carried to Saturn as a part of NASA's *Cassini* mission.



*Within Saturn's bright, icy rings is a dark division—usually called the Encke gap after Johann Franz Encke—that is relatively free of ring particles. If you look closely at this series of images, you can see what has been sweeping this gap clean for centuries: a small moon named Pan.* Voyager 2 *took these images in 1981, but Pan was not discovered for 10 more years, after painstaking investigations to determine what caused the gap. Mark Showalter predicted where a moonlet should be, and when he checked back through the* Voyager *images, there it was.*
*Images courtesy of Mark Showalter*

Just beyond Titan is Saturn's moon Hyperion. Initial studies indicated that Hyperion's rotation was completely chaotic, changing in direction and speed each time the moon passed Titan. More recent analyses point to a long-term regularity, with a rotation period near 13 days.

## The Uranian System

Uranus' bland, blue face was a bit of a disappointment for scientists during *Voyager 2*'s January 1986 encounter with the planet. Its thin, dark ring system could not compete with the glimmering disk around Saturn. But one member of the uranian system captured the attention of scientists and public alike: Miranda, the moon with some of the most bizarre terrain yet seen in our solar system.

Miranda's coronae (nearly rectangular areas of multi-concentric "racetrack" features at three locations on the surface) are continuing to offer a theoretical challenge to scientists. Initially, many thought that Miranda had been shattered, and that the present satellite of Uranus was reassembled gravitationally. It now seems more likely that the coronae were formed from partial localized melting and upwelling of partly melted ices, rather than from the total disruption of Miranda.

The International Astronomical Union's Nomenclature Commission has officially named the newly discovered satellites of Uranus. In order from the planet, the moons are Cordelia, Ophelia, Bianca, Cressida, Desdemona, Juliet, Portia, Rosalind, Belinda, Puck, Miranda, Ariel, Umbriel, Titania and Oberon.

## The Neptunian System

Neptune was the last encounter for *Voyager 2* before it headed off in search of the edge of the solar system. At the time of encounter, this beautiful blue world was marked in its southern hemisphere with a giant storm, called the Great Dark Spot because of its resemblance to the famous Great Red Spot on Jupiter. The jovian spot has been around for at least 300 years—as long as people have been able to see it. Neptune's spot seemed remarkably similar to Jupiter's, so some assumed it was a long-lived feature. But in June of 1994 the Hubble Space Telescope looked for it, and it was gone. Then, a few months later, a nearly identical spot appeared in the northern hemisphere.

Neptune is an extraordinarily dynamic planet that continues to surprise us. Its largest moon, Triton, provided surprises of its own during encounter. Ice geysers erupt through the surface of this icy moon in one of the strangest forms of volcanism yet seen in our solar system.

Triton's internal heat source is larger, relative to heating from the Sun, than that of any solar system satellite except Io. It has been suggested that some of this heat may arise from a solid-state greenhouse effect, in which sunlight penetrates through relatively clear nitrogen ice and heats the subsurface. Because the nitrogen ice is opaque to the resulting infrared radiation, the heat cannot escape, and heat buildup occurs.

Triton's surface temperature has been refined to 34.5 degrees Kelvin (minus 398 degrees Fahrenheit), even colder than previously thought. The warmest detected temperatures are found on the nightside of Triton, north of its equator. The derived temperature of 38 degrees Kelvin (minus 391 degrees Fahrenheit) provides the first evidence for an area of Triton's surface that is devoid of nitrogen ice.

Neptune's moons have also been officially named by the IAU; they are, in order from the planet, Naiad, Thalassa, Despina, Galatea, Larissa, Proteus, Triton and Nereid.

So, even though the *Voyager* spacecraft completed their last planetary encounter in 1989, they continue to surprise and delight us, even while teaching us more about the solar system in which we live. And if their power sources and other subsystems hold out, we may have 25 more years of this most extraordinary mission of discovery.

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*Ellis Miner is science manager for the* Cassini *mission to Saturn at the Jet Propulsion Laboratory in Pasadena.*

# Journey to the End of the

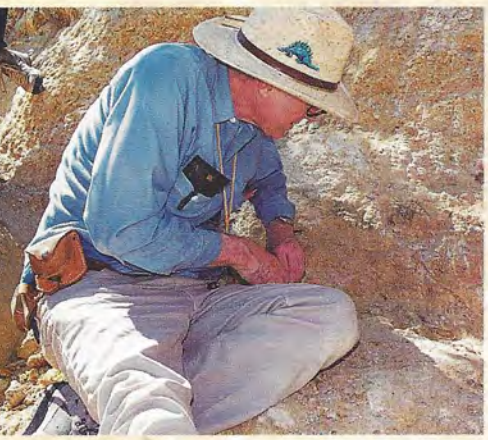
## A Society Expedition

by Adriana C. Ocampo

*Lyell said change is gradual, Mr. Darwin agreed,*
*Geologic time fulfilled their need.*
*But some cases were irreverent,*
*Sudden changes more evident,*
*Errant bodies from the heavens did the deed.*

*—Richard Weddle, January 1995*

As living organisms, we have a vested interest in the evolution of life and its intricacies. The geologic record contains evidence of mass extinctions, where large numbers of species that flourished for millions of years abruptly disappeared. Such extinctions pose a riddle whose solution concerns us all.



**Walter Alvarez, one of the discoverers of the iridium anomaly in the boundary between the Cretaceous and Tertiary periods, was a welcome participant in this Planetary Society expedition. Here he examines the rocks marking the K/T boundary in Belize.**
Photo: Lu Coffing

Among the five major mass extinctions that are recorded in the stratigraphic layers of our planet, the one that took place 65 million years ago at the K/T boundary—the boundary between the Cretaceous period and the Tertiary period that followed it—is perhaps the most relevant to humans.

Over 50 percent of all living species became extinct at that time. The dinosaurs, which had reigned for over 150 million years, disappeared, and mammals, which were represented by mere rodents at the time, assumed the evolutionary path to dominance. It is a challenge to explain the sudden disappearance of the dinosaurs. Certainly something significant happened that provided the opportunity for the emergence of mammals and eventually *Homo sapiens.* As we shall see, the phrase "Thank your lucky stars" has a very special meaning when it comes to our own evolution.

The first clue to the cause of the demise of the dinosaurs was found in Gubbio, Italy, in 1980 by a team of scientists led by Luis and Walter Alvarez. Team members found a large concentration of iridium, an element rare on Earth but relatively common in comets and asteroids, in a layer of clay that marked the K/T boundary. They proposed that such an unusually high concentration of iridium could only have come from an extraterrestrial object at least 10 kilometers (6 miles) in diameter that struck Earth 65 million years ago. Dust and debris from such a large impact, they suggested, would have enveloped the planet and blocked out the Sun, shutting down photosynthesis and cooling the surface dramatically. The Alvarez team proposed that this catastrophic change to the biosphere brought about what is known as the K/T mass extinction.

### Ground Zero Found

The Alvarez theory met with much skepticism, and for many people only the discovery of a huge crater would supply the necessary proof. Ironically, such a discovery was made in Mexico by a team of petroleum geophysicists led by Glen Penfield and Antonio Camargo at about the same time that the Alvarez theory was presented. However, few heard of this discovery, and it took 10 years to rediscover the crater now believed to be the protagonist in this melodrama.

The crater, over 200 kilometers (120 miles) in diameter, is located in the northwestern Yucatán peninsula in Mexico and has been named Chicxulub, "the devil's tail," in the local Mayan dialect. (Chicxulub is also the name of a small town near the center of the crater.) Overwhelming evidence has been gathered that points to Chicxulub as ground zero of this catastrophe: Shocked quartz (fractured crystals indicative of high-velocity impact), tektites (spherical glass droplets known to form during impact), impact-melted rock hundreds of meters thick that has been radiometrically dated to 65 million years ago, and tsunami wave deposits—all these have been found in or around the crater.

### A Scenario for Extinction

But the question is, did this impact produce the global catastrophe that caused the mass extinction? Current theory paints this picture: Immediately after the

# Dinosaur Era:

## to Belize

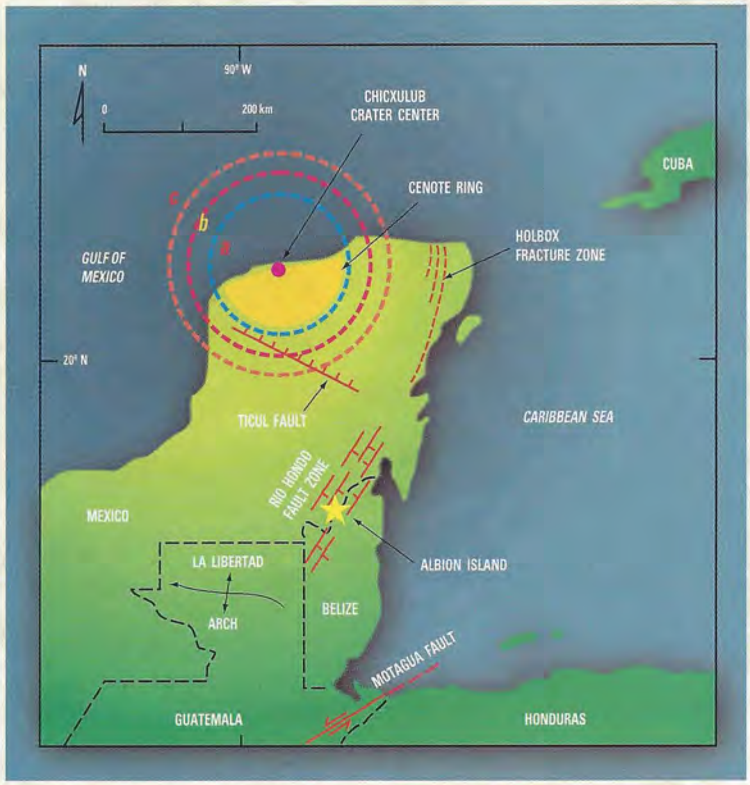
asteroid or comet hit the Yucatán peninsula, large amounts of dust and gas, several trillion tons worth, were ejected, reaching high above the stratosphere and encircling the globe.

The energy of the incoming projectile was high enough to vaporize much of the rock immediately in its path as it punched a hole many kilometers deep in Earth's crust. Large earthquakes devastated the region close by and reverberated around the globe. Tsunamis hundreds of meters high rushed out from the crater, across the Gulf of Mexico, and crashed on the shores as far away as Alabama. The waves continued to slosh around for perhaps days, as if the Gulf were a giant bathtub.

The heat produced by pieces of ejecta as they reentered the lower atmosphere in a tremendous meteor shower ignited global wildfires that blackened the sky with soot. The combination of the soot, dust and gases blocked out the Sun to the point that vision was impossible, temperatures plummeted and photosynthesis ceased. This period of near total darkness may have lasted about six to nine months, but perhaps no more than three, after which the skies mostly cleared and temperatures rose.

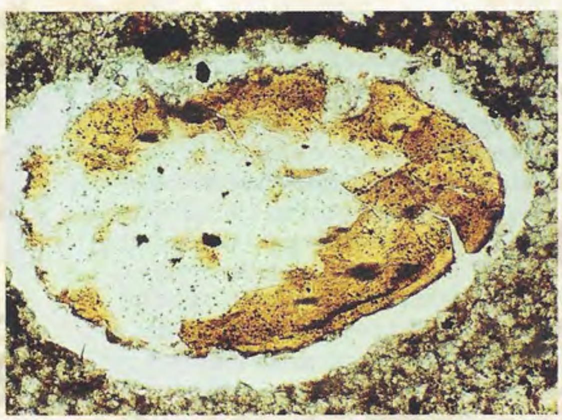
The show was not over, however. The gases that lingered in the upper atmosphere included sulfur dioxide, a product of the vaporization of sulfate-rich rocks. The sulfur dioxide began to produce massive sulfuric acid clouds, like those that engulf Venus today. These clouds blocked out 80 percent of the sunlight, and Earth settled into a decade of perpetual, severe winter. And as the sulfuric acid clouds condensed, surviving species were doused with acid rain. It is truly remarkable that any species survived, and those that did confirm the great tenacity of life on our planet.

Much of the foregoing scenario is the product of theory or of computer models that extrapolate our meager experiments and personal experience to catastrophic scales. However, our recent chance to observe the comet Shoemaker-Levy 9 impact on Jupiter confirmed that such impacts do happen, and while that impact was slightly removed from "personal experience," some of the events predicted for Chicxulub were observed on Jupiter. Nevertheless, geologists realize that while such models work well in a computer, the challenge is to find the evidence in the field to verify this cataclysmic scenario. Chicxulub certainly presents us with a fantastic opportunity to investigate what may have been the largest impact on Earth since complex life evolved.




***Albion Island in the Rio Hondo is the site of a quarry in which the Cretaceous-Tertiary boundary is exposed. Since this is the closest outcrop to the Chicxulub crater, the island is an excellent place to search for materials thrown out by the asteroid or comet impact.*** *Map: Adriana Ocampo, rendered by B.S. Smith*

***Expedition team members were in Belize to work, and that involved scientific fieldwork. Here geologist Eugene Fritsche gives a short lesson in three-dimensional mapping.*** *Photo: Lu Coffing*



***Tektites, small droplets of minerals melted into glass, are common markers of extraterrestrial impacts. This one, encased in carbonate rock, was found by our team within the K/T boundary layer in Belize. This provides more evidence supporting the impact theory for the extinction of the dinosaurs.*** *Photo: Adriana Ocampo*

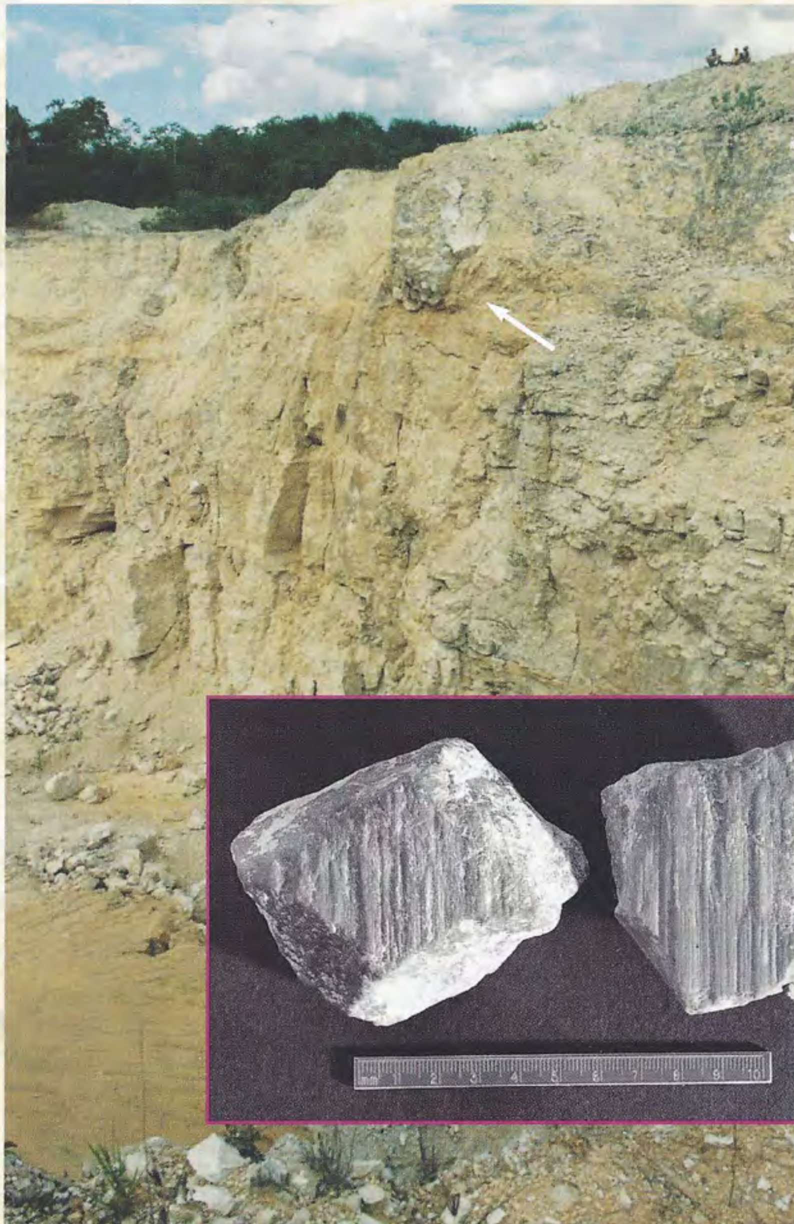
### We Begin in Belize

Today, the Chicxulub crater lies between 300 and 1,000 meters (about 1,000 and 3,000 feet) below the surface, and even though the crater is extremely well preserved

the protective blanket of younger sediments makes detailed studies difficult. As a result, much is still not known, and in fact the crater's exact size, between 180 and 300 kilometers (110 and 190 miles) in diameter, remains controversial. More geophysical studies are under way, including the use of a space shuttle imaging radar (SIR-C), which reveals subtle surface structures, to get at the diameter question.

In search of more evidence and an understanding of how the end of the Cretaceous came about, in January of 1995 an enthusiastic group of Planetary Society members and scientists traveled to the young country of Belize, about 364 kilometers (226 miles), or about three crater radii, from Chicxulub. Belize is unique in that it contains an outcrop of Chicxulub ejecta that is more than 100 kilometers (60 miles) closer to the crater than any other.

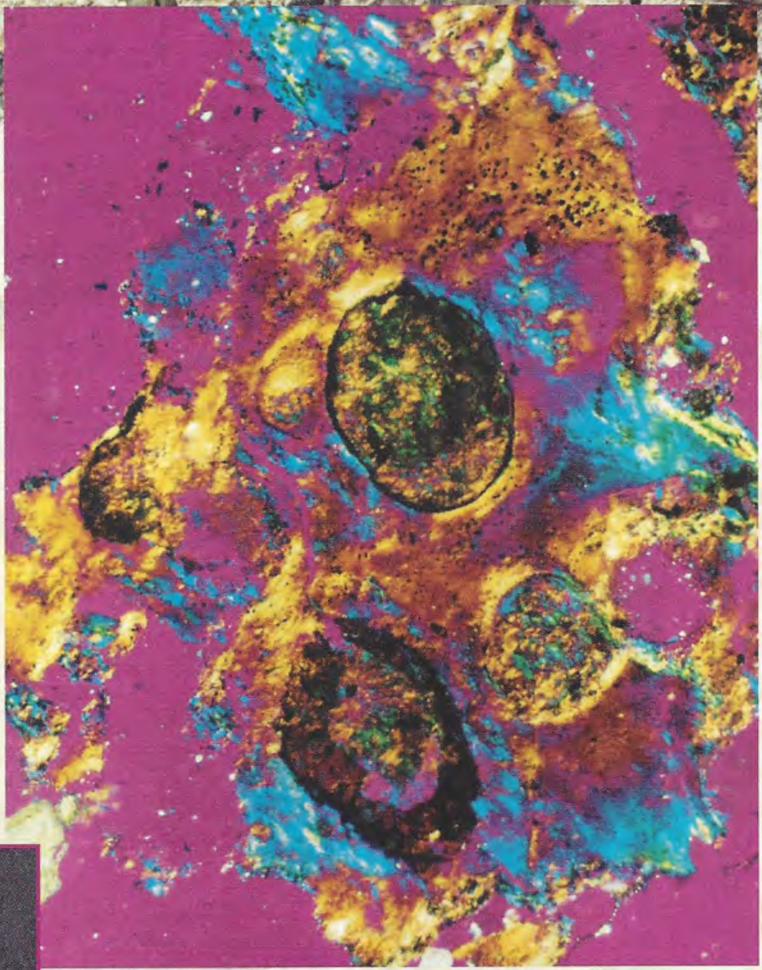
The expedition included avid supporters of the impact-extinction hypothesis, and skeptics as well. To keep us on the right track, we had the help of one of the fathers of the theory, Walter Alvarez; microtektite specialist Philippe Claeys; paleontologist Francisco Vera Vega; field geologist and mapping expert Eugene Fritsche; and an expert in the geology of northern Belize, Kevin Pope. The richness of the expedition was enhanced by the multitalented Planetary Society group that completed the "dream team": Millie Alvarez, Sandi Atwood, Lu Coffing, Robert Cozzi, Gene Giberson, Kenneth Jones, Carmen Musgrave,



*Left: This undulating layer is the K/T boundary near the top of the massive dolomite of the Albion quarry. It contains the evidence pointing to an extra-terrestrial object as the villain behind the disappearance of the dinosaurs.*

*Inset: The Albion quarry shows the grand vista of the K/T boundary.*

*Photos: Adriana Ocampo*



John O'Brien, Joyce Stark, Richard Stark, Richard Weddle, Christina Wilder and Norman Wilson. The challenges were many, but there was certainly no lack of enthusiasm, and sense of inquiry, wonder and discovery.

Our search started on Albion Island in the Rio Hondo, near the city of Orange Walk (about a two-hour drive from Belize City) in northern Belize. The island is home to the town of San Antonio (population 500) and a dolomite quarry. We spent the first nine days working at the quarry.

The quarry presented us with a magnificent vista of the K/T boundary. Here we took stereo photographs of the boundary and mapped it in three dimensions. The stereo photography was an excellent tool for recording changes in this active quarry and would help us verify details of the stratigraphy back in the lab. Mapping the quarry gave us insight into the three-dimensional structure of the strata and the ejecta thickness.

The strata in which the quarry has been excavated are dome-shaped, and the quarry contains two sinkholes (or *cenotes*), which formed relatively recently. The dome may have been emergent (above water) when the material ejected from Chicxulub was deposited. This possibility has important implications for the depositional environment and geochemistry of the rocks at Albion Island.

We constructed detailed stratigraphic profiles and collected numerous samples, our activities mixed with bouts with mosquitoes

*Above: Bubbles frozen in time testify to the tremendous power of the impact. Heat generated by the impact melted rock into glass. While the rock was in liquid form, gas bubbles formed within it. As the rock cooled and solidified, the bubbles were trapped forever. By studying the chemistry of such samples, team scientists hope to learn much more about the impact.* Photo: Adriana Ocampo

*Above left: This giant boulder (arrow) may have come from the Yucatán peninsula, deposited in Belize by the energy of the impact.*
Photo: Gene Giberson

*Left: This close-up of fragments from the large boulder shows the striations cut as the rock was scraped and tumbled by the explosion.*
Photo: Adriana Ocampo

*Geologists use embedded fossils to date stratigraphic layers, so finding animal remains of the right age was crucial to the expedition. At left is a cast of a very well preserved fossil snail; at right is a fossil crab discovered by Planetary Society members. Paleontologist Francisco Vera Vega was particularly delighted by the extremely well preserved crab.* Photos: Francisco Vera Vega (left), Gene Giberson (right)

and the dreaded "chechem" (a Belizean version of poison ivy that reaches tree size) and lots of camaraderie. The quarry provided us with a unique view of the last moments of the Cretaceous, complete with giant, 8-meter-diameter (26-foot) ejecta boulders that gave us but a glimpse of the tremendous power of the impact. The energy estimated to have been released by the Chicxulub collision is between $10^8$ and $10^9$ megatons, or equal to about twice all the world's present nuclear arsenal.

All these pieces of the puzzle are helping us understand and reconstruct an image of the end of the Cretaceous on Albion Island 65 million years ago, both before and after the impact. Impact events such as this one leave a complex array of deposits. During the expedition, we collected samples of carbonate from the ejecta that could give insight into our model predictions of target rock vaporization at Chicxulub. We are currently analyzing the relative amounts of heavy and light isotopes of carbon and oxygen in these carbonates to determine if fractionation due to vaporization has occurred. Isotopes fractionate when they change states, such as going from a solid to a gas. For Chicxulub, when the target material was vaporized by the heat of the impact, the carbon dioxide vapors released should have contained higher concentrations of the lighter carbon and oxygen isotopes, with the heavier isotopes remaining behind in the solid ejecta. This signature may have been captured in the rocks at Albion Island if some of the gases produced by the impact condensed from the vapor plume.

## Ferreting Out the Fossil Feast

During the last three days of our expedition, we concentrated on reconnaissance, searching for other K/T exposures farther south, near the Rio Bravo ecological reserve. This exploratory work took us deeper into the tropical forest, and although we have not confirmed any other K/T exposures more lab work and fossil identification are required. We did collect lots of samples and gained a greater respect for nature and the beauty of the lucky survivors of that dark episode 65 million years ago. By the end of the 12-day expedition, we had collected 200 kilograms (440 pounds) of rocks and fossils. Geologists use fossils as time markers in the geologic record. Among the discoveries made by Society members were fossil crabs and mollusks that proved to be critical in confirming the K/T age of the Albion deposits.

We left Belize with more questions than answers, as is often the case in the scientific process of discovery. Chicxulub and the K/T extinctions present the scientific community with a multidisciplinary set of problems that can be solved only by studying the intricate web of interactions that make up the Earth system. No single discipline holds the answers to this puzzle, and only a cooperative effort will bring about a complete understanding.

Another expedition to Belize to continue the search is planned for early 1996. Some of the questions that remain are these: How big was the impactor? Was it a comet or an asteroid? Was there more than one impact? Where did the big boulders at Albion Island come from? We gathered lots of data—now laboratory work and interpretation await us. With each step, we get closer to understanding the riddle of our place in the universe.

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*Adriana Ocampo is a planetary geologist at the Jet Propulsion Laboratory.* *This research is supported by The Planetary Society and the NASA Exobiology Program.*

*Join Adriana Ocampo and Kevin Pope in a special on-line conference on The Planetary Society's RoundTable on GEnie. The conference is scheduled for August 1, 1995, from 6:30 to 7:30 p.m. Pacific time.* *See page 19 for more information.*

*The expedition team (left to right): back row, Francisco Vera Vega, Millie Alvarez, Walter Alvarez, Robert Cozzi, Gene Giberson, Philippe Claeys, Sandi Atwood, Richard Weddle, Kenneth Jones, Norman Wilson, Joyce Stark, Richard Stark, John O'Brien; front row, Kevin Pope, Christina Wilder, Adriana Ocampo, Carmen Musgrave, Eugene Fritsche, Lu Coffing.* Photo: Adriana Ocampo's camera

# World Watch

by Louis D. Friedman

**Washington, DC**—NASA faces what may be the biggest threat in its 37-year history. After NASA had accepted a directive from President Clinton to cut $5 billion from the agency's five-year budget (1996-2000), the House of Representatives' Republican leadership ordered another $5 billion to be cut.

Administrator Dan Goldin had already announced plans to reorganize and reduce NASA's workforce by 28,000, to a level lower than at any time since 1961—the year President Kennedy launched the *Apollo* program. The administration's cuts were designed to preserve all current NASA programs. The space station, Mission to Planet Earth, *Cassini,* Near-Earth Asteroid Rendezvous, Mars Pathfinder and Mars Surveyor would have continued as planned, and even the Discovery Lunar Prospector and the New Millennium spacecraft would have been started.

As we reported in the May/June *Planetary Report,* the administration cut reduced NASA's five-year budget to about two-thirds of what was planned just four years ago. The fact that Goldin could take those cuts and restructure the agency was cited by both Vice President Gore and House Speaker Gingrich as an example of how government should be managed. But, the same week he announced the job cuts and agency restructuring, Goldin heard new plans from congressional Republicans to impose the even bigger cuts. They told the agency there would be "no new starts"—which would mean the end of the Lunar Prospector mission and plans for a New Millennium spacecraft. House Republicans also told the agency they could cut (or at least sharply reduce) Mission to Planet Earth.

The Senate budget action is expected to be less severe. But cuts in the Senate are still expected to reach $2.5 billion more than in the president's five-year proposal. These cuts would also affect programs now under way.

The budget path through Congress is just beginning as we go to press, and the final NASA budget will not be completed until September.

The Planetary Society is now campaigning to support the NASA program, and, we believe, the very future of space exploration. Member support—contacting congressional representatives and senators, newspapers, talk shows and so forth—is needed.

**Moscow and Washington, DC**—NASA and the Russian Space Agency (RKA) have decided to defer implementation of a joint mission to Mars until at least 2001. They gave up on implementing a 1998 mission because they could not answer all the technical questions prior to the Gore–Chernomyrdin meeting at which the commitment for the joint mission would be made. The meeting is scheduled for late June 1995.

The proposed 1998 joint mission included a Russian *Molniya* launch of the United States' Mars Surveyor orbiter, together with Russian small stations of the type being flown in 1996. (Officially, three options were being considered: the small stations, launch of a descent module carrying either the French balloon or the Mars Rover; a launch with the orbiter only in the event that no spacecraft could be readied on schedule. However, the small stations option was the most likely.) The planned US Med-Lite launcher with a Surveyor lander would have been the second launch of the mission.

In a mid-April meeting, Wes Huntress of NASA and Yuri Milov of RKA agreed to focus efforts for Mars Together not on 1998, but on a long-range program beginning in 2001 and continuing every Mars opportunity beyond that. Joint missions would be planned for each opportunity. They also agreed to initiate a plan for Russian scientific participation in the US 1998 lander.

Planetary Society members will recognize this as the Mars Together plan initiated by Dan Goldin in January 1994 and endorsed in Gore–Chernomyrdin agreements in June and December 1994. The new plan is simply a two-year delay in its implementation.

What Russia will now plan for 1998 remains to be decided. The efforts to meet November 1996 launch readiness are the first priority and dominate work at the Russian organizations involved. Furthermore, the Russian Academy of Sciences wants all post-*Mars '96* efforts (and money) focused on the Spectrum X-Gamma project. This is a large Earth orbiter carrying an array of international astrophysics experiments to make deep-space measurements observing the universe.

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

# Basics of Space

## Making Tracks

by Dave Doody

When *Voyager 2* passed Neptune, 4 billion kilometers (2.5 billion miles) from here, it hit its bull's-eye of an aim point, only a handful of kilometers wide, within a few seconds of its planned arrival time. How did this come about? How do you figure out the position and speed of a spacecraft so far away? How do you make it go exactly where you want it to go?

Mostly, it depends on its launch. As we saw in the first article in this series (March/April 1995), choosing the proper day of the year and the proper time of day for launch makes certain that the energy available in Earth's solar orbit, and Earth's rotation, are both working in your favor, and that the planned trajectory can be achieved. The launch vehicle and its upper stages are selected to provide just the right amount of energy to add to (in *Voyager*'s case) or subtract from (in *Magellan*'s case) Earth's orbital energy, and they are programmed to fly a carefully chosen course during the short launch period.

Once launched, the spacecraft will be free-falling along its trajectory. Only tiny corrections can be made, once in a while, by firing small onboard thruster rockets. These can do no more than fine-tune the spacecraft's course and speed.

During flight, the spacecraft must be kept in the desired attitude—for example, pointing its communications antenna toward Earth or pointing its instruments toward their targets. You need to be able to change the spacecraft's attitude, too, so that when the onboard thrusters are fired they propel the spacecraft in the proper direction. But attitude control is a whole topic in itself, and we'll take it up another time.

Determining a spacecraft's position in the sky and its velocity is a challenge. To do it you need highly accurate knowledge of Earth's movement in the solar system, knowledge obtained from astronomical measurements. Since measurements of a spacecraft's position are made from a moving planet, Earth, you have to know where Earth is, and just what its motions are, to make sense out of your calculations.

### Tuning In to Radio

Most techniques for pinpointing the location of a spacecraft use radio telescopes. One such technique measures the angle of the radio telescope antenna as you track the spacecraft's faint radio signal. If you know exactly which direction the tracking antenna is pointing in, it follows that you will know where the spacecraft is in Earth's sky. Typically, angles are recorded over time as the radio telescope tracks the spacecraft, and this information is sent to the agency monitoring it—for *Galileo* and for *Voyager*, the Jet Propulsion Laboratory (JPL)—for analysis.

Another technique provides the distance, or range, to the spacecraft. Known as ranging, this is done by a computer transmitting a coded signal to the spacecraft and noting the exact time the signal is transmitted. When the spacecraft receives the signal, it sends it right back. Then the time of reception of the signal on Earth is noted by computer. Now, since we know that the radio signal traveled at the speed of light, and we know exactly how much time the round-trip took, we can figure out the distance to the spacecraft and back.

How fast is the spacecraft moving? You can measure this by using the Doppler effect. If you have ever listened to the siren of an ambulance passing by, you know Doppler. You notice a higher-pitched sound as it approaches, and a lower pitch as it departs. You could measure the ambulance's speed by measuring the frequency of the sound you hear, if (a big "if") you knew exactly what the frequency of the ambulance siren was. I maintain that it's a big "if," because the siren doesn't emit a nice, pure, steady tone. It warbles up and down, its frequency varying greatly.

The same Doppler effect holds true with the radio waves a spacecraft is transmitting. But the key to accurate measurement is to know exactly what frequency the spacecraft is transmitting. If we rely on the spacecraft's self-contained transmitter, we'll get inaccurate results. Its lightweight transmitter is not very stable, and a number of factors—such as aging, or heating and cooling of the electronics—can cause its output frequency to vary over a period of days or years, not unlike the intentional warbling of the ambulance's siren.

### Uplink, Downlink

At the site of each ground tracking station in JPL's Deep Space Network (DSN), which is the worldwide system of radio telescopes that tracks interplanetary spacecraft, there's an extremely stable electronic frequency reference (called a hydrogen maser), kept in a special, temperature-controlled room in the basement. It's very complex, and massive, and could not be carried on a small spacecraft. So it is used to generate a high-power radio signal (called the uplink carrier) that is transmitted up to the spacecraft.

When the spacecraft receives the uplink carrier, it uses that signal, rather than its own unstable electronics, as a reference for generating its own transmitter's signal (called the downlink carrier). Now, when the downlink carrier is received back on Earth, its frequency can be compared with that of the uplink carrier. The difference between them is the result of Doppler effect rather than the result of any warbling spacecraft electronics, and it can be translated directly into a measurement of speed! The speed measured, of course, is the sum of the spacecraft's motion toward or away from Earth, and Earth's motion toward or away from the spacecraft. Since the latter is known precisely from astronomical measurements, it can be subtracted, revealing the spacecraft's speed.

Actually, there is one more factor I didn't mention. You can't have the spacecraft return the same frequency that it receives, or there would be radio interference. So, the spacecraft performs a fractional multiplication and returns the downlink carrier at a different frequency from the uplink. But since the fraction is known, it can be computed back out easily enough on Earth.

## Differenced Doppler

But there's still more information that Doppler can provide. You might want to try an interesting experiment with two other people. Twirl a battery-powered buzzer around on a string in a vertical circle, and have two friends listen to it. Station one friend several feet away from you and directly in the plane in which you're twirling the buzzer. This person will hear the buzzer seem to emit a higher-pitched tone when it is moving toward him or her, and a lower-pitched tone when it is going away. Regular Doppler! But your other friend, whom you've asked to stand a few feet off to the side, will hear a slightly different signal. The buzzer's pitch won't vary quite as much. You know this to be true, since if you had that person stand along a line perpendicular to its orbit, the buzzer would not vary its approach or retreat speed. So if your friend stands somewhere between the two extremes of edge-on and face-on to the buzzer's orbit, the signal will be different.

It turns out that the difference between what your two friends hear would be enough, if measured accurately, to mathematically determine the buzzer's position in its orbit. This very same approach can be used to measure the position of a spacecraft in its orbit around another planet. You have two radio telescopes, at different locations on Earth, watching the spacecraft for a period of time, and then you compare the results. You probably won't be surprised to learn that this data type is called differenced Doppler. To obtain it, of course, you have to have very accurate knowledge of the receiving stations' positions, and a very precise system of frequency and timing reference between them. These are present in the DSN.

## Quasar Signposts

Yet another technique uses two widely separated DSN stations. Both stations first observe the spacecraft's radio signal for a few minutes, taking tens of thousands of samples per second. Then both stations—one in California, for example, and one in Spain—simultaneously move their antennas away from the spacecraft and observe a quasar in the sky, still recording. Quasars (short for "quasi-stellar objects") are actually very distant galaxies that emit strong radio signals. Both antennas record the quasar's signal for a few minutes, and then both of them simultaneously turn back to the spacecraft to record for another few minutes. When the data from this observation are sent back to JPL and correlated, it permits a very accurate triangulation, yielding accurate angles and distances to the spacecraft. This technique is known as very long baseline interferometry, VLBI. The "very long baseline" part refers to the distance between the two stations. "Interferometry" refers to a computer-dependent correlation technique that actually measures the time difference between individual wave fronts of the radio energy from spacecraft and quasar arriving at the widely separated antennas. Quasars are used because they provide a very stable angular position reference in the sky.

## Old-Fashioned Optical Navigation

Now you know about angle data, ranging data, Doppler data, differenced Doppler data and VLBI. All these tools are commonly used to measure the flight paths of interplanetary spacecraft. But when a spacecraft is approaching a very distant planet, as *Galileo* is presently approaching Jupiter, there's another method of obtaining navigation data that, when combined with the previously mentioned types, yields tremendous accuracy: optical navigation. The spacecraft is commanded to assume a desired attitude, rotate its camera to point in precisely known directions, and then take pictures of the target planet or its satellites.

Back on Earth, after the pictures, called opnavs, have been received, they are analyzed to provide information about the spacecraft's trajectory. The analysis uses the location of the targeted planet or satellite in the pictures amid recognizable background stars also in the picture. Typically, this procedure is repeated several times as the spacecraft nears the target planet, providing ample opportunity to zero in on an exact description of the spacecraft's trajectory.

Once the spacecraft's trajectory has been accurately measured, it can be adjusted if it is found to be not exactly the desired path—which is commonly the case. Minor corrections are routine. Corrections can be computed here on Earth, and commands sent to the spacecraft. The commands cause the spacecraft to turn to the desired attitude and then fire its small rocket engines for a specific length of time. The commands then turn the spacecraft back to its original attitude. This is called a trajectory correction maneuver or TCM. *Galileo* will be executing a series of TCMs in July, first to adjust its aim point for Jupiter prior to releasing the atmospheric probe, and then again after probe release, to change the spacecraft's trajectory from an impact course to an orbital entry course.

Next time, we'll take a look at attitude control.

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*Dave Doody is a member of the Jet Propulsion Laboratory's Mission Operations Section and is currently working on the* Cassini *mission to Saturn.*

For more information, check out JPL's *Basics of Space Flight* on the World Wide Web at Universal Resource Locator http://oel-www.jpl.nasa.gov/basics/bsf.htm.

# News and Reviews

by Clark R. Chapman

This spring was difficult for planetary scientists. With NASA "reinventing" itself at a frenetic pace, my colleagues are resigned to the possibility that a casualty may be the field of planetary science, which could become just a sideline for a few academics. That shouldn't be allowed to happen.

The Republican ascendancy in Congress has fueled NASA's downsizing, but the process began in the Clinton administration, within NASA itself. Few would disparage the goals of politicians and agency officials: Make government efficient and less costly; for NASA, foster the research and development (R&D) that has been its goal since the Space Act of 1958. It is a mystery to me how these goals are served by what is actually happening.

Researchers at two NASA centers—Ames in California and Johnson (JSC) in Houston—are frantically looking for new jobs, taking early retirement, or just worrying if their careers are nearly over. In February, a high-level advisory group wrote the "Red Team White Paper," recommending termination (or transfer) of most scientific research at NASA centers, excluding only the Jet Propulsion Laboratory and Goddard Spaceflight Center. The *Apollo* Moon rocks are curated at JSC, where geoscientists conduct world-class research as well on Antarctic meteorites and cosmic dust. But the Red Team would restrict JSC research to the biology of human beings in space.

The planetary group at Ames is among the best in the world, comparing favorably with academia, industry and government labs. But the word from Washington was to rid Ames of science, perhaps by transfer or privatization. How that would save money (the reason behind reinvention) was unclear, since the chief "customer" for basic research concerning the solar system is NASA itself, on behalf of the American public. Yet, in May, NASA Administrator Dan Goldin announced that science at JSC and Ames would be privatized into new "institutes." Even as he spoke, the House voted to slash NASA's budget still more.

Naturally, inefficiencies exist in science as in other human endeavors. But the would-be budget-savers have yet to identify how cutting budgets and axing civil service jobs for scientists, without targeting specific inefficiencies, won't throw the baby out with the bathwater. Rigorous peer review and erosion in planetary research dollars over 15 years have already weeded out second-rate activities. Reinvention also means cutting the cost of missions in half and then quartering it again. That's the philosophy behind the Discovery program. The idea is to have more launches, but that won't make up for the slashed funds. When mission costs are sliced from a billion dollars to just $59 million (the price tag of the Lunar Prospector mission, selected in March as Discovery's next new start), so are scientists' salaries, student assistantships and funds that maintain laboratories in which new instruments are designed and data are processed and analyzed.

Unlike sciences deemed part of a classical education, such as physics and chemistry, planetary science is a new field in which few courses are taught in college physics, astronomy and geology departments. Tenured faculty salaries are supported by endowments or state regents only in an atmosphere where the professors attract additional NASA funds for prestigious research and to support students. Most university planetary scientists are on "soft money"—NASA funds. Even more planetary scientists work outside of academia, wholly on soft money, at private labs and observatories, or at NASA centers. Most of these jobs are now at risk.

Small, cheap missions may collect good data, but they are hardly even a partial (let alone comprehensive) approach to solar system research—the giant planets are off-limits for Discovery. Limited missions hardly inspire the wonder that motivates kids to take science seriously enough to pursue it in college. And they can support only a tiny fraction of the planetary research community. Even the Discovery program is in jeopardy, with Congress considering "no new starts." The new Congress may not realize that NASA requires continual new starts just to accomplish its short-lifetime missions, and that the notion that a new start begins a perpetual entitlement program does not apply. Faced with eroding funds, NASA managers have made ever more draconian (and ageist) attempts to cut short the careers of experienced planetary researchers and to close down laboratories in which the nation has invested for a quarter-century. Yet the sums saved can support only a few percent of the young scientists whose new talents could spur the nation's space science program.

Dan Goldin's rhetoric—and that of Al Gore and Newt Gingrich—would promote R&D and scientific excellence in America, and in NASA in particular. The rhetoric is not matched by the proposed changes, however. Scientists, no matter how brilliant and creative, cannot live by bread alone. Young people will turn to other careers as they find the doors shut on their dreams of becoming space scientists. Maybe taxpayers are hurting so badly that they really *want* to cut not only waste, but also items like scientific research that have helped create America's greatness. But then let's not pretend that scientific research will get *better* as a result of cutting budgets.

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*Clark R. Chapman is a member of the imaging team of the* Galileo *mission, which reaches Jupiter this December.*

# Society News

## Rovers, by George!

We are pleased to announce that George Powell is now working for the Society as a special consultant. He will be heading up the Society's exciting new student telerobotics project, Red Rover, Red Rover, a cooperative venture between us, Utah State University and LEGO Dacta, the educational division of the famous Danish toy company. (See the May/June 1995 *Planetary Report* for a story on how the project began.)

Now a systems engineer at the Jet Propulsion Laboratory, George started working with us while a graduate student at Utah State University, and he has been one of our key volunteers in the Mars Rover tests. You may have read his article in the January/February 1994 *Planetary Report* on the Kamchatka rover tests. His work with us on rovers and the Red Rover, Red Rover project remains a volunteer effort outside of his JPL work. We're happy to have him with us.
*—Louis D. Friedman, Executive Director*

## Micron Challenge Met

We (you) did it! Micron Technology's challenge to Society members to come up with $100,000 in matching funds has been met, and Micron will donate memory chips valued at that amount for use in our Billion-Channel Extraterrestrial Assay (BETA) search program. BETA is now set to begin on October 9, 1995—nearly 10 years to the day after the initiation of Project META (Megachannel Extraterrestrial Assay) and five years after the inception of META II in Argentina.

The enthusiastic response to the continuation of the Search for Extraterrestrial Intelligence, even with no government program operating, has motivated us to expand our program even more, including support for Project SERENDIP from Arecibo, the world's largest radio telescope. Thank you. *—LDF*

## Space Science Workshop

From November 6 to 10, 1995, the United Nations, the European Space Agency and The Planetary Society will hold the fifth Workshop on Basic Space Science in Karachi, Pakistan. The aim of this workshop is to enhance scientific cooperation in space science by providing a forum for the presentation and discussion of the latest developments in space research.

If you are interested in participating, please contact the Society, or get in touch with Adriana Ocampo via e-mail at aocampo@jpluvs.jpl.nasa.gov; also via the World Wide Web at URL ftp://ecf.hq.eso.org/pub/un/un-homepage.html.
*—Charlene M. Anderson, Director of Publications*

## Dinosaurs, Asteroids—and You

Join The Planetary Society's expedition to Belize, January 2 to 13, 1996, and help search for evidence of a major asteroid impact believed to have occurred 65 million years ago. A second expedition in 1996 will take us to Italy in the summer or fall to conduct core sampling in search of additional evidence on the impact event.

For details on both expeditions, contact me at Society headquarters or via e-mail at tps.sl@genie.geis.com. The deadline for applications for the Belize expedition is coming up soon—it's September 15—so please let me know if you're interested. *—Susan Lendroth, Manager of Events and Communications*

## Celebrate *Galileo's* Arrival at Jupiter

On December 7, 1995, *Galileo* will arrive at its long-awaited destination: Jupiter. That same day, a probe that the spacecraft is to deploy in July will enter Jupiter's atmosphere.

We'll celebrate these two arrivals with a special event at the California Institute of Technology in Pasadena, California. The evening program will include live updates on the mission from the Jet Propulsion Laboratory. There will also be a presentation on *Galileo*'s accomplishments since its launch, as well as on what's in store during its exploration of the jovian system.

To obtain tickets to this very special event, please contact me at the Society.
*—SL*

## Talk Live With Leading Planetary Scientists

We'll continue our real-time on-line conferences on GEnie with a July event focusing on *Apollo–Soyuz*. Details will be available on-line. On August 1, you'll be able to ask Adriana Ocampo and Kevin Pope about the extinction of the dinosaurs. To learn how you can attend the sessions, send e-mail to Kari Magee at tps.km@genie.geis.com or contact Society headquarters. *—Michael Haggerty, Information Services Manager*

## Society Launches NEO Newsletter

Since last year's historic collision of Jupiter and comet Shoemaker-Levy 9, the Society has been planning its newest publication—*The NEO News,* a quarterly newsletter about near-Earth objects. Launched on April 24, *The NEO News* is edited by Richard P. Binzel of the Massachusetts Institute of Technology. It covers comets, meteors, asteroids and other objects that orbit near Earth—and occasionally collide with it. Subscriptions cost $12 for Society members, but a special introductory rate of $10 is now available. To subscribe, or for more information about this and other Society newsletters (*The Mars Underground News* and *Bioastronomy News*), contact Society headquarters. *—MH*

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# Questions and Answers

***Why do Venus and Mars have such weak Van Allen belts while Earth and the gas giants have stronger ones?***

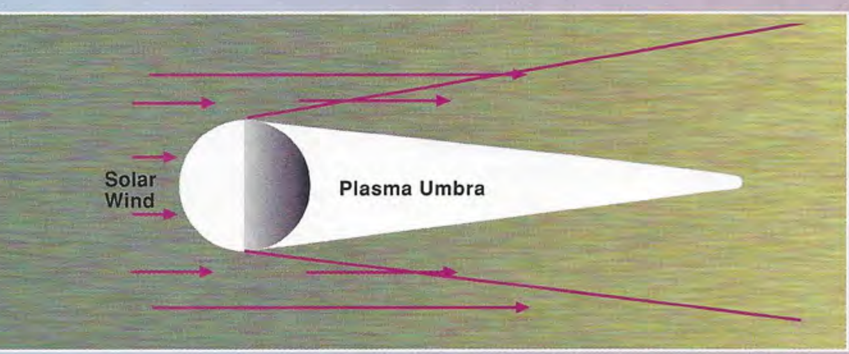
***Do any moons of the gas giants have noticeable Van Allen belts?***

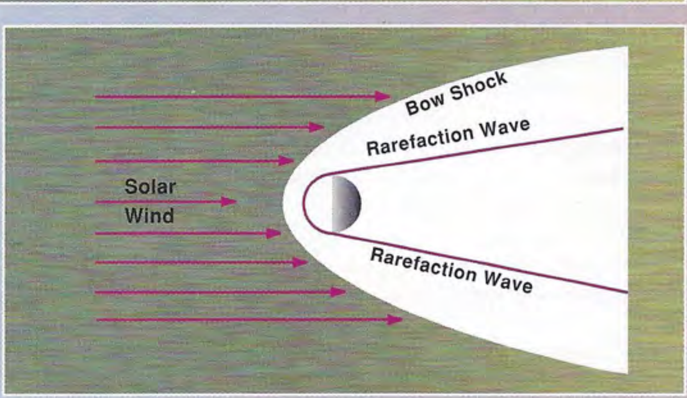
***How will weak Van Allen belts affect humans staying on Mars for long periods? Can they adapt?***
**—John Fitch, Herndon, Virginia**

The dominant constituents of planetary radiation belts are energetic electrons and protons. The two principal sources of such particles are the solar wind—the hot ionized gas that flows outward from the Sun—and decaying secondary neutrons from nuclear reactions of cosmic rays in the atmospheres and surfaces of the planets (and, in the special case of Saturn, its rings). The solar wind is now known by direct observation with the *Pioneer* and *Voyager* spacecraft to be present throughout the solar system out to and beyond the orbits of all of the known planets, including Pluto. The cosmic ray source is reasonably certain to exist throughout our galaxy.

However, a planetary body—planet, asteroid, cometary nucleus or satellite of a planet—can have a radiation belt only if it is sufficiently strongly magnetic so that charged particles can be durably trapped in its external magnetic field—that is, without escaping into space or without colliding with molecules in its atmosphere or with its surface.

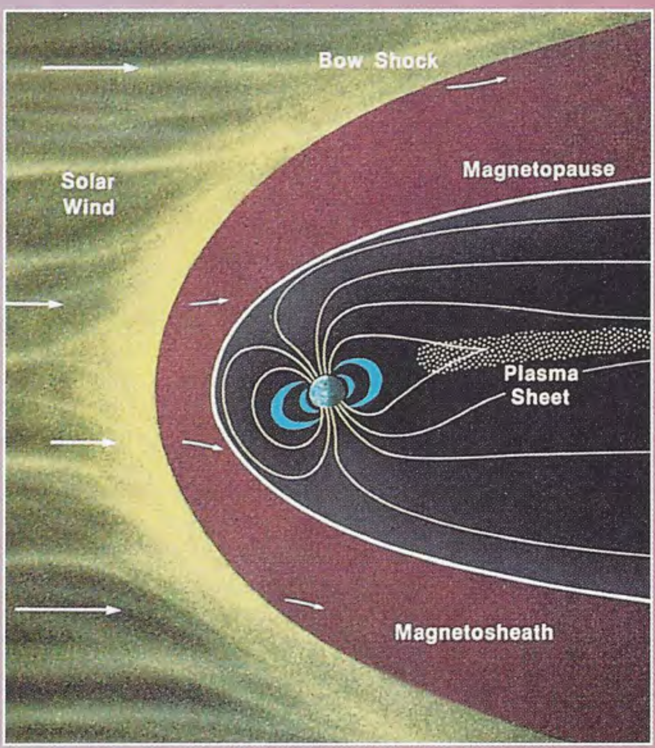
Earth, Jupiter, Saturn, Uranus and Neptune all have extensive radiation belts, the largest and most intense of which is Jupiter's. Because of their much weaker magnetic fields, Mars, Venus, Mercury and the Moon have no radiation belts, though some of the electrons and protons in the solar wind




*Top: Compared to planets with atmospheres or magnetic fields, the interaction of the solar wind with the Moon is fairly simple. The outward flowing solar wind plasma hits the lunar surface directly, and its flow past the Moon creates an umbra, or shadow, that is virtually devoid of matter.*

*Bottom: Although Venus has no appreciable magnetic field, a well-developed bow shock is still produced when its electrically conductive ionosphere interacts with the solar wind. Rarefaction waves are a common aerodynamic effect that occurs when a high-speed flow is interrupted by an inert, spherical body.* *Illustrations: B.S. Smith. Adapted, by permission, from* The New Solar System, *Sky Publishing Corporation*




*This diagram shows the general shape as well as the outlying and main features of Earth's magnetosphere, the region influenced by our planet's magnetic field. Note Earth's inner and outer radiation belts (blue). The outer limits of the magnetosphere are called the magnetopause. When the solar wind bumps into the planet's magnetic field, it creates a bow shock. The solar wind also creates electrical fields and turbulence that distort Earth's outer magnetosphere, allowing a bit of the surrounding interplanetary plasma to be injected into it.* *Illustration: Reprinted from* The New Solar System, *with permission from Sky Publishing Corporation* are weakly accelerated as they encounter these objects. It is extremely unlikely that Pluto, asteroids, cometary nuclei or planetary satellites have radiation belts.

A planet's general magnetic field, if present, is caused by electrical currents flowing in its interior. Necessary conditions for the generation of such current systems are that the planet have a fluid, electrically conducting interior and that the planet be rotating sufficiently rapidly. The strongly magnetized planets apparently qualify on both of these two necessary conditions. No fundamental theory is yet adequate to predict the magnitude of these current systems with quantitative confidence, but it appears that Venus is rotating too slowly and that Mars, Mercury and the lesser objects, including the Moon, have no fluid interiors or, at most, ones of inadequate size.

There is no radiation belt hazard at Mars but, because of its thin atmosphere and the absence of a deflecting magnetic field, its surface is subjected to continuous bombardment by the full intensity of primary cosmic rays and intermittent bombardment by solar energetic particles. It is important to recognize these hazards in a full assessment of the many hazards of missions to Mars, including those during the necessary interplanetary flight. The dense and extended atmosphere of Venus is an effective absorber of these radiations, but the high temperature of its surface precludes operation of even robotic equipment there except for very brief periods of time.
—JAMES A. VAN ALLEN,
*University of Iowa*

***What would have happened if comet Shoemaker-Levy 9 had remained intact and plunged into Jupiter's atmosphere in one piece? Would it have landed in the same region?***
**—Al Slater,**
**Nanaimo, British Columbia, Canada**

While the velocities of the cometary fragments were very well known, we're still uncertain about their masses and bulk densities. One estimate compared the plume height measured by the Hubble Space Telescope with smooth-particle hydrodynamic computer simulations of the impact. This method models the atmosphere as a collection of individual packets of air. The motions of these packets are computed individually, enabling us to track the depth in the atmosphere from which the material in the plume came. Using this technique, T.J. Ahrens of the California Institute of Technology and colleagues concluded that the largest fragment (Q) was about 2.5 kilometers (1.5 miles) in diameter and that the progenitor, before fragmentation, was between about 4.5 and 5 kilometers (about 3 and 3.5 miles).

Therefore, if the comet had not fragmented, Jupiter would have been hit by an object six to eight times more massive than the largest of the impact fragments actually observed. Computer simulations suggest that such an object would have penetrated up to 100 kilometers (about 60 miles) deeper into the jovian atmosphere than any of the fragments did.

According to models of Jupiter's atmosphere, the planet has three cloud decks. The top deck consists of ammonia; below this are clouds of ammonium hydrosulfide and below these we think there are water clouds, although the actual amount of water in Jupiter's atmosphere is unknown. We thought that penetration of these clouds by Shoemaker-Levy 9 (SL9) would help confirm the validity of the models. In addition, there's the question of how much water the fragments contained; to answer this question we have to know how much water in the plume came from Jupiter itself.

Simulations of the event suggest that although the fragments may have penetrated the water clouds, the material present in the plume originated from the upper layers of the atmosphere. This suggests that if the progenitor had hit instead, the result would have been qualitatively similar. Furthermore, since simulations suggest that most of the plume material was from the upper regions of the atmosphere, above the level of penetration, it is questionable whether the nature of the plume material would have been considerably different had the progenitor hit the planet.

All the main fragments hit just behind the limb of Jupiter, and the spread of impact sites was about 3 degrees of longitude. Had SL9 not broken up, it would have followed the same path as the center of mass for the fragments, and it would have hit Jupiter just behind the limb, just as the fragments did.
—MARK S. ROULSTON,
*California Institute of Technology*

# Factinos

According to a team of European celestial mechanicians, the fate of many Earth-crossing asteroids will be to fall into the Sun. This finding, published in the September 22, 1994, issue of *Nature*, is the result of long-term computer modeling of asteroid orbits.

The researchers, led by Paolo Farinella of the University of Pisa in Italy, used numerical integrations to predict the fates of 47 asteroids with orbits that either cross Earth's or approach it. The team found that nearly a third of the asteroids they studied will fall into the Sun in about 2 million years or less. Most dynamical astronomers had previously felt that planet-crossing asteroids would be more likely to collide with one of the planets.
—from *Astronomy*

❖

Recent observations with the Hubble Space Telescope show that weather on Mars has changed dramatically since the *Viking* spacecraft visited during dust storms in the late 1970s. Steven Lee, a University of Colorado scientist involved in Hubble's Mars studies, said that the average temperature on the planet has dropped 20 degrees Kelvin (36 degrees Fahrenheit) since the *Viking* missions.

The implications of these new findings go beyond planetary sciences to the practical aspects of planning missions to the Red Planet. Spacecraft such as *Mars Surveyor* and *Mars Pathfinder* will carry equipment bound for the surface to be slowed in descent (aerobraking) by the planet's atmosphere. Mission designers will have to develop aerobraking schemes that are capable of both handling the full range of atmospheric conditions on Mars and determining what the actual conditions are upon arriving so that the descent can be flown properly.
—from *Aviation Week & Space Technology*

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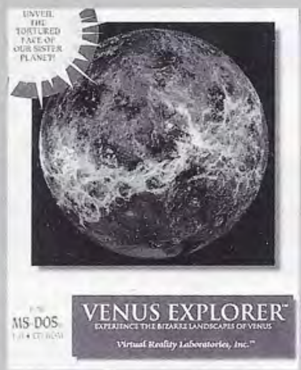


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### Mars Explorer

Photographs obtained from the NASA *Viking* mission bring you an unparalleled view of the surface of the Red Planet. An animated spherical projection displays Mars as it rotates. Easy to use graphical interface allows scrolling over the entire planet's surface and quick location of planetary features. Over 200 MB of images! 2 lb. **#720 $59.00**


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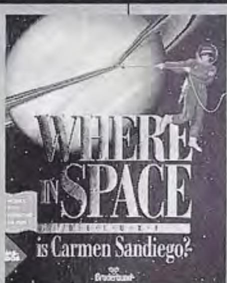


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Neptune's rapidly rotating cloud features may have been a pleasant surprise to scientists during *Voyager*'s flyby in 1989, but the star of the show was the planet's satellite, Triton. This icy world displays a stunningly complex array of surface features. In "Neptune From Triton," David Egge depicts the icy geysers that gush forth from Triton's interior.

David Egge has been producing astronomical artwork since 1977. Like many of today's space artists, he has been inspired by the work of the late Chesley Bonestell, known as the dean of space art.


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Printed in USA