The PLANETARY REPORT

Volume XVI Number 1 January/February 1996

Comet Hale-Bopp Is Coming

On the Cover:

The bright "pinwheel" of comet Hale-Bopp appears against the background of stars in the constellation Sagittarius in this image taken by the Hubble Space Telescope in October 1995. The comet is rotating about once a week, so evaporated debris ejected into space is flung out like water from a lawn sprinkler. This comet appears to be a large one, and some astronomers have dared to hope that it could be the most spectacular comet of the century. It is falling toward the Sun at about 54,000 kilometers (33,500 miles) per hour and by early 1997 it should appear as a bright streak hanging in the sky.

Image: H.A. Weaver, P.D. Feldman and NASA

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From The Editor

This issue is about the future: not a distant future of twirling spaceships cycling among the planets, but the next two years. The coming months promise both excitement and enlightenment for those interested in planetary exploration.

In 1996, we'll see three missions to the Red Planet: Mars *Pathfinder,* Mars *Global Surveyor* and *Mars '96*. This year begins what we hope will be a decade-long series of missions launched to Mars every two years. Such an ambitious, systematic and international campaign has long been advocated by Planetary Society members—and, as these missions launch, each one of you should feel pride that you helped make them reality.

In 1997, nature itself will provide another event generating excitement: the coming apparition of comet Hale-Bopp. The 20th century will not be known for its great comets; since the 1910 appearance of comet Halley, not much has stirred the public's interest in these events. With Hale-Bopp, we have a chance for a great comet, and it will be our responsibility to help alert and prepare the general public for its coming. This natural event could help us build support for planetary missions. Let's get ready to work!

—*Charlene M. Anderson*

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Members' **Dialogue**

SETI

I used to be a SETI optimist, but no more. Over the years Fermi's question, "Where are they all?" has increasingly disturbed me. I think I see where the bottleneck in the Drake equation may be. The problem is in the number of habitable planets that develop intelligent life. This number is very small because life is extinguished by repeated bolide collisions on the vast majority of planets where it has begun to evolve. On four occasions, life on Earth itself came fairly close to being wiped out. Had the comets or meteors been only slightly larger, we certainly would not be here. In short, we are extremely lucky.

We are finally realizing how large a part the bolides play in the evolution of the solar system—even though the evidence has been staring us in the face for millennia when we look up at the Moon. Only recently, with comet Shoemaker-Levy 9 and the announcement of serious searches for near-Earth grazers, have we come to a full appreciation of the dangers. Nevertheless, I see no evidence that this awareness has entered into the SETI debate.

I understand that George W. Wetherill of the Carnegie Institute of Washington has run computer simulations of solar system formation and has determined that gas giants are necessary to sweep the inner solar system free of bolides, in order that inner terrestrial planets may develop properly. But, as we see, even with gas giants to perform this function, bolides are still plentiful and strongly affect the development of the terrestrial planets.

It would be a good idea for a planetary scientist to develop a computer simulation for the inner planets to look at how often bolide impacts that are large enough to cause the extinction of all life occur—with and without a double star Nemesis equivalent. I think that this would greatly inform the SETI debate.

—LES WISOTSKY,
Orlando, Florida

We are at the very beginning of a systematic SETI program, covering the whole sky, the full radio frequency spectrum, etc. To me, this seems hardly the moment to give up. To search is key.

There is a very big difference between the Cretaceous-Tertiary event and an event that would sterilize all life on Earth. Of course, there gets to be a point of diminishing returns, but it could even be argued that a higher impact flux of large bolides is an aid, not an impediment, to evolution. This flux also forces all civilizations to eventually become either spacefaring or extinct.

—Carl Sagan, President

NASA Budget

There seems to be a debate about whether the few billion dollars spent on NASA would be better spent on social programs. The United States spends $260 billion a year on defense, an amount equal to the gross national products of China and India combined. I can't think of a bigger waste than that.

I believe that public opinion is in favor of cutting defense spending and increasing space exploration. Even though this is one of the world's most advanced democracies, what Washington does is not necessarily what Americans want.

Therefore, The Planetary Society should focus its limited resources on the following: (1) convincing members of Congress who represent large aerospace workforces that those jobs can not only be saved but made productive and contribute to the world's economy by moving from military projects to civilian space projects and (2) persuading defense contractors that it is in their best interests, since the Cold War is over, to lobby for and obtain contracts in civilian space projects rather than in military ones.

—A.P. VINAYAGAM,
Santa Clara, California

In response to Robert R. Reimer's letter in the November/December 1995 issue of *The Planetary Report*, if this country made education a top priority and truly pushed scientific research and exploration, we wouldn't have the many social and economic problems we have today. NASA programs transcend the disgusting situations we humans get ourselves into. Such noble and positive programs should be increased, never sacrificed, "for the good of many, and maybe all of us."

—MURRAY A. NEILL,
Camp Lejeune, North Carolina

Gravity Assist

About Arthur C. Clarke's letter in the November/December 1995 issue in which he discusses the early history of the gravity-assist idea: I know of at least one reference to the subject that is even earlier than the 1954 one he cites. The idea was used in Robert A. Heinlein's 1952 novel, *The Rolling Stones*.

In his story, a spacecraft launched from the Moon used a gravity-assist maneuver around Earth to help it on its way to Mars. The physics of the maneuver was discussed in some detail. Unless Heinlein worked the idea out for himself (which was entirely possible), he may have seen it in a still earlier technical paper.

—ERIK ZIMMERMANN,
Toms River, New Jersey

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.

Comet Hale-Bopp: Coming to a Sky Near You

by Don Yeomans

We are long overdue. It has been two decades since Mother Nature threw an impressive naked-eye comet our way. In March 1976, the great comet West stretched across northern hemisphere skies for several weeks, displaying an atmosphere and tail easily seen with the naked eye. On what was probably its first trip into the inner solar system, comet West's impressive performance on the celestial stage was most likely its last. Shortly after passing its closest point to the Sun, the comet's fragile nucleus broke up into several pieces. Unfortunately, truly great comets like West have been relatively rare throughout history.

Because ancient Chinese astrologers kept rather complete records of celestial apparitions over the last two millennia, we know that naked-eye comets have been observed with a frequency of about 30 per century, or about one every three years. Even with today's light-polluted skies, experienced observers can record several such comets in a lifetime, but most of these trophies result from knowing where and when to look. Armed with detailed predictions and finding charts, persistent observers can still see numbers of naked-eye comets. But what about those few comets like West that are so memorable? What about the great comets that are easily visible to anyone who glances heavenward on a clear, dark night? Ten to 20 years is the average interval between truly great comets, and comet West arrived 20 years ago. Yes, we are overdue, but comet Hale-Bopp is coming to a sky near you.

Detected on July 22, 1995, by American amateur astronomers Alan Hale and Thomas Bopp, comet Hale-Bopp was first noted near the globular star cluster M70 in the constellation of Sagittarius. Its fuzzy appearance, which allowed the discoverers to recognize the object as a comet, meant that it was actively throwing off gas and dust. The vast majority of comets become very active only when closer to the Sun than Jupiter's distance. The water ice of the central nucleus then warms and vaporizes, releasing the dust particles embedded in the ice.

Since Hale-Bopp was already surrounded by gas and dust when it was discovered well beyond Jupiter, at a distance of 7.2 astronomical units from the Sun, it was far brighter than most comets are at this distance. (One astronomical unit is equal to the distance from Earth to the Sun, which is approximately 150 million kilometers or 93 million miles.) Either this comet is unusually large, or it is unusually active.

Normally, a comet reaches its greatest activity level (and brightness) when it comes closest to the Sun. For comet Hale-Bopp, this so-called perihelion time is April 1, 1997. Even though the comet will be more than 1.3 astronomical units from Earth at this time, Hale-Bopp could easily become a naked-eye object during February, March and April of 1997. The intensity of its atmosphere (coma) may rival the brightest stars, and its long dust tail may be easily observable by an awe-struck audience for several weeks.

However, we must not forget the disappointing performance of comet Kohoutek in early 1974. That comet, too, was unusually bright when discovered beyond Jupiter's distance, and hopes ran high that it would become the comet of the century when it neared the Sun. Unfortunately, comet Kohoutek turned into the fizzle of the century when its hoped-for celestial display did not match the early promise. The embarrassment of comet Kohoutek was at least partly responsible for astronomers downplaying the predictions for comet West three years later. But West, not Kohoutek, would become the comet of the century. Will comet Hale-Bopp fizzle like Kohoutek, or will it put on a grand display like comet West?

It seems likely that comet Kohoutek was a fairly modest-sized comet that passed into the inner solar system for the first time. The comet proba-

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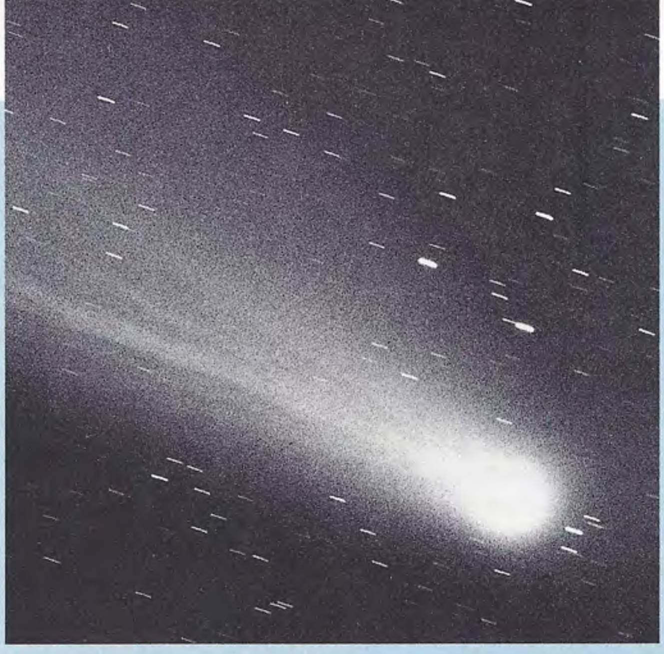


Left: Comet Kohoutek was one of the great astronomical disappointments of the 20th century. From observations made as it approached the inner solar system, astronomers speculated that this large hunk of icy debris would put on a spectacular show that would rival the display so many people remembered from comet Halley in 1910. But the show fizzled, and the only people who enjoyed Kohoutek were those with access to large telescopes. This photograph was taken with the 48-inch Schmidt telescope at Palomar Mountain Observatory.
Photo: Palomar/California Institute of Technology

Above: Where Kohoutek disappointed, comet West delighted. This 1976 comet went relatively unheralded as it neared the Sun. Astronomers felt ridiculed by the popular press after Kohoutek and were shy of going public with predictions of glory for this comet. As a result, few people outside the astronomical community enjoyed West, one of the best comets of the century. This photograph was taken by a Jet Propulsion Laboratory employee watching the sky from the San Gabriel Mountains that rise behind the laboratory.
Photo: Arthur Lane

Left: Comets gain their spectacular tails stretching across the sky only when they approach the Sun. Sunlight warms their icy surfaces and releases gas and dust long frozen in the solar system's outer reaches. The gas and dust then stream out from the nucleus in the direction opposite the Sun. These tails can stretch for hundreds of thousands of kilometers and provide an unforgettable sight for observers on Earth. ***Painting: David Egge***

bly had a frosting of very volatile carbon monoxide or carbon dioxide ices that vaporized at comparatively low temperatures at a great distance from the Sun. However, as the comet approached the Sun, the surface layer of volatile ices was vaporized, the underlying less-volatile water ice was exposed and the comet's behavior became decidedly less extraordinary. Telescopic observations of comet Hale-Bopp have already demonstrated that some volatile carbon monoxide ices are likely present. But are these ices just a surface layer like that presumed to have been on comet Kohoutek?

Unlike Kohoutek, Hale-Bopp has an orbital period of only a few thousand years, so it must have visited the Sun's neighborhood several times previously. In a sense, this comet has been broken in, so if it does have ices more volatile than water ice, they cannot be restricted to a surface layer; that layer would have been vaporized long ago during a previous return to the Sun.

If Hale-Bopp's activity at great distances from the Sun is not due to ices more volatile than water ice, the comet must be very large to explain the amount

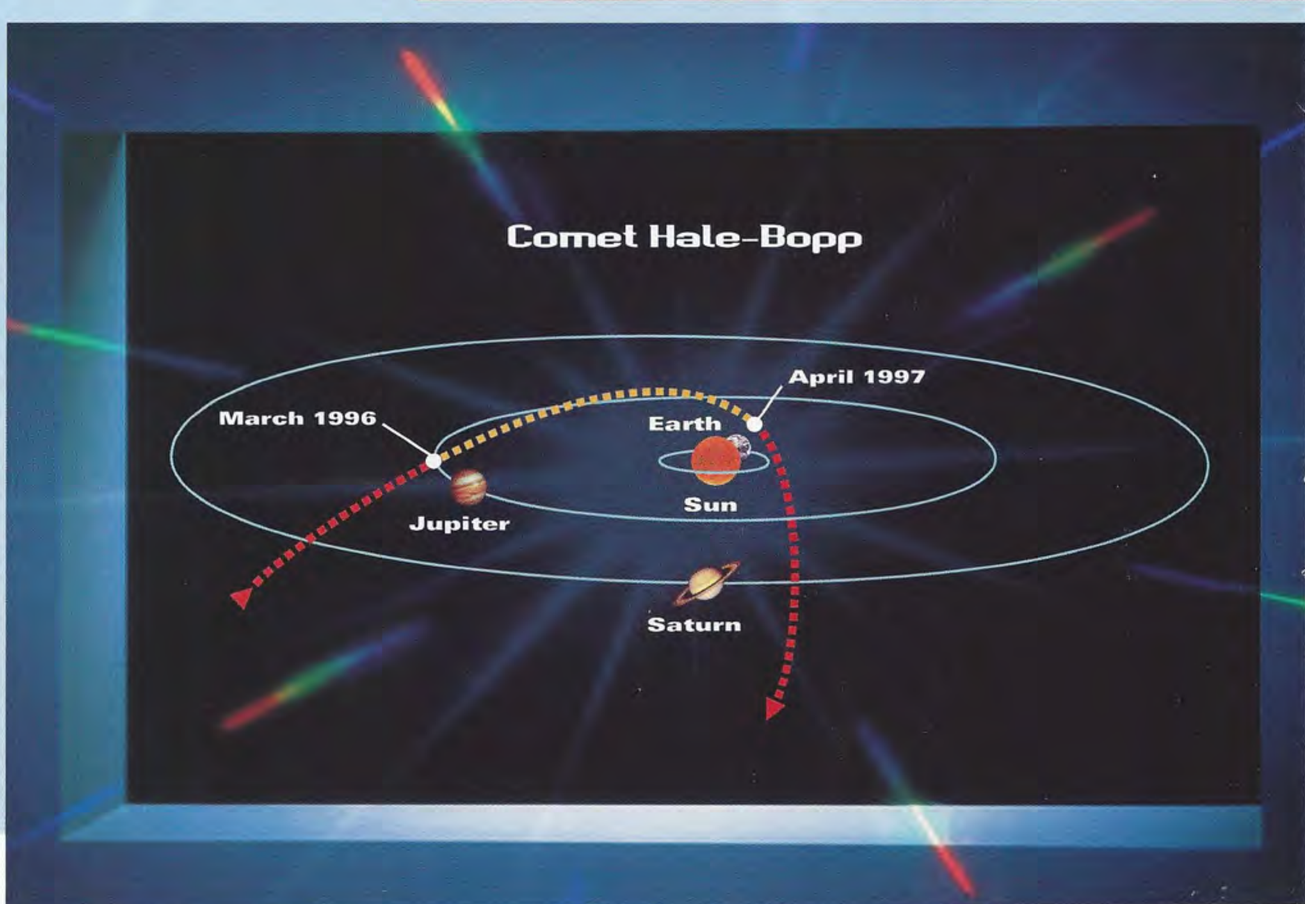
A Toast to the Great Comets

The Great Comet of 1811 may offer an analogy for comet Hale-Bopp. Both comets have orbits that are very highly inclined to Earth's orbital plane, both comets have orbital periods of a few thousand years and both were surprisingly bright when discovered at great distances from the Sun.

The Great Comet of 1811 was observable to the naked eye for nearly seven months and remained visible in telescopes over an interval of 17 months—a period then unprecedented. Comet Hale-Bopp will be observable telescopically for an interval far longer than 17 months, but it remains to be seen whether or not it will remain a naked-eye object for seven months.

Born in 1769 under the naked-eye comet of that year, Napoleon Bonaparte is said to have taken advantage of the notion connecting kings and great rulers with the appearance of comets. He greeted the comet of 1811 as a sign that his army would be victorious in his upcoming Russian campaign. In fact, the reverse would be true, and he and his army suffered tremendous losses at the hands of the Russian army and the cruel Russian winter.

In this illustration, the terrestrial effects of the comet of 1811 are displayed. The comet is represented by a woman whose long tresses are divided into two flowing branches similar to the twin cometary tails noted in October of 1811.



Comet Hale-Bopp is following a long, elliptical orbit that is highly inclined to the ecliptic, the plane defined by Earth's orbit about the Sun. Watched by an observer out beyond Saturn, the comet would appear from beneath the plane of the planets. It would rise above the ecliptic as it nears Jupiter's orbit, pass close by the Sun (at perihelion), then dive back down on its way to our solar system's outer reaches.

Chart: D.K. Yeomans; rendered by B.S. Smith

The woman is carrying two torches that illuminate a desolate landscape littered by a desperate populace.

Throughout much of recorded history, the appearance of comets was thought to presage a change of rulers or kings and to warn of pestilence, war and drought. Occasionally, however, a comet would be given credit for something beneficial. In the foreground of this illustration are bunches of grapes and a wine cask in reference to the great comet wine of 1811. It was supposed that the comet influenced the weather, allowing an unusually good Portuguese port wine vintage in 1811. In western Europe, and especially in Great Britain, the 1811 comet wine was celebrated by connoisseurs, wine merchants and auction houses for decades after the comet of 1811 and Napoleon had left the scene.

If comet Hale-Bopp lives up to its potential, will future wine merchants be extolling the virtues of the 1997 vintage? And while "le vin de Hale-Bopp" doesn't exactly roll off the tongue, it might be appropriate to salute this comet, and the Great Comet of 1811, by raising a glass of port wine while drinking in the coming cometary spectacle. *—DY*

Image from L'Illustration, *March 21, 1877*

of gas and dust seen in its atmosphere just after discovery. But whether Hale-Bopp is very large or composed of ices more volatile than water, it seems destined to provide an impressive display in early 1997. Nevertheless, we can't rule out the possibility of a Kohoutek-like fizzle for comet Hale-Bopp. Mother Nature has a peculiar propensity for pulling the rug out from under those who too confidently predict celestial apparitions. At this early stage, however, the likelihood of Hale-Bopp's being a truly impressive comet looks strong.

If the comet behaves itself, it will be at its best for mid-northern hemisphere observers during the months of March and April 1997. It will then be conveniently placed both in the northeastern sky just prior to dawn, and in the northwest just after twilight. Take your pick, and savor this celestial beauty in the early or late show.

Yes, comet Hale-Bopp has the potential for being a great comet—one that can easily be viewed in a dark morning or evening sky without detailed finding charts, a truly civilized comet. Mark your calendars and get ready for the big one. We are long overdue.

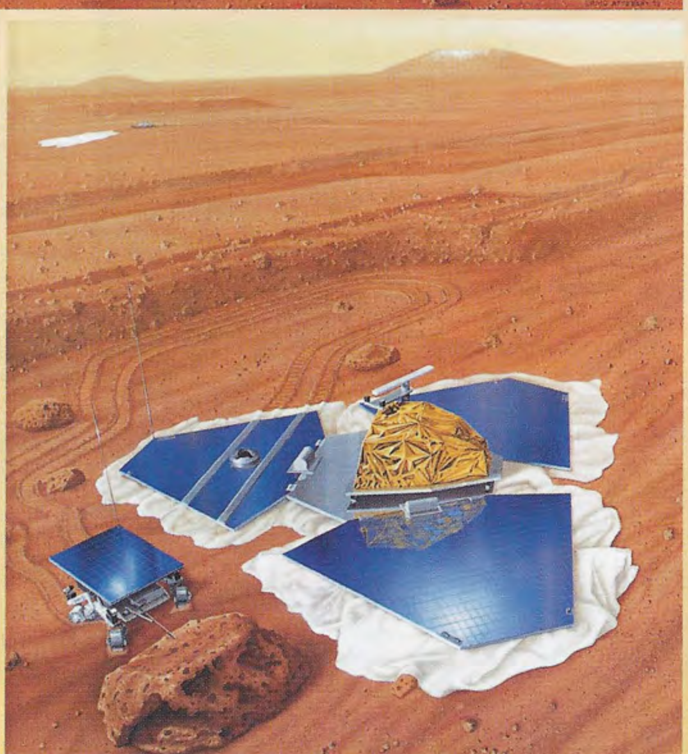
Don Yeomans is a senior research scientist at the Jet Propulsion Laboratory in Pasadena, California.

Taken during the first week of October 1995, this Hubble Space Telescope image of comet Hale-Bopp shows a remarkable pattern of emitted dust. The bright central nucleus is at the lower right, in the four o'clock position. The bright area above it is a cloud of dust that may surround a secondary nucleus that has split off. Spiral dust features apparently form as the comet's ices vaporize from the rotating nucleus and release the embedded dust, similar in effect to a rotating lawn sprinkler.

Image: H.A. Weaver, P.D. Feldman and NASA

Mars *Pathfinder:* Blazing a New Trail

by Matthew P. Golombek



Above:* Mars Pathfinder *will take a novel approach to landing on another world. After a parachute slows its descent, a complement of air bags will inflate to cushion the spacecraft as it contacts the surface. When* Pathfinder *is finally down, the air bags will deflate, three petal-shaped solar panels will open and the instruments will be deployed.

Right:* Sojourner, *the microrover aboard Mars* Pathfinder, *will be attached to one of the petal panels. When the petals are opened, it will roll onto the martian surface and begin its investigations.

Paintings: JPL/NASA

Mars *Pathfinder* will be the first spacecraft to land on the Red Planet since the *Vikings* in 1976. On December 2, 1996, over 20 years after those ambitious craft set down, this small spacecraft will be launched to Mars, with an expected arrival date of July 4, 1997, to resume the exploration of the most Earth-like world in our solar system.

The mission takes its name from the hope that it will be the pathfinder for a series of missions to follow every two and a half years, when the positions of Earth and Mars in their orbits allow for relatively quick passages between them. These "smaller, cheaper, faster" missions, now taking shape under the Discovery program, will initiate NASA's new way of exploring the solar system.

Pathfinder is a relatively small craft, weighing only 850 kilograms (1,870 pounds) when fully fueled at launch. The lander weighs about 300 kilograms (660 pounds), less than half the *Viking* lander weight, and carries a payload (science instruments, rover and rover support equipment) of 25 kilograms (55 pounds).

New Ways to Fly

On its way to Mars, and on the planet's surface, *Pathfinder* will be exploring more than its surroundings. It will also be testing new ways to fly to, land on and investigate a planet. Unlike its predecessors, the spacecraft will not orbit Mars on arrival but will enter the atmosphere directly from its interplanetary trajectory. An aeroshell will absorb the initial heat of entry, and then a parachute will open, slowing the craft. As it descends, the lander will be lowered on a tether beneath the backcover that protected it in space. Just before landing, three small rockets on the backcover will fire, protective air bags will inflate and the tether will be cut.

The air bags, possibly the most novel part of this mission, will absorb the final shock of landing. Once the spacecraft is down, they will deflate, and triangular, petal-like panels will open, righting the spacecraft and exposing its solar panels. Its rover, named *Sojourner* (see the November/December 1995 *Planetary Report*), will then drive off. The spacecraft carries three science instruments (lander imager, alpha proton X-ray spectrometer and atmospheric structure instrument/meteorology package). The lander is capable of surviving for at least 30 sols (martian days; 7 sols equal 7.2 Earth days), with a possible operational lifetime of up to a year. The rover may be able to explore its surroundings for up to a few months.

The rover is a small, 10-kilogram (22-pound), six-wheel-drive, solar-powered vehicle 65 centimeters (26 inches) long by 48 centimeters (19 inches) wide by 32 centimeters (13 inches) high. It will operate almost entirely within view of the lander cameras, never venturing more than a few tens of meters away.

Gathering Data

The rover's primary mission is to perform technology experiments designed to provide information to improve future planetary rovers. But, as a bonus, it will be able to gather valuable scientific information. It carries a set of monochrome stereo cameras that look forward to detect hazards in its path and to return images of the martian terrain. There is a single rear-facing camera, capable of color. Also mounted on the rear is an alpha proton X-ray spectrometer (APXS), which measures the elemental composition of whatever it is placed against. This instrument is mounted on a deployment device that will place its sensor head on rock and soil surfaces, in holes dug by the rover wheels and against rocks that have been scraped by a wheel. The rear-facing color camera will image APXS measurement sites with detail as fine as 1 millimeter (0.04 inch) across.

The lander carries a remarkably capable imaging system called the IMP (Imager for Mars *Pathfinder*). The imager is a stereo system mounted on a jack-in-the-box pop-up mast with 24 spectral filters sensitive to visible to near infrared light. This imager will work together with the rover imaging system to reveal martian geologic processes and surface–atmosphere interactions at a scale of centimeters to meters, a scale to date known only at the two *Viking* landing sites. They will observe the rock distribution, surface slopes and general physiography to help scientists understand the geologic processes that shaped the surface. Since the mission is designed to last up to a year, scientists will be able to assess any changes in the scene over time. Frost, dust or sand deposition or erosion or other surface–atmosphere interactions can change the landscape around the spacecraft.

The rover's wheels will be used as geologic tools to probe the surface. By examining pictures of the rover's tracks, scientists will be able to learn much about the mechanical properties of the soil. The wheels can dig shallow holes, thus revealing what lies directly below the surface. Plus, images of any depressions created during the spacecraft's landing may also prove valuable.

Working together, the APXS and the visible to near infrared filters on the IMP will help determine the composition and mineralogy of rocks and other surface materials. This information can help answer questions about the composition of the crust, its differentiation and the development of weathering products. IMP multispectral images of five sets of magnetic targets distributed around the spacecraft will discriminate the magnetization of accumulated airborne dust. Magnetic targets were carried by the *Viking* landers, and to many scientists' surprise, they all became saturated with dust, suggesting a highly magnetic component in the dust. Examination of the targets by the IMP and the APXS will determine the composition and potential origin of the dust.

Atmospheric Investigations

The atmospheric structure instrument will give us a pressure, temperature and density profile of the atmosphere (with respect to altitude) during entry and descent, which will take place just before sunrise in late northern summer. This will complement similar measurements taken by the *Viking* landers 20 years ago and will provide valuable information for the Mars *Global Surveyor* spacecraft, scheduled to aerobrake into the atmosphere a few months later.

Each day, the lander's meteorology package and the IMP will measure atmospheric pressure, temperature, opacity and wind. Three thermocouples, mounted on a mast about 1 meter (3 feet) tall on a petal away from the thermally contaminating lander electronics, will determine the temperature. A wind sensor on the top of this mast and three wind socks below will measure wind speed and direction. Regular sky and solar spectral observations by the lander camera will monitor dust particle size, shape and vertical distribution, as well as water vapor abundance.

The *Pathfinder* landing site was selected very carefully to provide both a safe and scientifically exciting mission. The chosen site is Ares Vallis (latitude 19.5 north, longitude 32.8 west; elevation 2 kilometers below Mars datum), where a catastrophic flood channel empties into Chryse Planitia (the Plain of Gold, about 800 kilometers or 500 miles from the *Viking 1* site).

This site is designed to sample a "grab bag" of different crustal materials, such as ancient cratered terrain; younger, ridged-plains materials; and reworked channel materials deposited by the flood. Even though scientists won't know the exact provenance of the materials discovered at the site, data from later orbital missions could then be used to infer the provenance for the "ground truth" samples studied by *Pathfinder*. The surface appears smooth at *Viking* orbiter camera resolution, except for streamlined islands nearby, small hills and small secondary craters.

At this site, *Pathfinder* has the potential to make discoveries that will not only increase our understanding of Mars, but also serve as guideposts for planning future missions. *Viking* was possibly the most ambitious planetary mission ever launched, and its scientific return was immense. But the days of launching such large and expensive missions are gone. To reach the planets now, we must uncover ways to do more with less. *Pathfinder* is a step in that new direction. In the realms of both science and technology, this small, inexpensive spacecraft is truly leading the way to a bright future in exploring other worlds.

Matthew P. Golombek is Mars Pathfinder *project scientist at the Jet Propulsion Laboratory.*

Mars *Global Surveyor:* What to Look For in the Results

by Michael Malin

Mars *Global Surveyor* will be launched in November 1996 on a Delta 7925 rocket from Cape Canaveral, Florida. After a 10-month cruise, the spacecraft will enter a 48-hour elliptical orbit. For about six months thereafter, it will gently dip into the upper portions of the martian atmosphere, using atmospheric drag to slowly shrink its orbit. In mid-March of 1998, it will begin its two-year mapping mission 400 kilometers (250 miles) above the martian surface.

Mars *Global Surveyor* will conduct five of the seven investigations originally planned for *Mars Observer,* using the thermal emission spectrometer, the camera, the magnetometer/electron reflectometer, the laser altimeter and the radio transmitter. A sixth activity, the Mars relay, will use a French-built radio receiver to collect data from Russian and American landers (*Mars '96* and *Pathfinder).*

Mars **Global Surveyor** *will use the technique called aerobraking to help slow it as it moves from an interplanetary trajectory into orbit about the planet. During aerobraking, a spacecraft dips into the upper reaches of a planet's atmosphere, using atmospheric drag as a brake. The trajectory must be precisely targeted—too low, and the spacecraft could be damaged or destroyed by heat; too high, and it will not slow enough to be captured by the planet's gravity.*
Painting: Michael Carroll

Thermal Emission Spectrometer

The most versatile instrument on Mars *Global Surveyor* is the thermal emission spectrometer (TES). By measuring the amount of heat coming from the surface and the atmosphere at many different wavelengths, TES will determine atmospheric temperature and pressure at several different altitudes, and the concentration of dust both in layers and spread throughout the atmosphere. These measurements will be the basis for martian weather maps.

TES will also measure the size of particles on the surface, from dust grains to areas of bedrock, by comparing the temperature during the day with that observed at night (the same effect that causes beach sand to be very hot during the day and to be cool at night). The sizes of particles on the surface tell us how the particles were moved (whether by wind, possibly by water, or by other processes). But, most important, TES will tell us what martian rocks, sand and dust are made of, and in what proportions. TES will be able to discriminate volcanic rocks like those found in Hawaii from those erupted by Mount St. Helens. It will search for minerals left behind as possible lakes or other bodies of water dried up, and for minerals that formed when the atmosphere was potentially thicker and wetter than it is today.

Camera

The three cameras on Mars *Global Surveyo*r will take thousands of pictures of Mars. The two low-resolution wide-angle cameras, capable of recognizing features as small as 500 meters (about 1,600 feet) across, can see every part of the illuminated surface every day. A daily low-resolution map of the planet will be constructed from swaths taken each orbit, to observe dust and ice clouds and variations in surface brightness caused by the movement of sand and dust. These maps will be just like weather satellite views of Earth. Movies composed of sequences of these daily maps will show the changing pattern of weather on Mars and, over longer periods, the changing seasons.

The narrow-angle camera, able to see things as small as 3 meters (10 feet) across, such as boulders the size of automobiles, is truly an instrument of discovery—little is known about what it may see. It will be used to search for traces of beaches and glaciers, the effects of water seeping from canyon walls, and layers in polar deposits that reflect climate changes. It will look for the two *Viking* landers, and the *Pathfinder* lander with its small rover. If successful, these pictures will finally tie together the view from the ground and that seen from orbit.

Magnetometer/Electron Reflectometer

This investigation will begin early, during the elliptical orbit phase of the mission. This phase is ideal for searching for a magnetic field resulting from processes inside Mars, and for mapping the interaction between this "intrinsic" field and the field associated with the solar wind, a stream of charged particles flowing outward from the Sun.

Later, from the near-circular final orbit, the magnetometer will look for variations in the magnetic field related to geological or geophysical processes, and the electron reflectometer will look for magnetized rock formations. The spatial resolution of the data collected from this low orbit will permit associations to be made with surface features, such as craters, volcanoes and canyons.

Laser Altimeter

Results from the laser altimeter, which acquires precision measurements of the altitude of the spacecraft relative to the surface of the planet, should very quickly tell us a great deal about the topography of Mars. Measurements made along a given orbit will show the depths of craters, the heights of volcanoes, the steepness of fault scarps, and the slopes of water-carved canyons.

The global shape of Mars, until now mostly inferred from stereo pictures, will become apparent as data from many orbits are used to "grid" the planet; there are plans to make new digital topographic maps of Mars within the first year of operations. Topography and gravity can be used together to probe the interior of Mars—look for discoveries about the thickness and strength of the crust, and about the way the enormous volcanoes in Tharsis maintain their great height.

Radio Science

Since it is important to spacecraft navigation to know the gravity of Mars very accurately, this will be a high priority early in the mapping mission. This investigation uses the Deep Space Network tracking system to monitor the spacecraft radio signal for changes induced by various properties of Mars. Frequency shifts that result from very subtle motion of the spacecraft as it orbits Mars can be related to variations in gravity stemming from subsurface mass distribution.

Over time, a map of gravity variations from place to place will be assembled to study such things as the size of the planet's core, the thickness of its crust, and whether or not there are near-surface anomalies such as those found under active volcanoes. The system may be accurate enough to measure the growth and shrinkage of the seasonal polar caps, which annually freeze out as much as 25 percent of the atmosphere at the poles.

Also starting early in the mission and extending throughout the two years are occultations, where the spacecraft moves behind the planet and the radio signal probes the pressure, temperature and density structure of the atmosphere until the signal is cut off by topography. These occultation measurements show not only how hot or cold the atmosphere is, but also the shape of the planet.

Michael Malin, a geomorphologist, is the principal investigator on the Mars Global Surveyor *orbiter camera. His research focuses on the processes that shape cold, dry areas on Earth and other planets. He was recently selected to provide both orbiter and lander cameras for Mars Surveyor '98.*

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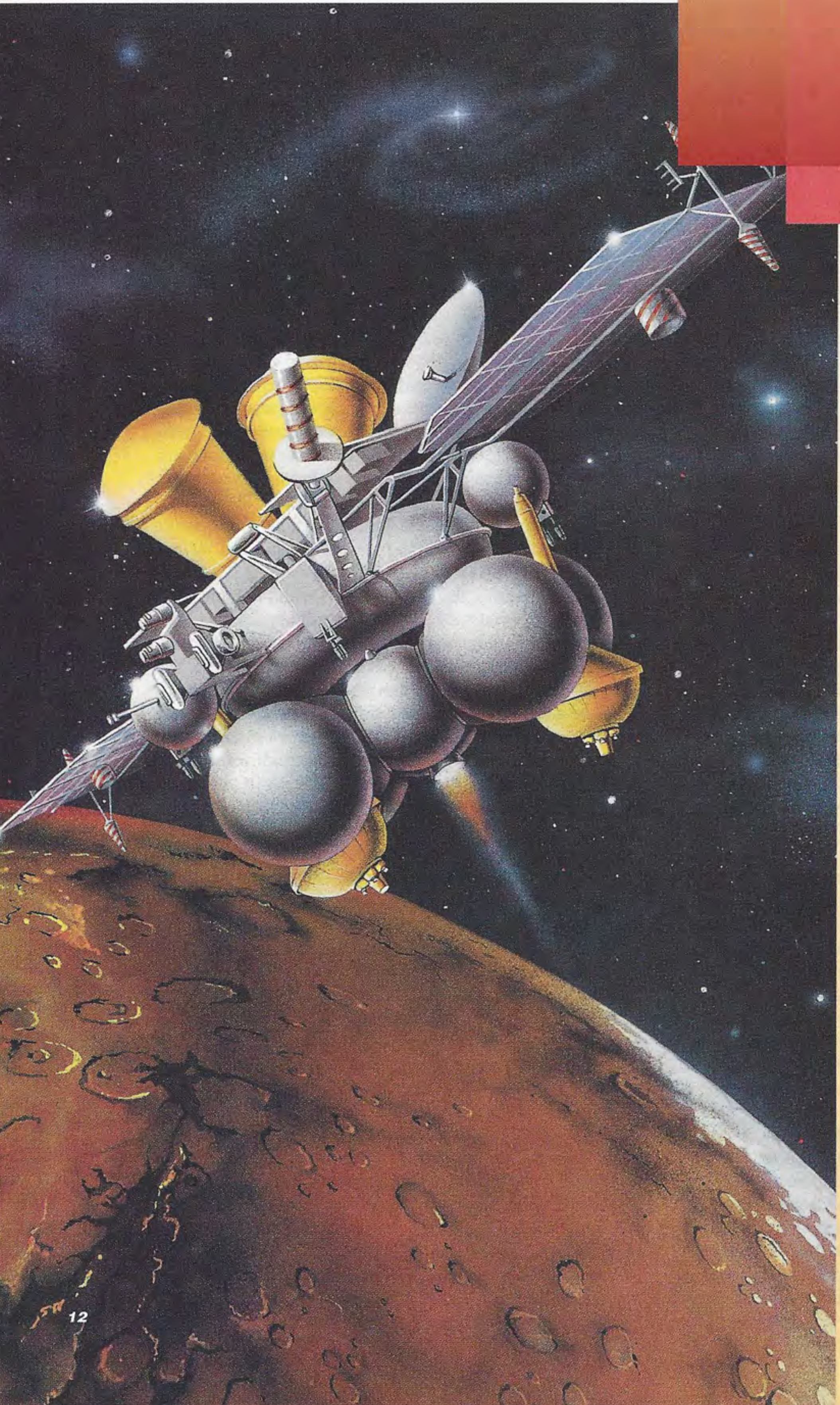


In November of 1996, a *Proton* rocket will be launched from the Baikonur launch site in Kazakhstan, propelling Russia's *Mars '96* spacecraft on its way to explore the Red Planet. The mission consists of the main spacecraft, which will orbit the planet, and the four descent modules it will deliver to Mars: two autonomous small stations (landers), and two penetrators that will pierce the surface. Its purpose is to study the processes responsible for the evolution of the martian surface, atmosphere and climate.

Mission Overview

The main spacecraft inherited its design from the *Phobos* mission, launched to Mars in 1988. Mass at launch will be about 6,700 kilograms (15,000 pounds), of which about 3,000 kilograms (6,600 pounds) will be fuel and 550 kilograms (1,200 pounds) will be scientific instruments. For comparison, *Viking*'s mass at launch was 3,530 kilograms (7,770 pounds).

The orbiter carries 12 different instruments to study the martian surface and atmosphere, plus six instruments to measure the plasma environment and the solar wind (the flow of ionized particles streaming out from the Sun); there are also four astrophysical experiments. The small stations and penetra-

The Mars '96 *spacecraft is based on a design developed for the* Phobos *mission, which was launched to the Red Planet in 1988. Both* Phobos *craft failed, one en route to Mars and one before its mission was completed, but the improved design for* Mars '96 *should eliminate the weaknesses that led to the failures. In this painting of the craft as it would appear before it enters Mars orbit, we can see its antenna on top, solar panels and instruments arrayed around the center, round fuel tanks beneath and, at the very bottom, the small stations as they would appear before their release.*

Painting: NPO Lavochkin

5: Science
ploration
and Scale

.I. Moroz

tors can carry up to 10 tiny instruments.

The spacecraft will take approximately 300 days to reach Mars, and it will make three orbital maneuvers before September 10, 1997, when it settles into a 43.09-hour orbit. Some three to five days before that orbital insertion, the two 75-kilogram (165-pound) small stations will split off. The 100-kilogram (220-pound) penetrators will stay attached to the orbiter for up to 25 days after orbital insertion. Then they too will separate, plummeting directly into the surface to a maximum depth of 6 meters (20 feet). The orbiter is designed to operate for one year after orbital insertion.

Surface Studies

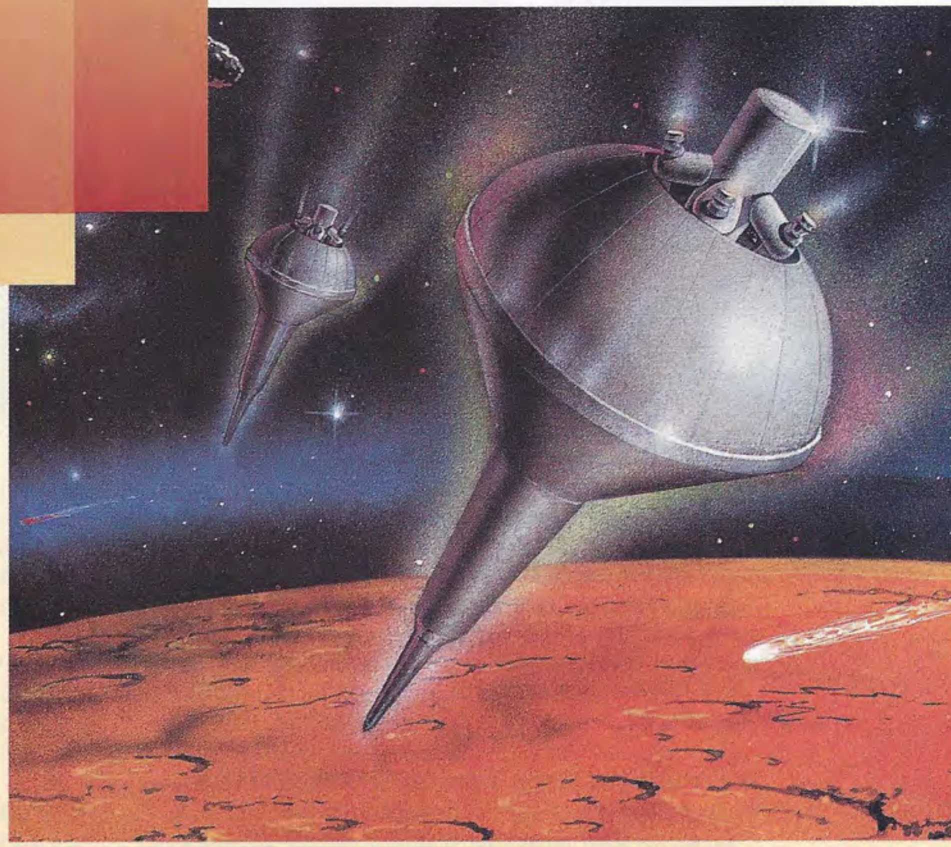
Geological, geophysical and geochemical mapping of the planet's surface will be achieved with television cameras, optical spectrometers, infrared radiometer, gamma and neutron spectrometers and long-wavelength radar. Simultaneous studies using tools covering differing wavelength ranges and measuring differing characteristics of the surface layer should give us a better understanding of tectonics, sedimentation, cratering, and fluvial and volcanic processes acting on the martian surface.

Cameras on the landers will give us more high-resolution images like those obtained many years ago by the two *Viking* landers. We have thousands of pictures taken by the *Mariner 9, Mars 5* and *Viking* orbiters that show us the diversity of the martian surface on scales from tens of meters to kilometers, but we have very little on the scale of centimeters or meters.

The instruments on the penetrators will measure chemical composition and physical properties of the material a few meters below the surface, where the processes that mix surface materials are absent or less effective; instruments on the small stations will measure the composition of the near-surface layers.

Both landers and penetrators will measure seismic activity and local magnetic fields, while

(continued on next page)



***Above:* These odd-looking craft are the penetrators that will be released from the Mars '96 orbiter before it reaches the planet. They carry an array of instruments that will be deployed once their needle-shaped ends are embedded in the planet's surface. This will be the first attempt to use this innovative technique on another planet.**

Painting: Vernadsky Institute of the Russian Academy of Sciences

***Left:* Mars '96 will carry two small stations to the Red Planet. The pod-like craft will hard-land on the surface. Once down, four petal-shaped panels will open, righting the craft no matter what position it lands in. After the petals open, the small stations will be activated and will start to monitor the martian environment.**

Painting: Michael Carroll

Mars '96 will send its small stations directly into the planet's atmosphere, where they will be protected during descent by heat shields. The small stations will monitor the martian weather and climate. They also carry a gift to future martian explorers from the members of The Planetary Society: the Visions of Mars *CD and a microdot inscribed with the names of all Society members as of October 1993. (See the November/December 1993* Planetary Report.*)*

Painting: Michael Carroll

the penetrators will measure temperature changes beneath the surface. Such studies should give new information on the internal structure of Mars, which is one of the important factors governing the evolution of the planet. Other measurements of the planet's magnetic and gravitational field, first by the magnetometer on the orbiter and second by its precise tracking, should further refine our picture of Mars' interior.

Investigating the Atmosphere

The martian atmospheric "machine," with its strong seasonal winds blowing surface materials around and its global dust storms, is a high-priority subject of investigation. Atmospheric temperatures, water vapor and dust and ice hazes will be mapped remotely by infrared spectrometers on the orbiter. Vertical distribution of aerosols, water vapor and some of the other minor constituents will be measured by means of solar and stellar spectra near the limb of the planet. In situ meteorological measurements will be made by the landers.

Mars '96 will also measure the composition and structure of the upper atmosphere. Some important gases (hydrogen, oxygen, nitrogen) escape the upper atmosphere. Mars may once have had a much thicker atmosphere, perhaps similar to that of early Earth. But much of that atmosphere has been lost, and it is important to understand how. These studies will be provided by observations of upper atmosphere emissions in ultraviolet light; in situ measurements by mass spectrometers; ionospheric sounding by radar; radio occultations; and observations of the spacecraft's orbit evolution due to atmospheric drag.

Martian plasma environments (also participating in the atmospheric gases' escape) will be studied by a set of instruments designed to measure the plasma composition, energies of ions and electrons and how they move about, and plasma waves. Related information was collected during previous Russian (Soviet) missions to Mars (*Mars 3, Mars 5, Phobos*), and more advanced experimental approaches will be applied now. Martian plasma environments were never measured by the United States' missions.

Some of the *Mars '96* scientific experiments will be done as the spacecraft makes its way to Mars. Of course, all plasma instruments will measure the solar wind. Instruments will look for gamma bursts in remote parts of the universe. Two instruments have been included for observing oscillations of the Sun and stars. Such observations are a kind of seismology to study the internal structure of the Sun and stars. So some astrophysical experiments are involved in the payload.

An Opportunity for the World

An outsider might say that the *Mars '96* mission is oversaturated by science. No one planetary mission (excluding *Phobos*) has carried such a complicated payload. Mission operations will be no simple task. However, it would not be wise if the tremendous abilities of this kind of spacecraft were not used to their fullest.

The Space Research Institute of the Russian Academy of Sciences is responsible for most of the scientific payload of the orbiter and small stations; the Vernadsky Institute of the Academy, mainly for the penetrators. NPO Lavochkin designed and built the spacecraft and will be responsible for in-flight mission operations. Most of the scientific and technical teams providing experiments for *Mars '96* are international. Experts from 20 countries are working with Russian team members. In some cases, foreign space agencies have taken the main responsibility for scientific instruments. For example, the German space agency was primarily responsible for the television cameras and one of the orbiter's memory units; ESA (the European Space Agency) provided the other memory unit. NASA was responsible for the MOx experiment that is located on one of the small stations; the French Centre National d'Études Spatiales (CNES), for the OMEGA and SPICAM-E spectrometers. The entire world planetary community is interested in the success of *Mars '96.*

V.I. Moroz is head of the Department of Planetary Physics at the Space Research Institute of the Russian Academy of Sciences.

World Watch

by Louis D. Friedman

The year 1996 promises a lot: the launch of four planetary missions, the initiation of the Discovery and Mars Surveyor programs and the rich data stream from *Galileo* at Jupiter.

It has been called the beginning of a new golden age of planetary exploration, recalling the 1960s and early 1970s when each year saw a planetary launch and/or encounter.

But experience dictates caution. Mishaps in recent years remind us to temper our expectations. And we must also keep in mind the smaller scale of these missions; most of them are many times smaller, lower in cost and more focused than their predecessors of a generation ago. Here are the missions to watch in the coming decade.

Current Missions:

Galileo—Jupiter orbit insertion and probe entry on December 7, 1995; from December 1995 to October 1997, orbital tour of the jovian moons; October 5, 1997, Jupiter magnetotail exploration.

Ulysses—Continues in polar orbit about the Sun.

1996: Near Earth Asteroid Rendezvous (NEAR)—United States; *Delta 2* launch in February 1996. Will reach the asteroid Eros in 1999 and orbit it for a year.

Mars *Global Surveyor*—US; *Delta 2* launch in November 1996. The first spacecraft in the Mars Surveyor program, *Global Surveyor* will carry many of the instruments in the *Mars Observer* payload.

Mars '96—Russia; *Proton* launch in November 1996. A large orbiter, two small stations and two penetrators. Many nations, including the US, have experiments on the mission. (This mission will also carry The Planetary Society's *Visions of Mars* CD-ROM.)

Mars *Pathfinder*—US; *Delta 2* launch in December 1996. A Discovery mission, *Pathfinder* will test new technology small landers to explore Mars.

1997: Lunar Prospector—US; launch in June 1997. A Discovery-class lunar polar orbiter; will map the surface composition of the Moon.

Cassini/Huygens—US and the European Space Agency; *Titan 4/ Centaur* launch October 6, 1997. A Saturn orbiter and Titan atmospheric probe; will arrive at Saturn on June 25, 2004. The probe release will be on January 9, 2005; probe entry, January 30, 2005; tour of the saturnian system, February 1, 2005, to June 25, 2008.

Lunar-A—Japan; *M-5* launch. A lunar orbiter that will send three penetrators to the lunar surface.

1998: Mars *Global Surveyor 2*—US; *Delta Lite* launch in January 1998. Includes part of the *Mars Observer* payload and two imaging cameras.

Planet-B—Japan; *M-5* launch in August 1998. This orbiter will study the interaction of the solar wind with the atmosphere of Mars.

Clementine 2—US Air Force mission; possible launch in 1998 to study a near-Earth asteroid.

New Millennium—This advanced technology program includes interplanetary flight tests of miniature components for future planetary missions.

1999: Stardust—US; launch in February 1999. A Discovery mission to comet Wild-2 to return samples of interstellar dust; will reach the comet in January 2004 and return a capsule to Earth in January 2006.

Mars Surveyor Lander—US; *Med-Lite* launch in December 1999. A lightweight lander targeted to a near-polar latitude.

2001: Mars Surveyor/*Mars '01*—Two launches on a *Delta Lite,* or one launch on a *Delta Lite* and one on a *Molniya* as part of Mars Together. There will be an orbiter and a lander in the Surveyor plan. Russia is studying a *Mars '01* mission, which may include a marsokhod (rover).

2002: Nereus Sample Return—Japan. This mission to the near-Earth asteroid Nereus is the first planetary sample return mission in development. Has not received final approval.

2003: *Rosetta*—ESA; launch in January 2003. Asteroid flyby and comet rendezvous; a science station will be deployed on the comet's nucleus.

Intermarsnet—US and ESA; *Ariane* launch. ESA will supply an orbiter for this Mars network of US Mars Surveyor landers. Mission not yet approved.

2005: Mars Sample Return and Phobos Sample Return—This mission has just been cited for study by the US/Russia Joint Working Group.

Also: Pluto Express and Solar Probe—Under development as a US mission and as part of Fire and Ice, an American/Russian initiative. Pluto launch in 2001, 2002 or 2003; solar probe launch possibly in 2003.

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

Basics of Spaceflight: Electromagnetics

by Dave Doody

Electromagnetic radiation and related phenomena are quite basic to every part of spaceflight, from making scientific observations to communicating with Earth. Radio, infrared, visible light, ultraviolet, X rays, gamma rays—all are types of electromagnetic radiation. To see why they're called "electromagnetic," do this experiment at home: Take a meter that measures electrical current and set it to the microampere scale to measure small amounts of current. Attach its test leads to the ends of a coil of insulated wire (a few feet wound around a pencil will do). Now move a magnet along the coil (or move the coil along the magnet).

What happens? The meter's needle deflects, registering the electric current induced in the wire by the moving magnet. Notice that the amount and direction of the meter's deflection depend on how you move the magnet. (By the way, virtually all commercial electricity is generated by moving coils of wire through magnetic fields.)

The reverse is true, too: If you cause an electric current to flow through a wire—for example, by hooking the wire up to a flashlight battery—it will generate a magnetic field. Try this with a second coil of wire. An "electromagnetic wave" is generated each time you connect and disconnect the battery. You'll be able to see its effects on a sensitive meter if your other coil is close enough, and if there are enough windings in your coils. But move the coils apart, and you'll soon fail to see its effect on the receiving coil. That's because the radiant energy thins out as though it were an expanding sphere whose radius is the distance to the transmitter. The amount of energy that can be received, then, decreases with the square of the distance—a loss of strength known as space loss.

Frequency and Wavelength

How frequently you change the field has a lot to do with the characteristics of the radiation produced. Vary a magnetic field once a second, and you'll send out radiation at 1 cycle per second. The term "cycle per second" has been replaced with the name "hertz" (named for German physicist Heinrich Hertz, and abbreviated Hz), so we'd properly call it 1-hertz radiation.

All electromagnetic waves radiate through empty space at the speed of 299,792 kilometers (about 186,000 miles)—almost the distance to the Moon—per second. So the physical distance between the high- and low-intensity peaks of the field (the peaks and lows you saw on your meter), as the wave radiates away, would be almost 300,000 kilometers for 1-hertz radiation. This distance is called its wavelength.

Vary the field about 300,000 times a second (300 kilohertz), and you'll have radio waves a kilometer long. A million times a second (a megahertz) produces shortwave radio. A billion times a second (a gigahertz), and it's called microwave radiation. The higher the frequency at which you vary the field, the shorter the radiation's wavelength.

With shorter and shorter wavelengths, you proceed up the spectrum into infrared, and visible light, which is the electromagnetic radiation that our eyes can sense. Shorter wavelengths yet produce ultraviolet, X rays and gamma rays.

Visible light occupies the neighborhood of 300 terahertz, which is 300×10^{12} cycles per second. The range from red light to violet light spans an octave, to borrow a musical term: Violet light is about twice the frequency of red.

Waves and Particles

Light doesn't just behave as waves; it also seems to behave as if it were made of particles, and this duality can be very interesting to research. "Particles" of electromagnetic radiation are called photons.

Go outside on a sunny day, and you'll be bathed in all kinds of electromagnetic radiation: photons of every sort, coming from the Sun, electric power lines, radio and TV stations miles away, and radar—from the speed sensors that the police use, weather-detecting radar in airplanes, and air traffic control facilities. At radar frequencies, radiation begins to lend itself to being confined into narrow beams, depending on how you construct your antenna. For example, bowl-shaped, parabolic radar antennas concentrate most of their energy in one direction, unlike the rod-shaped antennas used for lower-frequency radio, which broadcast in all directions.

Some of the warmth you feel from the Sun comes from the small amount of its infrared output that it sends out in all directions; only a portion can actually reach Earth's surface, because a lot of the infrared is filtered out by our moist atmosphere. About half of the Sun's light is visible: Since it penetrates the atmosphere, our mammalian eyes have evolved to be able to sense it. A small amount of ultraviolet radiation from the Sun will burn your skin if you let it, but fortunately a high, thin ozone layer in Earth's atmosphere filters out most ultraviolet. The atmosphere likeiwise filters out virtually everything else of shorter wavelength.

Fortunately? Well, for life to flourish on Earth, yes, it's very fortunate that the atmosphere filters out ultraviolet, X rays and gamma rays. Also, Earth's magnetic field diverts cosmic particles that could be harmful. If that were not the case, we wouldn't be here thinking about it. But if you're interested in observing stars and other objects in space, you're limited to using visible light and radio unless you go above the atmosphere!

Visible light can tell us a lot about an object: In addition to being able to see and measure the positions of celestial objects, and some of their motions, astronomers can directly measure their radial velocity, their temperature, even their composition. It's the Doppler effect that reveals a star's velocity toward or away from Earth (see the July/August 1995 issue of *The Planetary Report*).

Spectroscopy

The variety of wavelengths, called a spectrum, seen in a celestial object can reveal quite a bit more about the object. Its study, called spectroscopy, is a whole branch of science in itself. In 1859, Gustav Kirchhoff formulated three laws of spectral analysis: (1) a glowing solid or liquid emits light in all wavelengths—a continuous spectrum; (2) a glowing gas emits light at specific wavelengths (individual, pure colors); and (3) if light passes through a gas, the gas can absorb certain specific wavelengths (colors).

You can illustrate the first law by looking at a lightbulb (which contains a glowing solid filament) through a prism or reflected off the surface of a compact audio disc. You'll see the light broken into its whole range of colors, from red to violet, a continuous spectrum. A neon sign, or a neon nightlight, provides a fine illustration of the second law: The excited gas inside the clear glass tube emits a characteristic orange color.

For an example of the third law, a trip to a public observatory or science museum is in order. At the Griffith Observatory in the Los Angeles area, for example, there's a wonderful instrument that separates sunlight (on clear days) into a very long, very detailed spectrum for the public to view. As you scan the spectrum in the eyepiece of the instrument, called a spectroheliograph, you can see lots of black bands where you would expect colors to be. Some of these are an indication that the Sun's light is being absorbed at specific wavelengths by cooler gases in the Sun.

These laws are true for visible light, but they don't stop there. Emission and absorption occur all along the spectrum. Studies of spectra in radio, infrared, ultraviolet and more can reveal many details about the object being observed. This is why you'll find instruments on interplanetary spacecraft that cover many, if not all, of these areas of the electromagnetic spectrum. And by navigating your spacecraft close to another planet, your multispectral measurements can provide tons of information about targets at close range.

The Electromagnetic Spectrum

SIZE REFERENCE	NOMENCLATURE	FREQUENCY	WAVELENGTH
		3 kilohertz	100 kilometers
	Long radio waves	30 kilohertz	10 kilometers
	AM	300 kilohertz	1 kilometer
Football field	Short waves	3 megahertz	100 meters
Human	FM & TV	30 megahertz	10 meters
		300 megahertz	1 meter
	Radar	3 gigahertz	100 millimeters
		30 gigahertz	10 millimeters
Grain of sand		300 gigahertz	1 millimeter
	Infrared radiation	3 terahertz	100 micrometers
Bacterium		30 terahertz	10 micrometers
	Visible light	300 terahertz	1 micrometer
Virus	Ultraviolet radiation	3 petahertz	100 nanometers
		30 petahertz	10 nanometers
		300 petahertz	1 nanometer
Atom		3 exahertz	100 picometers
	X rays	30 exahertz	10 picometers
		300 exahertz	1 picometer
	Gamma rays	3×10^{21} Hz	100 femtometers
		30×10^{21} Hz	10 femtometers
		300×10^{21} Hz	1 femtometer
Atomic nucleus		3×10^{24} Hz	100 attometers
		30×10^{24} Hz	10 attometers
		300×10^{24} Hz	1 attometer

ABSORPTION

Chart redrawn by B.S. Smith

What the Instruments See

Magnetometers, typically placed on booms extending away from a spacecraft's internal magnetic fields, measure planetary magnetic fields. Plasma-wave instruments and radio receivers pick up emissions, ranging from a few hertz to millions, from within planetary systems.

Then there are the optical instruments. A camera operating in the range of visible light aboard a spacecraft creates images by measuring the relative intensities (and sometimes colors) across the surface of an object. A spacecraft may be equipped with one or more spectrometers, operating in infrared, visible light or ultraviolet, to provide all the details of emission and absorption. A mapping spectrometer captures the spectrum at many points in its field of view, all at once. Photometers measure the absolute intensity of light, and different photometers are sensitive to various wavelengths. Using a photometer to measure the intensity of light reflected from an object supplies hints to help identify the composition and structure of the material; for example, the highly reflective surface of Saturn's moon Enceladus corroborates the detection of frost or snow, while the dark surface of Uranus' moon Umbriel suggests the presence of carbon and its compounds.

The radiation that is measured by a spacecraft may be either reflected off the target from another source such as the Sun, which is common when taking pictures, or it may be radiation directly emitted from the target. Measuring or imaging the heat radiated from deep within Jupiter would be an example of the latter. You can also measure how much bending takes place in a ray of light or a radio wave as it passes through an atmosphere, to study the structure of that atmosphere. One observing technique used by interplanetary missions is to train a spacecraft's photometer on a distant star and measure the variations in its apparent brightness as the rings of a planet pass in front of the star. This lets you count the rings, see how thick or opaque they are and find out more about their structure.

Once the spacecraft makes its scientific observations in many different wavelengths, it sends the resulting data to Earth using microwave radio. Communications with interplanetary spacecraft typically use frequencies in the range of 2 to 10 gigahertz. That means, of course, that the spacecraft's transmitter is creating a field that varies billions of times per second. And that quickly varying field can be sensed billions of kilometers away on Earth, in the same way that one of your wire coils picked up the battery-created radiation from a second coil nearby.

In the next installment, we'll take a look at spacecraft propulsion systems.

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

News and Reviews

by Clark R. Chapman

A decade ago, I finally convinced the skeptical management of the Planetary Science Institute to invest in a "high-speed" 1200-baud modem and a Silent 700 thermal printer so I could read my electronic mail. One of my first e-mail messages came on February 11, 1986, from the Jet Propulsion Laboratory's Ken Klaasen. Sent to the *Galileo* imaging team, the message read, "As most of you are probably aware, NASA yesterday postponed the launches of *Galileo, Ulysses* and *Astro-1*. Revised launch dates will be determined after a schedule for resumption of shuttle launches has been established." Klaasen surmised that *Galileo* might not get to Jupiter "until 1991."

A decade after the *Challenger* accident, *Galileo* is beginning its long-delayed Jupiter orbital tour, and I'm still connected to the Internet. How it has changed! Last evening, from my home, I hit a few keystrokes on my laptop and called up the Space Telescope Science Institute's World Wide Web site. I clicked on the Hubble Space Telescope's images of the *Galileo* probe's entry point in Jupiter's equatorial cloud bands (http://www.stsci.edu/pubinfo/Pictures.html). With a few more clicks in my Netscape window, I downloaded the colorful images, which I can examine on my laptop whenever I wish.

In 1986, I received a few e-mail messages a week. Now I get two dozen messages a day. The Internet is now my chief method for communicating with my daughter in college, as well as for doing most of my collaborative scientific research. During instrument calibration for the Near Earth Asteroid Rendezvous mission, before the spacecraft was shipped to Florida for its February launch, NEAR scientists examined graphs posted on several Web sites and transferred the relevant data to our own computers for analysis.

For astronomers, printed journals will soon be obsolete. Today, with a Web browser, it takes only seconds to locate next month's issue of the venerable *Astrophysical Journal (Letters)* (http://www.aas.org/ApJ/). You can search the full text of all articles in the past year's *ApJ Letters* for any words you choose. For example, I just searched on "planets." In five seconds, I had a list of papers involving planetary systems or disks around other stars (one article was about the youthful age of the Beta Pictoris system), dust grains in the Kuiper belt of comets beyond Neptune's orbit, the implications for planetary origin of aluminum 26 inclusions in meteorites, and the discovery of oxygen 18 (not the usual oxygen 16) in Jupiter's atmosphere—plus a dozen other planetary articles. With a click, I could browse them, study illustrations and locate references to related articles. When the full *Astrophysical Journal* goes on-line later this year, I expect the hard-copy version—which must be printed, bound and mailed at great expense, requiring weeks of delay—will fade into oblivion.

Not only has the Web become the prime medium for communication among professional astronomers; its use is exploding throughout our culture. A recent poll showed that tens of millions of Americans now use the Internet, and the Web (which was just a novelty a couple of years ago) is increasingly the Internet's central arena. If you are not already familiar with the Web, find a friend who is, and see what's out there.

Amateur planetary enthusiasts can join Bill Arnett's "Nine Planets" tour of the solar system, and check out innumerable images to download, just by clicking on the home page of Students for the Exploration and Development of Space (http://seds.lpl.arizona.edu/). Many popular science magazines now have on-line editions and services. Check out *Astronomy Now* (http://www.demon.co.uk/astronow/) and *Sky & Telescope* (http://www.skypub.com/), just for starters. And don't overlook The Planetary Society's own Web site: http://planetary.org/tps/. Before ending a session on the Web, it's fun to check out the latest Hubble pictures. I, for one, will never tire of looking at the gorgeous portraits of star-birth clouds in M16, released November 2, 1995.

The Web provides more than text, graphs and pretty pictures. Readily available programs facilitate a truly multimedia experience. For example, the Hubble pictures of M16 have been arranged into a 451-frame movie, which zooms in on the fantastic interstellar clouds as though you were on the bridge of the *Enterprise*! A more serious movie, which helps amateurs and experts alike understand what mere words can never explain, is at an obscure site: http://www.eecs.wsu.edu/~hudson/Toutatis/toutatis.html. Here, Scott Hudson displays the oddly tumbling spinning motion of the asteroid Toutatis that he has deduced from radar observations.

Hudson's little corner of the Web is just one example of why it pays to spend a while browsing the Internet.

Clark R. Chapman, long of Tucson, Arizona, will soon be moving to Colorado to join Southwest Research Institute's Boulder office.

Society News

New Editor Directs Notes From the Underground

In October 1995, The Planetary Society welcomed a new editor for *The Mars Underground News:* scientist, writer and educator Kenneth Edgett of Arizona State University. A postdoctoral research assistant in Arizona State University's Department of Geology, he also edits *TES News,* a publication focusing on Mars *Global Surveyor*'s thermal emission spectrometer project.

Edgett is the director of the Arizona Mars K-12 Education Program, which provides real-life connections to NASA's Mars missions for teachers and students both in and outside of Arizona. The program's World Wide Web site is http://esther.la.asu.edu/asu_tes/.

The Mars Underground News is the Society's quarterly newsletter about Mars exploration. It features reports from the informal network of explorers known as the Mars Underground—scientists, engineers and others working toward a human landing on the Red Planet. In late 1995, new features were introduced, including a complete, up-to-date listing of all current Mars missions. For information on how you can subscribe, contact Society headquarters. *—Michael Haggerty, Information Services Manager*

Barney Oliver Dies at 79

The Planetary Society has lost a great friend and advisor: Bernard M. (Barney) Oliver died on November 23, 1995, at the age of 79.

Barney will be remembered by the world at large for the development of the handheld calculator while he served as a vice president of Hewlett-Packard Corporation. He received the 1986 National Medal of Science for this invention.

At the Society, we will remember Barney for his energetic support of the Search for Extraterrestrial Intelligence. He helped goad us to initiate our own program in the early 1980s. With his support, our first endeavor, Suitcase SETI, grew into Project Sentinel, which became Project META, and, just this last October, we initiated Project BETA, now the most powerful continuing SETI program on Earth. Barney also served as head of the NASA SETI program. After its close, he helped establish the SETI Institute of Mountain View, California, and was instrumental in getting its program off to a spectacular start.

Barney Oliver will be sorely missed. A memorial fund in his honor is being established at the SETI Institute. *—Louis D. Friedman, Executive Director*

M.A.R.S. on Wheels

Starting with the 1995–1996 school year, M.A.R.S. (for Mobile Access for Resources on Space) will go on the road—to schools, camps, museums and science-related shows and events in the Pacific Northwest. This 16-foot, 22,000-pound GMC truck, formerly a Boeing fleet vehicle, was donated to the Society's Volunteer Network in Portland, Oregon, in July 1994. Volunteers Tom Hanna (regional coordinator), Larry Clulow, Bob McGowen, Dave Dunbar, Mark Dunbar and Ben Missler, with the help of area businesses, put over 750 hours of labor into the conversion. M.A.R.S. has five computers (one with on-line capability), a TV/VCR setup, and resource material from NASA and The Planetary Society. It offers complete presentations on specific topics, teachers' resource guides, exhibits, pictures, videos, several computer programs on astronomy and a space shuttle simulator. *—Carlos Populus, Volunteer Coordinator*

Busy on the Web

Approximately 4,000 visitors browsed The Planetary Society's World Wide Web site (http://planetary.org/tps/) from mid-September to mid-October 1995. Over 39,000 files—308 million bytes of data!—were transmitted to people tuning in for the latest news on space exploration. On a daily basis, that's about 1,600 files and 12.3 million bytes of data. These numbers represent a 40 percent increase in the use of our Web site from the previous month. To handle this load, we're working closely with Les Weber, the Society member who hosts our site, to find ways to increase our bandwidth and reduce the time it takes to reach our home page. *—Kari Magee, Resource Center Manager*

Help Wanted

Interested in volunteer work? E-mail Kari Magee at tps.km@genie.geis.com for information on how to help with the design and maintenance of our Web page. We're looking for people to help manage content areas (knowledge of HTML welcome but not required). *—KM*

Attention All Members: Planetfest Rescheduled

Our three-day Planetfest celebration, originally slated for July of 1996, will now take place in 1997. It'll still be in the Pasadena/Los Angeles area, and we'll still need a lot of help from Society volunteers to make it happen. For information, please contact me at Society headquarters or by e-mail at tps.cp@genie.geis.com. *—CP*

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Questions and Answers

Could the Cretaceous/Tertiary impact have affected the tilt, rotation and/or orbit of Earth and, consequently, its climate?
—Hugh Hornbeck,
Swan River, Manitoba, Canada

Impacts are responsible for giving all planets their rotation and axial tilt. Planetary rotation is a natural outcome of the process of accretion, the growing of planets through relatively low velocity collisions among planetesimals. It has been suggested that very large collisions near the end of a planet's formation might dictate its final rotation state. Thus a late, but great, collision might account for the slow "backward" rotation of Venus compared with the somewhat similar rotation rates and axial tilts of Earth and Mars.

Although devastating to the biosphere, the K/T impactor was puny as far as planet Earth was concerned. The rotating Earth has a great deal of momentum, implying that it takes a large force to spin it up, slow it down or change its tilt. Even assuming a large size (10-kilometer-diameter), dense iron-rich impactor striking at a high velocity and optimum angle, the calculated effects on our planet are quite small. The K/T impactor could have changed Earth's rotation and tilt by no more than one ten-millionth of its present value. Measured over a year, this change would amount to a difference of about three seconds in the length of time for Earth to complete 365 rotations.

The effect on Earth's orbit is even less. The total duration of a century (the time for Earth to make 100 complete orbits) would be altered by only about one second. Thus any long-term effect on Earth as a planet is astonishingly small compared with the temporary havoc wreaked on the biosphere by the immediate heat and dust of the impact.
—RICHARD P. BINZEL,
Massachusetts Institute of Technology

How can it be determined if Europa contains water, and how much might be there?
—Joe Lestyan,
Edmonton, Alberta, Canada

Whether or not Jupiter's moon Europa contains liquid water beneath its surface (a mystery that we hope to solve soon with the help of the *Galileo* spacecraft) is really a multipart question.

Europa's surface is composed almost entirely of water ice, but this tells us little about the moon's interior. A simple calculation, based upon the assumption that Europa is a mixture of solid plus liquid water and of waterless rocky material like that of nearby Io, gives a bulk water content greater than 5 percent. If this water were concentrated into an outer layer by a differentiation process (such as melting), it would yield a layer more than 100 kilometers (62 miles) deep.

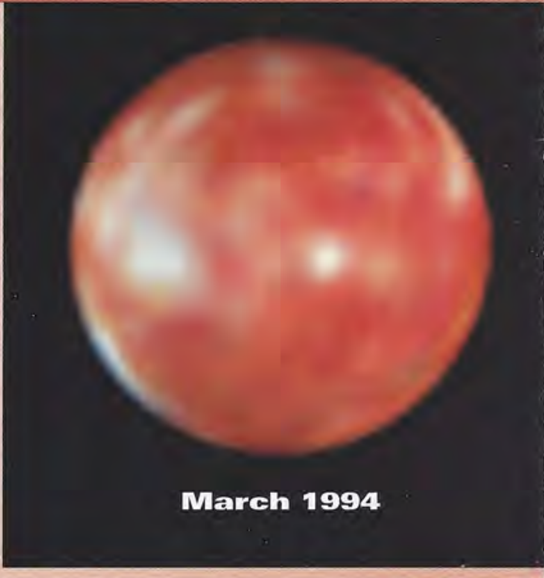
If Europa is differentiated, *Galileo* may help to verify this by obtaining information on Europa's internal density distribution from detailed measurements of the satellite's gravitational field. If Europa is not differentiated, however, this would not be sufficient to answer the question of water and its location. We would have to obtain seismic data from instruments placed upon the surface. This is not something that will occur in the foreseeable future.

Theoretical arguments, based on tidal heating, indicate that a global ocean might lie beneath a surface layer of ice. *Galileo,* with its high-resolution imaging, could shed light on this question, enabling us to identify and understand

Factinos

These Hubble Space Telescope images of Jupiter's moon Io (at right) show the surprising emergence of a large, bright feature near the center of the moon's disk. This is a more dramatic change in 16 months than any seen over the past 15 years, say researchers. They suggest that the spot may be a new class of transient feature on the moon. Each image is a composite of frames taken at near-ultraviolet, violet and yellow wavelengths with Hubble's Wide Field and Planetary Camera 2.

"The new spot surrounds the volcano Ra Patera, which was photographed by *Voyager*. It is probably composed of material, likely frozen gas, ejected from Ra Patera by a large volcanic explosion or fresh lava flows," according to John Spencer of Lowell Observatory in Flagstaff, Arizona. —from the Space Telescope Science Institute



The image of Io at near right, taken by the Hubble Space Telescope in March 1994, shows that the moon has undergone only subtle changes since it was seen by* Voyager 2 *in 1979. The image at far right, taken in July 1995, shows a large, bright spot in the same area as the smaller, whitish spot in the earlier image. Note the other even more subtle changes that have occurred during this 16-month period. *Images: J. Spencer, Lowell Observatory, and NASA*

In Memoriam

After nearly 22 years of exploration out to the farthest reaches of our solar system, NASA's *Pioneer 11*, one of the most durable and productive spacecraft ever flown, will slowly fade away.

The spacecraft is now out past Pluto's orbit, over 6.4 billion kilometers (4 billion miles) from Earth. On September 30, 1995, NASA discontinued daily communications with *Pioneer 11* because the spacecraft's power is now too low to operate its instruments and transmit data. At that distance, faint signals traveling at the speed of light take over six hours to reach Earth from the spacecraft. The spacecraft will continue to speed out into interstellar space toward the center of the Milky Way, carrying an engraved gold plaque bearing a message about Earth to other civilizations it may encounter.

"*Pioneer 11* has had a spectacular life," said project manager Fred Wirth of NASA's Ames Research Center. "It was the second spacecraft to visit Jupiter, roaring through the heart of the planet's huge radiation belts at about 173,000 kilometers (about 107,000 miles) per hour—by far the fastest speed ever traveled by a human-made object."

Launched in April 1973, *Pioneer 11* arrived at Jupiter in December 1974, a year after its sister craft, *Pioneer 10.* It flew past the planet's south pole and came within about 42,800 kilometers (26,600 miles) of Jupiter's cloud tops. *Pioneer 11* came so close to Jupiter that it was heavily bombarded by the giant planet's radiation belts, which are 40,000 times stronger than those of Earth. Only *Pioneer*'s extreme speed saved its electronics from serious damage.

Thanks to maps of this severe radiation environment provided by the *Pioneers*, subsequent, more sophisticated missions like the *Voyagers* and *Ulysses* were designed to survive Jupiter's radiation. These maps also paved the way for *Galileo*'s arrival at Jupiter in 1995 and the *Cassini* mission to Saturn in 1997.

Its close flyby of Jupiter gave the spacecraft a gravity assist that hurled it 160 million kilometers (100 million miles) above the ecliptic plane of the planets and 2.4 billion kilometers (1.5 billion miles) across the inner solar system to Saturn. En route, *Pioneer* flew high enough over the Sun's equatorial plane (17 degrees) that it discerned the character of our star's magnetic field for the first time.

Pioneer became the first spacecraft to visit Saturn in 1979 when it flew within 20,920 kilometers (13,000 miles) of the ringed planet. There it discovered two new moonlets and a new ring, and it charted the magnetosphere, magnetic field and the basic structure of Saturn's interior. The spacecraft also discovered that Saturn's planet-sized moon, Titan, is too cold to support life.

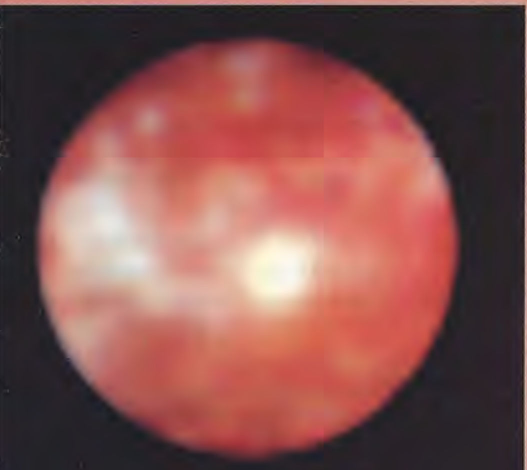
In 1990, *Pioneer 11* became the fourth spacecraft to journey beyond the planetary part of our solar system, traveling in the same direction that the Sun moves through space. *Pioneer 10* is moving in the opposite direction, and with the *Voyagers* will continue to return information about the Sun's influence deep in space.

Although it is running out of power, most systems aboard *Pioneer 11* are still healthy. For many years the spacecraft has been transmitting limited data on the solar wind, magnetic field and cosmic rays, but it can no longer be maneuvered to point its antenna accurately at Earth. Now NASA controllers will use the Deep Space Network antennas to listen for the spacecraft's signal for about two hours every two to four weeks to gather whatever information they can. This is down from about eight to ten hours a day.

"Sometime in late 1996, its transmitter will fall silent altogether, and *Pioneer 11* will travel as a ghost ship in our galaxy," said Wirth. "We plan to listen to it once or twice a month to learn about the fade-down process. This will help us to understand the future fate of its sister craft, *Pioneer 10*."

At almost 10 billion kilometers (6 billion miles) from Earth, *Pioneer 10* is the most distant object built by human hands.
—NASA Ames Research Center

surface features. If such an ice shell is thin and can be broken by tidal stresses, the spacecraft might even see plumes of water vapor. If *Galileo*'s observations are inconclusive, however, we may have to wait for surface seismic observations to settle this question as well. Thus the results from *Galileo* are being eagerly awaited by all those interested in the question of water on Europa.
—RAY REYNOLDS,
NASA Ames Research Center



July 1995

On October 6, 1995, Michel Mayor and Didier Queloz of Geneva Observatory in Geneva, Switzerland, announced their discovery of what appears to be a planet roughly the size of Jupiter in orbit around a Sun-like star. Their claim is based on 18 months of precise Doppler measurements using the ELODIE spectrograph at the Observatoire de Haute-Provence in France.

The star, 51 Pegasi, is visible to the naked eye about 40 light-years away within the Milky Way galaxy. It is roughly 8 billion years old and is similar to the Sun, which is some 5 billion years in age. The suspected planet takes only four days to orbit 51 Pegasi, compared to Earth's 365-day orbit of the Sun, and it has a surface temperature of around 1,000 degrees Celsius (about 1,800 degrees Fahrenheit), said Mayor. The planet cannot be seen through a telescope because of the brightness of its nearby sun, but the planet's movements cause changes in the rotation of 51 Pegasi, which is how the astronomers based in Switzerland deduced its presence. —from the University of Berkeley and the Harvard Smithsonian Center for Astrophysics

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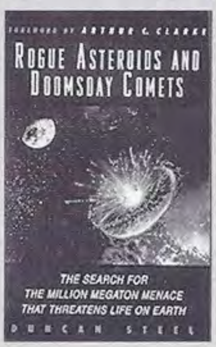

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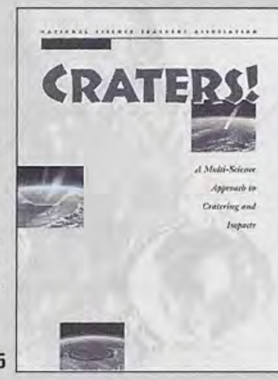

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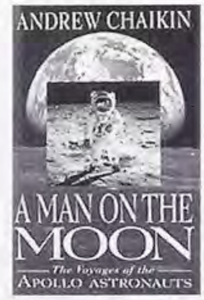

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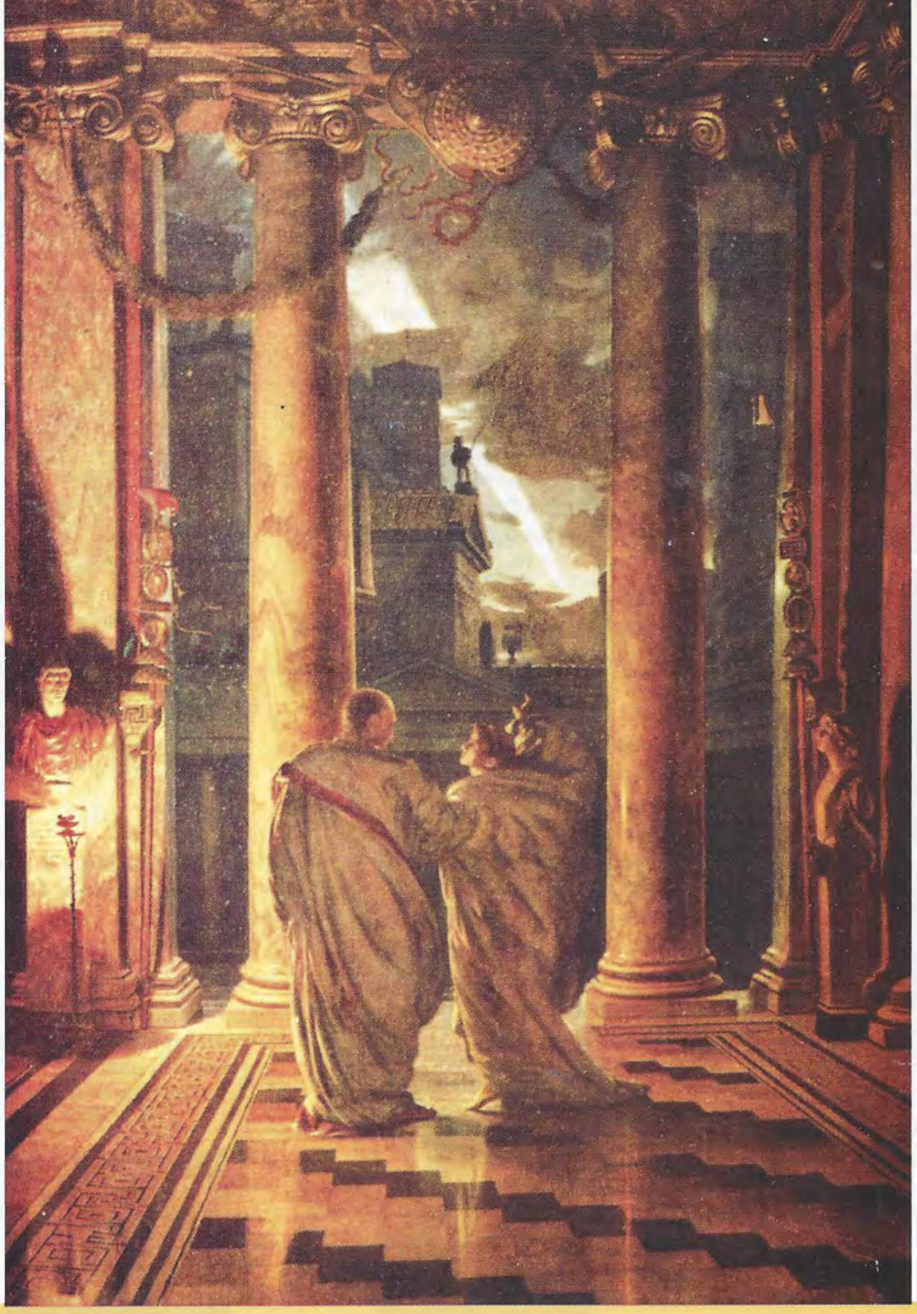

Throughout history, people have looked upon comets as portents (many of them bad) of things to come. In "The Ides of March," the wife of Julius Caesar points out an alarming apparition to her husband. Caesar actually died on March 15, 44 BC, before the comet's appearance in June of that year. Still, Julius' successor, Augustus Caesar, put a star (inspired by the comet) over the head of the statue he commissioned of Julius. It symbolized Julius' soul rising to heaven.

Painting: E.J. Poynter, P.R.A., 1883;

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