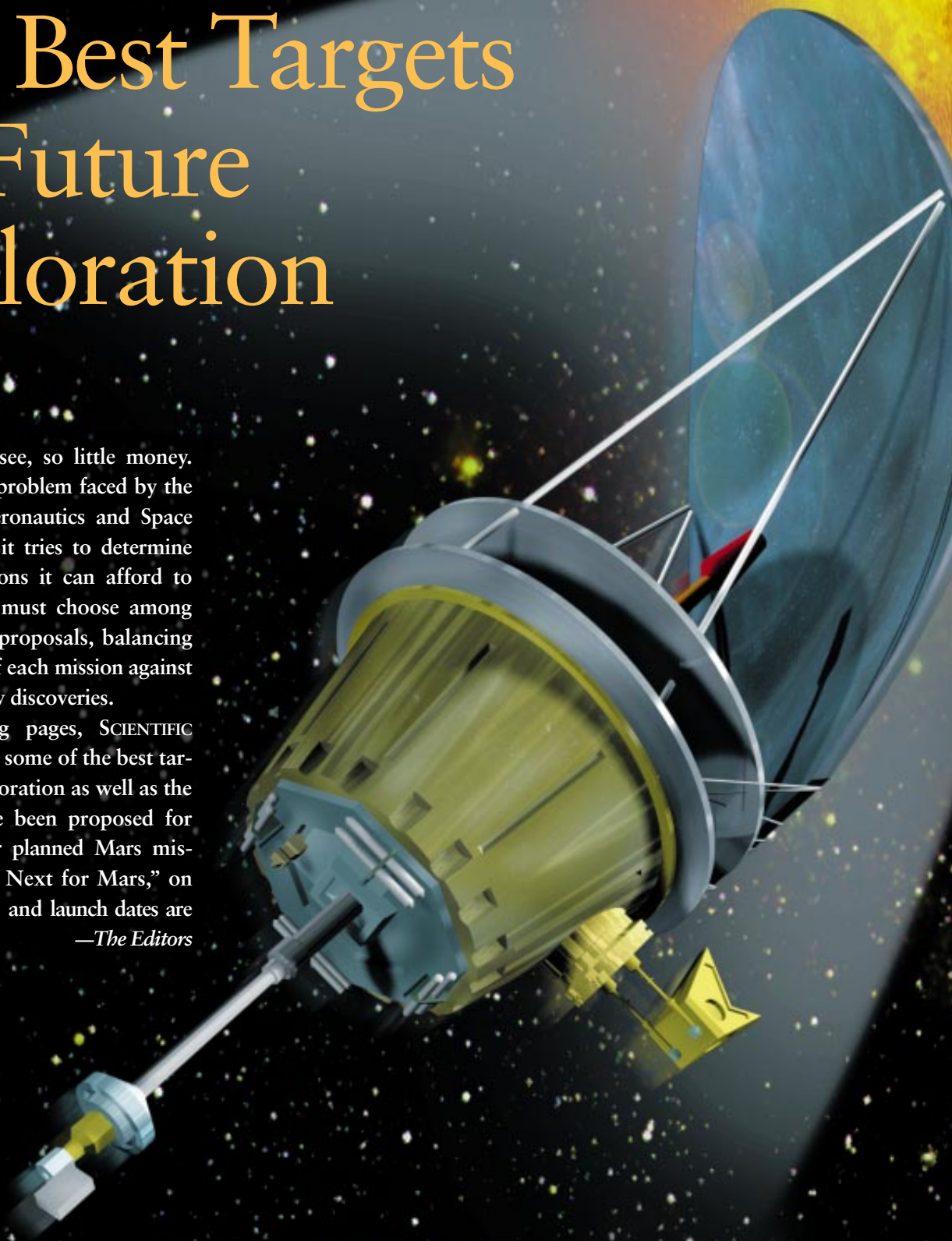


# The Best Targets for Future Exploration

**S**o much to see, so little money. That is the problem faced by the National Aeronautics and Space Administration as it tries to determine which space missions it can afford to fund. The agency must choose among dozens of worthy proposals, balancing the cost and risk of each mission against its potential for new discoveries.

In the following pages, *SCIENTIFIC AMERICAN* presents some of the best targets for future exploration as well as the missions that have been proposed for studying them (for planned Mars missions, see "What's Next for Mars," on page 40). All plans and launch dates are subject to change.

—*The Editors*





# The Sun

*Upcoming missions will investigate the sun and the powerful solar wind that it hurls toward the planets*

**L**ike an ill-tempered king, the sun is prone to violent outbursts. Shifts in the sun's intense magnetic fields send monstrous streams of charged particles hurtling through space. This solar wind buffets the planets and sparks the aurora borealis in Earth's Northern Hemisphere. Occasional surges in the solar wind can also silence communications satellites and cause power blackouts on Earth. In the next decade, space agencies in the U.S., Europe and Asia expect to launch a small fleet of spacecraft to study the sun and its fierce flare-ups. One of those probes will even venture into the corona, the sun's fiery outer atmosphere.

Recent solar missions have paved the way. For the past three years, the Solar and Heliospheric Observatory (SOHO) has provided breathtaking images of the sun and its corona. And the Ulysses probe has measured the solar wind and the sun's magnetic field while moving in a distant orbit that allows it to view the sun's north and south poles. These missions suggest that the fastest solar winds, flowing at up to 800 kilometers (500 miles) per second, may arise all over the sun's surface and not just from its poles, as astronomers had previously thought. But scientists still don't understand the physical processes that produce the solar wind, and they cannot predict the occurrence of the solar storms that wreak such havoc on Earth.

In 2001 NASA plans to launch Genesis, a spacecraft that will collect solar-wind particles from a near-Earth orbit. After a three-year mission, the probe will return the samples to Earth, where scientists can measure the abundance of various elements and isotopes. Russia, Japan and Germany are also developing spacecraft that will study the sun from a variety of vantage points. But the most ambitious mission is NASA's Solar Probe, scheduled for launch in 2007. This spacecraft will go into an eccentric orbit that in 2010 will send it through the corona, less than three million kilometers from the sun's surface—about one-twentieth the distance between the sun and Mercury.

During its first flyby of the sun, 14 hours from pole to pole, Solar Probe's heat shields will have to withstand temperatures of up to 2,000 degrees Celsius (3,600 degrees Fahrenheit). The spacecraft will measure the sun's magnetic fields and take high-resolution photographs of the sun's surface. The probe will also carry several spectrometers and an instrument to measure the sun's plasma waves. "It's the first mission to a star—our star," says Bruce Tsurutani, Solar Probe project scientist at the Jet Propulsion Laboratory in Pasadena, Calif. The spacecraft will return for a second flyby in 2015, when it will speed through the coronal holes where the fastest solar winds appear to originate.

Scientists hope the spacecraft will help explain how the solar wind is accelerated to such incredible speeds. The mission may also illuminate the most puzzling paradox of solar physics: why the sun's outer atmosphere is hundreds of times hotter than the sun's surface. And David Hathaway, head of solar physics at the NASA Marshall Space Flight Center, says the new data may help scientists forecast potentially damaging solar storms. "These scientific mysteries aren't just intellectual curiosities," Hathaway remarks.

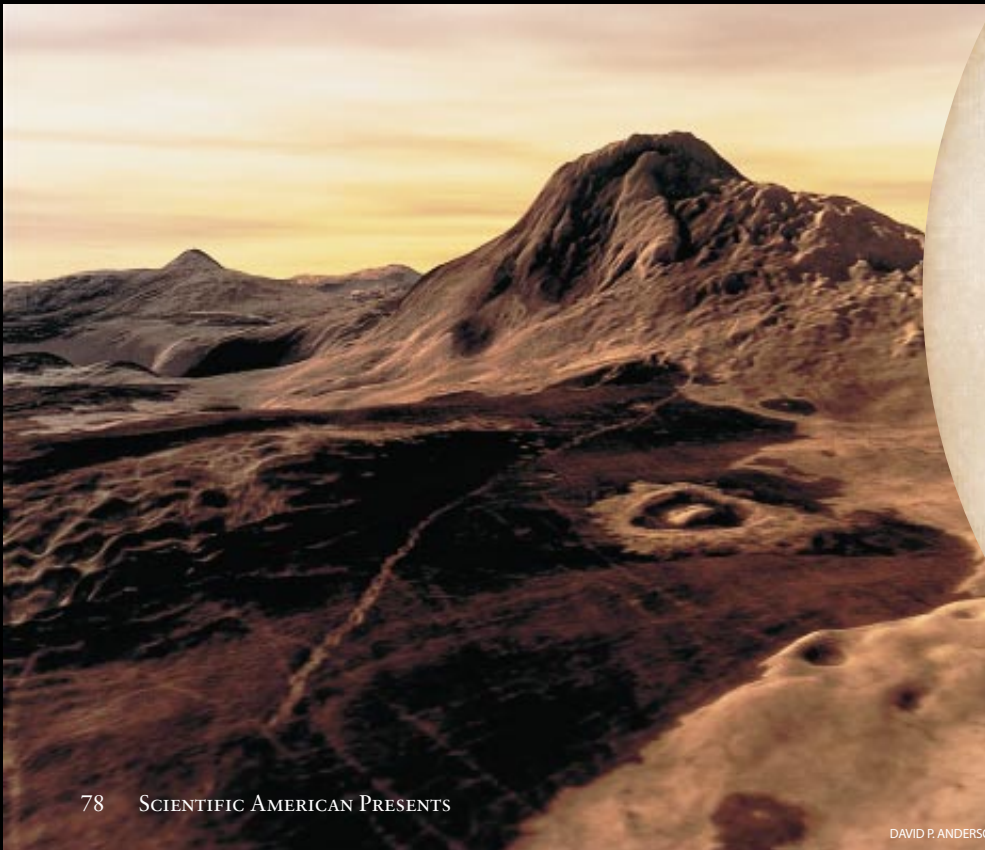
*SOLAR PROBE dives into the corona to take close-up pictures of the sun's surface. The daring mission is scheduled for launch in 2007.*

DON FOLEY



*MERCURY, the innermost planet, has a rocky and cratered surface (above left). An artist's conception shows the Discovery scarp, a 500-kilometer-long fault, at daybreak (above right).*

*SURFACE OF VENUS is obscured by clouds (right), but the Magellan orbiter used radar to map the planet. The radar data were processed to create a perspective of Maat Mons (below), a six-kilometer-high volcano.*



# Venus and Mercury



DON DIXON

*The inner planets are full of intriguing mysteries. Studying the atmosphere of Venus may teach scientists about global warming. And the surface of Mercury may hold secrets about the early history of the solar system. NASA is considering missions to both planets*

Venus provides a good example of the horrific effects of runaway global warming. The planet is a hellish place, with a carbon dioxide–choked atmosphere, clouds of sulfuric acid and a surface hot enough to melt lead. But planetary scientists believe that Venus started out much like Earth and simply evolved differently, like a twin gone bad. Venus offers researchers a unique opportunity to compare the planet with Earth and perhaps discover why the histories of the two bodies diverged.

In 2002 a proposed mission called the Venus Sounder for Planetary Exploration (VESPER) may travel to Earth's closest neighbor, following the trail blazed by the Mariner, Pioneer and Magellan spacecraft. VESPER is expected to orbit Venus for two and a half years, measuring atmospheric gases, wind speeds, air pressure and temperature—in short, recording the planet's weather. Mounted on a three-axis platform, VESPER's spectrometers, cameras and other instruments will pivot their fields of view to study Venus's environment from every angle.

VESPER will focus its instruments on Venus's middle atmosphere, 60 to 120 kilometers above the surface. It is here that yellow clouds of sulfuric acid form, causing the greenhouse effect that heats up the planet. Gordon Chin, VESPER's principal investigator at the NASA Goddard Space Flight Center, says the spacecraft could help scientists understand how to prevent such disastrous global warming on Earth. "For that, Venus is a wonderful laboratory," Chin observes.

Mercury, the planet closest to the sun, also intrigues scientists. It is the second densest planet in the solar system, next to Earth, and contains a much higher proportion of iron than any other planet or satellite does. Astronomers have developed several hypotheses to explain Mercury's unusual density. Some scientists speculate that early in the solar system's history, the sun vaporized the outer part of the planet, leaving only the metallic core intact. Others believe that a comet or asteroid impact may have blasted away Mercury's outer crust and mantle.

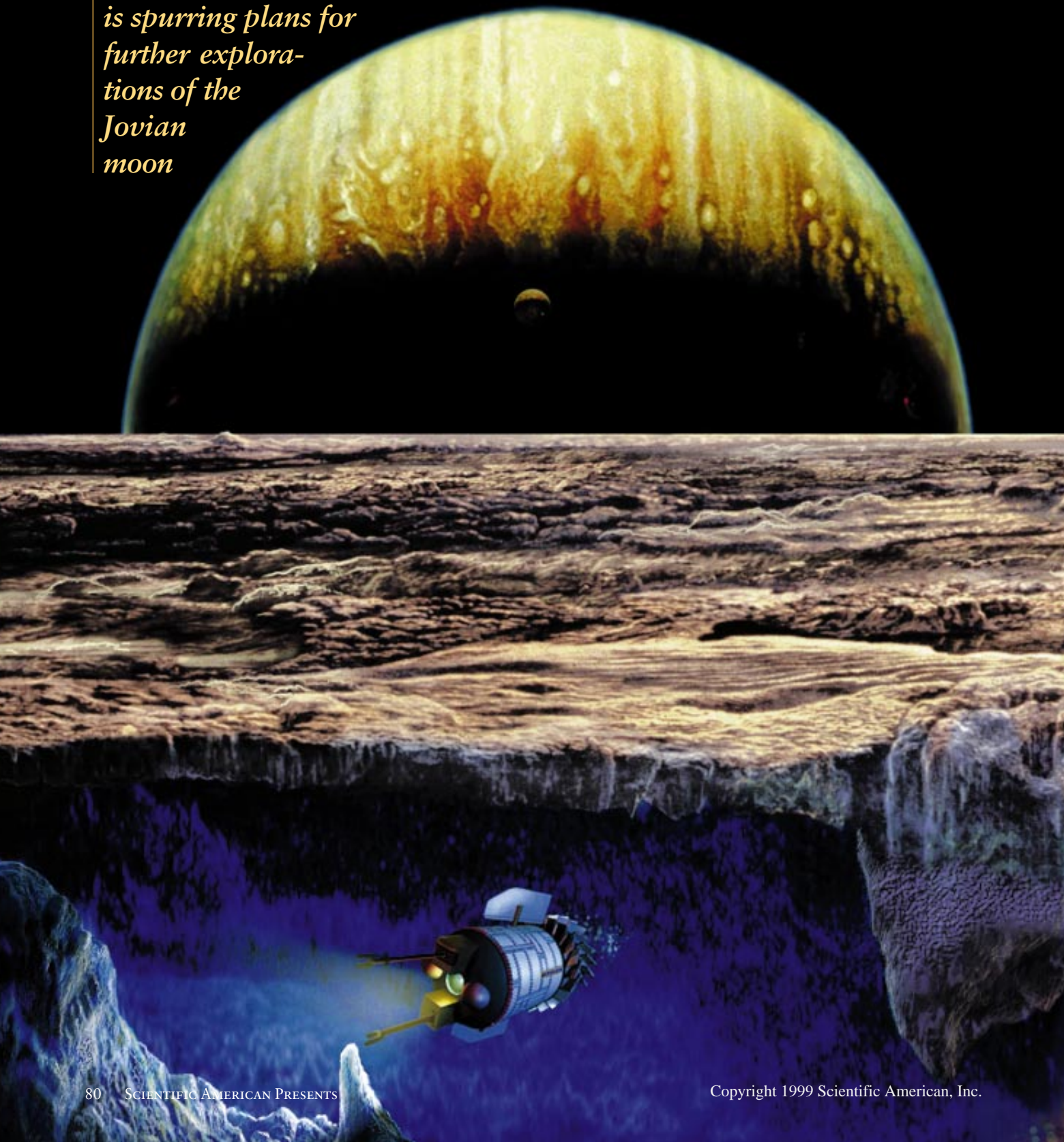
Only one spacecraft has ever visited Mercury: Mariner 10, which flew by the planet three times in 1974 and 1975. But NASA is now considering the Mercury Surface, Space Environment, Geochemistry and Ranging mission (MESSENGER), which is scheduled for launch in 2004. After flying by Venus and Mercury twice, the 300-kilogram spacecraft would go into orbit around Mercury in 2009. For the next year, MESSENGER would use its instruments—including an imaging system, a magnetometer and four spectrometers—to gather data on Mercury's surface features, magnetic field and tenuous atmosphere.

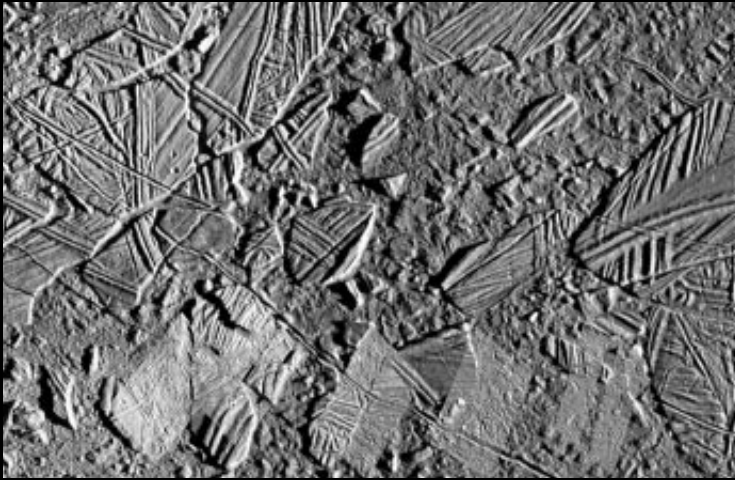
Because Mercury is so close to the sun—about one third as far from it as Earth—MESSENGER will carry a huge sunshade to protect the spacecraft's instruments from the intense solar radiation. Scientists hope that the probe can solve the mystery of Mercury's geologic past by determining the abundance of elements in the planet's crust. "It's just one example of the formation and evolution questions we can ask about terrestrial planets in the inner solar system," explains Sean Solomon, the Carnegie Institution of Washington geophysicist who is the mission's principal investigator. "And like so many questions, this one can only be answered in space."

NASA

# Europa

*The possible presence of an ocean under Europa's ice is spurring plans for further explorations of the Jovian moon*





#### FRACTURED ICE

*on the surface of Europa is shown in this mosaic of images (above) taken by the Galileo spacecraft in 1997. This 1,750-square-kilometer area lies near Europa's equator, where tidal forces are most likely to disrupt the icy crust. If the presence of a subsurface ocean is confirmed, scientists plan to send a robotic probe beneath the ice to search for signs of life (below). Bubbles rise from a hydrothermal vent (bottom right).*



DON DIXON/NASA (inset)

Europa is no ordinary moon. The surface of Jupiter's fourth-largest satellite is sheathed with a layer of scarred and fractured ice. Many scientists believe that at one point in Europa's past—and possibly still today—a briny ocean roiled under the ice pack. If still present, the ocean could be the first found on another world. It could even be home to extraterrestrial life, which might thrive near undersea volcanic vents.

In 1979 NASA's Voyager 1 probe first glimpsed Europa's craggy surface. Over the past four years, the Galileo spacecraft has repeatedly flown by Europa during its orbits around Jupiter and transmitted clearer images of the moon's icy shell. The ice is streaked with stress cracks, ridges and salt deposits—all evidence, scientists say, of a turbulent ocean underneath the ice. Although the temperature at Europa's surface is a chilly  $-160$  degrees Celsius ( $-256$  degrees Fahrenheit), friction generated by Jupiter's enormous gravity—which causes Europa's surface to rise and fall in a kind of tide—may be warming the moon's interior. Unfortunately, scientists do not know for certain whether an ocean of liquid water or slush lies below Europa's surface. Galileo's cameras cannot peer through the ice to find out.

So NASA is going diving. In 2003 the agency plans to launch a spacecraft called Europa Orbiter that will aim ice-penetrating radar at the moon. After the probe goes into orbit around Europa, a three-antenna radar array will beam signals of various frequencies toward the moon's surface. By recording the reflections of the signals, the instrument will measure the thickness of the ice layer and determine whether an ocean lies below it. If an ocean exists, the radar will provide a three-dimensional map of its distribution. In addition, a laser altimeter on board the spacecraft will measure the tidal deformation of Europa's surface caused by Jupiter's gravity. The tidal bulge should be much larger if there is an ocean beneath the ice.

Here on Earth, oceans mean life. Researchers have found hardy microbes, dubbed extremophiles, lurking in even the most punishing oceanic environments, from Antarctic sea ice to deep-sea hydrothermal vents. Could organisms do the same on a moon that is 780 million kilometers from the sun? Probably, says Torrence Johnson, project scientist for Europa Orbiter at the Jet Propulsion Laboratory. "Europa may be the only place where we can find extraterrestrial life in an ocean."

Europa Orbiter, slated to arrive at the moon in 2007, will stop short of looking for life. It will, however, identify prime landing spots for future missions. One idea for a follow-up mission is to use hydrobots, or remote-controlled underwater probes, that would penetrate the ice, possibly by melting their way through, and look for signs of life in the water below. JPL scientists have already designed a prototype, a 20-centimeter-wide cylinder equipped with a camera. They recently tested the probe at an undersea volcano off the coast of Hawaii. A research submersible lowered the probe to a depth of nearly 1.3 kilometers, then inserted it into a hydrothermal vent so that it could search for microbes in the superheated water. The scientists hope to test a similar hydrobot in Antarctica and finally on Europa. "If life is there," Johnson states, "we'd like to find it."

# Pluto and the Kuiper



*PLUTO, the outermost planet (right), and its moon, Charon (above), are pictured in this artist's conception. In 2012 a spacecraft may fly by these bodies and into the Kuiper belt, where both may have originated.*

# Belt

*Neither Pluto nor any of the bodies in the Kuiper belt have ever been visited by a spacecraft*

Pluto may be the smallest planet, but to astronomers it is Mount Everest. On the solar system's fringe, Pluto is the one planet that has never been observed up close by a spacecraft. For two decades, NASA scientists have been proposing missions to Pluto. Around 2012, a spacecraft called Pluto-Kuiper Express may finally get the chance. Shooting in a straight trajectory past Pluto, the probe will map the planet and its moon, Charon, in zoom-lens detail.

Discovered in 1930, Pluto is unusual inside and out. The planet's surface is a shell of frozen methane, carbon monoxide, nitrogen and oxygen. Underneath, its rock-and-ice body may be more similar to a comet's nucleus than to that of a typical planet. Pluto orbits near the edge of the Kuiper belt, a disorderly gang of comets and other objects too small to be considered planets. Pluto's distance from the sun varies from 4.4 billion to 7.4 billion kilometers during its eccentric 248-year orbit. Pluto's diameter of 2,340 kilometers is only twice as large as Charon's diameter, leading some astronomers to consider the pair a double planet.

Because Pluto is so far from Earth, the best images of the planet—taken by the Hubble Space Telescope—have very low resolution. But Pluto-Kuiper Express will whiz within 15,000 kilometers of the planet's surface, snapping photographs that will show features smaller than a kilometer across. According to Robert Staehle, the mission's deputy project manager, NASA plans to launch the probe in 2004, and it will travel at roughly 18 kilometers per second for almost a decade to make the five-billion-kilometer trek to Pluto. After its long journey, the spacecraft will spend only a few hours actually gleaning details from the farthest planet.

In keeping with NASA's focus on "faster, better, cheaper" missions, Pluto-Kuiper Express will be relatively lightweight—around 135 kilograms—and cost some \$250 million. About a meter wide, the spacecraft will carry an instrument package barely heavier than a backpack of books. Cameras and spectrometers will photograph landforms on both Pluto and Charon as well as characterize surface chemicals and take temperature and pressure readings. The probe will also measure Pluto's gravitational pull. And as the spacecraft flies past the planet, an ultraviolet spectrometer will determine the composition of its thin atmosphere by measuring the absorption of the sunlight passing through it.

Pluto's atmosphere captivates scientists because it is so variable. When Pluto is closer to the sun, the light causes some of the frozen chemicals on the planet's surface to sublimate into gases. Because the planet is so small, however, its meager gravity cannot hold the gases for long, and the atmosphere escapes into space almost as quickly as it forms. Some scientists suggest that as Pluto moves away from the sun into colder territory, the atmospheric gases refreeze and fall in chunks to the planet's surface. Pluto-Kuiper Express may help determine whether this theory is correct.

After passing Pluto, the spacecraft will continue on its trajectory into the Kuiper belt, where its cameras and infrared spectrometer will turn toward any icy bodies nearby and analyze their chemical makeup. If the Kuiper bodies have the same composition as Pluto, the similarity will corroborate suggestions that the planet may have emerged from the belt. Further analyses could help explain the mystery of Pluto's birth and perhaps shed some light on Earth's beginnings.

SAIC/PAT RAWLINGS



# Earth-like Planets



*EARTH-LIKE PLANET in another solar system is shown in this artist's rendering, which portrays the young world being buffeted by asteroids. The Terrestrial Planet Finder, an observatory scheduled for launch in 2010, may be able to view such planets.*

# in Other Solar Systems

*A squadron of space observatories may help scientists identify a life-bearing planet orbiting another star*

Perhaps the most exciting astronomical discovery would be the sighting of an Earth-like planet orbiting another star. If a futuristic telescope could find such a planet and analyze its atmosphere, it might be able to determine whether the planet is home to extraterrestrial life.

Ground-based telescopes have recently detected evidence of a handful of planets circling stars outside our solar system. But these observations have been indirect—the astronomers inferred a planet's presence based on the gravity-induced wobble of the star being observed. And because a planet must be very massive to produce a discernible wobble, all the planets detected so far are closer in size to Jupiter than to Earth.

In 2005 NASA plans to improve its searching ability with the Space Interferometry Mission (SIM), an observatory that would travel around the sun in a near-Earth orbit. SIM would capture images of unprecedented resolution by combining the light from two telescopes that are 10 meters apart. The observatory would be able to measure star positions so precisely that astronomers could detect the wobble caused by an Earth-like planet orbiting a nearby star.

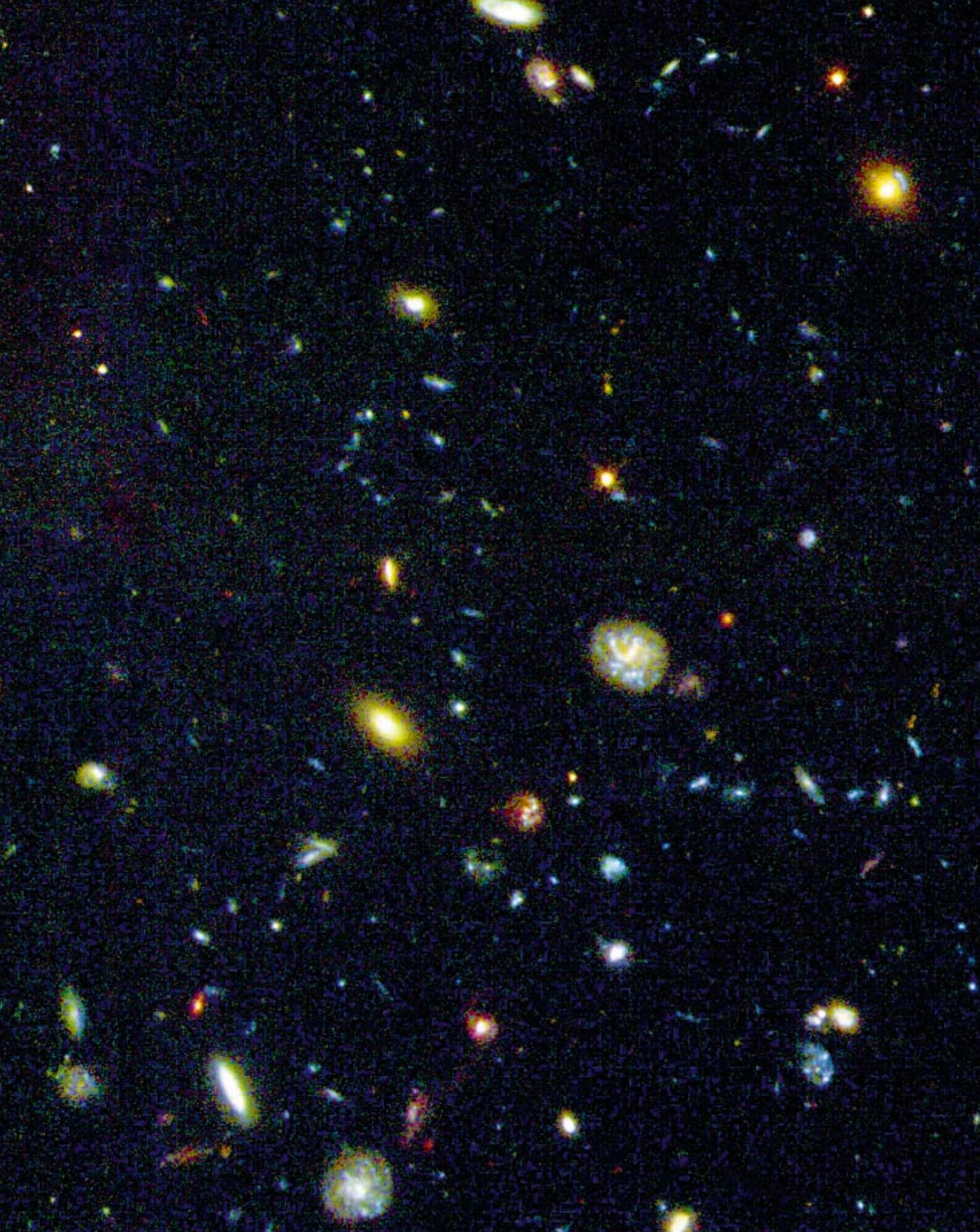
SIM would set the stage for the Terrestrial Planet Finder (TPF), an instrument that could directly observe the light reflected off Earth-like planets in other solar systems. The main challenge facing TPF is glare. A nearby star would shine one million times brighter than its surrounding planets, even in the infrared range of the spectrum, where planets are brightest. According to Charles Beichman, co-chair of the TPF science team, observing a planet in another solar system would be like trying to spot a firefly that is sitting on the rim of a searchlight. What is more, interstellar dust tends to scatter starlight, adding extra glare and making it harder to isolate a planet's faint glow.

Fortunately, TPF has a way to block the stars' glare. The observatory would consist of five spacecraft flying in formation in a near-Earth orbit around the sun. Four of the spacecraft would carry 3.5-meter-wide telescope mirrors that would be aimed at the target star. Each of the mirrors would reflect the star's infrared light toward the fifth spacecraft, a vessel flying in the middle of the group, where the image would be focused. The four beams would be combined so that the light waves interfered with one another, canceling out the starlight in the center of the image but preserving the light from any planets on the periphery.

NASA hopes to launch TPF in 2010, after SIM has identified the solar systems most likely to have Earth-like planets. TPF would observe several hundred stars up to 50 light-years away, spending a few hours at each star. After completing the survey, the group of spacecraft would pay closer attention to any discovered planet that is about the size of Earth. The observatory would then use spectrographic instruments to try to determine the chemical composition of the planet's atmosphere.

Carbon dioxide, water vapor and ozone are all promising signs of life that can be detected in the infrared spectrum. Ozone, for example, forms when light reacts with oxygen, which can be made by plants. "If you have ozone in the atmosphere, that's circumstantial evidence for primitive life on the planet," Beichman says. TPF will get about five years in space to conduct its search. Mission scientists believe that if they focus on the right stars and planets, they are bound to discover whether there is evidence of life in other solar systems.

SAC/PAT RAWLINGS



# The First Galaxies

*With the help of an enormous space telescope, astronomers hope to observe the very first stars and galaxies*

Can astronomers observe the birth of the universe? In 2003 NASA plans to begin building the Next Generation Space Telescope (NGST), a deep-space observatory that will allow scientists to peer into the farthest reaches of the cosmos, nearly 12 billion light-years from Earth. The new telescope would use an eight-meter-wide mirror to capture images of the very first galaxies, which astronomers believe started generating their light just a few hundred million years after the big bang.

The Hubble Space Telescope, which has been orbiting Earth since 1990, has revealed some tantalizing hints about the early history of the universe. Hubble has observed fully formed galaxies dating as far back as a billion years after the big bang. Astronomers want to know how those first galaxies coalesced from the dark primordial nebula. "Hubble whetted our appetite for the cosmic dark ages," says John Mather, the NGST project scientist at the NASA Goddard Space Flight Center. "NGST will help us see farther and sharper to learn about the history and shape of the universe."

Because the universe is expanding, the light from distant objects is redshifted—that is, converted to longer wavelengths. The amount of redshift is measured as the ratio of the change in wavelength to the original wavelength. The farthest galaxies have the greatest redshifts. The best current telescopes have spotted galaxies with redshifts of about five, but NGST will be able to observe objects with redshifts of 10 to 20. To see such objects, the new telescope will be designed to scan from the far visible to the mid-infrared range of the spectrum. (Hubble detects light in the visible to near-infrared range.)

NGST's lightweight, flexible mirror will be at least twice as wide as Hubble's and will gather 10 times more light. Because the new telescope will operate in the infrared range, the optics and cameras must be kept as cold as possible to prevent background heat from obscuring the images. The spacecraft will carry a massive sunshade to prevent overheating and will be located far from Earth to avoid the sunlight reflected from the planet's surface. Most likely, the telescope will orbit the sun near the L2 Lagrange point, one of five points where the sun's and Earth's gravity are in equilibrium. L2 is about 1.5 million kilometers farther from the sun than Earth is.

The images from NGST may help unravel the mystery of how density fluctuations left over from the big bang evolved into the large-scale structure of the universe. Astronomers are not sure whether galaxies formed from the contraction of larger clouds of matter or from the aggregation of smaller star clusters. The telescope may also provide new observations of stellar and planetary formation, which take place inside massive clouds of dust. Because dust does not absorb infrared light as much as it absorbs light of other wavelengths, NGST will be able to see deeper inside the clouds. "With the infrared, we can peer into dust clouds, learn about dark matter and find faint planets," Mather says. "There's a lot out there to discover."

Several groups are vying to construct NGST, which is expected to be launched in 2008. Lifted off Earth by an expendable rocket, NGST would shoot skyward in a folded-up position. Once in space, it would unfold like a giant bird opening its wings, pop up its sunshade and settle into its frigid orbit. If all goes well, the telescope will begin collecting images within days and operate for about a decade.

***NEXT GENERATION SPACE TELESCOPE, now in the design phase (near left), will be even more powerful than the Hubble telescope, which has observed ancient galaxies in its Deep Field South survey (far left).***

