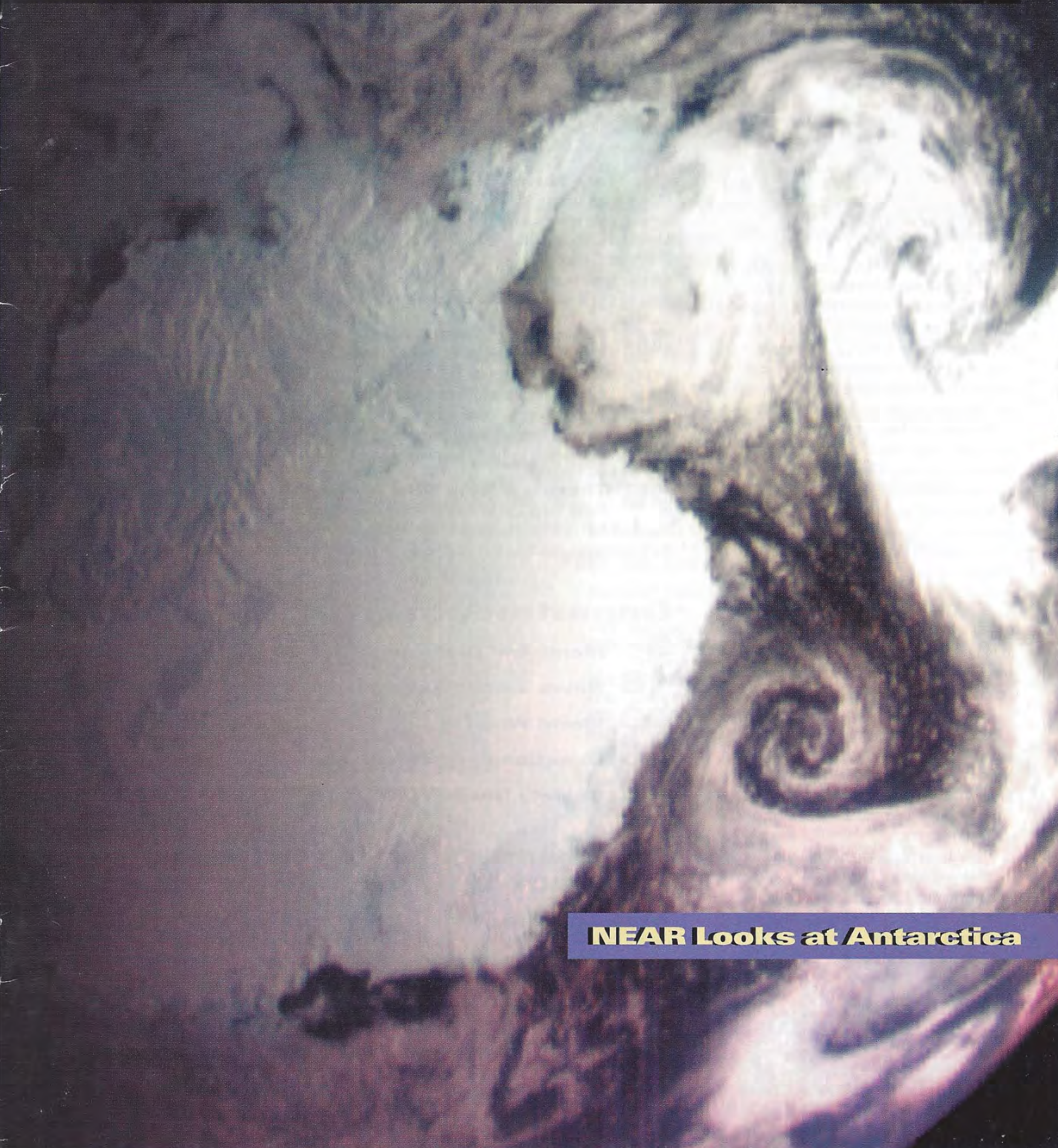
The PLANETARY REPORT

Volume XVIII Number 6 November/December 1998



NEAR Looks at Antarctica

On the Cover:

One universally acclaimed benefit of space exploration is the new perspectives it gives us of our home planet. The curve of Earth's sphere was first seen in early suborbital flights. The people of Earth had their first chance to appreciate their planet as a bright blue disk floating in blackness—as an oasis in space—when humans on the way to the Moon turned their camera back on their home world. In the decades since, a few interplanetary spacecraft have looked homeward on journeys to even more distant worlds. *Voyager* and *Galileo* each provided cover images for *The Planetary Report*, and now the Near-Earth Asteroid Rendezvous (NEAR) craft joins that select club. This view of the south pole of Earth was captured by NEAR as it swung by in January 1998.

Image: Northwestern University/APL/NASA

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From The Editor

Carl Sagan is irreplaceable. In the nearly two years since his death, we at the Planetary Society have struggled to fill an immense void. In the case of *The Planetary Report*, Carl actually read and approved every word before it was printed. His imagination, advice, and knowledge can never be duplicated.

However, we have gone on with the invaluable help of a distinguished Editorial Advisory Board. Their combined wisdom and advice have enabled us to publish *The Planetary Report* without missing a beat.

The board is chaired by Chris Chyba, who was once Carl's student and now, at the SETI Institute, holds the Carl Sagan Chair for the Study of Life in the Universe. I've called upon Chris often—to hunt down prospective authors, mediate occasional disputes, and even write articles himself for the magazine.

Rounding out the Editorial Advisory Board are Bill Hartmann, scientist and artist; Patrick Moore, astronomer and eminent popularizer; Phil and Phylis Morrison, educators extraordinaire; and Toby Owen, friend and another former student of Carl's.

I have been remiss in not introducing them to you sooner. But I know you'll join me in thanking them for helping to keep *The Planetary Report* true to Carl's vision and standards.

—*Charlene M. Anderson*

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Members' **Dialogue**

Water for the Moon

In James D. Burke's fine article ("The Hunt for Lunar Ice" in the July/August 1998 issue), he said, "If recoverable in useful quantities at acceptable cost, [water on the Moon] will transform the future of human efforts to live away from Earth."

Thought should be given to another source of water for the Moon as well. Several research and development projects for space transportation now under way offer the promise of sharp cost reduction for cargo delivery to low Earth orbit. Today's [sometimes disputed] "benchmark" cost for the shuttle is roughly $10,000 per pound.

The new report *International Cooperation in Space* by the American Institute of Aeronautics and Astronautics, the Canadian Aeronautics and Space Institute, and the Confederation of European Aerospace Societies suggests (on page 33) that reusable launch vehicles could "potentially offer reductions by a factor of 10, and eventually as much as 200 . . . ."

And if a potentially very large space tourism market (see page 26) is served efficiently, economies of scale could offer another order of magnitude. That is, consideration should continue to be given, depending on relative costs, to delivering water from Earth to the Moon.

—THOMAS M. ROGERS,
Arlington, Virginia

Life's Energy Sources

In your July/August issue, Robert Hazen argues that the first energy source for life on Earth [might have been] geothermal rather than photosynthetic. A phylogeny/lifestyle correlation provides compelling support for this hypothesis. The microbes closest to the root of life are hyperthermophiles, and the closer they are to the root, the higher their preferred temperature tends to be. He cites seafloor ecosystems near hydrothermal vents and underground ecosystems as evidence in favor of this view. The latter are actually much more relevant.

In the seafloor communities, both geothermal and solar energy are exploited. Most of the microbes at the bottom of these food chains obtain energy by oxidizing hydrogen sulfide (H_2S) from the vents with photosynthetically derived oxygen that has diffused down from the surface. Tube worm flesh is blood red because of a high concentration of several types of hemoglobin, which bring oxygen (O_2) and H_2S to symbiotic bacteria living within (as well as O_2 to the worm itself). Such ecosystems could not survive in environments lacking O_2 (such as the early Earth or the putative ocean of Europa).

At these vent communities and elsewhere, however, exist subsurface microbes that can obtain energy by oxidizing volcanically derived H_2 with carbon dioxide and sulfur or sulfate and truly do seem to be independent of the Sun. Ferrous iron present in the oceans of the early Earth (now long gone) may have once allowed organisms to also obtain energy from H_2S (by oxidation to pyrite) under anaerobic conditions.

—ALAN WOLFE,
San Francisco, California

A New Moon Mission?

On page 19 of the July/August 1998 edition of *The Planetary Report,* you referred to the cancellation of the *Euromoon* mission and the lack of any other European missions to the Moon. While it is true that *Euromoon* was cancelled, I'd like to point out that the European Space Agency will propose a lunar orbiter mission called the Lunar Academic Research Satellite (LunARSat) by the end of this year.

—ANDY PHIPPS,
Guildford, Surrey, England

Rename the Mission

I have enjoyed my membership in the Planetary Society since 1983. Now I finally have my own computer and access to a flood of information on the Internet. "Pluto" was one of the first sites I visited.

I am glad that there is hope for a Pluto mission by 2003 or 2004. But I cannot believe all of the modifications to it. It sounds promising, and yet the mission has been called *Pluto 350*, *Pluto Fast Flyby*, *Pluto Express*, *Pluto-Kuiper*, and *Fire and Ice* (whew!).

Why not simply call it "Tombaugh" after the planet's great discoverer? This would be a fitting tribute to Clyde Tombaugh, since he passed away last year. I'll bet almost every Society member would agree. Either way, I am hoping for Congress to approve the Pluto mission. Maybe renaming it after Clyde Tombaugh will bring it luck. Keep up the excellent work.

—PERRY PEZZOLANELLA,
Utica, New York

Please send your letters to
Members' Dialogue
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tps.des@mars.planetary.org

NEAR So Far: Approaching

by Scott L. Murchie, James V. McAdams, Mark S.

These are exciting times in planetary science. We're learning more and more about the possibilities for life on Mars and Europa, and the news pours in about planets around other stars. And now the NEAR mission (Near-Earth Asteroid Rendezvous) is about to make a decisive contribution to our understanding of asteroids—the raw material for terrestrial planets.

In January 1999, NEAR will begin a year-long study of asteroid 433 Eros, mapping its surface features, measuring its composition, and probing beneath its surface. What will we learn from this first-ever investigation of an asteroid from orbit? The answer lies in the rocks.

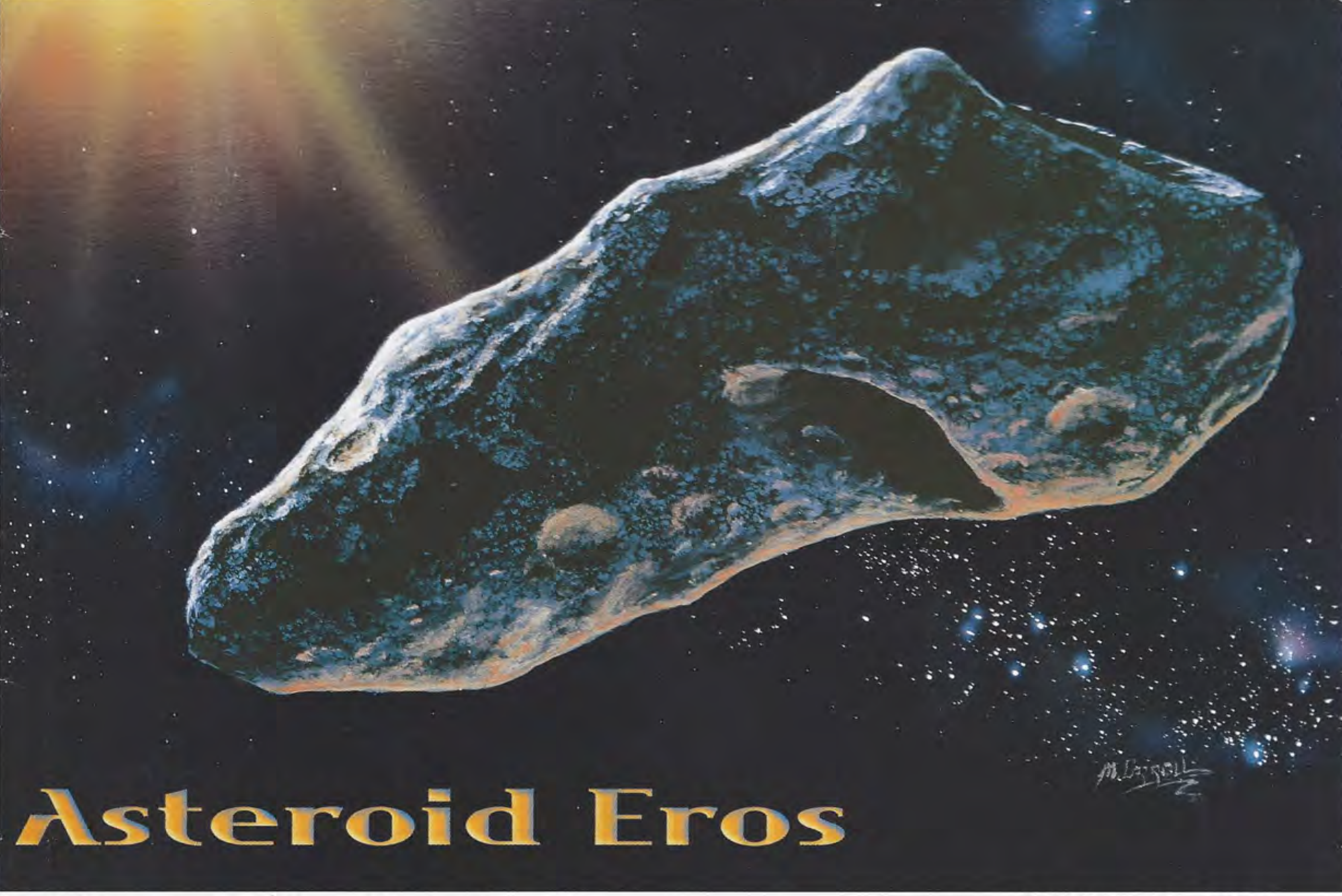
Rocks on Earth are a record of our planet's history, telling about dinosaurs, bygone oceans, and shifting continents. But Earth is so dynamic that the rock record of our planet's earliest history, the first billion years, has been largely lost to erosion and plate tectonics. Rocks on the airless Moon record earlier events, but even the Moon was active enough to obliterate the rock record of the primordial evolution of the planets. Asteroids, however, are nearly unchanged since the solar system's first hundred million years.

Much of what we know about asteroids comes from study of meteorites, most of which are fragments of asteroids. In their chemistry and mineralogy, some meteorites are nearly the same as when they first formed out of the solar nebula (the whirling disk of dust and gas that condensed to become the solar system). Other meteorites show signs of brief but intense activity that went on inside large asteroids, including melting, settling out of dense minerals, and buoyant rising of lighter ones that erupted onto asteroid surfaces as volcanic flows. Unfortunately meteorites are like fragments torn from an ancient manuscript: we don't know which asteroids are the sources of which meteorites, so the "big picture" of the evolution of the early solar system remains mysterious and controversial.

S-Type Asteroids

Telescopic surveys show that different asteroid types predominate in different parts of the solar system. C-type asteroids, thought to be rich in carbon, prevail in the outer part of the asteroid belt. In June 1997, NEAR's flyby of asteroid 253 Mathilde gave us our first look at a C asteroid (see the September/October 1997 *Planetary Report*, page 20). S-type asteroids, rich in silicate rock, prevail in the inner part of the asteroid belt and are common among near-Earth asteroids. The *Galileo* spacecraft flew by two S asteroids, 951 Gaspra and 243 Ida (asteroid numbers refer to their order of discovery). Both bodies proved to be irregularly shaped, heavily cratered, and mottled with subtle color variations that hint at different rock types. Ida even has a small moon, named Dactyl.

Flybys were not enough to answer the big questions we have about S asteroids: whether they are made of primitive



Asteroid Eros

Robinson, and Jonathan Joseph

The NEAR spacecraft zooms in for its encounter with Eros. Painting: Michael Carroll

or evolved rocks, where these asteroids come from, what their interiors are like, how their surfaces have been shaped by hundreds of millions of years of exposure to space, how meteorites are related to asteroids, and what it all means for our understanding of solar system evolution. We don't even know for certain whether asteroids are solid chunks or piles of rock fragments bound loosely by their gravity.

That's where NEAR comes in. NEAR will address these questions with detailed, systematic mapping and careful measurements, the kind that can only be done from orbit.

We chose Eros as NEAR's target partly because it's a "mainstream" S asteroid and partly because its global characteristics are well enough understood for planning an orbital mission. There was a campaign of telescopic and radar observations in 1975 when the asteroid passed within 13 million miles of Earth.

Eros is elongated and shaped much like a giant boat hull, roughly 35 kilometers long and 14 kilometers wide (22 miles long, 9 wide), with one side flattened and the other rounded. Eros orbits the Sun once every 643 days at an average distance of 1.46 AU (Astronomical Unit, the mean distance between the Sun and Earth). However, the orbit is eccentric, and Eros approaches the Sun as closely as 1.13 AU. A "day" on Eros, its period of rotation, is only 5 hours, 17 minutes long. Like the planet Uranus, Eros has a rotational axis that is tipped sideways, so the asteroid has exaggerated "seasons." When NEAR approaches Eros, the south pole will be pointing almost to the Sun, and the north pole will be in total darkness. Over the course of our year-long mission, the Sun will cross Eros' equator, reach its highest northern latitude on December 19, 1999, and then return toward equatorial latitudes.

Mission Design

The NEAR mission—designed, built, and managed for NASA by The Johns Hopkins University Applied Physics Laboratory (APL) in Laurel, Maryland—represents a number of "firsts" in planetary exploration. Besides being the first launch in the Discovery program of "faster, better, cheaper" missions, NEAR will also be the first to put a spacecraft in orbit around an asteroid and the first to accomplish orbit around a body whose mass and exact size won't be known until arrival. As a result, the design of the mission has to be flexible.

The six science experiments aboard the spacecraft contribute in different ways to answering our questions about the surface and interior of Eros. Two of the experiments perform double duty as both science and navigation tools.

Through much of the asteroid encounter, the multispectral imager (MSI) will image Eros four times per day or more. Specialists using a technique called optical navi-

(continued on page 7)

“Impossible” Imaging

To produce maps of an irregular, potato-shaped body like Eros, NEAR scientists will use two software tools: shape modeling and map projection. These were used to map Mathilde when NEAR imaged it on June 27, 1997 and to assemble views of Earth from images taken when NEAR swung by for its gravitational “kick” on January 23, 1998.

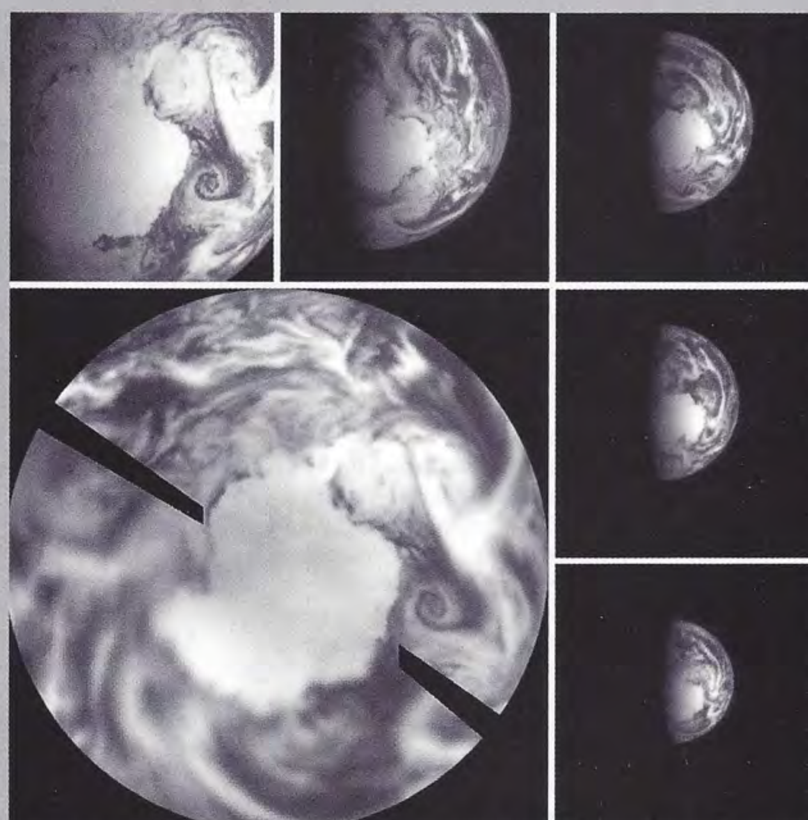
A shape model is a mathematical representation of the asteroid’s shape. To generate a shape model, we use data (numbers) from sets of stereo images or from laser range-finder measurements. The shape model provides a framework onto which images and other data can be overlaid. During its close approach to Mathilde, NEAR acquired 10 sets of images from different geometries. These were used to generate a shape model, onto which the Mathilde images were electronically pasted (or “registered,” technically speaking).

The resulting graphic can be mathematically rotated and viewed from any distance or perspective, providing a rendered view of what the asteroid would have looked like from different vantage points. This process was used to create a highly accurate “movie” showing how Mathilde looked from NEAR as it sped by—all from only those ten sets of images!

A map projection shows images or other information on a standardized latitude-longitude grid, so that a particular location always appears at the same point on the map. A map projection is valuable for comparing images or other data that show the same scene from different locations or with different illuminations, because it removes the effect of perspective on where a feature appears to be. For example, during the January 1998 swingby, NEAR took several hundred images looking down on Antarctica as Earth rotated below. Of course, no single image showed all of Antarctica illuminated at the same time, and images showing different parts of Antarctica at different distances gave different impressions of the continent’s size. Projecting the various images onto a map made it possible to assemble an image of the whole continent illuminated at once, which was at once a highly useful and paradoxical result from scientific information—an accurately detailed view of something that never occurs in nature.

The three image mosaics at left are the highest-resolution views of Mathilde obtained by NEAR. The extrapolated renderings from the shape model of Mathilde, at right, correspond to the gap in time between acquisition of the top and middle image mosaics.

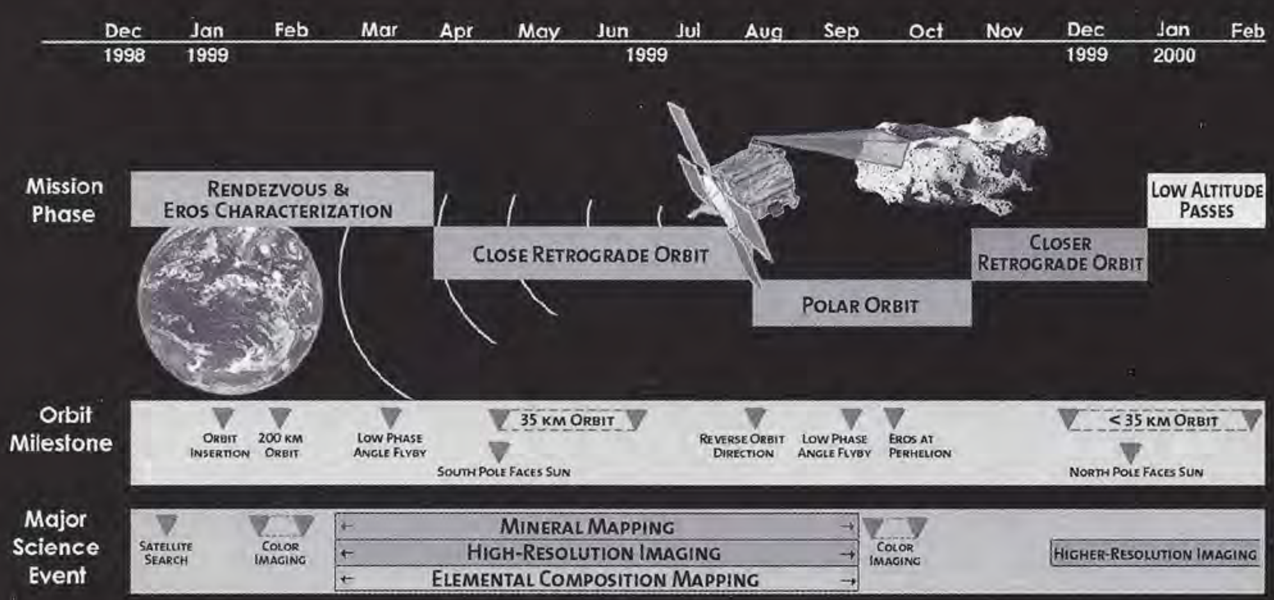
Images: Cornell University/APL/NASA



These five images of Earth, beginning clockwise from upper left, were among several hundred acquired over one and a half days as NEAR sped away after the January 1998 swingby. These and other images of Antarctica and the Southern Ocean were projected onto a map to show the whole continent illuminated at once. The difference in resolution of different parts of Antarctica reflects the difference in the distances at which the images were acquired.

Images: Northwestern University/APL/NASA

Timeline of Major Events at 433 Eros



(continued from page 5)
gation will track the landmarks that appear in the images, precisely determine NEAR's position relative to Eros, and use that information to plan maneuvers to keep the spacecraft on course. For science purposes, MSI will systematically map the shape, landforms, and color properties of the asteroid to determine the configuration of its different rock types and the processes that have shaped the surface.

The radio science experiment tracks tiny changes in NEAR's radio frequency caused by changes in the spacecraft velocity (the Doppler effect) as the spacecraft is pulled by Eros' gravity. Once we know its gravitational pull, we can calculate the asteroid's mass, which we need for planning close-in orbital maneuvers. The shape of Eros, discerned from imaging, and the mass measurements will be used together to determine Eros' density. Density is a critical clue to the structure and configuration of rock types inside Eros.

The remaining science instruments will perform detailed measurements of Eros' surface and interior. The near-infrared spectrometer (NIS), measuring the spectrum of sunlight reflected by Eros, will help us map the composition of the surface. The X-ray/gamma-ray spectrometer (XGRS), sensitive to emissions from natural radioactive elements and to fluorescence caused by high-energy solar and cosmic radiation, will provide a measure of major rock-forming elements, like silicon, magnesium, and iron, as well as key minor elements, like uranium, thorium, and potassium. Used in tandem, the NIS and XGRS will give a much clearer picture of the rock types on Eros' surface than would either instrument alone.

NEAR's laser range-finder, a "laser radar," will read the shape of the asteroid with accuracy down to a few meters. This extremely accurate shape measurement, together with radio-science measurements of the gravity over different parts of Eros, will reveal whether Eros' interior mass is distributed uniformly or in a lumpy fashion. This key result will help to determine if Eros is a coherent chunk or a loose pile of fragments.

The magnetometer will determine whether Eros has a magnetic field and, if so, its strength and shape. A magnetic field would be strong evidence for abundant metallic iron, like that in iron-nickel meteorites.

Trajectory Tricks

Getting the NEAR spacecraft to its target took a bit of ingenuity on the part of the mission designers. A direct route from Earth to Eros would have required a bigger launch vehicle than Discovery missions can afford. Instead NEAR was launched on a long, looping path out to the asteroid belt and back toward Earth for a gravitational "kick," which inclined the spacecraft's trajectory to match that of Eros. The asteroid's orbit is inclined 11 degrees from the ecliptic, the imaginary plane in which Earth's orbit lies.

NEAR's main engines will fire four times to slow the spacecraft, beginning on December 20, 1998. Three weeks later, the spacecraft will enter a high, elliptical orbit around the asteroid. By the end of January 1999, mission controllers will have learned enough about Eros to guide the spacecraft into a circular mapping orbit at an altitude of 200 kilometers (120 miles).

For NEAR to maintain a stable orbit, the spacecraft's orbit must nearly cancel out gravitational tugs caused by irregularities in Eros' shape. To achieve this stability, NEAR will be in a retrograde orbit, moving in the direction opposite the asteroid's rotation. Early in the mission, when the south pole is pointing toward the Sun, NEAR's orbit will follow the terminator, the line dividing the day and night sides of the asteroid. The NEAR spacecraft, which has fixed rather than movable solar panels and instruments, was built with this orbital orientation in mind.

Though its design was kept simple to keep costs down, NEAR will do some fancy flying later in the mission. August 1999 will bring Eros' spring equinox, as the Sun begins to illuminate previously dark northern latitudes. To maintain a retrograde orbit and at the same time keep the solar panels pointed at the Sun and the instruments viewing the asteroid, NEAR will have to reverse its direction of flight. This turnaround will be accomplished by shifting the equatorial orbit to an orbit that crosses both poles. The spacecraft will then swing out to high altitude, turn itself around, and return to low altitude. During the polar orbit, all of NEAR's instruments will come on to map northern and southern latitudes that were previously seen edge-on.

By late February 2000, NEAR will have precisely measured all parts of Eros, both sunlit and shadowed. In preparation for the end of the mission, NEAR will lower its altitude to 5 kilometers (3 miles) above the surface to acquire very high-resolution measurements.

See the Movie

Today, as the spacecraft approaches its target, the NEAR mission offers fantastic opportunities, via the World Wide Web, for everyone who's interested to follow the scientific study of a solar system body. Science operations begin in earnest December 27, 1998, when we obtain the first of four image mosaics of the space surrounding Eros in a search for asteroidal moons. Over the following weeks, one of the main science products will be sequences of images acquired as Eros rotates. These image sequences, forming a "movie" of the spinning asteroid, will survey the shape, colors, and landforms of all illuminated surfaces. The last sequence in which Eros fits entirely in the image frame will be taken January 9, 1999 from a range of about 1,300 kilometers (800 miles). The resulting movie, along with other NEAR movies and science results, should make ours the hottest site on the Web.

Once the spacecraft has reached its circular mapping orbit, you can expect to see unprecedented views from NEAR through much of 1999. By the end of March, we'll image Eros' southern hemisphere and equatorial regions in stereo and in color, showing features as small as 12 meters across. By mid-1999, the multispectral imager and near-infrared spectrometer will be taking daily strips of images and spectral measurements of the whole surface, resolving details as small as 2.5 meters. Finally, when NEAR descends to 5 kilometers (3 miles) above the surface, it will acquire images showing features smaller than 1 meter across!

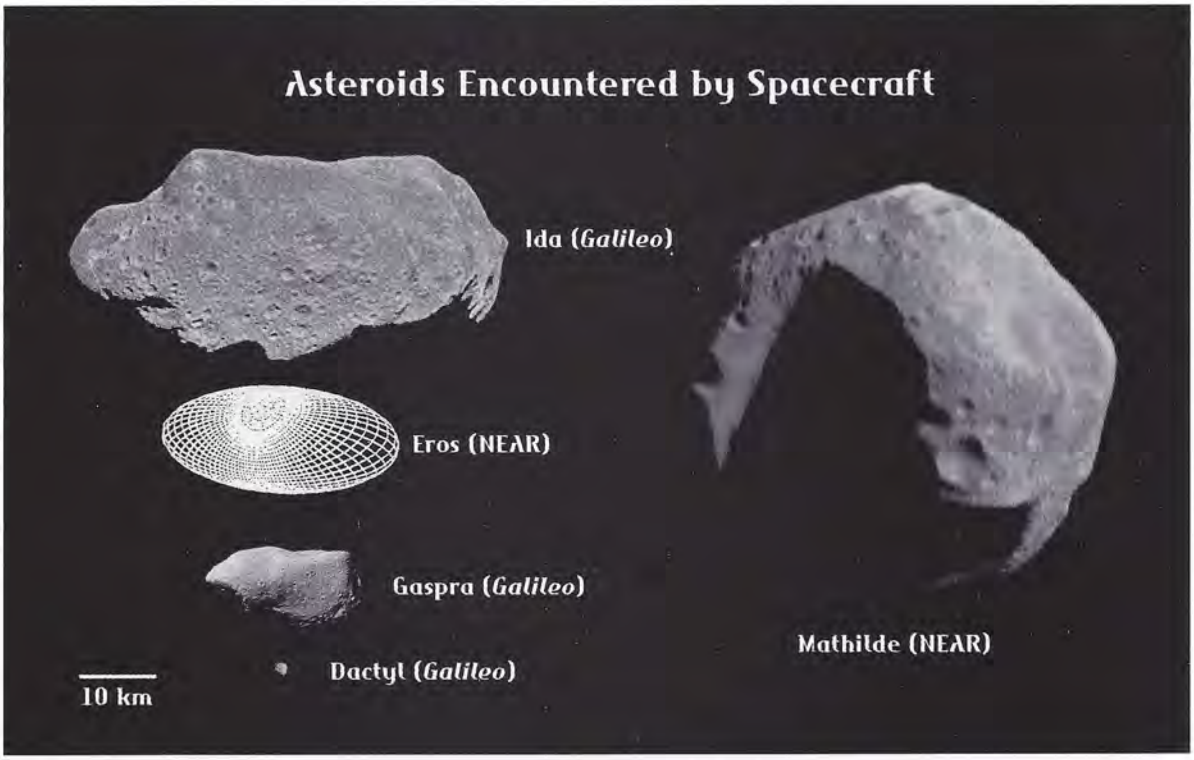
The year to come promises to be the time when the details of asteroids move from science fiction to science fact. To see it happen, stay tuned to the NEAR site on the World Wide Web.

Scott L. Murchie, on the NEAR MSI-NIS team, and James V. McAdams, on the Mission Design team, are both affiliated with The Johns Hopkins University Applied Physics Laboratory. Mark S. Robinson of Northwestern University is on the MSI-NIS team. Jonathan Joseph of Cornell University works with the MSI-NIS team

Images and movies from the NEAR mission can be found at the NEAR site on the World Wide Web.

http://near.jhuapl.edu

Now Showing: Mathilde, Antarctica, the Southern Ocean!



This montage of* Galileo *and NEAR images shows the asteroids visited by spacecraft at their correct relative sizes. The ellipsoid shown for Eros has the dimensions estimated for the asteroid from radar and telescopic studies.

Image: APL/Cornell University/NASA

Help Name the Craters on Eros!

433 Eros

Discovered 1898 August 13 by G. Witt at Berlin. Independently discovered 1898 August 13 by A. Charlois at Nice.

Named after the Greek god of love, son of Mercury and Venus. He protected the beautiful Psyche (see planet 16) from the vengeance of his mother, and when he later married her, she became immortal.

Dictionary of Minor Planet Names
Third Revised and Enlarged Edition
Editor Lutz D. Schmadel, New York: Springer-Verlag, 1997

The authoritative citation in *Dictionary of Minor Planet Names* gives the reason for the name of the asteroid Eros, soon to be encountered by the Near-Earth Asteroid Rendezvous (NEAR) spacecraft. The citation follows conventions established by the International Astronomical Union (IAU) for the naming of astronomical bodies.

Discoverers of asteroids receive the honor of naming the new bodies. And to the discoverers of features on these bodies —such as craters—goes the privilege of naming new features. As NEAR approaches its target, the mission team is faced with the daunting challenge of naming more than 100 craters that may be found on Eros and for which names will be useful, as when making reference to unique features or geographic position. The team would like a little help.

The NEAR team has asked Planetary Society members to suggest crater names, which will later be submitted to the IAU for official consideration. The selection process will follow the strict rules laid down by the international organization to ensure that the names chosen are appropriate and worthy.

Once a planetary body's discoverer has selected a name, there follows a theme for naming the geologic features such as craters. For example, Gaspra, the first asteroid imaged by *Galileo*, was named for a resort in the Crimea. Its craters are called after spas of the world. *Galileo*'s next asteroidal target, Ida, was named for a nymph who lived on the shores of Crete. Its craters are called after caverns and grottos of the world.

The name Eros suggests an obvious theme: love. The craters of Eros can be named after famous lovers, legendary romantic locales, aspects of love, and so on. (The IAU will reject obscene or offensive names.)

You are invited to submit names for Eros' craters. Each suggestion should be accompanied by a short explanation (50 words maximum) of why the name is appropriate. Please use a separate sheet of paper for each suggestion. Send your entries to:

Names on Eros
The Planetary Society
65 N. Catalina Avenue
Pasadena, CA 91106 USA

At the Planetary Society, a committee of planetary scientists, engineers, and staff will winnow the submissions and send the best names to the NEAR team. They will choose their favorites, assign the names to craters as they are discovered, and send the suggested names on to the Task Group for Small Bodies Nomenclature, chaired by Brian Marsden of the Working Group for Planetary System Nomenclature of the IAU. The task group will forward their recommendations to the IAU's Executive Committee, which will check the names for conformity to IAU standards. Finally, the names will be presented to the IAU's General Assembly for approval.

It will be a long process, but Planetary Society members will see their patience rewarded as the names they suggest become a permanent part of the language of planetary science. That is an honor given to very few.

—Charlene M. Anderson, Associate Director

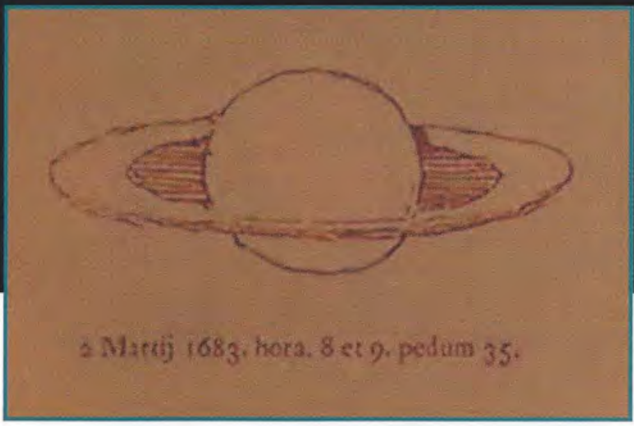
Naming Rules and Conventions

Here are some of the rules to be followed in suggesting names for craters on Eros.

- Nomenclature is a tool, and the first consideration should be to make it simple, clear, and unambiguous.
- Duplication of names on other bodies is to be avoided.
- Solar system nomenclature should be international in its choice of names.
- No names having political, military, or religious significance, or names of modern philosophers, may be used.
- Names of political figures prior to the 19th century are acceptable.
- Persons being honored must have been deceased for at least three years before his or her name can be assigned to a feature. Exceptions to the rule were made for living astronauts and cosmonauts because their contributions to space exploration were unique.

A complete overview of the IAU's naming process is available on the World Wide Web. This site has an alphabetical list that makes it especially useful for checking duplicate names. The address is **http://wwwflag.wr.usgs.gov/USGSFlag/Space/nomen/nomen.html.**

Planetary Rings: Endless Allure



While Galileo was the first person to observe Saturn through a telescope, it was the Dutch scientist Christiaan Huygens who figured out that those strange "handles" were actually rings around the planet. He made this drawing on March 2, 1683.

BY ANDRE BORMANIS

The starship *Enterprise* probes deep into the heart of a swirling interstellar gas and dust complex somewhere in the far regions of the galaxy. The discovery of strange, new worlds is routine in the 24th century, but hidden behind the veil of glowing nebulosity, Captain Picard and his crew discover a mesmerizing sight: a terrestrial planet with a stunning system of rings.

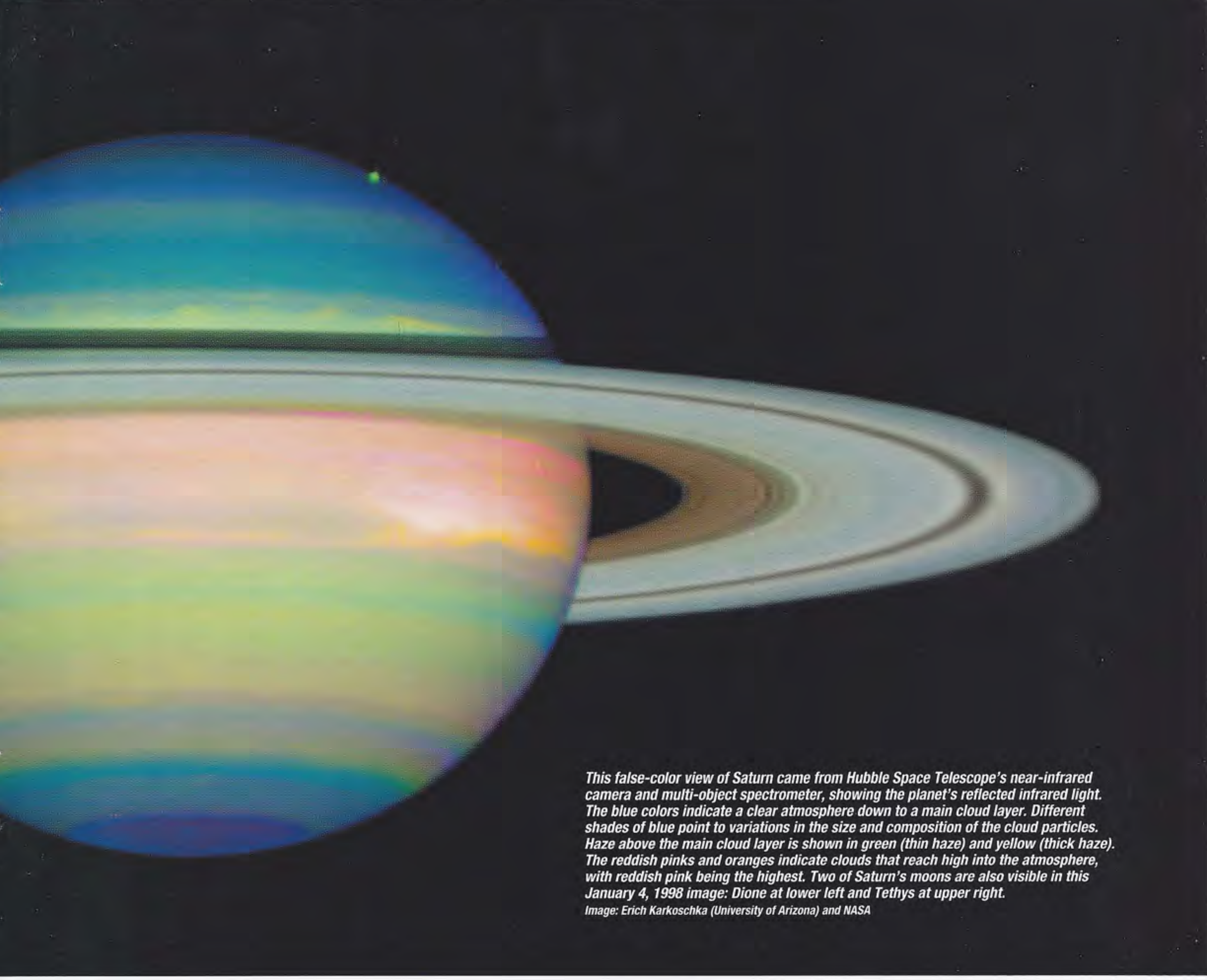
This ringed planet will be encountered by Jean-Luc Picard and company in the upcoming Paramount Pictures film *Star Trek: Insurrection*, the ninth movie in the highly successful feature-film series based on the legendary television program. The rings themselves play a crucial role in the movie's storyline.

Astronomers and laypeople alike have marveled at the phenomenon of planetary rings ever since Saturn's lovely loops were first resolved in a telescope. We've learned in recent years that Saturn isn't the only planet in our solar system encircled by a set of celestial hula hoops. Discovering how these features came to be has given us important insights into the formation and evolution of solar systems.

RIDDLE OF THE ANSAE

The scientist Galileo is well remembered as the first person to explore the night sky with a telescope. His discovery and subsequent observations of Jupiter's moons in 1610 provided strong evidence for the radical Copernican theory, which proposed that all of the planets, including our own, orbit the Sun.

He was also the first person to observe Saturn through a telescope. But Galileo was puzzled by what he saw. Instead of appearing as a simple disk, Saturn showed a central disk with two smaller disks on either side that almost touched the



This false-color view of Saturn came from Hubble Space Telescope's near-infrared camera and multi-object spectrometer, showing the planet's reflected infrared light. The blue colors indicate a clear atmosphere down to a main cloud layer. Different shades of blue point to variations in the size and composition of the cloud particles. Haze above the main cloud layer is shown in green (thin haze) and yellow (thick haze). The reddish pinks and oranges indicate clouds that reach high into the atmosphere, with reddish pink being the highest. Two of Saturn's moons are also visible in this January 4, 1998 image: Dione at lower left and Tethys at upper right.
Image: Erich Karkoschka (University of Arizona) and NASA

one in the middle. He tentatively assumed that the small disks were satellites, like the moons of Jupiter. Pointing his small telescope at Saturn again in 1612, Galileo was astonished to find that the two smaller disks had disappeared! He wondered, "has Saturn, perhaps, devoured its children?" Deepening the mystery, in 1616 Galileo noted that Saturn appeared to be girded by crescent-shaped objects, called *ansae* ("handles" in Latin).

Saturn's mysterious, mutable countenance was finally puzzled out by the Dutch astronomer Christiaan Huygens in 1656. Huygens had discovered Titan, Saturn's largest moon, the previous year. If the *ansae* were moons, they would take less time to complete an orbital circuit than Titan, since they were closer in. But Huygens saw no change in the appearance of these features over the course of a Titan orbit. He reasoned that since the *ansae* must be moving faster than Titan, they must be symmetric about the rotational axis of Saturn; otherwise their appearance would have changed in a matter of days. In what must have been an exciting "eureka" moment, Huygens realized that a wide, flat, continuous ring encircling Saturn would explain these and earlier observations.

Continuing observations with better telescopes revealed new ring details. In 1675, Jean-Dominique Cassini reported a thin dark line in the ring, dividing it into separate inner and outer sections. The outer ring was eventually designated ring A, and the inner, ring B. Later observers reported other, narrower gaps in the rings.

PHYSICAL NATURE OF RINGS

The physical nature of the Saturnian rings was debated for decades. Some astronomers argued that the rings were solid sheets of material; others claimed the rings consisted of hoards of tiny particles orbiting Saturn like miniature moons. Solid rings drew objections on the grounds that the gravitational force on the inner edge of each ring would be stronger than the force on the outer edge; this disparity would tend to pull the ring apart (unless it were made of some extraordinarily strong material). Solid-ring defenders countered that each broad ring "sheet" was really a series of extremely narrow

Bangles of Dust: A Mystery Solved

Unlike the icy chunks that encircle Saturn, Jupiter's more delicate system of rings is formed by tiny dust particles kicked up as interplanetary meteoroids smash into the giant planet's small inner moons. On September 15, 1998, scientists studying data returned by *Galileo* announced that they had discovered the workings and origin of the wispy and once-mysterious Jovian ring system. These revelations emerged from a series of images that *Galileo* captured during three orbits of Jupiter in 1996 and 1997.

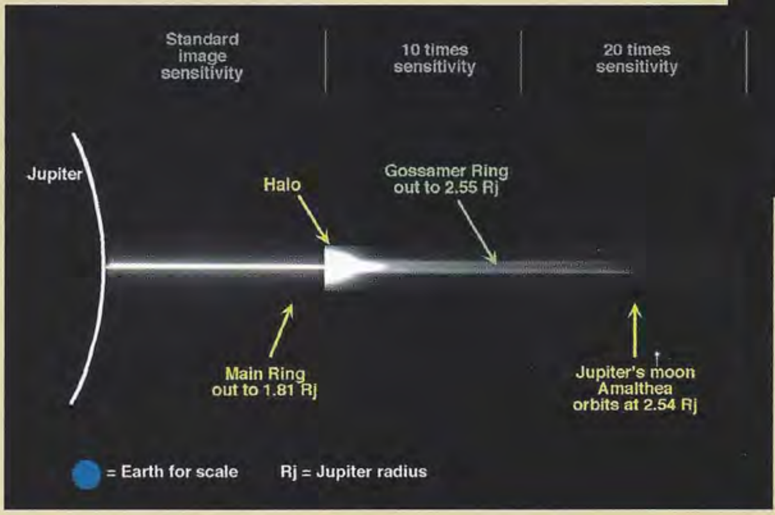
Researchers from Cornell University in Ithaca, New York and the National Optical Astronomy Observatories (NOAO) in Tucson, Arizona said that the dust particles are created as Jupiter's huge gravity field sucks in meteoroids (fragments of comets and asteroids) from surrounding space. When the speeding objects strike the moons (which are relative sitting ducks due to their closeness to the planet), the result is a powdery cloud—like the chalk dust that flies off two erasers banged together.

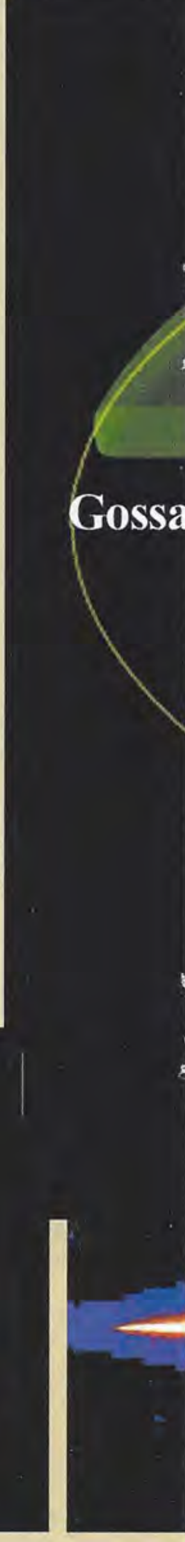
A larger satellite, such as Earth's moon, would have enough gravity to pull the dust back down to its surface. But Jupiter's relatively tiny inner moons—Thebe, Adrastea, Metis, and Amalthea, which is the largest with a mean radius of 85 kilometers (53 miles)—are too small to hang onto the debris. The particles enter orbits similar to those of their source satellites. Each of these ghostly rings is bordered by the orbit of its parent moon.

About 20 years ago, the *Voyagers* gave us our first look at the structure of Jupiter's rings: a flattened main ring and an inner, cloud-like ring called the halo, both made up of tiny, dark particles. One *Voyager* picture seemed to show a faint outer ring. New images from *Galileo* reveal that this third ring, called the gossamer ring because of its transparency, is actually two rings—one embedded within the other. Both rings are composed of microscopic dust from Amalthea and Thebe. "For the first time, we can see the gossamer-bound dust coming off Amalthea and Thebe, and we now believe it is likely that the main ring comes from Adrastea and Metis," said Cornell scientist Joseph Burns. Michael Belton of NOAO added, "The structure of the gossamer rings was totally unexpected. These images provide one of the most significant discoveries of the entire *Galileo* imaging experiment." —*Donna Stevens, Associate Editor*

Top right: This cutaway view of Jupiter's ring system shows the geometry of the dust rings in relation to the satellites that form them. These four little moons all orbit closer to Jupiter than the large Galilean moons —Io, Europa, Ganymede, and Callisto. The 1,000-kilometer (600-mile) separation between the orbits of Adrastea and Metis is not shown here. Data gathered by the Hubble Space Telescope were used to create the image of Jupiter. *Illustration: JPL/NASA*

Right: This mosaic of Jupiter's rings comprises a trio of images taken at three different sensitivities by Galileo's *solid-state imaging system. The pictures were obtained on October 5, 1997, when the spacecraft was in Jupiter's shadow and looking back at the Sun. At left, the white, vertical arc is sunlight filtering through Jupiter's atmosphere. In the middle frame (which shows fainter material), we see the overexposed main ring and the halo. The right panel, imaged at the greatest sensitivity, shows the tenuous gossamer ring. This ring is unusual in that its top and bottom edges are about twice as bright as the center. Unlike the main ring, it ends abruptly without narrowing at the outer edge.* *Image mosaic: JPL/NASA*

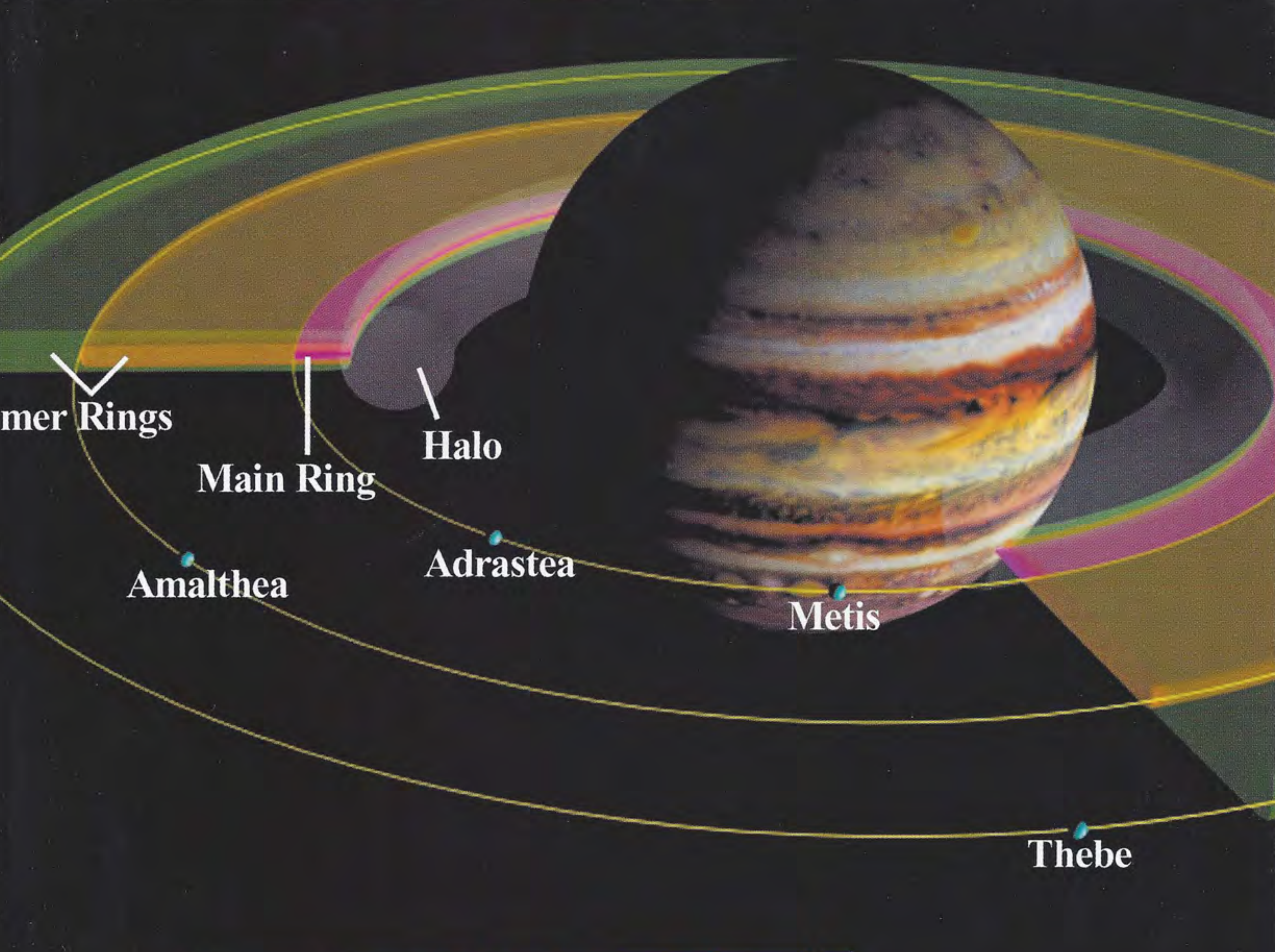


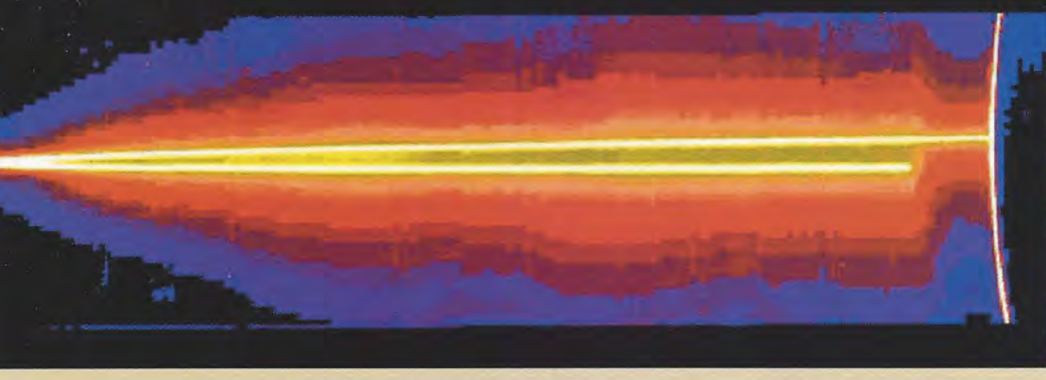


ring bands, so gravitational forces would be too small to create significant stress.

The argument was ultimately settled in favor of orbiting particles. In the mid-1850s, astronomers at Harvard College detected a new, tenuous ring inside the B ring, which they dubbed the "crepe" ring (now commonly called the C ring). The disk of Saturn was faintly visible through the C ring, strongly suggesting that the ring was not solid. In 1857, a young Scottish physicist, James Clerk Maxwell (who would later become the father of modern electromagnetic field theory), used Newtonian physics to argue convincingly that solid rings, no matter how narrow, could never be stable.

Modern planetary spacecraft, beginning with *Pioneer 11* in 1979, have provided scientists with much clearer views of Saturn's ring system. Echoing the speculations of some 19th century astronomers, spacecraft images show that the A, B, and C rings each comprise numerous thinner rings made up of particles ranging in size from dust grains to boulders. As the *Pioneer* and *Voyager* spacecraft passed behind Saturn, the attenuation of their radio signals was used to determine the





Left: Galileo *captured this view of Jupiter's ring halo—a nimbus of fine particles that extends from the planet out to about 122,500 kilometers (76,600 miles)—on November 8, 1996. The dust cloud floats above and below the main rings, shown in yellow. Scientists believe that the halo is probably caused by electromagnetic forces, which can push small grains out of the ring plane. False color was used to accentuate faint features in this image, with white and yellow being the brightest and purple the dimmest.* Image: JPL/NASA

density of the various rings. By comparing infrared, visible-light, and ultraviolet observations, scientists also determined the chemical composition of the ring particles: mostly water ice, with trace amounts of iron and sulfur, which accounts for the brownish-yellow color variations we see in the rings.

When the *Voyager 1* spacecraft hurtled past Saturn in 1980, it captured images of ring spokes—transient, shadow-like projections extending out above the B ring. No one had predicted the presence of these strange features. Dr. Carolyn Porco, currently a professor of planetary science at the University of Arizona and head of the *Cassini* mission imaging team, discovered as a graduate student that there was a definite connection between the ring spokes and Saturn's magnetic field, but theorists are still hard pressed to explain the exact mechanism by which this connection comes about.

Most planetary scientists believe that the ring spokes are made of microscopic dust grains that are broken free from larger ring particles by meteoritic impacts, which leave the dust electrically charged. The dust is temporarily suspended above the ring plane by a combination of magnetic and gravitational effects. A number of scientific models and computer simulations have been developed to figure out precisely how the spokes arise, but according to Dr. Mark Showalter, a NASA/Ames Research Center scientist from Stanford University, "none of the models is completely satisfactory."

How Ring Systems Form

Saturn's magnificent ring system was crafted by that relentless planetary sculptor, the force of gravity. The gravitational tidal force invoked by Maxwell to prove that the rings of Saturn couldn't be solid also acts on moons. At the distance of Titan, the difference in force on the moon's near and far sides is too small to pull it apart. But closer in, the tidal force is greater. There is a point, called the Roche limit, where the tidal force exceeds the strength of the forces that hold a typical moon together. If a moon that is not strong enough to resist disruption drifts in closer than the Roche limit, it will be slowly torn apart. The shredded fragments will continue to orbit the planet, bumping and grinding each other into yet smaller fragments that distribute themselves into wide bands and, eventually, complete rings.

One would expect that all this constant jostling and knocking around would tend to make narrow rings spread out as each orbiting particle seeks to maximize its elbow room. And yet the *Pioneer* and *Voyager* images clearly show a number of very narrow, distinct rings encircling Saturn. What keeps these rings ordered into neat, narrow bands? Planetary astronomers Peter Goldreich and Scott Tremaine proposed that small satellites, orbiting just outside and just inside a narrow ring, would act like ring shepherds, herding their flock of rocky debris through gravitational forces. This idea explains the empty space at Cassini's division: Saturn and its moon Mimas play a game of tug-of-war on any particles that wander into this segment of the ring plane. Dr. Porco notes that certain locations in the rings "have amazingly sharp boundaries" due to the gravitational interplay of Saturn and various shepherd satellites.

Several lines of evidence suggest that the rings of Saturn are on the order of a hundred million years old. Planetary scientists are still wondering how Saturn's rings might have formed so recently (in terms of astronomical time). One possibility is that Saturn captured a satellite from another part of the solar system, which collided with another moon or wandered past the Roche limit. But according to Dr. Showalter, there are "lots of uncertainties" in both the estimated age of Saturn's rings and their origin.

Ring experts hope that these and other uncertainties will be resolved by the *Cassini* mission. *Cassini* thundered spaceward atop a Titan IV rocket on October 15, 1997. The 5,600-kilogram (12,000-pound) spacecraft is arguably the most ambitious planetary probe ever launched, and it will be the first to orbit Saturn. Its purpose is to do for Saturn what the *Galileo* mission has done for Jupiter: systematic planetary exploration that will follow up on questions raised by the first flyby missions.

After a nearly seven-year journey that includes four gravity-assist planetary flybys (two swings by Venus, one past Earth, and a final push by Jupiter), *Cassini* will settle into Saturn orbit to begin four years of scientific studies. A dozen instruments on the orbiter will scrutinize the planet, its rings, magnetic field, and moons.

Cassini will also release a probe, built by the European Space Agency, to penetrate the hazy atmosphere of Titan and descend to the mysterious moon's surface by parachute. Named *Huygens* in honor of the moon's discoverer, the probe will relay to Earth the first in-situ images and data ever gathered at this fascinating world. *Cassini*, now speeding through interplanetary space at over 100,000 kilometers per hour (60,000 miles per hour), is scheduled to arrive at Saturn on July 1, 2004.

Rings Around Other Planets

Saturn was thought to be uniquely endowed until astronomer James Elliot and his colleagues at the Massachusetts Institute of Technology discovered a ring around Uranus in 1977. On the night of March 10, Elliot was aboard the Kuiper Airborne Observatory, using the aircraft's infrared telescope to observe a star as it passed behind Uranus. The plan was to measure how the light of the star faded as it passed behind the edge of the planet. This technique, called occultation, is a clever means of measuring the density of a planet's atmosphere: the star's light fades in proportion to the density of the atmospheric layer blocking it, until the star disappears entirely behind the planet's solid surface.

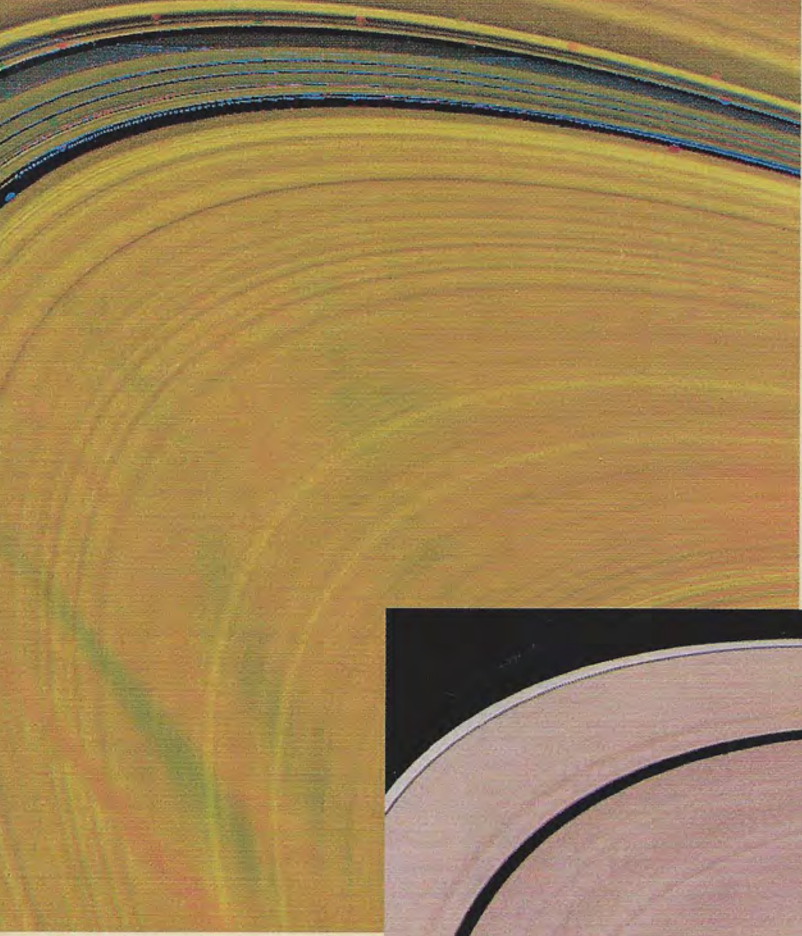
Elliot began his observations well before the predicted moment when Uranus was to eclipse the star. To his great surprise, the star flickered several times before it finally winked out behind Uranus. As the star reemerged, the same pattern of flickering occurred on the other side of the planet. Elliot and his team concluded that Uranus must be surrounded by a set of thin rings.

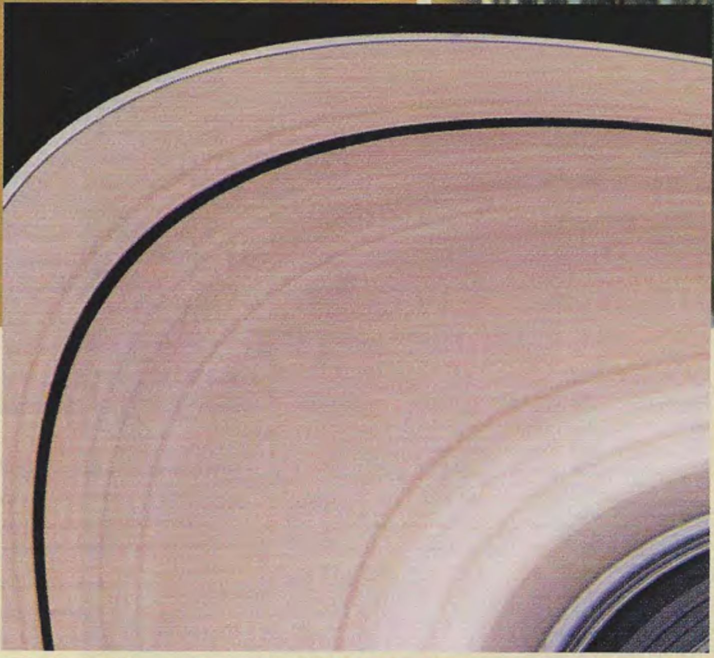
Thin rings proved to be common in the outer solar system. *Voyager 1* detected a slender, dusty ring around Jupiter in 1979. More recently, data from the *Galileo* spacecraft suggest that Jupiter has an outer ring made of interstellar dust (see the July/August 1998 *Planetary Report*, page 21). The occultation method indicated ring segments around Neptune in 1984. Using *Voyager 2* images, Dr. Porco verified that these segments owe their arc-like configuration to the shepherding action of a nearby Neptunian satellite, Galatea, also discovered by *Voyager*.

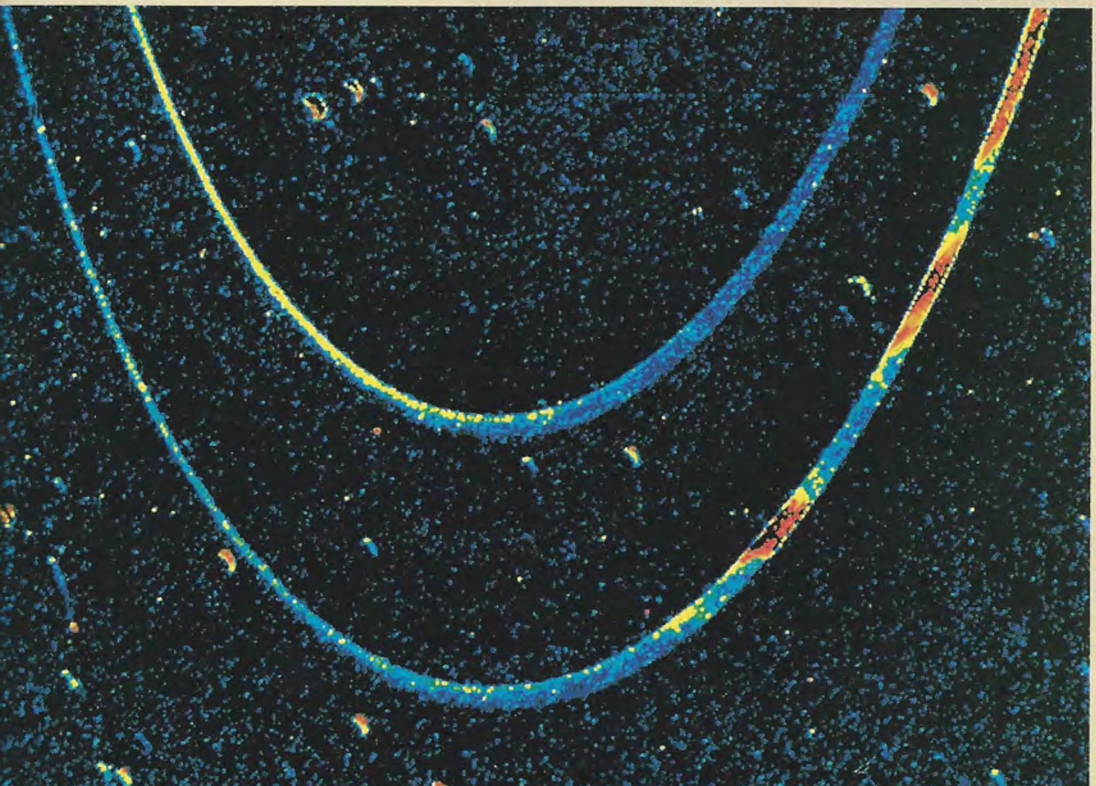
None of the terrestrial planets in our solar system is ringed. Here in the inner solar system, the fierce solar wind and tidal forces generated by the Sun act to disperse terrestrial rings fairly quickly. However, Mars may briefly possess a ring system in about 100 million years. Its moon Phobos is slowly spiraling in toward the planet and will eventually cross the Roche limit. Phobos itself may be strong enough to resist crumbling, but rubble and dust grains on the moon's surface will probably shake loose and spread into a thin ring. Without shepherding satellites, the ring probably won't last longer than a few hundred thousand years—a cosmic heartbeat.

All planetary rings are ephemeral features on the cosmic scale of time. Thus it may be sheer good luck that we live in one of the rare moments when our solar system features a ring system as magnificent as Saturn's. As astronomers report discoveries of Jupiter-scale planets orbiting nearby stars, suggesting that planetary systems are common in the universe, it is tempting to wonder how many other sentient beings are privileged to live in solar systems that host such an inspiring sight.

Andre Bormanis, a Planetary Society consultant, is science advisor for the Star Trek *television and movie series.*







Top left: Saturn's dark ring spokes, clearly visible in this Voyager 2 *image, are most likely caused by clouds of microscopic dust grains that are levitated by electrostatic forces. The spokes form as fine lines and widen over a period of 10 minutes, then fade away in a few hours.*

Top right: This Voyager *view shows a wealth of detail in Saturn's C ring (which occupies most of the frame). The bright area at top and left is the B ring.*

Center: This color shot of Saturn's rings was created from three black-and-white Voyager 2 *images, showing (from upper left to lower right) the A ring, Encke division, B ring, and C ring.* *Images: JPL/NASA*

Bottom: This Voyager 2 *image of Neptune's rings, processed to enhance differences in brightness, shows the Adams (outer) and Leverrier (inner) rings. Arcs in the Adams ring are visible as red and yellow, with red showing the brightest areas. The small crescents floating in the background are stars whose images have been smeared by spacecraft motion. That same motion makes the rings and arcs appear broader than they actually are.*

Image courtesy of Carolyn Porco, University of Arizona

There's a New Bird Aloft—Hope

Japan's *Planet B* Mars Mission Renamed After Successful Launch

by John M. Logsdon

The M-5 rocket sent Nozomi *on its way to Mars on July 4, 1998 at 3:12 a.m. local time.*

Photo: Courtesy of ISAS

The fourth of July, an important date in American history, is also becoming a milestone in Martian exploration. It was on that date in 1997 that *Mars Pathfinder* bounced onto the surface of the Red Planet. Those with long memories will recall that July 4, 1976 was the original target date for the landing of the first *Viking* spacecraft (the landing took place July 20, 1976). And this year, in the early morning hours of July 4, Japan launched the *Planet B* mission to Mars from its Kagoshima Space Center in the southernmost part of the country. In doing so, Japan became only the third nation to launch a spacecraft to another planet.

The solid-fuel M-5 launch vehicle was certainly the largest Fourth of July firecracker I have ever experienced! I was there representing the Planetary Society, as chair of the Society's Advisory Council. A few hours earlier, I had addressed a group gathered from throughout Japan and the world for the launch. I observed that the *Planet B* mission, which has been renamed *Nozomi*, was just the kind of activity the Planetary Society was founded to promote. The mission addresses important scientific questions. It is international in character, incorporating instruments from four countries in addition to Japan. And it involves the public. The spacecraft carries signatures of more than 270,000 Japanese citizens to Martian orbit. It seems fitting that the Planetary Society is now discussing with Japanese colleagues the organization of a Planetary Society affiliate in Japan. The time is propitious, as Japan enters the circle of nations carrying out planetary exploration.

Nozomi is a mission of Japan's space-science organization, the Institute of Space and Astronautical Science (ISAS). However, calling ISAS a space agency is a little deceptive. Although its funding comes from government, ISAS operates as a large, university-style research institute—albeit one with its own rockets and launch site! Its 324-person staff is directed by 114 professors;

174 postdoctoral and graduate students are involved in every facet of its activities. The current ISAS yearly budget is 29.7 billion yen ($212 million at current exchange rates). By contrast, the other Japanese space organization, the National Space Development Agency (NASDA), receives 1,778.8 billion per year. (NASDA is charged with technology development, while ISAS is focused on space science.)

On its bare-bones budget, ISAS designs, procures, launches, and operates its own spacecraft. It averages one high-quality science mission a year. There are no frills to the ISAS operation, as I could see while touring the launch center a few hours after *Nozomi* started its long journey. ISAS is clearly the original home of the "faster, better, cheaper" concept.

The Nozomi *spacecraft will study Mars from orbit for two years.*

Image: MSSS/NASA

The primary scientific objective of the *Nozomi* mission, which will orbit the Mars equator at various heights (coming as close as 150 kilometers, or 90 miles), is to investigate the interaction of the upper reaches of the Martian atmosphere and the solar wind. Understanding this interaction may give clues to the mechanisms through which Mars lost most of its original water, an understanding potentially relevant to Earth's future. The 540-kilogram (1,080-pound) spacecraft is carrying 15 scientific instruments—ten from Japan, two from the United States, and one each from Sweden, Canada, and Germany.

The mission was sent on its way by the second launch of the M-5 rocket. This three-stage vehicle was developed specifically to give ISAS the capability to carry out more ambitious scientific missions requiring heavier spacecraft. Even so, *Nozomi* had to be launched on a complex, gravity-assist trajectory that takes it past the Moon twice before the spacecraft swings by Earth for a last boost on December 20. *Nozomi* is scheduled to go into orbit around Mars and begin its two-year mission in October 1999.

Nozomi is the first Japanese mission to another planet, although two ISAS spacecraft investigated the coma and tail of comet Halley in 1986. Other missions will follow. *Lunar A*, scheduled for launch in 1999, will go into Moon orbit and fire penetrators into the lunar surface to carry out seismic measurements. The *Muses C* mission in 2002 will demonstrate technologies for asteroid sample return. ISAS and NASDA plan to collaborate on the ambitious *Selene* mission to the Moon in 2003.

The parent agencies of ISAS and NASDA are to merge in 2000; what lies ahead with respect to Japanese space programs is at this point unclear. Given its wishes, ISAS would prefer to maintain its independence and operating style.

Japan has a tradition of renaming its spacecraft once they are successfully launched. The rechristening of *Planet B* as *Nozomi*, which means *hope*, is highly appropriate, for the mission carries the hopes not only of Japanese space scientists but of exploration advocates around the world, who are hoping that the new entrant into the solar system exploration club will meet with resounding success.

For more information about ISAS, check out their site on the World Wide Web at **http://www.isas.ac.jp**.

John M. Logsdon, Director of the Space Policy Institute at George Washington University's Elliott School of International Affairs, is Chair of the Advisory Council of the Planetary Society.

Logsdon met with ISAS Professor Yasunori Matogawa, Director of the Kagoshima Space Center, a few hours before the Nozomi *launch.*

Atop Japan's M-5 launcher, the Nozomi *probe carries an international payload of instruments.*

Photos: Courtesy of ISAS

News and Reviews

by Clark R. Chapman

I've just attended a workshop on public policy implications of predictions about natural hazards (like earthquakes, hurricanes) and about environmental degradation (global warming, nuclear waste storage). The participants included philosophers, ex-staffers of the congressional House Science Committee, the operations director of Fargo, North Dakota (who dealt with the 1997 floods), a former emergency management director for Los Angeles, economists, structural engineers, social scientists, a Nebraska rancher (who relies on climate forecasts), a public utility official, a science journalist, a National Science Foundation official, a reinsurance analyst, and experts in the several predictive earth and environmental sciences.

Prediction Councils

I attended the workshop to present a case study of the asteroid/comet impact hazard. I felt a bit out of place. Most of the presenters of the other nine case studies dealt with hazards for which institutions and protocols have long existed. For example, the problematic selection of Yucca Mountain (Nevada) as the permanent repository for nuclear wastes during the next 10,000 years was the outgrowth of an elaborate, two-decade-long governmental process. Forecasts about whether the mountain will or won't contain the wastes successfully emanate from an official deliberative body, the Nuclear Waste Technical Review Board. When and if California seismologists dare again to make any short-term earthquake predictions (like the failed Parkfield prediction of 1985), they will be endorsed by the governor of California only after being vetted within the California Earthquake Prediction Evaluation Council (CEPEC).

Space scientists, on the other hand, are woefully unprepared to deal with the social impacts of their science. The heavens normally play little role in earthly affairs, despite the quackery of astrologists. Solar flares were the unique exception until the recent recognition of the impact hazard. Eight years after a congressional mandate to evaluate the hazard, NASA has only begun to augment the limited funding of telescopic searches for hazardous objects. I am hard-pressed to think of any research project on the nature and consequences of the modern-day impact hazard that has been funded by NASA. Among well-funded earthquake, hurricane, and climate-change researchers at the workshop, I felt alone in relying on my employer's overhead to pay for my participation.

Lack of institutionalized experience led, no doubt, to the mistaken forecast last March of an impact impending in 2028. A South Carolina banker at the workshop recalled his anger upon hearing the retraction two days after the apocalyptic headlines. We now know, as reported at the October meeting of the American Astronomical Society/Division for Planetary Sciences in Madison, Wisconsin, that the positions of asteroid 1997 XF11 observed just two weeks after its early-December discovery were already sufficient to rule out an impact in 2028. Those data, given normal celestial mechanics, imply a chance of impact less than the chances of a poker player in an honest game being dealt seven royal flushes in a row. This reassuring information would have been available, had anyone been adequately funded to use existing software to evaluate the probabilities.

Calculations and Protocols

Obvious lessons from this fiasco are that (1) NASA should fund experts to make valid impact-probability calculations and (2) formal protocols should be established for evaluating impact predictions before entities like the American Astronomical Society publicly endorse them. The widely promulgated, face-saving story that the unearthing of prediscovery (1990) images of 1997 XF11 saved the day might lead NASA to conclude that all it needs to do is fund more observations (benefitting observers and those who archive observations) when in fact we really need better early calculations. Case studies presented at the workshop document that economic and institutional biases often strongly influence predictions as well as conclusions drawn from them.

As for protocols, much discussion on the Internet has chided NASA for proposing to "censor" impact predictions. But consider this: NASA's establishment of an impact prediction evaluation council would no more censor the predictions of quacks (or of mistaken professionals) than CEPEC has censored amateur earthquake predictions (including one based on prophecies of Nostradamus), but it would provide a forum for evaluating predictions to which responsible news media would (one hopes) turn before printing scary headlines.

Predictive Space Science

It is odd that space scientists should be so unfamiliar with risk assessment and prediction. After all, astronomers are renowned for accurately predicting eclipses, and NASA engineers routinely predict the arrival of spacecraft at targets years in the future. The occasionally less successful predictions of comets and meteor storms "of the century" at least have no social consequences, other than causing would-be watchers to lose a few hours of sleep. Yet there *are* real social and economic costs in the use and misuse of predictions in the space sciences that extend beyond impact prediction. The *Challenger* astronauts were lost in part because of NASA's failure to heed a cold-weather forecast. The successes or failures of expensive spacecraft depend not only on space-qualified engineering but also on predictions from scientific models about planetary radiation belts, micrometeoroid fluxes, and planetary environments. Space scientists should catch up with other scientific disciplines and learn about risk assessment and the pitfalls of predictive science.

Clark R. Chapman attended the September 10-12, 1998 "Workshop on Prediction in the Earth Sciences: Use and Misuse in Policy Making," organized by the Geological Society of America and the National Center for Atmospheric Research.

World Watch

by Louis D. Friedman

Washington, DC—In the early days of October, Congress passed the necessary appropriations bills for NASA and the rest of the federal government. They also passed the Commercial Space Act, to encourage US private industry in the development of launch vehicles and other space services.

The Commercial Space Act was of particular interest to the Planetary Society because of an attempt in the House Science Committee to remove a clause that excepted international-cooperation science missions from the restriction of flying only on US launchers. The Planetary Society lobbied for the exception, which was included in the final bill that passed Congress. At stake were such endeavors as the France-US cooperation in Mars exploration: the 2005 Sample Return mission is planned for launch on the Ariane 5 rocket.

The appropriations bill contained increased allocations for space science and particularly for Mars exploration—above the amounts requested by the administration. This backing from Congress represents a great victory for the Planetary Society, as reported in the September/October installment of this column. The Mars program now enjoys unprecedented support. We have a national space policy signed by the President that calls for a "sustained robotic presence," and we have solid congressional funding for the robotic missions.

No commitment for human flight to Mars has been even hinted at by the administration or Congress. The main impediments to acceptance of that goal are the significant difficulties in the International Space Station program. NASA has had to request additional funds to compensate for the Russian government's lack of funding and for delays in their space station work. The Russians are developing the crucial service module, necessary before any human flights can occur. It is scheduled for launch in mid-1999. Until that launch is certain, the first two elements of the space station, which are ready now, cannot be flown to orbit.

Despite the problems and protestations about the increased cost and delays of the space station, Congress is expected to go along with the NASA request so that the project can keep moving forward.

Australia—Despite the lack of government support, Australia's near-Earth object (NEO) observation program has made gains in public support. Michael Paine, New South Wales Coordinator for the Planetary Society and head of Spaceguard Australia, reports increased media attention as well. *Quantum*, a popular news-magazine television show about science, recently devoted a segment to NEOs that included an interview with me. I cited the public support we had focused on this issue and the many letters that Australians have written to their government in support of the NEO observation program.

Cape Canaveral—We are in the midst of a busy five months, as four planetary missions launch between October 25 and February 15. Only a few years ago, many of us had to laugh when NASA Administrator Dan Goldin spoke of sending out a planetary mission every month—we had just come through a decade in which only two had been launched! And now, at least for this immediate time period, we're coming pretty close to Goldin's vision. Scheduled for launch in these five fruitful months are: *Deep Space 1*, heading to asteroid 1992 KD and perhaps to comets Wilson-Harrington and Borrelly; *Mars Climate Orbiter; Mars Polar Lander;* and *Stardust*, which will scoop a sample of comet Wild 2 and bring it to Earth for study.

The Planetary Society will host public events at Cape Canaveral for the launches of *Mars Polar Lander* and *Stardust.* Watch our home page on the World Wide Web for announcements, or call Susan Lendroth at the Planetary Society.

Moscow—In cooperation with the major space agencies around the world, the Planetary Society organized a workshop on human expeditions to Mars that was hosted in Moscow by the Space Research Institute and the RKK Energia Company. Participants held wide-ranging discussions on technical and social issues related to human missions to Mars. Even though the meeting was held during the week of a change of government in Russia, the workshop received a great deal of press attention.

A NASA representative commented on the similarities in parallel studies conducted by the US and Russia concerning the key technical issues and technology requirements for a human Mars expedition. Russian mission designers described their interest in solar-electric propulsion for such a mission and their plans to build a prototype, a robotic vehicle to be tested in a flight from *Mir* or the International Space Station.

Conference participants agreed that now is not the time to seek project approval for a human expedition to Mars but that advanced technology preparations were urgently needed to continue bringing down the cost for a mission in the early part of the 21st century.

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

Questions and Answers

What will happen to the* Huygens *probe if it chances to land in an ocean on Titan? Will it float? What kind of data will it send and for how long?
—Everett Greene,
Cedar Rapids, Iowa

The *Huygens* probe, built and operated by the European Space Agency, *is* designed to float! *Huygens* will spin away from the *Cassini* spacecraft on November 6, 2004 and, after free-falling for three weeks, will enter the dense, hazy atmosphere of Saturn's largest satellite.

The probe's main mission is to parachute down through Titan's clouds, transmitting measurements of the atmosphere and of the approaching surface back to *Cassini* for relay to Earth. The data return will include images taken in visible and near-infrared light.

After its 2.5-hour descent, *Huygens* may survive landing. If so, whether it encounters solid or liquid, *Huygens* will continue to transmit data for half an hour or more.

Huygens is designed to report how "hard" the surface is by telling how much deceleration it felt when it hit. If the surface is liquid, sensors will measure its density, temperature, refractive index, thermal conductivity, heat capacity, and electrical permittivity. A tilt sensor will report any motion due to waves. Also, an acoustic sounder will measure the speed of sound in the liquid and, possibly, even its depth.
—DAVID F. DOODY,
Jet Propulsion Laboratory

Since the larger planets in our solar system are gas giants and the smaller ones are solid, it makes me wonder if there is a limit to how large a planet can become before it can no longer remain solid. Do distance from the Sun and temperature play important roles here?
—Daniel Paul Medici,
Syracuse, New York

It is possible in principle that a planet as massive as Jupiter could be solid. But in practice this is unlikely because composition matters here more than mass, and the elements that make up solid matter are not sufficiently abundant.

The reason the most massive planets are gas giants is that they are made primarily of the most abundant stuff in the universe—hydrogen. Less massive planets are made of less common elements, such as those needed to make ice or rock. The gas giants are fluid because hydrogen does not liquefy or solidify under the conditions that one finds in the atmosphere or inside the planet.

(In the so-called gas giants, the deep interior—which makes up most of their mass—is not gaseous in the everyday sense of the word. *Fluid* is a much better term since it encompasses both low and high densities. *Fluid* is not synonymous with *liquid,* which is what you usually get if you cool a gas or heat a solid sufficiently. The dense fluid that makes up most of Jupiter arises from immense pressurization of gas at temperatures so high that one never encounters a transition to liquid.)

If one had enough of the heavier elements to make a ball of rock the same mass as Jupiter, and if that body did not have a massive atmosphere, then it could have a solid surface and a mostly or entirely solid interior. It would have a high heat flow (because of radioactivity and heat of formation), much higher than Earth's, but that heat would be eliminated in a way somewhat like the process we see on Earth—that is, by convective flow of solid material, perhaps manifested at the surface by plate tectonics.

But it is unlikely that any such planet (very massive yet solid) would form in any solar system because there is not enough of the right stuff and because it

In early November 2004, the Huygens *probe will descend into Titan's atmosphere, where it will collect measurements and capture images of this murky, mysterious world.*
Illustration by Don Davis, from The New Solar System, *4th ed., to be published December 1998*

New high-resolution images of Phobos taken by Mars Global Surveyor*'s Mars orbiter camera show many never before seen features on the Martian satellite. Large boulders appear partially buried in the layer of surface dust. Light and dark streaks trailing down the sides of Stickney crater (top left) prove that even in a gravity field about one-thousandth that of Earth's, debris still tumbles downhill.*
Image: MSSS/NASA

is difficult to avoid aggregating gas as well when a planet becomes that massive.

Distance from the Sun plays very little role in this issue once the body forms. For example, if Jupiter were removed to a very great distance from the Sun, the planet would not change its temperature structure by a large amount and would not liquefy or solidify. The reason is that Jupiter is partly self-luminous (deriving its atmospheric temperature in large part from internal heat rather than heat from the Sun).

In principle, a planet with Earth-like composition (but not necessarily Earth's mass) could be liquid throughout if it had a very massive and opaque atmosphere, because of the greenhouse effect. This all-liquid composition would depend partly on distance from the Sun but would be unlikely to occur except when the planet was very young. (It might have been briefly true for Earth!)

Lest all this seem well understood, I should mention that the issue of whether the deep interior of a planet is liquid or solid is complicated. The hottest place inside Earth (the center) is solid, but the material overlying the center is liquid. This very large, liquid-iron region is called the outer core, and it is the place where Earth's magnetic field is generated.

The complex thermodynamic behavior of mixtures and the interplay of temperature and pressure are responsible for these complications. Pressure tends to cause materials to solidify even when they are very hot (as hot, in the case of Earth's solid core, as the radiating temperature of the Sun). But the conditions deep inside Jupiter (pressures tens of millions of times greater than in Earth's atmosphere and temperatures more than twice those in the Sun's atmosphere) do not allow solidification of hydrogen, even though they turn hydrogen into a (fluid) metal.

—DAVID STEVENSON,
California Institute of Technology

Factinos

The surface of Phobos is hip-deep in fine powder—produced by aeons of meteoroid impacts—according to data from *Mars Global Surveyor* (see image at left). Temperature measurements from the spacecraft's thermal emission spectrometer show the powder to be at least one meter thick.

Measurements of the day and night sides of the Martian moon also reveal such extreme temperature variations that the sunlit side is like a winter day in Chicago, while only a few kilometers away it is colder than a night in Antarctica. Highs on the potato-shaped moon reach – 4 degrees Celsius (25 degrees Fahrenheit), while lows dip to –122 degrees Celsius (–188 degrees Fahrenheit).

According to Philip Christensen of Arizona State University, principal investigator for the thermal emission spectrometer experiment, a blanket of dust would explain the rapid heat loss as Phobos rotates. With no atmosphere to hold in heat during the night, the fine particles cool off quickly after the Sun has set.

In addition to the new Phobos data, *Mars Global Surveyor* has obtained the first global-scale infrared spectra of Earth and Mars, which may lead to new comparative insights on these three very different worlds.
—from the Jet Propulsion Laboratory

❖

Cosmic grit that survived a fiery ride from space 1.4 billion years ago has been discovered in a layer of sandstone in Finland. The particles, known as cosmic spherules, measure a fraction of a millimeter in diameter. At least 18 were deposited in a layer of red sandstone at a time when oxygen-rich, life-giving conditions on Earth were just developing.

The micrometeorites are by far the oldest extraterrestrial debris found on this planet, according to the German and Finnish field team that published the discovery in the September 10, 1998 issue of *Nature*.

Scientists who specialize in cosmic dust described the discovery as spectacular. They said the composition of the Finnish meteorites will open a window onto the environmental conditions of early Earth.
—from the Associated Press

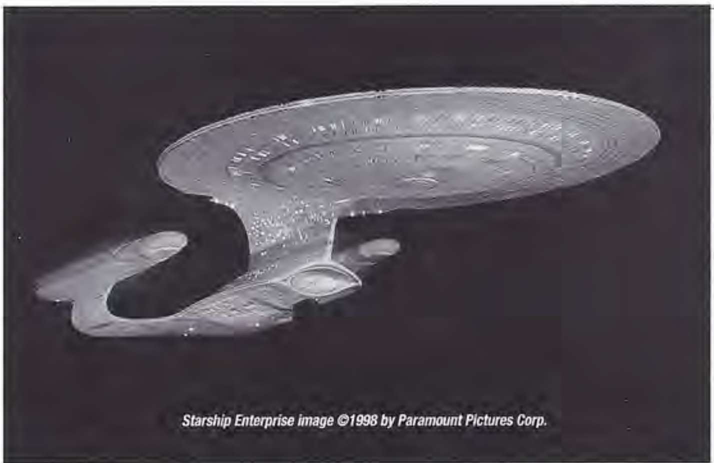
❖

The volcanoes of Io produce the highest recorded surface temperatures in the solar system, according to a team of scientists reporting in the July 3, 1998 issue of *Science*. "The very hot lavas erupting on Io are hotter than anything that has erupted on Earth for billions of years," says lead author Alfred McEwen of the University of Arizona. "They are the highest surface temperatures in the solar system other than the Sun itself."

At least 12 vents on the Jovian moon spew lava at temperatures greater than 1,200 degrees Celsius (2,200 degrees Fahrenheit). One volcanic vent may be as high as 1,700 degrees Celsius (3,100 degrees Fahrenheit), which is about three times hotter than the hottest sunlit surface of Mercury. Except for the volcanic hot spots, the surface temperatures on Io stay well below freezing.

McEwen and his colleagues calculated Io's temperatures using two instruments on *Galileo*. Their report provides an important insight on geophysical processes within Io, which may be similar to the early stages of evolution for Earth and other planets.
—from the University of Arizona

Society News


Starship Enterprise image ©1998 by Paramount Pictures Corp.

Society Joins SETI@home

Recently, the University of California at Berkeley's SERENDIP IV switched on at the Arecibo Observatory radio telescope in Puerto Rico—300 meters across, the world's largest, single-dish radio telescope. Typically, the Arecibo dish completes a scan of all the sky visible to it every six months or so, providing SETI (the Search for ExtraTerrestrial Intelligence) with a thorough survey of that region of our galaxy. The data from SERENDIP IV will eventually be used in an even more ambitious SETI project—SETI@home, an innovative screen-saver program that will harness the spare power of hundreds of thousands of Internet-connected home computers around the world to crunch data from SERENDIP IV.

The brainchild of SERENDIP project director Dan Werthimer, computer scientists David Anderson and David Gedye, and University of Washington astronomy professor Woody Sullivan, SETI@home is a unique screen-saver program that can be downloaded onto home computers, allowing recipients to become active members in this SETI effort. The software will be available free to anyone wishing to participate in the program.

As part of a grand scheme for data crunching, SETI@home will change the way we evaluate SETI data, according to Werthimer. "By the time hundreds of thousands of PCs are involved, the scope of the search will rival other current SETI projects," he says. The screen saver will not only bring valuable information about ongoing search efforts to participants but will expand current efforts.

In a new partnership for the Planetary Society, Paramount Pictures has joined us by matching our $50,000 grant in support of the Berkeley SERENDIP team and SETI@home.

For more than three decades, Paramount's popular *Star Trek* television series and films have had a mission "to explore . . . new civilizations." Now, SETI@home offers Star Trek fans worldwide the chance to participate directly in the scientific search for life elsewhere. Paramount will promote SETI@home and help sign up participants for the project in conjunction with the December 11, 1998 premiere of its newest Star Trek adventure feature, *Star Trek IX: Insurrection*.

Those interested in joining the search should visit the Planetary Society's site on the World Wide Web at **http://planetary.org** or the Star Trek site at **www. startrek.com**.

—Charlene M. Anderson, Associate Director

Your Society MBNA Credit Card Helps Us

A big thank you to all members who used their Planetary Society MBNA VISA card over the course of last year. The Society received more than $44,000 from this program. Every time card members make a purchase, they continue to support the Planetary Society. Platinum and gold cards are also available and display the Planetary Society logo.

Support the Society by getting one of these cards. For information about the program, contact me at Society headquarters.

—Lu Coffing, Financial Manager

Volunteer Network Growing

Thanks to the generous efforts of our volunteers and regional coordinators around the world, the Planetary Society is getting more and more involved in international public events related to space, increasing our presence as never before.

You can help educate the public and help our membership grow by becoming a volunteer or coordinator. We're working to maintain an updated volunteer section on the Planetary Society's home page at **http://planetary.org/society/volunteers.html**. If you'd like to get involved, contact me at Society headquarters.

—Alice Wakelin,
Volunteer Coordinator

More News

Mars Underground News
Water and Mars: What Is Surface Morphology Telling Us About the Planet's Past?

Bioastronomy News
The Planetary Society Hits $1 Million in SETI Donations.

The NEO News
Nano-rover goes to an asteroid aboard Japan's *Muses C*; sizing up the largest asteroids.

For more information on the Planetary Society's special-interest newsletters, phone (626) 793-5100.

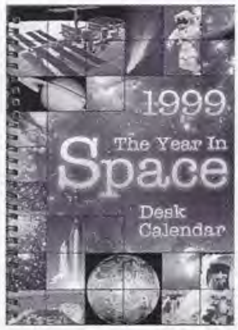
See the Last Solar Eclipse of the Century

A few tickets are still available for the Planetary Society's two exciting solar-eclipse tours in August 1999: a land tour in Turkey and a Black Sea cruise. For more information on how you can be there for the last total solar eclipse of the century, just ask for the free brochure. Send your postal address to the Planetary Society by mail or by e-mail to **tps.sl@mars.planetary.org**.

—Susan Lendroth, Manager of Communications and Events

HOLIDAY GIFT GUIDE!

Make this holiday season fun and easy by shopping with the Planetary Society. Use this gift guide and the catalog (in the September/October 1998 issue of The Planetary Report) to make everyone happy!



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Deserts on our planet come in a wide variety of forms—from the baked, cactus-covered terrain of the American Southwest to the cold, dry valleys of Antarctica. It is not temperature or even a particular type of geology, such as sandiness, that defines an area as desert—but the scarcity of liquid water. These arid, sparsely populated regions help us understand and explore other worlds with characteristics similar to Earth's—places like Mars. *Desert* by Tina York portrays the wind-sculpted sand dunes found in some deserts on Earth, such as Death Valley and the Sahara.

Tina York has paintings in 49 public collections in institutions around the world, including NASA Headquarters in Washington, DC; Columbia University in New York City; the Tokyo International Art Gallery in Japan; and Hyatt International in Paris. She lives and works in Fountain Hills, Arizona.

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