The PLANETARY REPORT

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Mercury Revisited

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From The Editor

We welcome some pretty amazing people through the doors of The Planetary Society. Recently, we've been seeing a bit of Pascal Lee, a former student of our cofounder Carl Sagan. For the past five years, Lee has been organizing the fascinating field research project on Devon Island in the Canadian High Arctic.

The overall effort is called the NASA Haughton-Mars Project (HMP), after Haughton Crater, which serves as the focus for the scientific research. The Mars Society has built its Flashline Mars Analog Research Station on Devon Island and cooperates with Pascal's research program.

Last summer, Society Executive Director Lou Friedman visited Devon Island to further develop a new initiative called Mars Outposts. Under the leadership of Bruce Betts, our new director of projects, we are investigating technology for Mars exploration that might include remote-controlled airplanes, smart rovers, instrumented balloons, or other novel means to study difficult terrains.

All this leads, of course, to what we hope will be a human presence on Mars. Since 1985, human missions to Mars have been an avowed goal of The Planetary Society. With the help of friends like Pascal, as well as our members, we are making progress toward that goal.

—Charlene M. Anderson

On the Cover:
This mosaic of Mercury is compiled from images taken by *Mariner 10* as it approached the planet on March 29, 1974. Mercury's ancient cratered surface can tell us much about the formation of the inner solar system. In the next decade, two new spacecraft will visit Mercury, the least-explored terrestrial planet, to continue the exploration *Mariner 10* began almost 30 years ago.

Image: JPL/NASA. Reprocessed by Mark S. Robinson, Northwestern University.

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Members' **Dialogue**

A Science Mystery

The "Strange Acceleration of *Pioneer 10* and *11*" in the November/December 2001 issue of *The Planetary Report* was one of the best articles of its kind I've read in a while. It explained complex technical concepts to nonspecialists while conveying a very real sense of the mystery of space. Congratulations to the authors!
—NEIL L. INGLIS,
Bethesda, Maryland

Nuclear Propulsion

I was somewhat alarmed that the latest NASA budget focuses on the development of nuclear propulsion systems, and even more surprised that The Planetary Society seemingly supports these plans. While I generally appreciate all efforts to develop new technology for more efficient planetary exploration, I'm worried about the possible risks involved with nuclear systems, especially since these systems need to be transported into orbit. Once in space, they would probably not cause any damage, yet the thought that some nuclear reactor could land (or crash) on Mars or Europa, for example, leaves me uncomfortable.

Maybe you could clarify what these new technologies might look like, what risks are involved, and how they could possibly be managed.

In any case, I'd prefer that NASA and The Planetary Society focus on less harmful new technologies such as ion propulsion and solar sailing.
—JOERG BENSCHEIDT,
Aachen, Germany

We welcome the nuclear power initiative, recognizing the need for it in future exploration. We also recognize the need for nuclear power use to be environmentally safe and ethical. Our position, which we will be developing as the proposal moves forward, will consider both needs.
—Louis D. Friedman,
Executive Director

I think the decisions by President George W. Bush and [NASA Administrator] Sean O'Keefe to cancel the Outer Planets program (including the Pluto–Kuiper Belt mission) and replace it with New Frontiers (nuclear energy development) is a prudent choice. Pluto can wait. So can Europa.
—RUSSELL B. CLOUSING,
Lansing, Michigan

On Clearing the Air

In the November/December Members' Dialogue, Zenon Kulpa repeats his prerequisite that Planetary Society programs impact our ability to live in space to be worthwhile. However, the Society's website states that it "supports and advocates exploration of the solar system and the search for extraterrestrial life" and that it was founded on those principles.

Unless someone breaks the light-speed barrier, space exploration, even within the solar system, will continue to rely heavily on remote and earthbound hardware, not on astronauts.

As for SETI, a discovery would have tremendous ramifications. A host of questions scientific, philosophical, and theological would be generated by evidence of the existence of intelligent extraterrestrial life. Consider the excitement sparked by the possible evidence of ancient microbial life on Mars. How much more public interest would be generated by picking up a radio signal from another planet? Even if unsuccessful in finding life, SETI could yield other scientific discoveries.

Kulpa extends my SETI/car radio analogy by saying that "if our listening to the radio, while having no impact on our driving ability, would cost so much as to deplete our gas budget for the drive, then certainly we should stop listening to that radio."

I must respond, only half-jokingly and with a nod to Carl Sagan's *Contact*: but what if, while listening to the radio, we learn where to get cheaper gas or, better yet, how to make our car more fuel efficient?
—SCOTT PEARSON,
St. Paul, Minnesota

Erratum

The caption for David Hardy's painting, *Millennium Planet*, which appeared on the back cover of the November/December issue, did not mention that the painting is from Hardy's new book, *Hardyware: The Art of David A. Hardy*, published by Paper Tiger. (Read a review of the book on the Society's website, *planetary.org*.)

Please send your letters to
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OPINION:

Whither, O Splendid Ship?

Is it humankind's destiny to be a multiworld species? We have already left our footprints in lunar soil. Focusing our steps next on an international program of policy change, public involvement, and technological development will place the people of Earth on the path to a sustainable future in space.
Illustration: David Hardy

by James D. Burke and John Young

Where are we going next in space? After a brief, glorious lunar foray driven by national pride yet also expressing humankind's greatest aspirations, people in industrial nations retreated to a more limited vision for human spaceflight. They seemed content to occupy a thin shell of space around Earth.

Meanwhile, the rest of the world continued on with grand achievements, accompanied by injustice, pestilence, pollution, and war, and with misery sometimes relieved and sometimes aggravated by modern technology.

But now, the human race has passed a threshold: barring a failure of resolve and commitment, there will always be human beings living, first, in nearby space stations and, then, elsewhere. What does this mean for humankind as a whole? Is this just another flashy stunt, or is it the start of a new phase in history?

Here, two of us, seasoned in the trials and joys of, respectively, robotic and human probing into the cosmos, present our own ideas. We've seen it all from the very beginning. Still, our appetite for new adventures is lively. We do not claim any special predictive skills. But we do believe firmly in the rightness of our cause.

We assert that the future is what human energy can make it. We aim to show how that energy might fuel civilization to break through to a new state of functioning: a society with two established homes and a thriving planetary outreach, a society immune to Earthly devastation and open to unprecedented evolution.

The Opportunity

With *Skylab*, *Mir*, and now the International Space Station, the world community of in-space builders is laying foundations for a structure whose final architecture is yet to be known. Meanwhile, robotic missions are relaying new knowledge whose ultimate uses also remain unknown.

Yes, human beings seem able to function for long periods in microgravity. Yes, near-Earth space, the Moon, the asteroids, and Mars are rich in resources of energy and building materials. And yes, some few—as yet only a few—applications of space technology do make money. But a vast field of ignorance, and hence of opportunity, remains. Chipping away at that ignorance is the task of a vigorous and diverse array of space projects worldwide.

As people in more and more nations take up the challenge, not only are space sciences and technologies advancing, but the idea is spreading that spaceflight is essential. As the world is organized today, there is some duplication and waste. But there are benefits, too, including survival of the best concepts and management tools and, most important, wide public acceptance.

Increasingly binding international agreements are sustaining long-term commitments to programs both on Earth and in space. More than any technical advance or bold individual or national advocacy, this slow and halting shift in public perspective points toward a time when humans will again travel to the Moon—this time to stay.

Once that happens, not only will humankind be building a safe haven against natural or self-inflicted terrestrial catastrophe, but also civilization may develop in unparalleled, even unintended, ways. Whether that will be good or bad in some historic sense is now unknown, but we had better not remain ignorant for long.

We have real wars—the war on terrorism, the war on

Views expressed in this article are those of the authors and do not necessarily represent those of The Planetary Society.

crime, the war on hunger—but the war we must win, which hardly anyone realizes we are in, is the war on ignorance. In the exploration of space and Earth, we have discovered, just last summer, good evidence that the four major extinctions of life-forms on Earth since Permian times (about 250 million years ago) were caused by impacts.

This tells us that sooner or later, single-planet species don't make it. But when we develop the technologies needed to live and work successfully on the Moon, Mars, and the asteroids, we will also have technologies enabling us to better survive on Earth. It would be ironic to have to terraform Earth to survive, but it might be necessary if we cannot avoid a large asteroid or comet impact.

Many years ago, H. G. Wells said it best: "The future is a race between education and catastrophe." What we have learned tells us Wells was right. We have no idea when large impacts or supervolcanoes will devastate Earth. But they are inevitable. So, we'd better continue educating ourselves, because we may not have a lot of time.

A splendid opportunity is before us: we can reinvigorate serious discussion of a two-world future, while at the same time defining and advocating the technical and political measures that can make that future happen. Now, we hope to contribute to this enterprise.

The Needs

From where we stand today, what would it take to bring us into the happy state that we here imagine? People tend to think first of money, and indeed a lot of money will have to flow. However, budgets, whether national or nongovernmental, are not a cause; they are a result. Human decisions lead to allocation of resources, and human judgments set priorities. Thus, the central need is in the realm of policy.

As market-driven democracy has spread around the world, a pattern of public decision making is emerging. Evidence of investment in longer-term futures is abundant. Look, for example, at the dawning worldwide commitment to remedying the human impact on Earth's environment.

As this kind of forward-looking view takes hold among people who have some voice in their government, it is logical to promote a long-term perspective toward spaceflight. An international program would aim to meet these needs: first, to develop a policy base and public advocacy structure; second, to maintain an active technology program; third, to launch robotic precursor flight missions; and fourth, to continue to develop the skills humans require for living off-Earth.

The Actions

We believe that certain steps are feasible and necessary, toward a time when people will be living productively on the Moon, exploiting extraterrestrial resources, and exploring Mars.

We envision a progressive program, starting with today's policy framework and evolving at whatever rate world public opinion permits. At the same time, we advocate working to influence public opinion by showing, through modest early successes, what is possible.

- Let's enhance education and encourage space advocacy among people of all ages, so as to call forth a worldwide community of leaders who can sustain multidecade spaceflight commitments.
- Let's build, both on the ground and in low Earth orbit, practical knowledge of human survival in space.
- Let's determine the accessibility and value of lunar resources, including those in the Moon's polar environments.
- Let's drive technology in directions that support long-term inhabitation outside Earth, including access to and from the Moon and Mars, cultivation of plant and animal life off-Earth, approaches for dealing with hazards, assurance of human contentment and productivity, and development of information systems supporting these goals.
- Let's implant on the Moon an archive of human knowledge and wisdom, both for its intrinsic worth and as an aid for recovery in the event of a catastrophe on Earth.
- Let's extend the robotic exploration of Mars from planetary science research toward applications for human exploration.
- Let's develop a real understanding of the resource potential of near-Earth asteroids and of the hazard from asteroid and comet impacts on Earth.
- Let's find clean, sustainable energy resources for Earth, including, possibly, solar power from space.
- Let's experiment with space commerce, allowing markets to determine what is realistic at each stage in humankind's penetration of the cosmos.
- Let's apply our new findings to ameliorating the condition of people on Earth. Without that, the whole enterprise will be doomed.

The Payoff

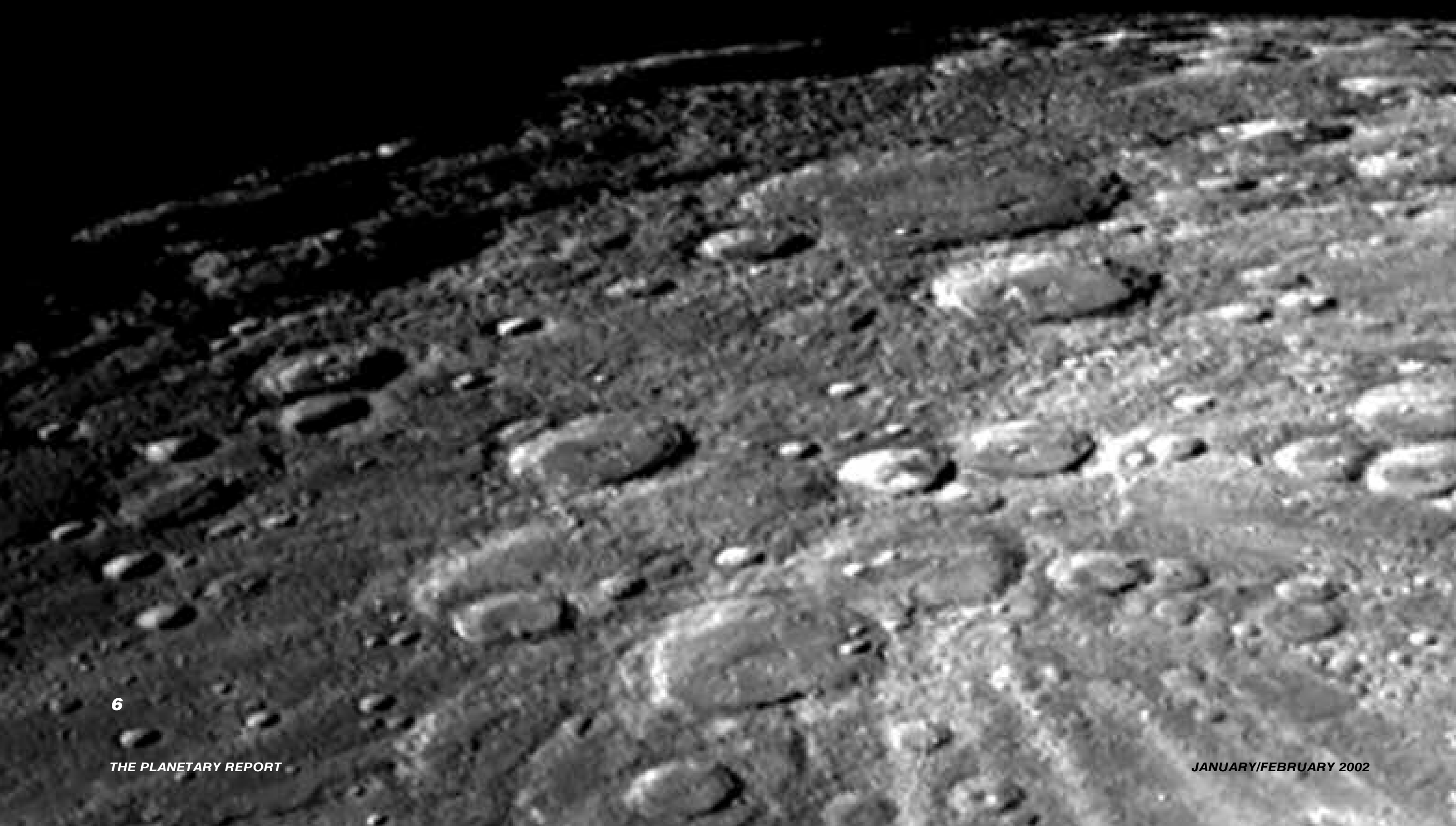
What we propose above is not an idle wish list. Many items on the list are already in development, and all have been thought about and discussed among serious space advocates.

The opinion we wish to leave with readers is this: with the coming of spaceflight, we humans have launched ourselves into yet another unknown future. But in this future, we are unconfined.

James D. Burke, technical editor of The Planetary Report*, recently retired from the Jet Propulsion Laboratory, where he had worked since 1949. In 1960–62, he managed the first American attempts to place scientific instruments on the Moon. Since then, he has participated in many other robotic space projects. He is a member of the faculty of the International Space University, where he seeks to encourage new space leaders to continue exploring the cosmos. John Young is associate director (technical) at NASA's Johnson Space Center in Houston. He has been an active astronaut for almost 40 years, flying on the* Gemini 3 *and* 10*,* Apollo 10 *and* 16*, and* STS-1 *and* STS-9 *missions.*

The Little Planet With the BIG IRON HEART

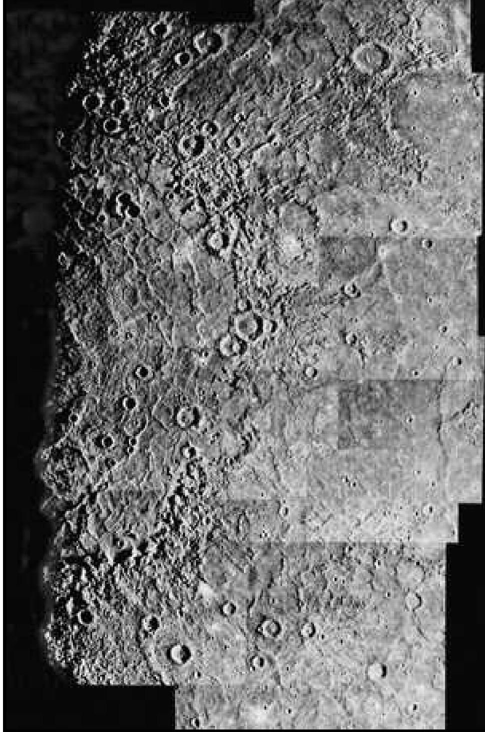
Long ignored, the planet nearest the Sun is back on mission designers' agendas. Planetary scientists are looking to Mercury for help in understanding Earth and the other rocky planets.



by Robert Burnham

The planet Mercury is famous for being hard to find in the sky. It's also hard to find in the annals of solar system exploration. Only one spacecraft has ever gone there, and that was more than 25 years ago. Meanwhile, a dozen probes have flown to Mars alone.

Yet, Mercury has recaptured the attention of planetary scientists, and both the United States and Europe are building missions to take another look. Why now? One answer is better technology. More significantly, however, the trickle of Mercury research over the years has reached critical mass, and scientists feel that revisiting this baked little cinder is vital. Mercury anchors one end of the planetary spectrum, and understanding it has become essential for knowing how all terrestrial planets work, including Earth.



Left: Mariner 10 *closely studied the Caloris Basin, visible at left in this image mosaic, on its first pass by Mercury in 1974. More than 1,300 kilometers (800 miles) in diameter, Caloris is not only Mercury's biggest impact structure but also one of the largest basins in the entire solar system. Caloris, the Latin word for* heat, *got its name because it sits near the subsolar point (the spot closest to the Sun) when Mercury is at perihelion.*
Image: JPL/NASA

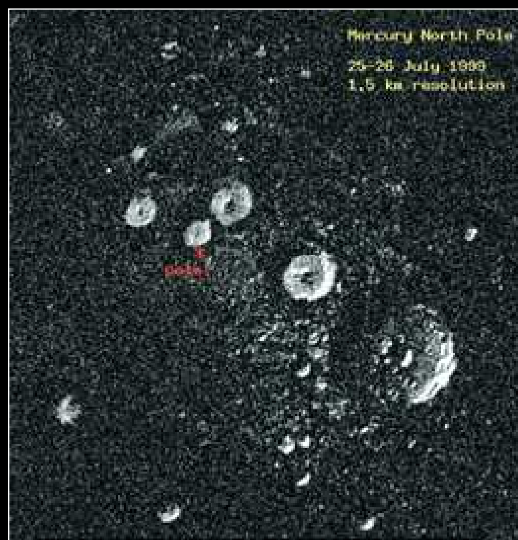
An Elusive Planet

Mercury has never been an easy target. Its orbit deep in the Sun's gravity well puts many constraints on mission designers, from supplying sufficient fuel to providing adequate heat shielding. Even for Earth-bound study, Mercury is tough. It always lies less than 28 degrees from the Sun, or about three fist-widths at arm's length. This means telescopes must view Mercury either through thick air near the horizon or during full daylight. (Unfortunately, the Hubble Space Telescope can't point near enough to the Sun to catch Mercury.) In a telescope eyepiece, Mercury resembles a tiny, featureless Moon trembling in turbid air.

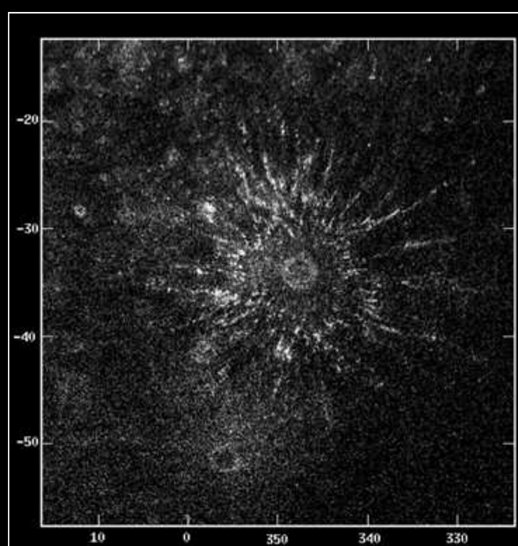
Such conditions long prevented scientists from knowing even the length of Mercury's day. They once thought the Sun's gravity had forced Mercury's rotation to match the planet's year, which is about 88 Earth days long. One side would eternally face the Sun and roast, while the other looked away and froze.

But in 1965, radar signals bouncing off the planet showed that Mercury rotates about once every 59 days. This means Mercury's day lasts two-thirds of its year and that it spins three times for every two trips around the Sun—which produces a very peculiar day. For example, depending on the location, you might see either a double sunrise or sunset, or you could watch the Sun slide backward in the sky at noon.

In 1991, radar gave planetary scientists another shock: strong radar echoes came from small areas near the poles. After working through possible explanations, scientists settled on the least unlikely: subsurface ice. The source is probably comets or water-rich asteroids. Their impact would briefly generate a thin atmosphere of water vapor. Some



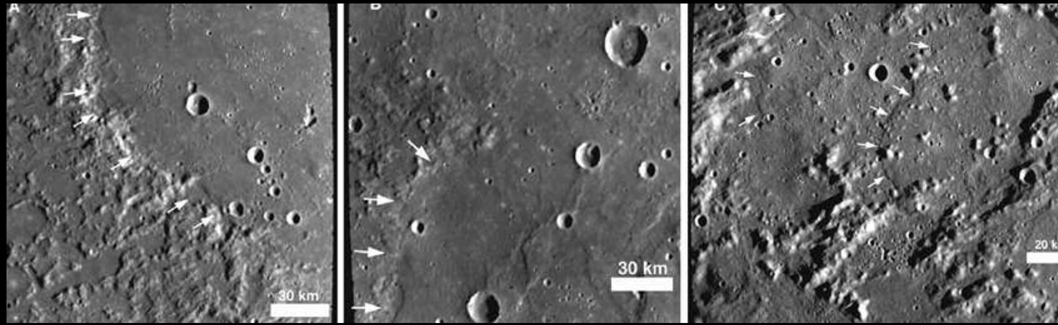
Right: Improbable as it may sound, Mercury might have water-ice trapped inside the craters near its poles. Scientists speculate that water delivered by comet or asteroid impacts might be a permanent fixture in these forever-shaded holes. This radar image of craters at the planet's north pole was captured in July 1999 with the Arecibo telescope. The craters' bright floors have the radar signature of ice, but doubts remain because some of the apparent ice deposits seem to be in craters too small and too far from the pole to be cold enough.



Below: Although Mariner 10 *revealed only one hemisphere of Mercury to us, Earth-based radar images suggested that there might be at least one large volcano on the unexplored side. However, this recent observation from the upgraded Arecibo telescope in Puerto Rico exposes the suspected volcano as a bright-rayed impact crater. Such observations suggest that much of the unexplored side looks similar to the side* Mariner *saw—but we need more data to be sure.*

Radar images: John Harmon, Arecibo Observatory

Left: The bulk of our limited knowledge of Mercury was gathered during Mariner 10*'s three passes by the innermost planet in 1974 and 1975. By recalibrating the old data, scientists have gained new insight into the planet's evolution and geological history. This reprocessed view of Mercury's south pole (rotated here so that south is at the top) was created from data captured on September 21, 1974. The pole is located on the left edge of the large dark crater whose far rim is illuminated at the center of the planet's limb.*
Image: JPL/NASA. Reprocessed by Mark S. Robinson, Northwestern University.



Scientists have debated the existence of volcanic features on Mercury's surface since Mariner 10 *first reached the planet. Comparisons with the Moon's dark lava mare have led many researchers to conclude that Mercury's smooth and intercrater plains were formed by volcanism. Others think that they might be more like the light lunar plains formed by crater ejecta. The above images, located east of the Caloris Basin's rim, resemble both the lava flow fronts of the Imbrium Basin and ejecta flow lobes of the Oriental Impact Basin on the Moon. The white arrows in the first and second frames show the margins of smooth plains. In the third frame, the arrows point to scarps of possible impact or tectonic origin.* Images: JPL/NASA, courtesy of James W. Head, Brown University

Prominent fault scarps, often called rupes, snake across Mercury's cratered surface. Scientists think that the rupes might have formed as the young planet cooled and condensed, causing its crust to pleat in some places. This feature, called Discovery Rupes, is more than 500 kilometers (310 miles) long and up to 1.5 kilometers (1 mile) high.

Image: JPL/NASA. Reprocessed by Mark S. Robinson, Northwestern University.

would migrate to the polar regions and be trapped by the cold ground in craters whose floors never see sunlight. Water-ice could last billions of years, buried by the dust of later impacts.

Mariner's Reconnaissance

What we know today of Mercury comes largely from NASA's *Mariner 10* spacecraft, which made three flyby passes in 1974–75. By current standards, *Mariner 10* carried a few crude instruments. Moreover, its trajectory allowed it to photograph only 45 percent of Mercury. Still, it was a great advance over Earth-based views.

Mariner found Mercury looking superficially lunar. The planet has craters and impact features that range from the Caloris Basin, 1,300 kilometers (810 miles) across, down to the camera's best resolution limit, about 100 meters. The craters show familiar features: central peaks, ejecta blankets—even rays. But the craters are shallower than lunar ones, and secondary impacts from debris lie closer to their primary craters. Both effects follow from Mercury's stronger gravity, 2.5 times the Moon's.

Mercury also lacks the Moon's dark lava "seas." Instead, it has bright, rolling intercrater plains that appear to be the planet's oldest surface, some 4 billion years old. They may be volcanic flows or impact debris. Inside the Caloris Basin and elsewhere, geologists mapped smooth plains, cratered more lightly and therefore younger (about 3.9 billion years). These, too, may be volcanic, but *Mariner*'s images weren't sharp enough to reveal telltale features, such as domes or lava flowfronts. Such features might emerge, however, in sharper views taken by future missions (see page 9).

Cutting across craters and plains alike are ridged scarps a kilometer or two high. They appear to be thrust faults marking where the crust has been squeezed and broken. Scientists calculate that if Mercury's diameter shrank by only a couple of kilometers, perhaps as its core cooled, this would compress the surface and produce the fault scarps.

Most surface materials appear rich in anorthosite, a lightweight, light-color feldspar rock deficient in iron. A recent analysis of old *Mariner* images shows considerable mineralogical variations from place to place. Yet, whether these betray lava flows of differing compositions or variegated rock units excavated by impacts—or both—is unclear.

Mercury's surface is regolith, a layer of debris deeply fractured by repeated impacts. If you could scuff it up, you'd find fine powder, bits of impact-produced glass, tiny rock chips, and stones ranging from pebbles to boulders. During the Mercurian day, the regolith reaches a maximum temperature of about 740 kelvins (467 degrees Celsius, or 873 degrees Fahrenheit); it cools at night to perhaps 100 kelvins (– 173 degrees Celsius, or – 279 degrees Fahrenheit). This day-night temperature range, the greatest known in the solar system, results from strong sunlight falling on a virtually airless surface.

Mercury does have a tenuous atmosphere, but its pressure is less than a trillionth that of Earth's. *Mariner* found that the atmosphere contains hydrogen and helium (and possibly oxygen). Ground-based studies added calcium, sodium, and potassium, with the last two being the most dominant elements. Surface rocks provide the main source.

One of *Mariner*'s surprises was a huge iron core. Occu-

See Mercury in 2002

Mercury is at best visibility this year around the times listed below. Look for a brightish "star" low in the west (evenings) or in the east (mornings). A good time of day to look is about 45 minutes after sunset (evenings) or before sunrise (mornings). Binoculars help. Best viewing opportunities are in **boldface**.

Northern Hemisphere evenings:
first three weeks of January, **late April to early May**, late August, mid-October, last half of December

Northern Hemisphere mornings: mid-February, mid-June to early July, **October**

Southern Hemisphere evenings:
first three weeks of January, late April to mid-May, **August to mid-September**, December to early January 2003

Southern Hemisphere mornings: **mid-February to late March**, early June to early July, early October

pying three-fourths of Mercury's radius (Earth's reaches only halfway to the surface), the planet's core makes up some 70 percent of its mass. (Earth's core contributes only 32 percent of its mass.) Its large core gives Mercury a density (corrected for pressure) of 5.3 times that of water, greater than that of any moon or planet, including Earth.

The core is probably the source of the magnetic field surrounding Mercury, *Mariner*'s other big surprise. Its shape is a dipole, like Earth's field, though it has only 1 percent the strength. An important task for new missions is to map the field thoroughly and determine what is generating it.

In retrospect, *Mariner 10* did its job almost too well. It gave Mercury a geography and a history, even as it left more than half the planet still unphotographed. Ironically, *Mariner*'s Mercury looked too Moon-like to make finishing the job seem urgent. Thus, as the 1970s drew to a close, other planet destinations—chiefly Mars, Jupiter, and Saturn—made stronger claims on the limited budgets available, and Mercury was set aside.

Two New Missions

After a quarter century, Mercury is back in the lineup, with two missions in development. One is a $300 million, US-built probe called *MESSENGER* (for MErcury Surface, Space ENvironment, GEochemistry, and Ranging). The other is the European Space Agency's (ESA's) *BepiColombo*. It is named for Guiseppe "Bepi" Colombo, a now-deceased Italian planetary scientist who suggested to NASA how *Mariner 10* could make multiple flybys of Mercury.

MESSENGER comes from the Carnegie Institution of Washington and Johns Hopkins University's Applied Physics Laboratory. Plans call for a launch in March 2004, followed by two flybys of Venus (June 2004 and March 2006) and two of Mercury (July 2007 and April 2008). The spacecraft arrives in Mercury orbit in April 2009, and the nominal mission lasts one Earth year (four Mercury years).

Multiple planet encounters make for a long journey but reduce the fuel the spacecraft needs. Nor is the cruise just a snooze: instruments will be running during all four flybys. In fact, the first Mercury pass will image the unknown hemisphere, a key prelude to the mission's orbital phase.

The instrument package focuses on sampling charged particles, probing the magnetic field, studying the scanty atmosphere, mapping the surface geology and composition, and unraveling Mercury's internal structure. Geologists anticipate that surface features will be imaged at 125 meters or better resolution. Global imaging at 250 meters per pixel will yield accurate topography from stereographic pictures and laser altitude measurements.

Spectrometers (infrared, X-ray, neutron, and gamma ray) will map the mineral composition of the surface. Other instruments will sniff the flux of particles from the Sun and hunt for those sputtered off the surface. Tracking the spacecraft and analyzing its radio signals will tell about Mercury's gravity field and the structure of its atmosphere.

After *MESSENGER* comes *BepiColombo,*

Mercury Discovery Guide

ONLINE:

BepiColombo's Mission Page
www.sci.esa.int/home/bepicolombo/index.cfm

Goddard Space Flight Center's Mercury Page
nssdc.gsfc.nasa.gov/planetary/planets/mercurypage.html

JPL's Mercury Page
pds.jpl.nasa.gov/planets/welcome/mercury.htm

The Mercury Chaser's Calculator
www.fourmilab.ch/images/3planets/elongation.html

Messenger's Mission Page
messenger.jhuapl.edu

NASA's Planetary Photojournal (images)
photojournal.wr.usgs.gov/cgi-bin/PIAGenPlanetPage.pl?Mercury

BOOKS:

Davies, Merton, Donald Gault, Stephen Dwornik, and Robert Strom. 1978. *Atlas of Mercury.* NASA SP-423. Washington, D.C.; U.S. Government Printing Office.

Murray, Bruce, and Eric Burgess. 1977. *Flight to Mercury.* New York; Columbia University Press.

Strom, Robert. 1987. *Mercury, The Elusive Planet.* Washington, D.C.; Smithsonian Institution Press.

Vilas, Faith, Clark Chapman, and Mildred Shapley Mathews, eds. 1988. *Mercury.* Tucson; University of Arizona Press.

Above: The MESSENGER (Mercury Surface, Space Environment, Geochemistry, and Ranging) *mission, scheduled for launch in March 2004, will carry a set of miniaturized instruments. The mission has been designed to answer key questions about the planet's crust, its high density and tectonic history. Scientists also hope to learn more about Mercury's minimal atmosphere and magnetic field as well as the nature of its mysterious polar caps.*

Illustration: Johns Hopkins University Applied Physics Laboratory

Right: BepiColombo, *named for the late, beloved planetary scientist, Guiseppe "Bepi" Colombo, is still on the drawing board at the European Space Agency (ESA). Current plans for this ambitious mission include two orbiters and a lander, which will launch on two rockets in August 2009. Once they arrive at Mercury in October 2012, the orbiters will study the planet's crust and magnetic field, while the lander measures the crust's chemistry and mineralogy and, perhaps, samples the subsurface ice at the north pole.*

Illustration: European Space Agency

ESA's more complex mission, still in the planning stage (and hence without a final price tag). The current scenario calls for three separate probes. These are the Mercury Planetary Orbiter, the Mercury Magnetospheric Orbiter, and the Mercury Surface Element. The last is a lander targeted for the northern polar regions.

If all goes as planned, *BepiColombo* will be launched on two rockets in August 2009. In October 2012, after flybys of the Moon and Earth, Venus, and Mercury, the planetary and magnetospheric probes will brake into Mercury orbit while the lander touches down. The orbiters have design lifetimes of an Earth year or longer; the lander, one week at a minimum.

Each component has a specific aim. The planetary orbiter flies an orbit measuring 400 by 1,500 kilometers (250 by 930 miles) for detailed studies of the surface with cameras and spectrometers, while the magnetospheric craft follows a looping orbit some 400 by 12,000 kilometers (250 by 7,500 miles). This lets its instruments map the magnetic domain from near Mercury to thousands of kilometers out. And the lander, which may be sent to a shadowed polar crater, will make in-place chemical and mineralogical observations—and perhaps tap into subsurface ice. The lander uses chemical rockets and an airbag to land and deploys a tethered microrover and a burrowing mole. (An alternative design features an impact penetrator instead of the mole.)

Between *MESSENGER*'s primary mission (2009–10) and *BepiColombo*'s (2012–13) lies a gap in which *MESSENGER* results can help target *BepiColombo*'s mission plan—and *BepiColombo* will seek to fill gaps in coverage left by *MESSENGER*. Yet, both missions fly independently, partly to ensure against one mission's failure dooming the other.

A New Model of Mercury?

Both missions have sophisticated questions to address, plus some basic ones left from *Mariner 10*. These include:

- The surfaces of many planets and moons show marked differences between hemispheres—does Mercury's also?
- What is Mercury's cratering history? Can Moon rock dates help calibrate it?
- When and how was Mercury volcanic? Do its rocks vary much in composition? What explains their iron deficiency?
- Are the polar deposits water-ice?
- How much of Mercury's core is molten? How does it generate a magnetic field with such a slow rotation?
- Was Mercury born with a large core? Did a gigantic collision strip off much of its crust? Or were the outer layers vaporized by the young Sun's activity?
- What can Mercury tell us about the birth of rocky planets?

The modern era for Mercury began when *Mariner 10* flew by and found it a Moon-like body. Yet, as scientists learn more about our satellite, it increasingly appears to be a special case by itself—and Mercury seems a lot more than merely a scaled-up Moon. Planetary scientists are now delving into these differences. They also want to fit the new Mercury into the evolving picture of the terrestrial planet family. This will finally let the little planet with the big iron heart take its proper place alongside Venus, Mars, and Earth and its Moon.

Robert Burnham is the author or editor of several recent books on astronomy and earth science. His forthcoming constellation guide, Exploring the Starry Sky, *will be published in 2002 by Cambridge University Press.*

Mercury Data Download

Diameter:
4,880 kilometers (3,032 miles)

Mass:
3.3 x 1020 tons
(Earth = 18.1 times greater)

Uncompressed density:
5.3 (Earth = 4.1, water = 1.0)

Albedo (reflectivity):
0.17 (lunar highlands = 0.11)

Average distance from Sun:
57.9 million kilometers
(36 million miles)

Distance from Sun:
0.387 AU (Earth = 1.0 AU)

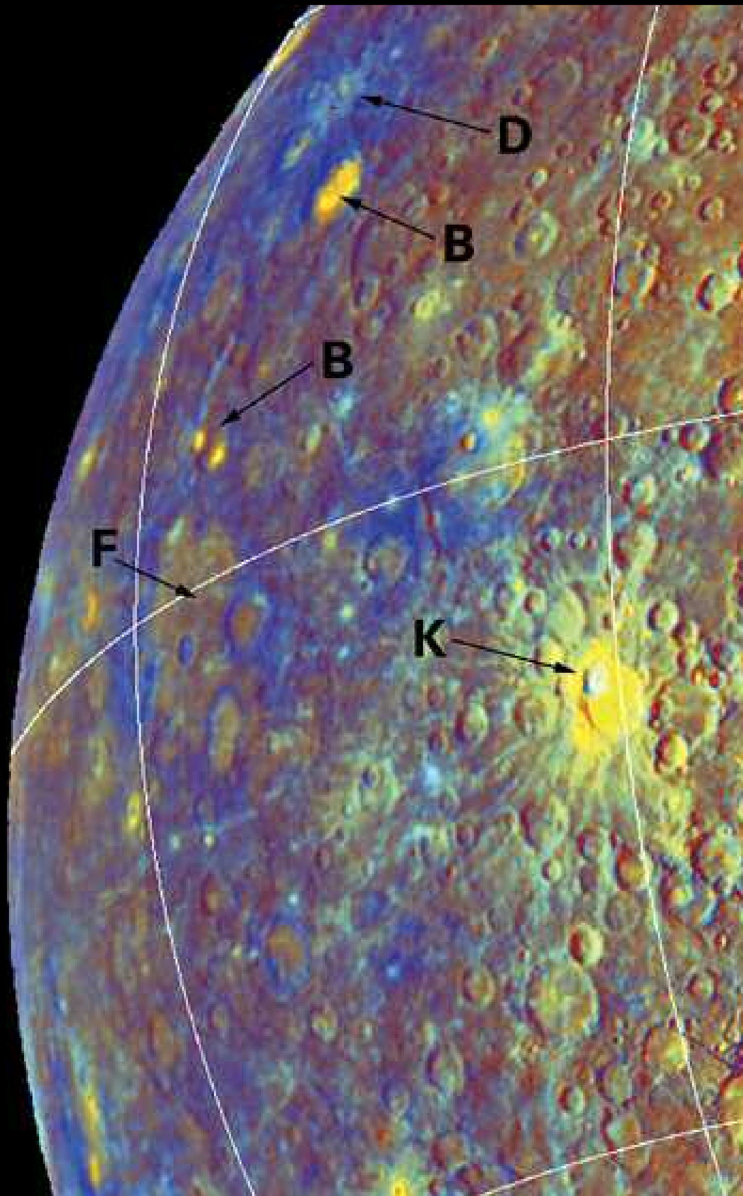
Orbital eccentricity:
0.2056 (Earth = 0.0167)

Year: *87.97 Earth days*

Day: *58.65 Earth days*

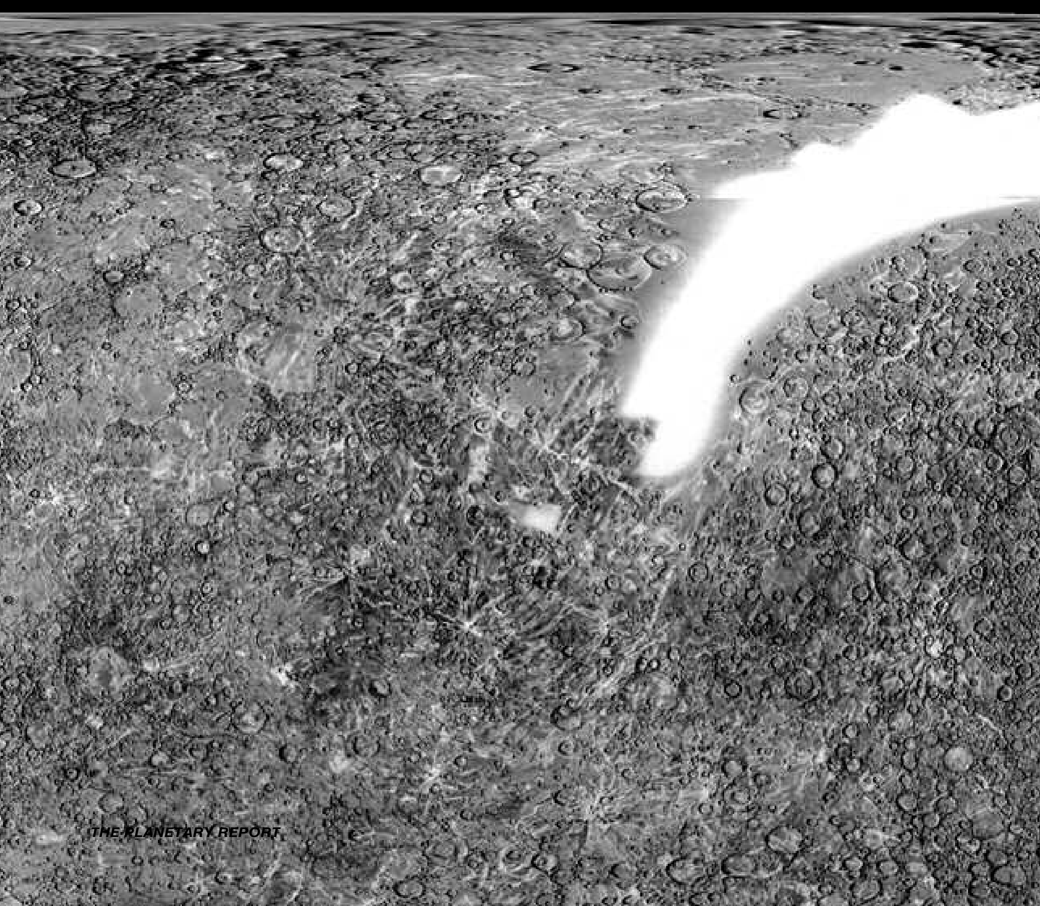
Above: This geologic map of Mercury, based on Mariner 10 *images, was built to show surface rock types and their relative ages. Browns represent primitive crater, basin, and intercrater plains deposits. Blues depict crater and basin deposits (note the outline of Caloris Basin) from Mercury's middle era. Pinks and reds stand for smooth plains deposits, probably volcanic in origin, from the planet's middle and early eras, respectively, while greens and yellows show crater deposits from its youngest geological periods. The yellow swath covers an area for which no image data are available.*

Illustration: Paul Spudis, Lunar and Planetary Institute



Above: This color composite of Mercury's surface was developed to highlight differences in certain soil compositions, origins, and ages. The shade of blue denoted by D *represents enhanced levels of titanium. Primitive crustal material is shown as the bright yellow marked by* B*. Orange, shown by* F*, follows plains boundaries and is thought to be lava flow, while the lighter yellow of* K *indicates fresh subsurface material (which may have an unusual composition) around the crater Kuiper.*

Image: JPL/NASA. Reprocessed by Mark S. Robinson, Northwestern University, and Paul Lucey, University of Hawaii.



Left: A large portion of Mercury's gray and pockmarked face is revealed by this shaded relief map, produced in 1979 from Mariner 10 *images. Unfortunately, this was a face that bore too close a resemblance to Earth's Moon to hold mission planners' interest. In the past 25 years, however, scientists have amassed a collection of new questions about Mercury. With luck, two new missions to this rocky enigma will answer some of these questions.*

Map: United States Geological Survey, Flagstaff, Arizona

FROM THE EARTH TO MARS Part

Above: This topographic map of Haughton Crater and surrounding terrains is helping researchers reconstruct the glacial and erosional history of the site. Levels of elevations are represented by different colors in this digital elevation model, provided by the Geological Survey of Canada. The highest points (500 meters) surrounding the crater are shown as brown; the lowest are green. White and bluish-white indicate a possible stage of ice cover.
Map: NASA/Haughton-Mars Project

Right: Just outside Haughton Crater lies Von Braun Planitia, the rocky polar desert landscape at Haynes Ridge. The rocks at this site are dominated by fossil-rich carbonates that are 350 to 400 million years old. This surface was exposed, following glacial retreat, only 8,000 to 10,000 years ago. The landscape preserves little obvious signature of glacial occupation or erosion. Previously glaciated terrains on Mars might likewise be difficult to recognize. Intense frost fracturing caused the angular shape of these rocks, and the pits on the rocks are due mainly to carbonate dissolution from melting ice and snow. Photo: Pascal Lee, NASA/Haughton-Mars Project

A wide variety of terrain types are present at Haughto smooth, fine soils. The bright material in the distance mation, once part of a vast pool of molten carbonates Crater today. An isolated community of landlocked Ar

Far north in Nunavut Territory in the Canadian High Arctic lies Devon Island, the world's largest uninhabited island. Devon is home to one of the northernmost impact structures on Earth, Haughton Crater. Measuring about 20 kilometers (12.4 miles) in diameter, it formed 23 million years ago when either an asteroid or a comet collided with our planet. At that time, during the Miocene epoch of geologic time, the climate was warmer. Boreal forests experiencing months of continual daylight followed by months of darkness covered the land. Among the thick growths of conifers and birch trees roamed giant rabbits and small rhinoceroids (ancestral cousins to the modern rhinoceros). Streams and lakes teemed with fish.

In an instant, things changed dramatically. A giant meteorite, perhaps 1 kilometer (0.6 mile) in diameter, plowed into the scene. It may have happened in the broad daylight of summer or in the bleak darkness of winter—we may never know. In either case, the impact, delivering an energy equivalent to 100 million kilotons of TNT, would have produced a blinding flash of light, then a monumental air blast that obliterated almost all life for several hundred kilometers around. A colossal shock wave expanded through the ground as the impactor dumped its cosmic momentum into the Earth, blending into the target rocks and vanishing as a superheated gas. The rocks themselves were crushed, melted, vaporized, pushed aside, and ejected. A cavity some 20 kilometers (12.4 miles) wide and 1.7 kilometers (1 mile) deep appeared, only to grow shallow as its unstable walls collapsed inward. Once the dust cleared, a smoldering hole with a vast pool of molten carbonate rocks appeared. Within seconds, Haughton Crater was born.

A UNIQUE MARS ANALOG

My interest in the site began while I was still in graduate school, in the Department of Astronomy at Cornell University. I wondered if we could find an impact crater on Earth that would be uniquely Mars-like, serving as a new "Mars analog." Mars analogs are settings on Earth where environmental conditions, geologic features, biological attributes, or combinations thereof offer opportunities for comparisons with possible counterparts on Mars and for partial simulations of Martian conditions.

t One: A Crater, Ice, and Life

by Pascal Lee

The distinctive orange-colored mineral deposits on the rocks behind these Haughton-Mars Project team members are pipelike structures through which impact-heated water once flowed.
Might similar structures be found at impact sites on Mars? Could such sites have supported life there, if only transiently?
Photo: Pascal Lee, NASA/Haughton-Mars Project

on Crater. In some places, there are abrupt transitions from angular block fields to e is not snow but remnant deposits of the Haughton impact breccia melt sheet for-s. Ice-covered Lake Sapphire (right) is the largest permanent lake inside Haughton rctic char (a troutlike fish) lives inside. *Photo: Pascal Lee, NASA/Haughton-Mars Project*

No place on Earth is truly like Mars, so there is no such thing as the perfect Mars analog. But many partial analogs do exist on our planet, and their study, with attention to both similarities and differences between Earth and Mars, may offer insight into the evolution of both worlds and of other planets as well.

Antarctica is the coldest and driest continent on our planet and is in many ways of unique value to Mars analog studies. Yet, the continent possesses no positively identified impact structure. With Haughton Crater, the Arctic's Devon Island offers the only terrestrial impact structure known to lie in a cold, relatively dry, windy, rocky, dusty, ultraviolet (UV) light–drenched (in the summer), and nearly unvegetated polar desert. From that standpoint, it promised to serve as a parallel to Mars.

Although conditions on Devon remain significantly milder than those prevailing on Mars (for instance, the average temperature on Devon is – 17 degrees Celsius, or 1 degree Fahrenheit, versus – 60 degrees Celsius, or – 76 degrees Fahrenheit, on Mars), they are a step in the right direction.

Early research efforts at Haughton had focused on studies of the crater, but the Mars analog angle remained unexplored. I approached Chris McKay at NASA Ames Research Center (now a Planetary Society Board member) to do just that and, with his visionary support, obtained a grant from the National Research Council to visit Haughton Crater.

A four-person team traveled to Devon Island in August 1997. Comprising the field team were James W. Rice Jr. (then at NASA Ames, now at Arizona State University), John W. Schutt (today, still the chief field guide for the US Antarctic Search for Meteorites program), Aaron Zent (of NASA Ames), and myself. The site proved interesting beyond our wildest dreams. We found not just one feature that might serve as a potential Mars analog but several.

This initial reconnaissance led to what is today the NASA Haughton-Mars Project (HMP). The HMP is an international, interdisciplinary field research project comprising both a science program—which focuses on learning more about Earth and Mars, impact cratering, and life in extreme environments—and an exploration program looking to develop new technologies, strategies, and experience with human factors that will help plan the future exploration of Mars and other planets by robots as well as humans. The present article focuses on the science program. A follow-up piece will cover the exploration program.

THE CRATER

It is hard not to imagine oneself on Mars when exploring Haughton Crater on Devon Island.

In this wonderland, you can rove over thick deposits of fused impact debris and intracrater sediments laced with ground-ice. While rocks on Devon are dominated by carbonates, and Mars does not seem to possess large quantities of these rock types, the physical properties of impact deposits at Haughton are of interest. For instance, might the distribution of ground-ice in these deposits shed light on where to find ground-ice in impact-derived materials on Mars? Our ground-penetrating radar surveys and shallow excavations at Haughton Crater reveal that such substrates can hold massive amounts of ice (sometimes more than 80 percent by volume), most occurring in the form of interstitial lens-shaped concentrations micrometers to meters thick.

Haughton Crater also presents sites of ancient hydrothermal activity once powered by the tremendous heat released at the time of impact. Evidence for these impact-induced hot springs was only recently uncovered by the HMP team. Gordon "Oz" Osinski, a graduate student in geology from the University of New Brunswick, and his adviser, John Spray, are helping us reconstruct the geologic history of the crater. The impact-induced activity has long ceased, but the hydrothermal sites are preserved in pristine condition, having been spared substantial weathering under the increasingly frigid climate in the High Arctic since the Miocene.

Understanding the nature, evolution, location, and preserved record of impact-induced hydrothermalism at Haughton helps us assess the biological potential of similar sites on Mars as well as on other planets. Impact-induced hot springs would have been places where liquid water and warmth would have coexisted, if only transiently. They are places where life, perhaps imported from elsewhere, might have gained a foothold and thrived.

The Haughton Crater also once contained a lake or, more exactly, a network of water bodies whose shapes evolved through time. This happened very shortly after the crater's formation and might not have lasted more than a few million years. Although lake waters are long gone, sediments that were laid down are beautifully preserved. Indeed, Haughton's paleo–lake beds represent the only sedimentary record of the Miocene preserved on our planet in the Arctic. They provide the only snapshot we have of what the Arctic was like 23 million years ago.

It is in Haughton's lake beds that our colleague Leo Hickey of Yale University and his collaborators found the remains of Miocene faunal and floral species. Bone is not petrified but remains bone. Similarly, wood remains wood. Also, the fine, silty layering and its climate record are hardly disturbed. Haughton's intracrater lake beds suggest that records of paleoenvironments might be well preserved in the sheltered setting of an impact crater on Mars. Many craters there, whether or not they once

Left: Fine layers of ancient lake bed sediments are still beautifully preserved inside Haughton Crater. They were deposited in a lake system that occupied the impact crater shortly after its formation 23 million years ago. The topmost part of the silty soil has been churned and disturbed by repeated cycles of freezing and thawing. However, within a depth of a couple of feet, the layering has remained almost untouched since the Miocene period.

Could there be ancient lake beds inside craters on Mars, still preserving a record of the planet's past environments?

Photo: Pascal Lee, NASA/Haughton-Mars Project

Right: This Viking *orbiter mosaic shows the small valley networks of Maumee and Vedra Valles on Mars. (North is to the right.) On Mars, networks span a range of scales. These are among the largest—others can be more than 100 times smaller.*

By (temperate) terrestrial standards, the Martian valley networks look odd. They maintain relatively constant width and depth throughout, isolate big islands, and leave large areas between their branches, and between networks, undissected. How did they actually form?

The crater at bottom center is Crater Newport. Like Haughton, it is 20 kilometers (12.4 miles) in diameter and is transected by a valley.

Image: JPL/NASA

harbored liquid water, are filled with layered deposits that might provide clues to past surface environments.

In fact, the overall state of erosion at Haughton Crater might be telling us something important about Mars. In spite of Haughton's young age compared with that of many similar-size craters on Mars preserved since the end of the Heavy Bombardment (a period of high impact rates early in the history of the solar system) about 3.5 billion years ago, and considering the relatively moderate erosion, by terrestrial standards, that Haughton has been subjected to, the crater is less well preserved than the majority of its Martian counterparts. This suggests that the cumulative effect of weathering and erosion on craters of Haughton's size on Mars over 3.5 billion years has amounted to less damage than what Haughton itself has experienced over the past 23 million years in the Arctic. If Mars ever had a wet and warm climate over the past 3.5 billion years, it was probably not for long.

THE ICE

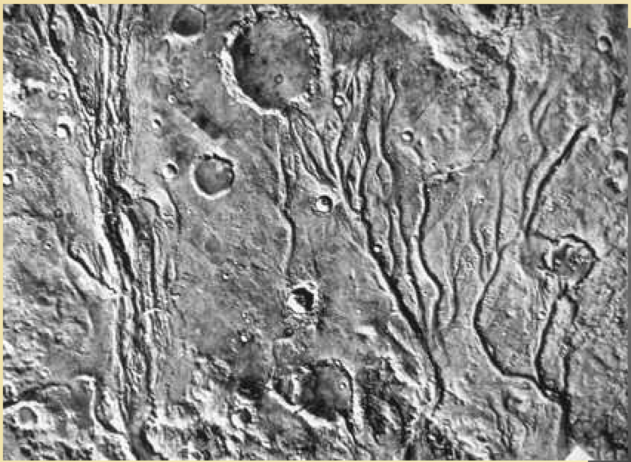
Many features outside Haughton Crater itself are also contributing to solving, and sometimes deepening, the mysteries of Mars.

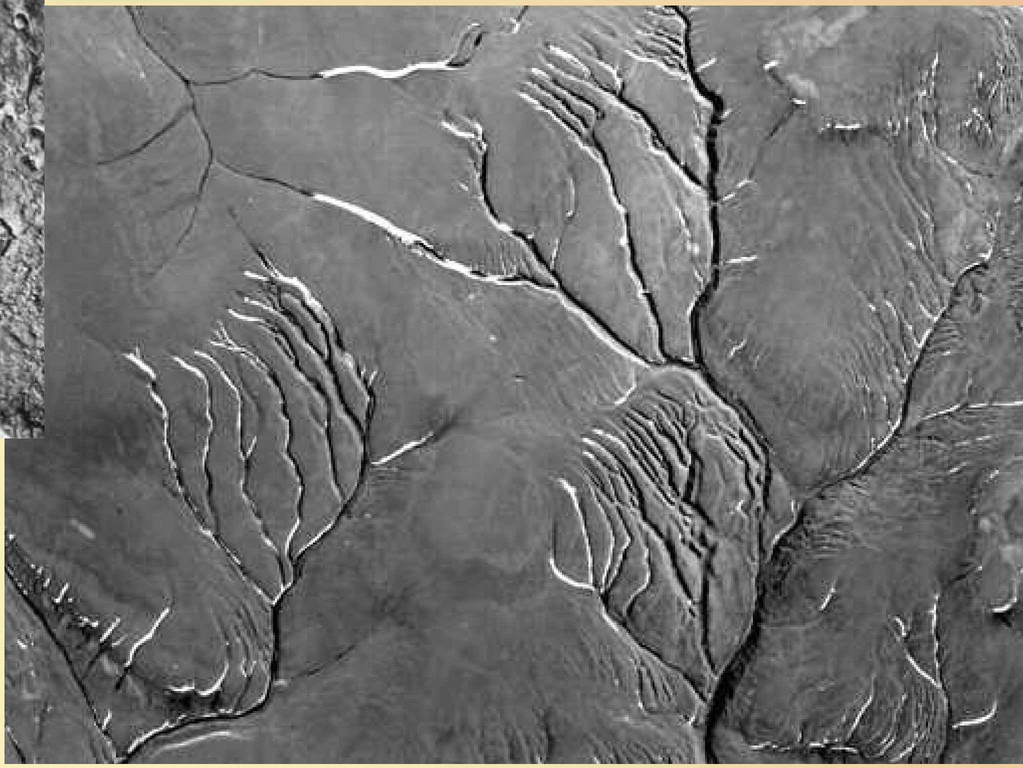
Networks of channels found on Devon Island bear similarities to the so-called Martian small valley networks. Most of the latter date from the end of the Heavy Bombardment, while some are also found on more recent terrains, such as the flanks of relatively young volcanoes. The Martian small valley networks are classically thought to be the result of liquid water runoff flowing across the Martian surface (not in the form of gigantic floods, as in the case of the Martian outflow channels, but in more modest trickles) after either localized rainfall, groundwater release, or mud flow.

These interpretations require a fairly warm climate for liquid water to flow at the Martian surface over distances of tens to hundreds of kilometers without freezing. Such a conjecture has forced Mars climate modelers over the past decades to invoke increasingly elaborate mechanisms of climate warming for early Mars, particularly given Mars' relatively great distance from the Sun, small planetary mass, the early Sun's fainter light, and how impacts may have stripped Mars of its early atmosphere(s).

Devon Island is incised by a multitude of small valley networks that bear an uncanny morphologic resemblance, including in their bizarreness, to many of the small valley networks on Mars. The Devon networks formed neither by rainfall, groundwater release, nor mud flow but by the melting of vast ice covers that once occupied the land above the now-exposed surface. Sections of valley floors slant uphill as one hikes downstream, indicating that some valleys are actually channels that formed by confined flow when meltwaters gushed under a wasting ice cover. Because these ancient ice sheets were very cold and mostly static, uplands off to the sides of the channels were spared significant glacial erosion. If anything, the ice cover protected them.

So, is it possible that the many small valley networks on Mars are actually cold climate features instead of evidence that Mars once had a relatively mild climate? Might they have resulted from the subglacial melting of insulating ice covers, which accumulated above the highlands and on the flanks of volcanoes when the ground was warmer and





Right: The National Geographic Society Network of small valleys on Devon Island appears in this image covering an area 4 kilometers (2.5 miles) across. These small valleys are comparable in morphology and scale to some of the smaller valleys seen in networks on Mars.

Scientists think that glacial meltwater erosion is responsible for these and similar networks on Devon. Some branches are partially filled with snow and ice. Note the relatively constant width and depth of the branches, the presence of steep-walled islands, and relatively large, undissected areas between branches and between networks.

Air photo: Geological Survey of Canada.
Image processed by NASA/Haughton-Mars Project.

water more readily recycled to the surface by impacts and active volcanism—though in a frigid climate? Might Mars have been cold climatically throughout most of its history, with liquid water at most a local and transient phenomenon at the surface?

The mighty canyons of Devon Island might, independently, reinforce this picture. They seem to have specific morphologic counterparts on Mars, in particular the broad, winding V-shaped valleys of Ius Chasma in western Valles Marineris. Some believe the latter formed by sapping—that is, the slow release of groundwater accompanied by progressive "headward" erosion of rocks in the direction of the source. The canyons on Devon, however, are the result of glacial erosion (the carving done this time by ice, not meltwater, as in the case of the island's channel networks). Might their counterparts on Mars result from glacial carving as well?

While not settling the mystery of past climates on Mars, our work on Devon Island is offering new interpretations for many of the Red Planet's so-called fluvial landforms. Our research suggests that surface ice deposits have played a much greater role throughout Martian history than classically suspected.

On another front, the ubiquitous presence of ground-ice near the surface in the Arctic is visible, if indirectly, across the landscape on Devon. Terrain features such as rock glaciers, ice-cored mounds, polygons, rock circles, rock stripes, and myriad other forms of "patterned ground" abound. Such features are the trademark of periglacial processes, or processes shaping the landscape in environments that are rich in ground-ice.

Viking orbiter and *Mars Global Surveyor* (*MGS*) images of Mars reveal the presence in many locations (mostly at high latitudes but also elsewhere) where similar-looking features occur. One implication is that ground-ice might have been abundant near the Martian surface when the features formed. Given how fresh some of these features look today, might ground-ice still be present at their locations on Mars?

LIFE AT THE EDGE

Devon Island is also astonishing by the resilience of its life. Life in the polar desert persists at the edge. Liquid water is rare and so are nutrients. Our studies of microbial life at Haughton, led by HMP Chief Biologist Charles Cockell of the British Antarctic Survey, are revealing stories of survival and adaptation that might have implications for our search for life on Mars and elsewhere.

For instance, in spite of the high UV radiation environment prevailing in the High Arctic during the summer, with its 24 hours of unrelenting sunlight, microorganisms are able to avoid radiation damage and indeed thrive by remaining shielded. Many do so simply by colonizing sheltered areas underneath rocks or in soils. But others, such as algal mats living at the bottom of open, shallow ponds and puddles, have evolved natural sunscreens. Like humans donning a spacesuit allowing them to survive in an otherwise lethal environment, these microbial colonies coat themselves with a secreted gelatinous, pigment-rich UV-screening compound forming a protective biofilm. Long after the microorganisms themselves have died, such biofilms can remain intact, designed as they are to withstand weathering. Should the search for past life on Mars therefore involve a

Inset: This detailed segment of a* Viking *Orbiter mosaic shows a broad, winding canyon branching into Ius Chasma in western Valles Marineris on Mars. Notice the canyon's V-shaped profile, stubby tributaries, and the undissected surrounding upland plateau. The widest point in this valley is 20 kilometers (12.4 miles). Might such valleys have formed not by sapping (the classical hypothesis) but by glacial erosion?
Image: JPL/NASA

Right: Devon Island also has a V-shaped winding canyon with stubby tributaries and relatively undissected surrounding uplands. The widest point in this valley is 2 kilometers (1.2 miles) wide. Geologists interpret this feature to be a glacial trough valley formed through erosion by a fast-moving ice stream flowing from a vast, otherwise static ice cap that once covered Devon at this site. *Air photo: Geological Survey of Canada. Image processed by NASA/Haughton-Mars Project.*

Above: This intricate maze of canyons on Devon Island is also interpreted as having formed by glacial erosion.
Photo: Pascal Lee, NASA/Haughton-Mars Project

search for resistant biocompounds that putative microorganisms might have evolved to survive in the planet's harsh, UV-drenched, near-surface environment?

At Haughton, we have also found that the inside of the crater's battered rocks can host enhanced colonization by cyanobacteria. Endolithic microbial communities (microbes living inside rocks) are not new. They were first reported by Imre Friedmann in sandstones from the Antarctic Dry Valleys more than two decades ago. But until now, they had not been reported in crystalline rocks, which are typically very compact and opaque, only in more porous and translucent sedimentary rocks. At Haughton Crater, however, crystalline rocks have been so heavily fractured and rendered porous that they are now home to thriving colonies of cyanobacteria.

This finding shows that impacts are not necessarily bad news for life. While they might threaten highly evolved and narrowly adapted organisms such as dinosaurs and mammals, impacts could have offered microbial life shelter and warmth when needed most—that is, on early Earth and possibly early Mars. In addition, impacts are capable of launching rocks from one planet to another. Thus, not only do impacts serve as Nature's interplanetary launch mechanism, they might also create suitable lithic vessels for the successful transfer of microbial life.

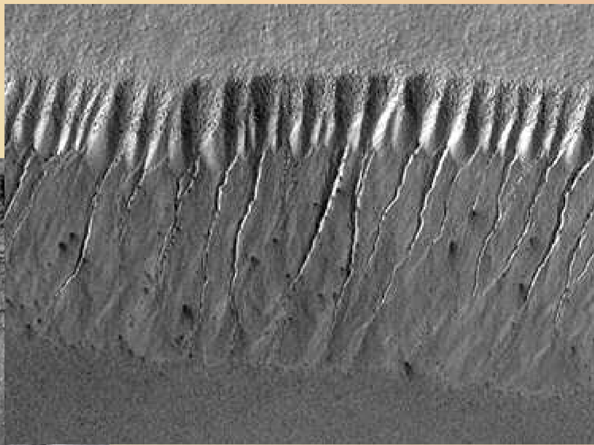
THE JOURNEY CONTINUES

Summer after summer, the geologic and biologic wonders of Devon Island and Haughton Crater continue to surprise us. Gullies eerily similar in both morphology and context to those recently reported on Mars by Mike Malin and Ken Edgett (operators of the Mars Orbiter Camera on *MGS*) have been found on the island and are currently being studied in detail. Rather than involving significant groundwater seepage or even ground-ice melting (prevailing hypotheses for the Martian gullies), the features on Devon appear to be due mainly to the repeated melting, year after year and possibly glaciation after glaciation, of transient deposits of surface snow and ice. Might snow and ice deposits have formed and melted on Mars in recent times, perhaps as a result of short-term obliquity (tilt) swings of the planet? Might there be microbial life close to the Martian surface today?

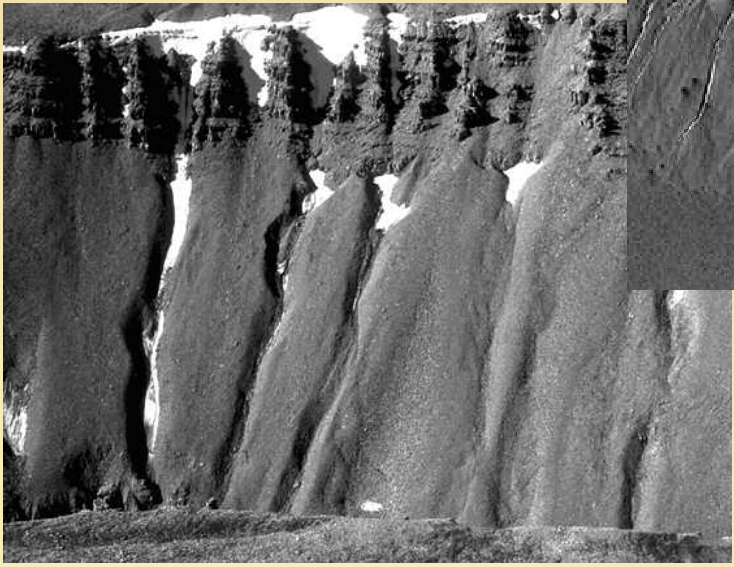
In the end, it may be difficult to ever understand Mars without exploring it in situ. And even then, it might be impossible to resolve some mysteries, as may be the case here on Earth. But our studies in the Arctic are increasing our understanding of our own planet as well as helping look at another world with new insight. It is part of the journey from the Earth to Mars.

Pascal Lee, a planetary scientist at the SETI Institute, is based at NASA Ames Research Center in Moffett Field, California. He is the project lead and principal investigator for the NASA Haughton-Mars Project on Devon Island, Nunavut, Arctic Canada.

For more information on the NASA HMP, visit *www.marsonearth.org.*



Mars Global Surveyor*'s Mars Orbiter Camera returned this image of a fresh-looking gully system on Mars on July 14, 1999. (See the September/October 2000 issue of* **The Planetary Report** *for more details.)*
Image: NASA/JPL/Malin Space Science Systems



This gully system on Devon Island is similar in morphology, scale, and context (they usually form along the cold, north-facing walls of valleys) to some of the recent gully systems reported on Mars. The gullies on Devon result from the repeated melting, year after year, of seasonal snow or surface ice patches that accumulate and linger in the nooks and crannies of rocky bluffs along the top part of canyon walls. Could the gullies on Mars have formed not by the prevailing hypotheses of groundwater seepage or ground-ice melting, but by a mechanism similar to that observed on Devon Island? *Photo: Pascal Lee, NASA/Haughton-Mars Project*

World Watch

by Louis D. Friedman

Edinburgh, UK—The science ministers responsible for space funding in the member countries of the European Space Agency (ESA) met in Edinburgh to set the agency's budget and programming.

Next year, ESA will launch two missions: *Mars Express* and *Rosetta*. *Mars Express*, which includes both an orbiter and the *Beagle 2* lander, will reach its target in late 2003. *Rosetta* will rendezvous with comet Wirtanen in 2011 and land in 2012. ESA is also a major player in the *Cassini* mission, having built the *Huygens* probe that will descend through Titan's atmosphere in 2005.

As a result of the Edinburgh meeting, the European ministers supported an ESA science program that includes development of a Mercury orbiter. They also provided a 14.1-million-euro budget for a three-year project known as Aurora. The Aurora team will develop a long-term plan for robotic and human exploration of the solar system, including the search for extraterrestrial life. The funding for both the Mercury mission and Aurora was less than ESA requested, however, and the ministers refused to grant any increase to the science budget above inflation. Consequently, ESA officials say the Mercury mission may have to be scaled back or delayed. Also, a more aggressive Mars exploration program under the Aurora plan failed to materialize.

Washington, DC—NASA has selected two more planetary Discovery missions. *Kepler*, the first spacecraft devoted to the search for planets around other stars, will be launched in 2006. Using a 0.95-meter telescope from a heliocentric orbit, *Kepler* will estimate the number of planets around other stars. The NASA Ames Research Center project will be led by William Borucki.

Dawn is an asteroid mission targeted to rendezvous with Ceres and Vesta, the most massive known asteroids in the solar system. These two main-belt objects are very different from each other, but both hold clues to the origin and evolution of the solar system. *Dawn* is also scheduled for a 2006 launch, with the Vesta rendezvous planned for 2010–11 and the Ceres rendezvous for 2014–15. The mission is managed by Christopher Russell of UCLA and supported by the Jet Propulsion Laboratory.

Puerto Rico—In late December, NASA announced plans to curtail all radar science from Arecibo, the world's largest radio telescope. One of the primary goals of such science was accurate determination of orbits and sizes of near-Earth objects (NEOs).

NASA's action was taken as a budget-saving device. Congress had mandated a NEO discovery program with the goal of finding 90 percent of objects larger than 1 kilometer (0.6 mile) in diameter by 2008. Funding the program made less money available for the follow-up work of tracking and characterizing the objects. Yet, the dangers of limiting our knowledge of approaching NEOs became readily apparent. The Planetary Society, in collaboration with the planetary science community, took a strong public stand against the decision. Within 24 hours, NASA reversed its position. It has now agreed to review the entire project with an eye to maintaining the radar observation program.

Washington, DC—NASA launched into 2002 with a new administrator, Sean O'Keefe. O'Keefe had been deputy director of the Office of Management and Budget (OMB) in the Bush administration, leading efforts to constrain funding on the space station.

As we went to press, Bush's fiscal year 2003 budget proposal was submitted to Congress. Although it included a remarkable 19 percent increase in space science, funds for the development of the space station were severely cut, while cancellation of the development of current Pluto–Kuiper Belt and Europa orbiter missions was proposed in favor of a future line of planetary missions called New Frontiers.

The major new initiative proposed was development of space nuclear power and propulsion. The large Mars rover being planned for 2007 is now delayed for a 2009 mission in order to take advantage of the nuclear power technology, which will make possible long lifetimes and range.

O'Keefe cited the advantages of nuclear electric propulsion for a later Pluto mission, which could theoretically arrive around the same time as the currently planned mission because of the shorter travel time. That assumes, however, a relatively quick and straightforward development of the nuclear electric capability.

This is the third time that cancellation of the Pluto mission has been proposed. Each time, Congress has intervened to restore it. The Planetary Society has strongly advocated the mission, and while we welcome the new initiatives and solid support for planetary exploration in the budget proposal, we oppose the proposed cancellation. How this will all play out in Congress will be determined in the next few months.

Visit our website, *planetary.org*, to keep up-to-date on political decisions affecting planetary exploration. As with our efforts on behalf of the Mars program two years ago, the Pluto mission last year, and, most recently, the Arecibo radar program, we can make a difference.

Louis D. Friedman is executive director of The Planetary Society.

THE 2002 SHOEMAKER NEO GRANTS—IT'S TIME TO PROPOSE!

BY DANIEL D. DURDA

The Planetary Society is now accepting proposals for the next round of Gene Shoemaker NEO Grants, which continue to make possible the valuable scientific work of detecting, tracking, and characterizing asteroids and comets in the near-Earth environment.

The Shoemaker NEO Grant program was initiated by The Planetary Society in 1997 in honor of planetary geologist Eugene Shoemaker, who pioneered our understanding of asteroid and comet impacts on Earth. The founding goal of the Shoemaker NEO Grant program was to increase the rate of discovery and follow-up study of NEOs (near-Earth objects) by providing dedicated amateurs and observers in developing countries with seed money to increase their contributions to critical NEO research. Indeed, by awarding grants to nearly a dozen recipients in countries spanning the globe, Planetary Society members have helped support tremendously important NEO search and recovery efforts that would have otherwise lacked adequate funding.

Large search programs like LINEAR, LONEOS, NEAT, and Spacewatch, which are funded primarily by the US government through NASA, are certainly doing a good job of meeting the Spaceguard goal of finding 90 percent of the kilometer-and-larger near-Earth asteroids (NEAs) by the year 2008.

Although we are discovering NEAs at about two-thirds the rate needed to meet that goal, the best estimates are that we have already discovered about half the roughly 1,000 NEAs 1 kilometer (0.6 mile) and larger that roam the inner solar system. While planetary scientists continue to make great strides toward determining the number of potential Earth-impacting objects, much work remains to be done.

The major survey programs are expensive to operate, and after allocating funds among them, the government has little, if any, money left to support vital astrometric follow-up and physical characterization observations. Astrometric follow-up (precise observations of the positions of objects in the sky) defines accurate orbits for newly discovered NEOs so that their paths can be tracked into the future to check for potential Earth impacts. Physical characterization (determining the size, rotation, and composition of objects) allows scientists to understand the material properties of NEOs so that the stuff that formed the planets can be studied and impact hazard mitigation strategies developed.

Here is where smaller programs funded by The Planetary Society's Shoemaker NEO Grants can play a major role. With more and more NEOs being discovered every month, all the necessary follow-up and physical study observations are overwhelming professional astronomers. The need, then, is for programs that can follow up and observe NEOs that are fainter than magnitude V = 19.5 or so (about 400,000 times fainter than can be seen with the naked eye). Such observations require the use of modest-size telescopes. Phenomenal advances in telescope, camera, and computer technology in recent years have placed professional-quality instrumentation in the hands of many capable amateurs. For example, observers utilizing thinned-chip CCD cameras on telescopes with apertures larger than 0.3–0.4 meter (12–16 inches) can make a useful contribution to NEO research. In fact, inspection of the Minor Planet Electronic Circulars announcing new NEOs shows that the best amateur contribution to astrometric follow-up observations currently comes from a group regularly using a 0.75-meter (30-inch) telescope. Facilitating more contributions from groups like this, particularly in the Southern Hemisphere, is what the Shoemaker NEO Grant program is all about.

Lights twinkle on an unsuspecting Earth moments before a devastating asteroid impact. To increase our chances of spotting an unwelcome visitor ahead of time, The Planetary Society's Gene Shoemaker NEO Grant program awards funding to amateur astronomers who perform observations of recently discovered NEOs.

Illustration: Chris Butler

The Shoemaker NEO Grant's panel of internationally recognized NEO researchers will consider proposals for projects that can enhance the rate of follow-up of faint NEOs or help advance our knowledge of the physical properties of NEOs. The selection committee will be looking for "leveraged" proposals rather than projects solely supported by Shoemaker NEO Grant funds. Leveraging could include upgrading an existing facility, matching funds from other sources, procuring specific hardware items (such as a thinned-chip camera), and so on.

Applications are due April 1, 2002 and will be considered from anyone, anywhere. Three to seven grants will be awarded, with average grant amounts ranging from $3,000 to $10,000. The awards will be announced in June 2002.

For further information and instructions for completing a proposal application, visit the Society's NEO website at *www.planetary.org/html.neo*.

Daniel D. Durda is a planetary scientist at the Southwest Research Institute in Boulder, Colorado, where he studies the collisional evolution of asteroids. He is also the coordinator for The Planetary Society's Shoemaker NEO Grant program.

Questions and Answers

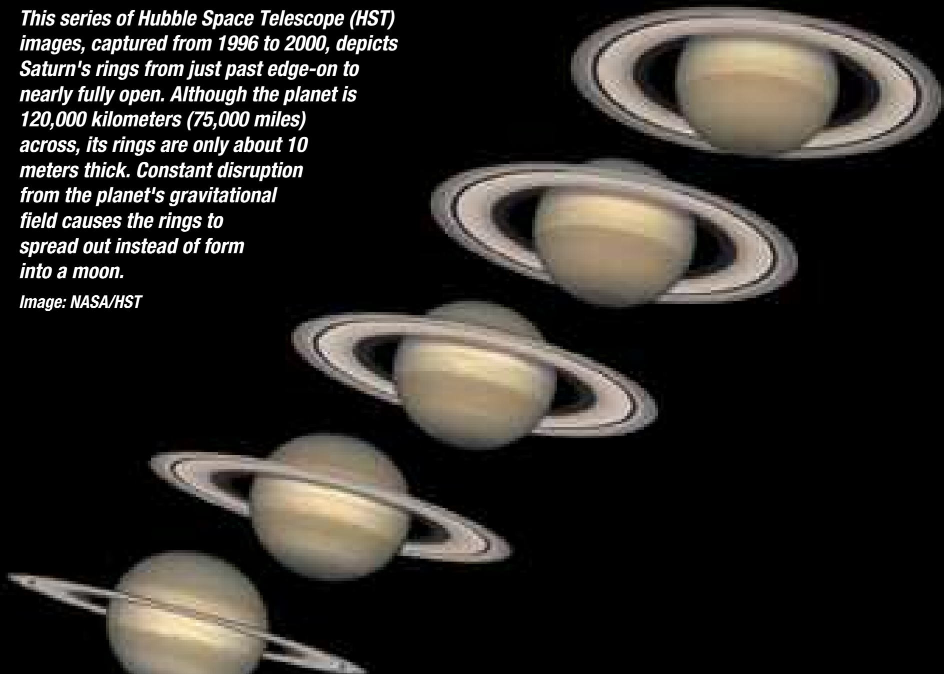
Why do only the gas giants have rings, while the rocky planets have none?
—J. HOWARD,
Halifax, Nova Scotia

Planetary rings are made of myriad small particles in orbit around a planet. We cannot see them individually but only collectively—like the droplets of water in a cloud, they reflect the Sun's light. Rings are found only close to their parent body, where the planet's gravity is strong enough to overcome the ring particles' tendency to stick together and grow into a small moon—the same way the planets coalesced around our Sun when the solar system formed.

Planetary rings are transient. They are created either continuously from dust knocked off small satellites by meteoroid bombardment or episodically, as when a comet smashes into a moon. Likewise, rings disappear as their ring particles are ground down by collisions and swept away by frictional drag. Friction from gas, from charged particles around the planet, and even from sunlight slows the ring particles in their orbits—they are swept away and leave the ring system or burn up in the atmosphere the way *Skylab* did. The balance between these acts of creation and destruction yields the rings we see today.

Mars may have very tenuous rings made of dust blasted off its moons Phobos and Deimos. After the giant impact that created our Moon, Earth temporarily had a ring—before the Moon went on to consolidate into a single body.

Maybe every planet had rings once in its history. Rings represent random events that are unpredictable. Think of it this way: each planet is like a gambler who started with a certain stake (its original retinue of small moons). The rocky planets have all lost their stacks of chips, leaving only the giant planets, which still have their families of small moons (the raw material for rings) as players in the "ring creation" game.
—LARRY ESPOSITO,
University of Colorado



This series of Hubble Space Telescope (HST) images, captured from 1996 to 2000, depicts Saturn's rings from just past edge-on to nearly fully open. Although the planet is 120,000 kilometers (75,000 miles) across, its rings are only about 10 meters thick. Constant disruption from the planet's gravitational field causes the rings to spread out instead of form into a moon.
Image: NASA/HST

I've read that half the stars we see are binary stars. Could these double stars have solar systems similar to our own, or would the orbits of their planets be radically different?

Also, are the odds for finding life in binary-star systems greater than in single-star systems?
—LEE VAUGHAN,
The Woodlands, Texas

At least half the stars one sees at night are members of binary- or multiple-star systems. As our ability to detect unseen companions to stars improves, the number of known binary- and multiple-star systems can only increase. Because each binary or multiple system consists of two or more stars, only a minority of the total number of stars in our galaxy are single stars like our Sun. Therefore, it is natural to wonder about the likelihood of habitable planets in binary- and multiple-star systems.

Unfortunately, there is no definitive answer to your question at this time, because we do not understand how the planet formation process proceeds in a binary- or multiple-star system. Most theoretical studies on planet formation have been devoted to understanding the genesis of our solar system—with mixed results. While scientists generally agree on the basic formation mechanism of terrestrial planets, there is much more controversy surrounding the formation of the gas and ice giants.

Preliminary studies on the formation of terrestrial planets through collisions between planetesimals (small bodies that will evolve into planets) suggest that having a binary star companion may well accelerate planets' growth processes and lead to a new type of runaway growth in which colliding orbits are created more by gravitational pulls from the binary companion than from nearby planetesimals.This is an important question for ongoing theoretical study.

Another approach is to determine in which binary systems an Earth-mass planet could have a stable orbit, regardless of how it formed. Generally speaking, for an Earth-like orbit around a star like the Sun to be stable, any binary star companion to that sun would have to be on an orbit at least as distant as that of Jupiter, depending on the binary companion's mass and orbital shape.

About half of all binary stars are separated by distances less than the Sun-Jupiter distance, so these binary stars would not be good candidates for extrasolar Earths; stable planetary orbits at large distances from a close binary star pair would be too cold for habitability unless the stars were very luminous. The other half remain viable candidates—in fact, ground-based extrasolar planet searches have already discovered Jupiter-mass planets in orbit around several stars with binary companions on wide orbits.

NASA's recently approved *Kepler* mission will be able to assess the frequency of Earth-like planets around a large sample of both single and binary stars, providing the ultimate answers to your questions.

—ALAN P. BOSS,
Carnegie Institution of Washington

Factinos

A planet has been discovered in orbit around the giant star Iota Draconis, located 100 light-years from Earth in the constellation Draco. This is an especially important finding because it provides insight into the fate of planets during the late life cycles of stars.

The discovery was announced in January 2002 at the American Astronomical Society in Washington, D.C., by Sabine Frink, David S. Mitchell, and Andreas Quirrenbach of the University of California, San Diego; Debra A. Fischer and Geoffrey W. Marcy of the University of California, Berkeley; and Paul Butler of the Carnegie Institution of Washington.

What makes the discovery remarkable is that the host star is not a Sun-like star but an old star that has already burned the hydrogen fuel in its core. Such "giant stars" grow much bigger toward the end of their lives, and Iota Draconis has expanded to a radius that is 13 times the radius of the Sun.

"Until now, it was not known if planets existed around giant stars," says Frink. "This provides the first evidence that planets at Earth-like distances can survive the evolution of their host star into a giant."

—from the University of California, Berkeley

Deep below the surface of the Beaverhead Mountains of Idaho, a research team led by Derek Lovley of the University of Massachusetts and Francis H. Chappelle of the United States Geological Survey has found an unusual community of microorganisms. This community may help us understand how life could survive on Mars. The team's findings are spelled out in the January 17, 2002 issue of *Nature*.

"The microbial community we found in Idaho is unlike any previously described on Earth," said Lovley. "This is as close as we have come to finding life on Earth under geological conditions most like those expected below the surface of Mars. This study demonstrates, for the first time, that certain microorganisms can thrive in the absence of sunlight by using hydrogen gas released from deep in the Earth's surface as their energy source."

"Over 90 percent of the microorganisms were Archaea, which are microorganisms considered to be most closely related to ancient life on Earth. In this case, the Archaea were methane-producing microorganisms that live by combining hydrogen with carbon dioxide to make methane gas. They do not require organic carbon in order to grow," Lovley explained.

Now that such a microbial community has been found, Lovley added, scientists can test hypotheses about hydrogen-based subsurface life. They also can develop strategies for searching for similar microbial communities on other planets.

—from the University of Massachusetts

Two hundred fifty million years ago, something unknown wiped out most life on our planet. Now, inside tiny capsules of cosmic gas, scientists are finding clues to this mass extinction.

Luann Becker of the University of California, Santa Barbara led a team of scientists to sites in Hungary, Japan, and China where 250-million-year-old rocks can still be located. There, the team found telltale signs of a collision between our planet and an asteroid 6 to 12 kilometers (3.8 to 7.4 miles) across—as big as or bigger than Mount Everest.

Below a certain point in the accumulated layers of earth, the rock the team studied shows signs of an ancient world teeming with life. In more recent layers just above that point, signs of life all but vanish.

Scientists call this event, which occurred at the boundary between the Permian and Triassic periods, "The Great Dying"—not to be confused with the better-known Cretaceous-Tertiary extinction that signaled the end of the dinosaurs 65 million years ago. Whatever happened between the Permian and Triassic periods was much worse, as life on our planet almost came to an end.

—from NASA Science News

Society News

Generous Donation to the *Cosmos 1* Project

The Planetary Society is honored to announce a donation of $750,000 made by Peter Lewis to the *Cosmos 1* solar sail project. The gift, secured by Society Board member and Cosmos Studios CEO Ann Druyan, provides valuable additional funds for the project. Cosmos Studios is the chief sponsor, along with the Arts and Entertainment Network, which will broadcast a documentary on the making of the mission.

This is the largest donation in our history and represents not only an important financial contribution but also a new step in public participation in space exploration. A bold, pioneering venture in science and technology, *Cosmos 1* is financed entirely by the private sector.

Lewis is the former chairman and CEO of Progressive Insurance Co. A philanthropist as well as a leader in the art community, he chairs the Board of the Guggenheim Museum of Art in New York and is a major contributor to Case Western Reserve University and to Princeton University. We gratefully acknowledge his donation.
—Louis D. Friedman, Executive Director

Surprise Bequest Helps Society

We are very pleased to note a remarkable bequest to the Society from nonmember John Getzman. His bequest, like others from nonmembers in our history, testifies to The Planetary Society's growing impact beyond even our large membership. The Board and staff would like to gratefully acknowledge Getzman, as well as the following for their generous bequests to the Society in 2001: George Carey, Jonathan Kamin, and Robert Gibson.

For more information on making bequests to the Society, call Lu Coffing at (626) 793-5100, extension 234, or e-mail her at *lu.coffing@planetary.org*.
—Lu Coffing, Financial Manager

Use PayPal and Double Your Donation

The Life to Mars Foundation has pledged to match donations made to The Planetary Society on our website through PayPal, the world's leading Internet payment system. Life to Mars is an organization that seeks to further the establishment of a self-sustaining human base on the Red Planet. Elon Musk, chairman of the Life to Mars Foundation, is a director and founder of PayPal.

We encourage members to use our website for all member services. If they wish to make a donation or dues payment with PayPal, they will know their gift will be doubled by the Life to Mars Foundation.
—LDF

We Thank Our Supporters

Besides needed funding, support from nonmembers as well as members adds to the positioning of the Society as an important representative of public interest. In addition to the individuals already cited, we wish to acknowledge two corporate sponsors who have made new ventures possible. Cosmos Studios, the exciting new science media venture led by Ann Druyan, has supported the largest project: the *Cosmos 1* solar sail. The LEGO company has joined with us to create the first student exploration project that will go to another world: Red Rover Goes to Mars.

We also acknowledge the support and leadership of the New Millennium Committee as well as major individual donors who helped the Society last year, including David Brown, Don Cline, Manuel Cortes, Cosimo DiBella, Raymond Frazier, Christopher Fulton, Dan Geraci, Irene Gleason Jordan, Jack Lasee, Bill Nye, Ray Olszewski, Harvey Schussler, Stephen L. Shields, John Tricou, and Akira Urita. *—LDF*

Annual Audit Completed

The firm of Hensiek & Caron has completed its yearly audit of The Planetary Society. The firm determined that the Society's 2001 financial statement was in conformity with generally accepted accounting principles. Copies of the financial statement are available upon request. *—LC*

Another Expedition?

Interested in accompanying us on our next expedition? We are considering traveling to Argentina to study some intriguing outcrops in Patagonia in January/February 2003. The expedition is still in the initial planning stages, so details are not yet available. If you're curious and want to be added to a list for updates, call Lu Coffing at (626) 793-5100, extension 234, or e-mail her at *lu.coffing@planetary.org*.
—LC

INSPIRATION FOR THE NEW YEAR!

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In February 1990, *Voyager 1* looked back at its home planet for the last time. The image of Earth as a tiny bluish dot inspired Carl Sagan to write one of his best-known essays, which starts off his book *The Pale Blue Dot*. The poster features Carl's timeless words and the full frame of the profound image captured by *Voyager 1*.
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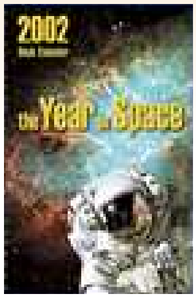

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In Roman mythology, Mercury was the messenger of the gods. Like his Greek counterpart, Hermes, Mercury had a winged hat, staff, and sandals. Because it moves so quickly across the sky, the little planet closest to the Sun takes its name from this mythological figure. *Mercury* from *The Seven Planets and Ages of Men* by Adriaen Collaert is from a series of 16th– or 17th–century engravings depicting the Roman gods after whom various bodies in our solar system are named.

Adriaen Collaert (1560-1618) was a Flemish draftsman, engraver, print publisher, and dealer from Antwerp, Belgium. He produced an extensive oeuvre of engravings of the natural world, depicting flowers as well as birds, fish, and other animals, along with a series featuring the four elements of Classical thought: earth, fire, water, and air.

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