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Heading Back to the Forgotten

Mercury has spent the last 25 years in scientific exile. Now, with two new spacecraft in the works, this little planet steps to center stage.

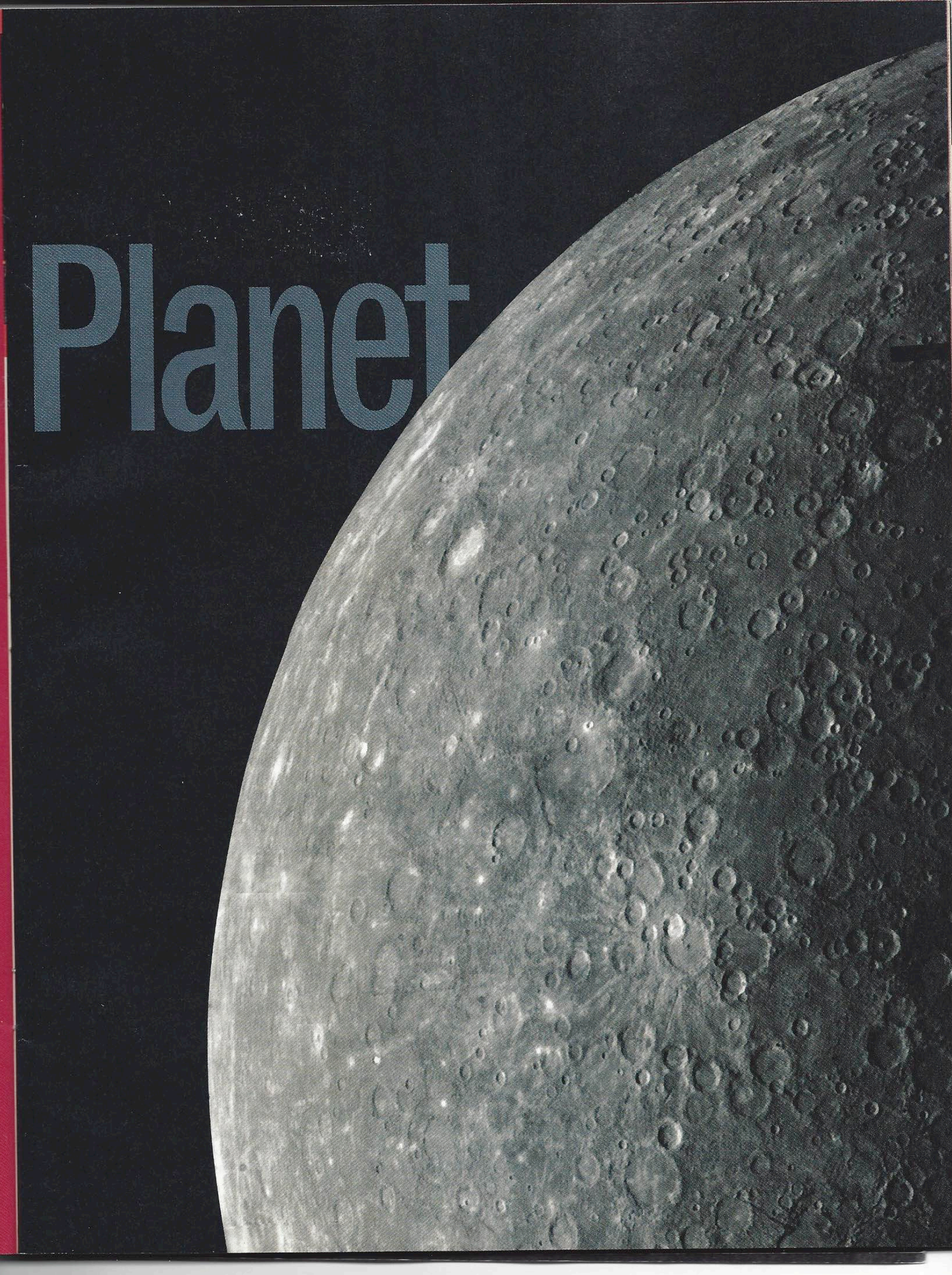
by John Armstrong

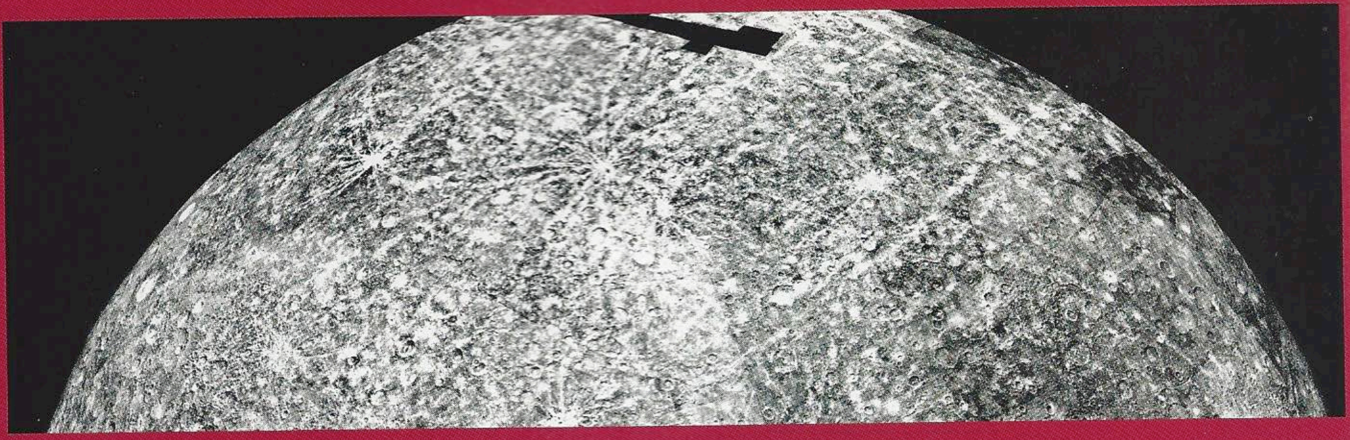
Maybe it's too small, or perhaps it looks just a little too much like the moon. Whatever the reason, minute Mercury rarely enjoys the limelight.

Pluto aside, Mercury remains the least-studied and least-appreciated planet in the solar system. Despite its proximity to the sun, Mercury tops very few "Best of…" lists. It's not the smallest planet — Pluto wins that contest. Nor is Mercury the hottest — that title goes to neighboring Venus. And it makes the "Top 10 planets in the solar system" list largely because there are slots to spare.

Mariner 10's first image of Mercury revealed a pockmarked surface similar to — but different than — the moon's. NASA/JPL/U. S. Geological Survey

Planet





Above: Mercury's southern hemisphere shows an abundance of fresh, rayed craters. NASA/JPL
Left to right: A 61-mile-wide crater shows a central peak and interior terraces; Discovery Scarp runs 220 miles and crosses two large craters; Ridges and fractures cover the floor of the Caloris basin. NASA/JPL/Northwestern University

At first glance, little distinguishes Mercury from any other rock in the solar system. It bears no icy rings, and no active volcanoes disturb its surface. It's not a potential abode for life and probably never will be. People have never been there and are unlikely to go. It's a planetary backwater — the Gobi Desert of the solar system.

To top it off, Mercury proves notoriously difficult to study. Viewed from Earth, Mercury never ventures more than 28° from the sun. This makes it visible to the naked eye only during morning or evening twilight, and then only low in the sky. Professional astronomers have it worse, observing the planet during daylight when it's higher in the sky. Most operators of large telescopes shudder at the thought of risking million-dollar optics for a fleeting glance at a small, barren rock perilously close to the sun. That's why the Hubble Space Telescope is forbidden to look at Mercury, lest the eyes of the most famous telescope in history get damaged. Radar offers the safest way to view Mercury, but that gives about the same resolution as Earth-based optical observations of the moon.

That leaves space missions. A year ago, NASA announced funding for the full-scale development of the MESSENGER probe to Mercury, set to launch in 2004. Not to be outdone, the European Space Agency plans an even more ambitious mission to the innermost planet late this decade. (See "BepiColombo: A European Flair," page 43.) Both missions aim to answer some long-standing puzzles about this enigmatic planet.

MESSENGER — short for MErcury Surface, Space ENvironment, GEochemistry and Ranging — marks NASA's first return to Mercury since Mariner 10. That pioneering mission, which flew past the planet a total of three times in 1974 and 1975, sent back the first glimpses of Mercury's surface. Yet Mariner 10 photographed less than half the surface, leaving scientists with a desire for more images that has gone largely unsatisfied over the last quarter century.

"Much of Mercury hasn't even been seen," says Ralph McNutt, Project Scientist for MESSENGER at Johns Hopkins University's Applied Physics Laboratory. "This is the first time we'll get high-resolution images of the unseen half. It will be like getting the first good images of the back side of the moon."

In past missions to other solar system objects, photos of the "other half" often revealed exceptional surprises. For instance, the first images of the moon's far side divulged a surface largely devoid of the dark, lava-filled basins visible on the Earth-facing hemisphere. More striking were the giant volcanoes on Mars, which remained undiscovered until the fourth mission to the Red Planet.

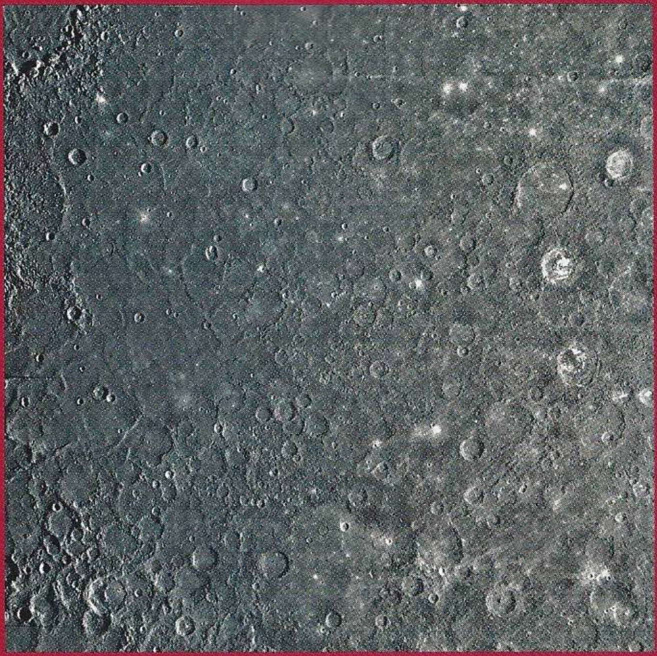
"When we've had other first glances, it is often not representative," says Clark Chapman, a planetary scientist at the Southwest Research Institute in Boulder, Colorado, and member of the MESSENGER science team. "The other half is largely *terra incognita*."

Even so, Mariner 10 revealed some very odd phenomena. MESSENGER and BepiColombo will visit a world where the temperature difference between night and day can reach over 1100° Fahrenheit (600° Celsius) at the equator. Scarps and cliffs, some more than a mile high, stretch across the surface, presumably a result of the planet shrinking as it cooled. Giant impacts blasted the pockmarked crust, marring it with craters. The largest of these impacts left the Caloris basin, some 800 miles (1,300 km) in diameter.

Mercury's "year," which lasts 88 Earth days, is almost exactly 1.5 times as long as its rotation period. Coupled with the planet's eccentric orbit — it differs from a circle more than any planet besides Pluto — this gives rise to some startling effects. As Mercury passes perihelion, its closest approach to the sun, its orbital speed surpasses its rotational speed.

That makes the sun appear to halt its motion in the sky and reverse direction, only to return to its course as the planet slows in its orbit. This phenomenon, known as retrograde motion, is similar to the effect seen as one car passes another on the highway. Even though both vehicles are traveling in the same direction, the passengers in the overtaking vehicle

The brightest crater on Mercury (at bottom center), measures 25 miles across and is named Kuiper after the famed planetary scientist. NASA/JPL



Areas of level to gently rolling ground cover much of Mercury. These plains range from fairly smooth to chock-a-block with craters. NASA/JPL

see the other car appear to move backward momentarily.

In light of recent discoveries of Jupiter-like planets orbiting close to their parent stars, Mercury's existence as a dense, rocky world orbiting close to the sun is as important to understand as why our planet is covered with water. It is, as Chapman calls it, an end-member planet, whose very existence brackets the spectrum of planet formation. To understand Mercury, why it is so dense, what it's made out of, and why it has a magnetic core, is essential to understanding our solar system as a whole, says Chapman.

"It is extreme in a bunch of ways," explains Chapman. "It is at the end of the spectrum in terms of bulk density, it is at the end in terms of distance from the sun, and it is also at the end in terms of temperature difference between night and day. It is extreme, and in science, one often learns from studying the extremes."

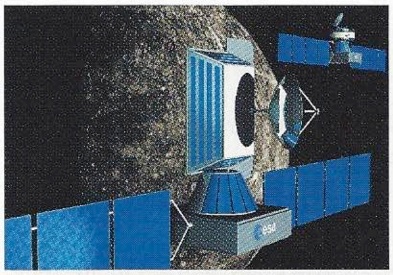
And there is still much to learn. "To the uninitiated," adds Chapman, "it looks a lot like the moon — but it is quite different." The formation and evolution of Mercury remain almost completely unknown, and the MESSENGER science team believes they may hold the key to understanding planet formation. Mercury represents the ideal physical laboratory. It is like, and yet completely unlike, any of the other terrestrial planets. "As a laboratory, Mercury changes the properties enough to test the generalities

BepiColombo: A European Flair

The European Space Agency has big plans for its own mission to Mercury. Under development as a "cornerstone" mission, BepiColombo promises to be one of ESA's most important long-term planetary projects. Named after Italian mathematician and engineer Giuseppe "Bepi" Colombo, who calculated the Mariner 10 spacecraft's trajectory, the mission aims to answer many of the same questions as MESSENGER. But it plans to do so in a unique way.

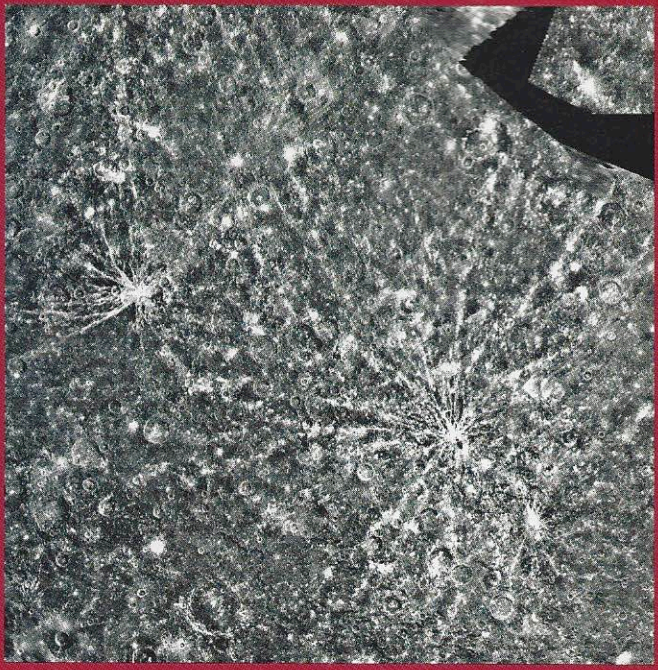
Preliminary studies envision sending three separate probes to the planet. The Planetary Orbiter will consist of two cameras and half a dozen other remote-sensing instruments that will examine Mercury from a polar orbit. A smaller Magnetospheric Orbiter will house seven instruments and observe the planet's magnetic field and its interactions with the solar wind.

Finally, a Surface Element will land near one of Mercury's poles. Its suite of instruments includes a camera, a seismometer, a detector to analyze chemical composition, and a package to measure the temperature, density, hardness, and heat capacity of Mercury's "soil." The Surface Element should operate for at least a week and the orbiters for about 12 months.



The BepiColombo spacecraft arrives at Mercury. European Space Agency

BepiColombo will use a different tack to gain the energy it needs to reach its orbit around Mercury. Although the flight path will take it past both Venus and Mercury for gravity assists, the spacecraft will also use a new ion propulsion system to provide a small but continuous acceleration for many months. A standard chemical propulsion system will ultimately place the spacecraft into orbit. Scheduled for launch in 2009, the mission will take two-and-a-half years to reach Mercury. — *Richard Talcott*



Bright rays emanate from the youngest, freshest craters on Mercury. These rays appear similar to those seen on Earth's moon . NASA/JPL

Mercury's south polar region displays innumerable craters that chronicle the iron-rich planet's violent history. NASA/JPL

of our models," says Sean Solomon, Director of the Department of Terrestrial Magnetism at the Carnegie Institution of Washington, and Principal Investigator on the MESSENGER mission.

But Mercury's proximity to the sun makes getting there difficult. At a distance of 35 million miles, the sun holds Mercury deep in its gravitational well. The change in velocity needed to get from Earth's orbit to Mercury's orbit makes a trip to the moon look like a walk to the pub. It's hard enough to lift a one-ton spacecraft out of Earth's grip at 6.9 miles per second, but the craft must then accelerate an additional 11 miles per second to match Mercury's much faster 88-day circuit around the sun. "Even though it is close by, it takes a lot of energy to get there," says Chapman.

Until Chen-Wan Yen, at NASA's Jet Propulsion Laboratory in Pasadena, California, figured out how to use gravity assists to get spacecraft to the inner planets, the cost in mass and propellant made getting a probe into orbit around Mercury prohibitive. After the Mariner 10 flybys, NASA shelved further missions to Mercury, in part because the agency didn't know how to get a craft into orbit without using vast amounts of fuel. With their atmospheres to help slow the arrival of incoming spacecraft, Mars and Venus became easier targets. Yen, however, changed all that. Like a sailor on the high seas, she devised a plan to use the natural forces generated by the planets to guide her ships into port. But instead of wind, Yen uses the gravitational energy of other planets to carry spacecraft into orbit.

"We use Venus and Mercury to shrink the spacecraft's orbit so we can get to Mercury and allow for an easy capture," says Yen. "MESSENGER is the most challenging because the energy change involved is large and the number of gravity assists one can consider are many."

This time, NASA's orbiter will allow a far more detailed study of the surface, making the added challenge worth the effort. Scheduled for launch in 2004, MESSENGER will steal energy from Venus and Mercury, making two flybys of each planet, before finally settling into orbit. With each visit, the craft siphons an infinitesimal amount of the planet's orbital energy to speed it on its way and ultimately maneuver into Mercury's orbit. This greatly reduces the number and duration of rocket firings, cutting the mass and total cost of the mission.

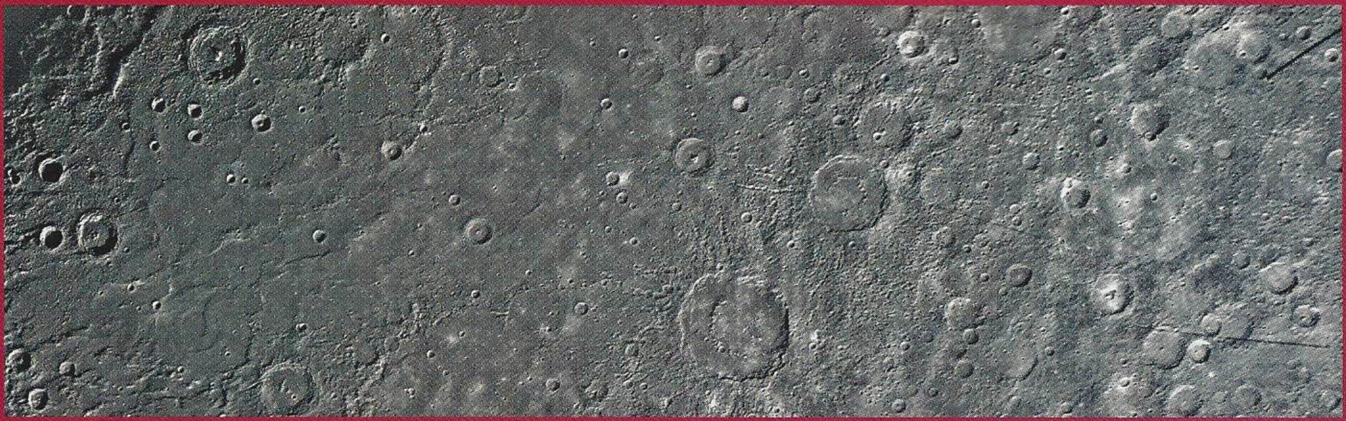
Of course, nothing in life is totally free. What MESSENGER saves in fuel it spends in time — nearly five years' worth — before reaching orbit in 2009. "By the time we reach orbit, it will have been almost 35 years since the last Mercury mission," says Solomon. "After Mariner 10, there was a great deal of interest in a Mercury orbiter, but nobody then knew how to put a craft into orbit around Mercury using conventional propulsion."

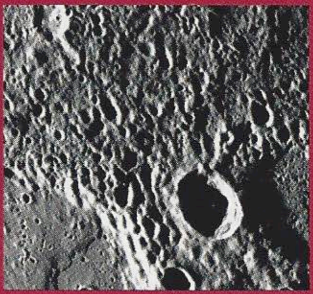
Even with all the help along the way, the spacecraft still requires a lot of old-fashioned rocket power. "MESSENGER, for the most part, is a flying fuel tank," says McNutt. "This is a very mass-constrained mission, and it's a hard mission to do."

But the MESSENGER science team certainly believes it is a mission worth doing. The team hopes to answer some fundamental questions about Mercury's composition and evolution in an effort to tie together competing theories of how planets form.

For one thing, Mercury, although just slightly larger than the moon, is nearly as dense as Earth. Larger planets use gravity to compress their material, which increases their overall density, but Mercury's small size indicates that the bulk material of the planet must contain a huge fraction of denser elements like iron. "We know almost nothing chemically about Mercury except that it is incredibly dense," says Solomon. "How did it get this way?"

Planetary scientists have concocted a number of theories to explain the high density. If Mercury formed near the sun, only the elements capable of condensing out of the solar nebula at high temperatures, like iron, would have been incorporated into the planet. Or, perhaps the sun's searing heat burned off the crustal material, leaving only a cinder of iron and nickel. It is even possible that





Above: Part of the 800-mile-wide Caloris basin fills the left side of this Mariner 10 image. NASA/JPL **Left to right: A young crater sits at the center of a much older one; A prominent scarp stretches hundreds of miles across the top left of this region; Craters pile on craters in many parts of Mercury.** NASA/JPL/Northwestern University

a giant impact knocked off the lighter crust as well as the underlying mantle, unveiling the metallic core.

Whatever the reason, MESSENGER's instruments should help answer the questions. Using x-ray, gamma-ray, and neutron spectrometers in conjunction with visible and near-infrared measurements, the team expects to pin down the planet's surface composition. "We know the bulk density of Mercury, but as for actual minerals on the surface, we really don't have a clue," says Chapman.

And those clues are important to understanding the formation of the planet, according to McNutt. "The spectrometers will give us our first good look at the properties of the surface," he says. "Potentially, there is a rich scientific harvest to come out of this."

The team also hopes MESSENGER will answer other pressing questions about surface materials. In 1991, radar images showed highly reflective regions deep inside craters near the poles of Mercury. "We want to know what this material is," says Solomon, "and we are applying a number of remote sensing techniques to find out."

The top culprit may be surprising: "The best guess is that water ice lurks just inches below the surface at the poles," says Chapman.

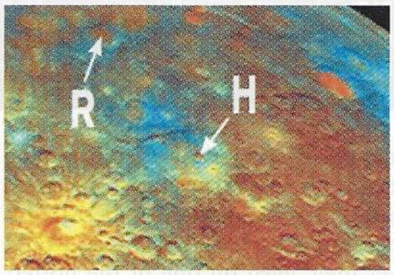
Unlike Earth, Mercury's axis tilts exactly 90° to the planet's orbit around the sun. At the poles, therefore, the sun

Seeking the Volcanic Plains

Bright and colorful may not be words normally associated with Mercury, but it all depends on how you look at it. More than two decades after the Mariner 10 flybys, Mark Robinson of Northwestern University and Paul Lucey of the University of Hawaii reanalyzed the old data to create color maps showing differences in composition across the planet's surface. The images reveal a dynamic planet that likely once experienced lava flows and explosive volcanic eruptions.

Planetary scientists had long suspected that Mercury experienced a volcanic past, though they had no way of knowing for sure. Venus, Earth, the moon, and Mars all have large tracts of relatively smooth terrain covered with lava, and all except the moon possess large volcanoes. Although black-and-white images of Mercury revealed smooth plains that appeared similar to the lava-filled lunar maria, looks can be deceiving.

Robinson and Lucey's images, created from Mariner 10 data at two wavelengths, helped make the case. An area near the crater Rudaki (labeled R in the false-color image) makes a good example. Suspected lava flows west of (above) the crater appear red, which suggests a low amount of titanium. This stands in marked contrast to its surroundings — a key sign that lava flooded the region and buried material of a different composition.



False-color images suggest Mercury had a volcanic past. NASA/JPL/Northwestern University

A more explosive origin appears likely for material near the Homer basin (labeled H). Robinson and Lucey suspect that a weakness in the crust became a fissure that allowed magma to reach the surface, where it erupted explosively. The boundaries of the blue material to the upper left of the basin appear diffuse; just what would be expected from such an eruption. — *R. T.*

A Long and Winding Road

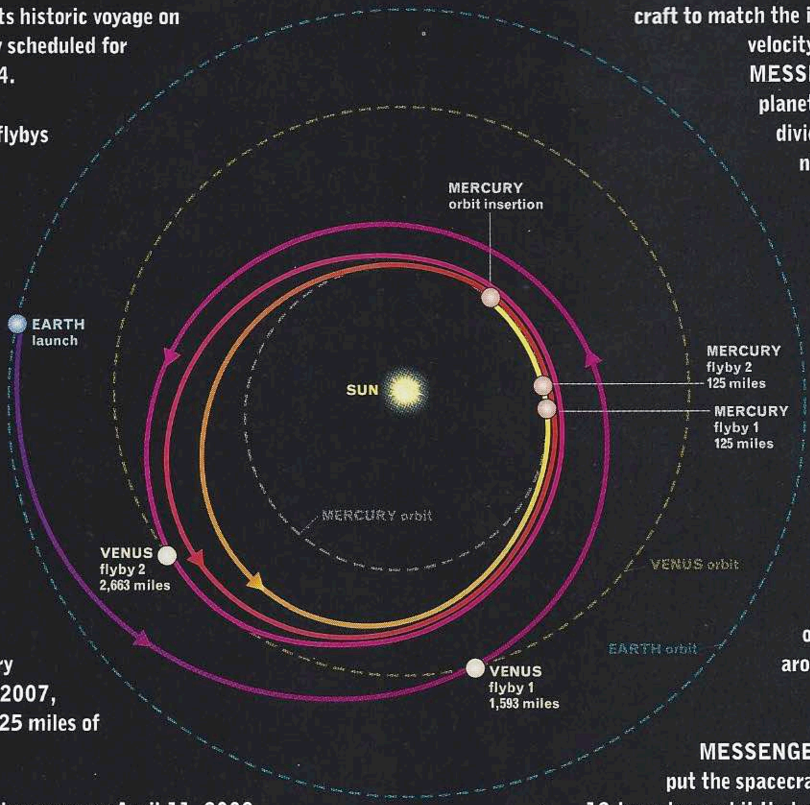
1] MESSENGER begins its historic voyage on a Delta II rocket currently scheduled for launch on March 10, 2004.

2] The first of two Venus flybys occurs just three months later, on June 24. The spacecraft approaches Venus from the night side and passes 1,593 miles above the planet's surface.

3] After three trips around the sun, MESSENGER once again encounters Venus, on March 16, 2006. It zips past the day side at an altitude of 2,663 miles.

4] The first of two Mercury flybys arrives on July 21, 2007, when it dips within just 125 miles of the planet's surface.

5] The second Mercury flyby comes on April 11, 2008, once again at an altitude of 125 miles. The sequence of four planet flybys (and two firings of the onboard rocket) will allow the spacecraft to match the innermost planet's orbital velocity. At both Mercury flybys, MESSENGER will approach the planet near the terminator (the dividing line between day and night) and depart from the day side. These sunlit views will give scientists their first close-up views of the half not seen by Mariner 10 and help plan observations once the spacecraft achieves orbit.



6] MESSENGER arrives at Mercury for the final time on April 6, 2009. The spacecraft will fire its engine once again to achieve orbit around the enigmatic planet.

MESSENGER's science team plans to put the spacecraft into a highly eccentric, 12-hour-long orbit that comes within 125 miles of the planet's surface at closest approach and goes out as far as 9,440 miles. The mission should last at least one Earth year.

remains forever on the horizon, and the bottoms of deep polar craters never see sunlight. Ice that collected there, from comet impacts or other sources, would never melt, even on one of the hottest planets in the solar system.

Perhaps more important is Mercury's magnetic field. According to Solomon, the other two small objects in the inner solar system exhibit only weak signs of magnetic activity. The moon once had a magnetic field, and Mars shows evidence of having had one early in its history, but neither object currently possesses a global magnetic field. Mercury, on the other hand, halfway in size between the moon and Mars, has an active and relatively strong magnetic field.

Why tiny Mercury should be magnetically active continues to be one of the great unanswered questions. Planetary scientists think that planets require a liquid core to sustain such a field, but the smaller the planet, the faster it cools. Mercury, by all rights, should have a core as cold and dead as the moon's. Yet the magnetic field persists. According to the science team, this may result from the existence of elements like sulfur that, when mixed with iron, lower the melting point and keep the core molten. Determining the state of Mercury's core is one of the primary goals of the mission.

Mercury's magnetic field also creates the only other Earth-like magnetosphere in the inner solar system. "Mercury has a miniature Earth's magnetosphere," says Solomon. The magnetosphere interacts with the solar wind, creating a physics experiment studied in detail, so far, only on Earth. "The dynamics are very similar to Earth's magnetosphere, but much faster," according to Solomon.

Mercury should provide an extraordinary physics laboratory. Planetary astronomy aside, it has been a proving ground for Einstein's theory of general relativity. Observations of Mercury in the last century supported the theory, because it explained perturbations in Mercury's orbit that were unexpected in Newton's classical theory of gravity. MESSENGER, as the first artificial satellite to orbit this close to the sun, may provide more information. "By simply having a spacecraft that near the sun, we will be learning things relevant to gravitational physics," says Solomon.

After 25 years of neglect, humans are finally rekindling their interest in Mercury. MESSENGER and BepiColombo stand to answer some of the most vexing questions in planetary astronomy. With new planets being discovered around other stars every month, developing a detailed understanding of our own solar system becomes even more important. Mercury, long ignored as the boring sibling in a solar system burgeoning with superstars, is finally drawing attention. The next decade should bring Mercury's moment in the sun. ■

Animations of MESSENGER's path on the way to Mercury can be found on *Astronomy's* October issue page at www.astronomy.com.

John Armstrong is an astronomy graduate student at the University of Washington. This is his first article for Astronomy.