The MESSENGER spacecraft enters orbit around the innermost planet in March to explore its geological history, thin atmosphere, dense core, and the strange stuff at its poles.

by Richard Talcott

Messages from Mercury

The MESSENGER spacecraft will have skimmed within 296 miles (477 kilometers) of Mercury's surface. If all has gone according to plan, the probe's main engine will have fired for 15 minutes—just long enough to slow the craft so the planet's gravity captures it. Within 12 hours, the probe will have settled into a highly elliptical orbit that carries it from 124 miles (200 km) to 9,440 miles (15,193 km) of the surface. Orbit insertion marks the end of a 4.9-billion-mile (7.9 billion km) journey—and the start of a yearlong mission to explore the innermost planet.

MESSGER — an acronym standing for MERCury Surface, Space Environment, Geodesy, Imaging, and Ranging—promises to solve many of the planet's closely held secrets. Why is it so dense, with an iron-rich core reaching three-quarters of the way to the surface? What drives its magnetic field and creates its thin atmosphere? What forces have shaped its surface? And, perhaps most intriguingly, does water ice lurk in permanently shadowed craters near the planet's poles?

So many questions remain because Mercury is notoriously difficult to observe. It never strays far from the Sun in Earth's sky, so scientists can't get clear views from our home planet. Mercury's proximity to the Sun also keeps Earth-orbiting observatories, including the Hubble Space Telescope, from pointing in its direction.

Most of our knowledge about this inner world comes from six previous spacecraft flybys: three by NASA's Mariner 10 in 1974–5 and three by MESSENGER in 2008–9. (MESSENGER used the flybys to put it on course for its current orbit.) A quirk in Mariner 10's trajectory meant that the Sun illuminated the same hemisphere of Mercury during each flyby. As a result, scientists could image only 45 percent of the planet.

MESSER filled most of the gaps from its first flyby in January 2008. In the upcoming orbital mission, the probe will image the planet's entire surface at three times better resolution, from 120 miles (200 km) to 9,440 miles (15,193 km). The end of the journey, GEochemistry, and Ranging—promises to solve many of the planet's closely held secrets. Why is it so dense, with an iron-rich core reaching three-quarters of the way to the surface? What drives its magnetic field and creates its thin atmosphere? What forces have shaped its surface? And, perhaps most intriguingly, does water ice lurk in permanently shadowed craters near the planet's poles?

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Mercury also features winding cliffs that reach up to a mile high and stretch for hundreds of miles. Planetary scientists think these so-called scarps form as Mercury cooled billions of years ago. The entire planet contracted, buckling the surface. Although the Lunar Reconnaissance Orbiter recently discovered similar features on the Moon, they don’t have anywhere near the global coverage that they do on Mercury. The relative uniformity of Mercury’s surface also stands out. Most of the other inner worlds have major geological differences between their hemispheres. “On the Moon, dark volcanic plains are con- centrated on the nearside and are nearly absent from the farside,” says MESSENGER co-investigator Mark Robinson of Arizona State University. “On Mars, the southern hemisphere consists of older, cratered highlands, whereas the northern hemisphere consists of younger lowlands.”

Even on Earth, the Pacific Basin dominates one hemisphere while a mix of continents and oceans inhabit the other. But based on MESSENGER’s preliminary reconnaissance, Mercury’s mix of ancient, heavily cratered terrain interspersed with large expanses of younger volcanic plains appears pretty uniform.

Despite the homogeneous surface, Mercury’s subsurface seems to be a more complex region. After each of the three flybys, MESSENGER scientists created false-color images to highlight differences in composition. In the images, made by combining shots taken through multiple filters, bright blue ejecta surround many impact craters. These thin deposits are subsurface material exca- vated by impacts.

Yet in some places, images show one crater surrounded by blue ejecta while a similarly sized neighboring crater is not. This shows that the region below the planet’s surface can’t be homogeneous. Robinson likens Mercury’s crust to a marble cake rather than a layer cake. The false-color images don’t reveal actual composition, however. MESSENGER will study the crust’s makeup during its orbital mission.

Digging even deeper Mercury’s surface may be unusual, but its interior borders on the bizarre. Overall, the planet has a density 5.4 times that of water — just 2 percent less than Earth’s. Yet it has a mass barely 5 percent of Earth’s. On our planet, the gravitational force exerted by this extra material crushes the interior to a far higher density than it would otherwise have.

On Mercury, the high density means heavy elements must dominate the planet’s inside. Researchers long ago realized that the world has a huge core composed largely of iron. This metallic core extends 75 percent of the way from the planet’s center to its surface and holds at least 60 percent of the planet’s mass — twice the amount of Earth’s core.

Mercury also has a global magnetic field, only Earth among the other inner worlds has one. The field most likely arises from electrical currents flowing through the outer part of its core. Earth-based radar observations show subtle changes in the planet’s spin rate that conform the outer part of Mercury’s core is molten, like Earth’s.

Yet Mercury’s small size argues that it should have radiated its heat into space long ago. As Solomon observes: “As a family member, Mercury’s a real oddball.” Scientists think modest amounts of lighter elements must be mixed with the iron in the outer core to lower its melting point and keep the region fluid.

Theorists have developed three ideas that tie Mercury’s current high metal content to the planet’s formation. One explanation takes place just as planets started accreting in the dust-rich solar nebula. In this scenario, drag forces exerted by the nebula’s gas affect iron and silicate particles differently, enhancing the concentration of iron. The other two ideas operate much later in the accretion process, after iron in the proto-Mercury had sunk to the core and lighter silicates had risen to form the mantle and crust. One explanation holds that radiation from the surrounding nebula vaporized much of the silicates and the solar wind then carried them away. In the other, a near-Earth-sized protoplanet smashed into the developing world and removed much of its outer layers.

The three models predict different compositions for Mercury’s silicate crust and mantle, and MESSENGER’s three main spectrometers will study this material’s precise makeup. If the spacecraft helps scientists understand why Mercury is so dense, it will open a window on the early solar system and shed light on how the inner planets developed their different compositions.

Bubbling up below Mercury’s hot outer core naturally raises the question of what role, if any, volcanic activity played in the evolution of the planet’s surface. Martian 10 wasn’t much help on this score: Its relatively low-resolution images did not reveal any obvious volcanic structures. MESSENGER’s three flybys changed that. A key piece of evidence came from the laser altimeter, which measures the height of surface features along a narrow strip beneath the spacecraft. In one case, the altimeter took the topographic profile of a pair of side-by-side craters, each 60 miles (100 km) in diameter. The instrument revealed that one crater is some 4 times deeper than the other, implying lava filled its neighbor to a depth of more than 1 mile (2 km).

The spacecraft’s cameras likewise found proof of rampant volcanic activity early in the planet’s history. The giant Caloris impact basin, which spans 960 miles (1,550 km), is a great example. Smooth plains inside the basin have a different color — and thus composition — than the basin’s rim and ejecta, which

A ceramic-fiber sunshade that measures about 8 feet (2.5 meters) tall and 6 feet (2m) wide will protect MESSENGER from solar radiation, which will be far more intense at Mercury than at Earth because it lies much closer to the Sun. Here, Neal Bachell of Johns Hopkins University attaches the sunshade’s middle section before the spacecraft launch. NASA/JHUAPL/CIW

MESSENGER will study Mercury from orbit for at least 1 Earth year (about 4 Mercury years). The Sun shines up to 11 times brighter at Mercury than at Earth, and surface temperatures can reach 800° Fahrenheit (427° Celsius). Still, a heat-resistant sunshade will keep the probe’s instruments at room temperature. NASA/JHUAPL/CIW

A thin blanket of blue covers the right side of this false-color image. Impacts dredged up this material from beneath the surface and scattered it across relatively young, smooth plains, which appear yellow-orange. The long and winding road

The Sun
Mercury
Venus
Earth
Launch 5 August 2004
3 Earth flyby
At August 2, 2006
Altitude = 1,458 miles
(2,347 km)
3 Venus flyby 1
At October 24, 2006
Altitude = 1,346 miles
(2,163 km)
3 Venus flyby 2
June 5, 2007
Altitude = 710 miles
(1,145 km)
3 Moon orbit insertion
March 17, 2008
4 Mercury flyby 1
January 14, 2008
Altitude = 125 miles
(201 km)
4 Mercury flyby 2
October 6, 2008
Altitude = 144 miles
(231 km)
4 Mercury flyby 3
September 29, 2009
Altitude = 146 miles
(235 km)
5 Mercury orbit insertion
March 16, 2011
8 Mercury flyby 4
October 6, 2009
Altitude = 124 miles
(199 km)
6 Mercury flyby 5
July 23, 2010
Altitude = 166 miles
(267 km)
7 Mercury flyby 3
September 29, 2009
Altitude = 144 miles
(231 km)

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formed from pre-existing surface and subsurface rocks. In addition, these plains have fewer craters than other areas dating to the time of the impact, showing that they consist of fresher material. Images also show several volcanic vents dotting the outer sections of Caloris. Oddly enough, the plains inside Caloris (and many other basins) reflect more light than the plains beyond the rim — the opposite effect seen with most lunar basins. Perhaps the impacts on Mercury dredged up deeper, brighter material, or the magma that later resurfaced them originated deeper in the planet. The impact that created Caloris happened during the so-called late heavy bombardment, a period of intense cratering in the inner solar system that ended about 3.8 billion years ago. The magma that formed the smooth plains inside the basin may have oozed out not long after. But MESSENGER revealed a much younger basin with signs of volcanism during its third flyby. Rachmaninoff is a double-ring basin spanning 180 miles (390 km). The smooth plains that fill its inner ring have a different color and a lower crater density than the outer ring.

“We interpret these plains to be the youngest volcanic deposits we have yet found on Mercury,” says planetary scientist Louise Prockter of Johns Hopkins University Applied Physics Laboratory. “Other observations suggest the planet’s volcanism spanned a much greater duration than previously thought, perhaps extending well into the second half of solar system history.”

**From hot to cold**

Mercury’s hottest interior and its proximity to the Sun don’t sound like recipes for ice, but many scientists think the frozen liquid lurks in some craters near the poles. Astronomers discovered mysterious polar deposits in 1991 when they shot radar beams at the planet and studied the return signals. The radar-bright regions appear eerily similar to those of Mars’ south polar cap and to the icy moons of the outer solar system. But how could ice survive on a planet where noontime temperatures can reach 800° Fahrenheit (427° Celsius)? The key is that Mercury’s spin axis tilts nearly perpendicular to its orbit around the Sun. So, the Sun never shines on the floors of deep craters near the poles. The thin atmosphere can’t transport heat from hot to cold areas, either. Theory says any ice that collects in these “cold traps” could survive for billions of years.

Not all scientists agree that the bright spots are ice, however. Some suggest sulfur could create a similar radar signature, and others think the craters appear bright because of unusual surface conditions in the low-temperature environment. MESSENGER may have a hard time learning the truth. Images won’t reveal anything because these deep crater floors lie in perpetual darkness. And the other instruments have wide fields of view that make it difficult to target small areas. The best chance may come by looking for atmospheric signatures above the poles or by using the craft’s neutron spectrometer to detect hydrogen (water’s key ingredient) at the surface.

**Into thin air**

Hydrogen also exists in Mercury’s atmosphere, along with helium, oxygen, sodium, potassium, calcium, magnesium, and probably other elements MESSENGER will find. The atoms in the atmosphere spread so thinly that they rarely, if ever, collide. (Astronomers call this an “exo-sphere.”) The atoms form a “tail” that stretches away from the Sun and extends for hundreds of thousands of miles. Scientists don’t know exactly where all of Mercury’s atmosphere comes from. The hydrogen and helium probably originate in the solar wind. Heat elements may diffuse from the planet’s interior or derive from surface impacts by meteoroids, solar photons, or solar ions. More than likely, several of these sources may play a role. The answer awaits a detailed analysis of MESSENGER’s orbital observations of both the atmosphere and surface.

**Up to the task**

To accomplish its mission, MESSENGER carries a slew of scientific instruments. The imaging system has both a wide-angle and a narrow-angle camera. The wide-angle camera covers a 10.5° by 10.5° field of view and can take images either in black and white or in color by combining exposures through 11 filters arrayed across the visible and near-infrared parts of the spectrum. The higher resolution narrow-angle camera captures a 1.5° by 1.5° field of view and sees features as small as 55 feet (18 meters) across.

Separate gamma-ray, X-ray, and neutron spectrometers measure the composition of Mercury’s surface. The Mercury Atmospheric and Surface Composition Spectrometer studies the atmosphere’s constituents as well as complements the other spectrometers viewing the planet’s surface. MESSENGER’s magnetometer maps the planet’s magnetic field while the Energetic Particle and Plasma Spectrometer analyzes charged particles trapped in the magnetic field. Finally, the laser altimeter measures surface topography and tracks the slight wobble in Mercury’s spin axis, which will help scientists understand the planet’s core.

Protecting this delicate hardware is a heat-resistant sunshield designed to keep the instruments at normal room temperature (68° F, or 20° C) even though the Sun shines up to 11 times brighter at Mercury than at Earth. The shade has two thin layers of ceramic fiber that surround several inner layers of plastic insulation. For this spacecraft, the past is merely prelude to the real show just beginning.

As Solomon says, “MESSENGER has been on a long journey, but the promised land lies ahead.”

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**Mercury’s thin atmosphere contains sodium, calcium, and several other gases. MESSENGER observations from its second flyby show sodium peaks near the planet’s poles (left) while calcium concentrates near the equator (right). Both elements originate on the planet, so the different distributions mean they get released in different ways.**

**Ice at the poles? Observations of Mercury’s surface show areas near the poles that reflect high amounts of radar signals (shown in red) beamed from Earth. The large red area near the top of this image corresponds to the planet’s north pole. Scientists think the reflective substance is water ice; MESSENGER should reveal whether they are right.**

**The massive Caloris impact basin, which measures about 900 miles (1,500 kilometers) across, ranks among the largest in the solar system. It is the circular yellow-orange feature that fills much of this image. Scientists think the bright orange spots near the rim are volcanic features.**

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**A long cliff runs diagonally across this image from top left to lower right. This cliff (scientists call such features “scarp”) cuts across a much older crater just above center. Mercury’s numerous impact craters on its surface indicate that the planet has experienced a large number of impacts over its 4.5 billion-year history.**

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**The double-ring basin Rachmaninoff below the center of this image has a smooth inner ring that suggests magma oozed from below to fill the impact site. The bright yellow area at top right sits at the center of a rimless depression that may have been an explosive volcanic vent.**