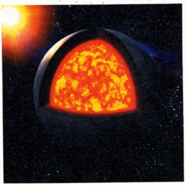
Mercury remains one of the most mysterious bodies in the Solar System, but **Sean C. Solomon** has plans to change all that

Return to the iron planet

Illustrations: Peter Crowther



'What manner of heat or violence smelted Mercury from the ore of the early Solar System?'

IT IS A PLANET where sunrise to sunset is an entire year. The Sun can be 11 times brighter than it is in Earth's sky. With almost no atmosphere, the planet's equatorial surface bakes at a sizzling 450 °C near noon, but cools to below –170 °C late at night. The landscape, after billions of years of explosive impacts by comets and asteroids, is scarred and lifeless. The floors of the craters nearest the planet's poles, in permanent shadow, are deep freezes that may hold ice deposited by aeons of cometary collisions. And every 116 days a prominent blue dot appears at its brightest in the ink-black sky.

This alien world is Mercury, the innermost planet of our Solar System, and one known to the astronomers of ancient civilisations as the morning and evening star that darted most rapidly across the heavens. Mercury is the Roman counterpart to Greek Hermes, the messenger of the gods of Olympus.

Despite the fact that Mercury is sometimes the closest planet to Earth, we know less about it than we do about any of the others except Pluto. It has been visited by only one spacecraft, Mariner 10, which made three flybys in 1974-75. But in July last year, NASA approved a mission called Mercury Surface, Space Environment, Geochemistry and Ranging—or Messenger. The projected cost is $286 million. And in September 2009, it should become the first spacecraft ever to orbit Mercury.

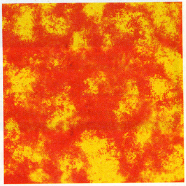
Messenger will reveal the hidden geology of the half of Mercury never before imaged at close range, probe the details of its mysterious magnetic field, and analyse its tenuous atmosphere. But above all, Messenger will try to discover what manner of heat or violence smelted the iron planet from the crude ore of the early Solar System.

Any spacecraft launched headlong towards Mercury would be accelerated by the Sun's gravity and fly past so fast—at around 10 kilometres a second or more — that no existing propulsion system could stop it. So Messenger will follow a more roundabout route, using the gravity of the planets to adjust its trajectory and slow down. It will take off in 2004 and then fly by the Earth once, Venus twice and Mercury twice before going into Mercury orbit. Even then, Messenger will have to decelerate by 1·6 kilometres per second. At launch, more than 60 per cent of its mass will be fuel, primarily for this orbit-insertion burn.

So every other component must be trimmed to its lowest possible mass. Two small phased-array antennas replace the usual big dish for communicating with Earth, and Messenger's seven miniaturised instruments and their electronics will weigh only 32 kilograms. Instead of heavy, complicated refrigerators, a thermal shade made of ceramic cloth will shield these instruments from the heat of the Sun. And to protect them from the bright sunlit face of Mercury, the designers chose an elliptical orbit that takes the spacecraft far away from the planet, allowing it to cool down.

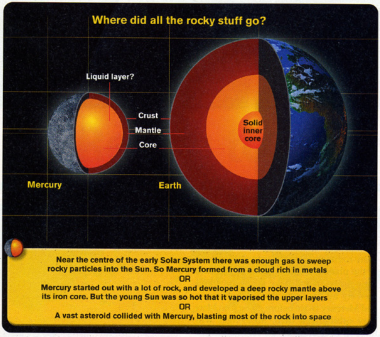
What do we already know about this enigmatic planet? The most crucial single fact is that Mercury is remarkably dense. At 5430 kilograms per cubic metre, it is denser than Venus and nearly as dense as the Earth. That is all the more remarkable because, whereas the interiors of Venus and Earth are highly compressed by the weight of overlying material, Mercury is too small for that to happen. The most likely explanation is that about two-thirds of the mass of the planet is iron—a ratio of metal to rock more than twice that of Earth. If most of the metal has sunk into the centre, the iron core has a radius 75 per cent as large as the planet's.

Why is Mercury made mostly of iron?



The inner planets, we believe, formed as a cloud of gas and dust surrounding the Sun coalesced and condensed. Rocky silicate particles and metals stuck together, gradually forming larger lumps of matter called planetesimals, which in turn collided and merged to form the planets. Most simulations of this process fail to produce an iron-rich planet like Mercury. Somehow, Mercury must have lost most of its silicates. There are three possible ways for this to have happened. It could be that in the inner part of the solar nebula, where Mercury formed, thick gas dragged the lighter silicate particles into the Sun, leaving dense iron-rich particles behind. Another idea is that the young Sun was so dazzlingly bright that its radiation vaporised most of Mercury's outer silicate layers. Or did some huge body hit the embryonic planet, blasting most of the rock into space? In short, the silicates could have been sifted, seared or smashed away.

Whatever happened to Mercury must also have affected the other inner planets, because they all formed at about the same time and by similar processes. We know that all four inner planets have different compositions. Some of these differences



'The outer shell of the planet could be a giant permanent magnet that retains an ancient field'

may be due to the random nature of accretion, particularly the final phases when Mercury-sized and even Mars-sized objects were hitting the larger planets. Others may be a function of distance from the Sun. If Mercury's silicates were sifted away, for instance, then such sorting should have had a smaller but perhaps important effect on the ratio of metal to rock in the other planets.

Fortunately, each hypothesis for Mercury's high iron content predicts a different composition for the planet's rock. If the impact model is right, there should be low levels of elements such as aluminium and calcium that tend to concentrate in planetary crusts, as these outer layers of the planet would have been blasted away. The sorting model implies that the rock-forming elements should be in proportions expected for solar material in the planet-forming nebula at Mercury's distance from the Sun. The vaporisation model predicts that there should be lower concentrations of volatile elements, which have low boiling points.

Messenger will aim a battery of instruments at this problem. Three of them will analyse gamma rays, neutrons and X-rays emitted by different elements on the planet's surface. Another spectrometer will look at visible and near-infrared wavelengths to map the distribution of different minerals.

We already have one tantalising clue to this puzzle. In 1985, Andrew Potter of NASA's Johnson Space Center in Houston and Thomas Morgan, then of Southwestern University in Georgetown, Texas, detected the characteristic emission lines of sodium in Mercury's atmosphere, using Earth-based telescopes. A year later, they found potassium, too. This result might seem to kill off the vaporisation theory—such volatile elements would have been eradicated if the Sun was bright enough to boil off most of the planet's rock. But it has a lifeline: the sodium and potassium we see might have been brought in by meteorites over the past few billion years. Messenger will be able to concentrate its gaze on recent craters, where deeper crust is newly exposed, in order to settle whether the vaporisation theory can work.

Mercury's huge iron core is involved in another mystery. When Mariner 10 flew by Mercury, the biggest surprise was finding a magnetic field—one that is strong enough to generate an Earth-like magnetosphere that largely shields the planet from the solar wind. Such strong fields are not the norm in the inner Solar System: Venus doesn't have one, and neither does our Moon. Mars did have a magnetic field, but it turned off less than half a billion years after the planet formed. So why does Mercury retain a strong field?

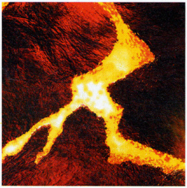
Earth's magnetism is produced by dynamo action in a liquid metal outer core. And indeed, Mercury's core must have been molten once. Otherwise it is hard to explain the planet's peculiar spin rate. In 1965, astronomers discovered with ground-based radar that the planet rotates in 59 Earth days, precisely two thirds of its year—and it is because of this peculiar resonance that the solar day on Mercury, the time between successive appearances of the Sun at a given position in the planet's sky, lasts for two Mercury years. Mercury's spin was probably slowed to this rate by tides raised by the Sun, a process that is much easier to explain if Mercury had a fluid core at the time.

Frozen core

But being smaller than Earth, Mercury must have cooled faster, which leads many planetary geologists to think that its core should have frozen solid by now. Perhaps a high concentration of a light element such as sulphur lowers the melting point of the iron, permitting a thin outer shell of metal to remain molten. Dynamo generation in such a thin shell might produce a magnetic field, but that process is not well understood.

To find out the origin of Mercury's field, Messenger will measure the field's shape. If Mercury's magnetism is caused by a dynamo in a mostly liquid core, as on Earth, then the field should be roughly a simple dipole. If the field geometry is messier, then the liquid fraction of the core may be much smaller than on Earth, or another mechanism may be at work—perhaps

'Water ice trapped in shadowed craters could provide a vital resource for future explorers'



thermoelectric effects at the core-mantle boundary. It is even possible that the outer rocky shell of the planet is a giant permanent magnet that retains an ancient field, set up when the core was liquid.

Messenger has a second way of testing for a fluid outer core. The Sun's tides still affect the planet's spin rate, making it vary slightly throughout the year. If there is a fluid outer core, this variation will be about twice as large as it will be if the core is entirely solid. By measuring the shape of the planet with an altimeter over several Mercury years, the spin rate and its variation can be determined precisely enough to distinguish between these possibilities.

A hot planetary interior might also have produced volcanic activity. Mariner's images covered only about 45 per cent of the surface at a resolution of about 1 kilometre, which is too coarse to see volcanic flow fronts. So Messenger's third task is to determine Mercury's geological history in much greater detail—and not just for the portion seen by Mariner.

What Mariner did see was a landscape dominated by craters—so many that the imaging team, led by Bruce Murray of Caltech, argued that the surface must date from the first third of Solar System history. In other words, no major geological activity has occurred for the past 3 billion years. The surface of Mercury viewed by Mariner is a dead landscape like the Moon, not an active one like the Earth.

Shrinking surface

Cooling of a planet can influence the geological history in other ways. Cutting across every type of terrain, Mariner 10 found strange linear features called lobate scarps. To Robert Strom of the University of Arizona's Lunar and Planetary Laboratory, and others on the imaging team, these scarps looked like compressive faults, formed by shrinking and cracking of the surface as the interior of the planet cooled. Messenger's high-resolution mapping should confirm or refute this idea.

More importantly, Messenger will map the 55 per cent of the surface never before seen by a spacecraft—one of the last uncharted surfaces in the Solar System. There could be big surprises from this unseen hemisphere. Radar images obtained by John Harmon of Arecibo Observatory in Puerto Rico, although coarse compared with spacecraft images, show features that resemble the youngest volcanoes on Mars and Venus. Mercury could be like Mars, with one ancient, cratered hemisphere and one hemisphere of volcanoes and lava plains shaped by volcanic eruptions or disruption of the crust, perhaps as recently as a few hundred million years ago.

A by-product of imaging the planet's unseen face will be the discovery of hundreds of geological features, which will all have to be named. The International Astronomical Union has decreed that Mercury's features should honour figures from literature and the fine arts. There are already craters named after Monet, Mozart and Shakespeare, but Messenger will provide opportunities for many others. After 2009, Mercury maps might bear the names Picasso, Prokofiev and Faulkner.

However romantic the names, Mercury's landscape will remain hostile to humans and their machinery. But perhaps not all of it. In 1991, two groups of astronomers detected radar-bright deposits at Mercury's poles, concentrated in the floors of large impact craters. The deposits polarise radar in the same way that water ice does on Mars and the Galilean satellites of Jupiter. If water ice really is trapped in the permanently shadowed crater floors, it could provide a vital resource to future explorers. But some astronomers think that the signals could come from sulphur, not water. Messenger will adjudicate, using neutron and gamma-ray spectrometers to look for emission from hydrogen and sulphur.

The new mission will deepen our understanding not only of the solar family's innermost outpost, but of all Earth-like planets. And there may be many other Mercurys out there, beyond our Solar System. We cannot yet detect a planet as small as Mercury, or even the Earth, around another star, but more than half of the giant planets found so far are at least as close to their parent star as Mercury is to the Sun. Although a hellish extreme from the perspective of our otherwise chilly Solar System, Mercury is in good extra-solar company. □

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Further reading: The messenger site is at **http://sd-www.jhuapl.edu/MESSENGER**

The New Solar System edited by J. Kelly Beatty, Carolyn Collins Petersen and Andrew L. Chaikin (Cambridge University Press, 1999)