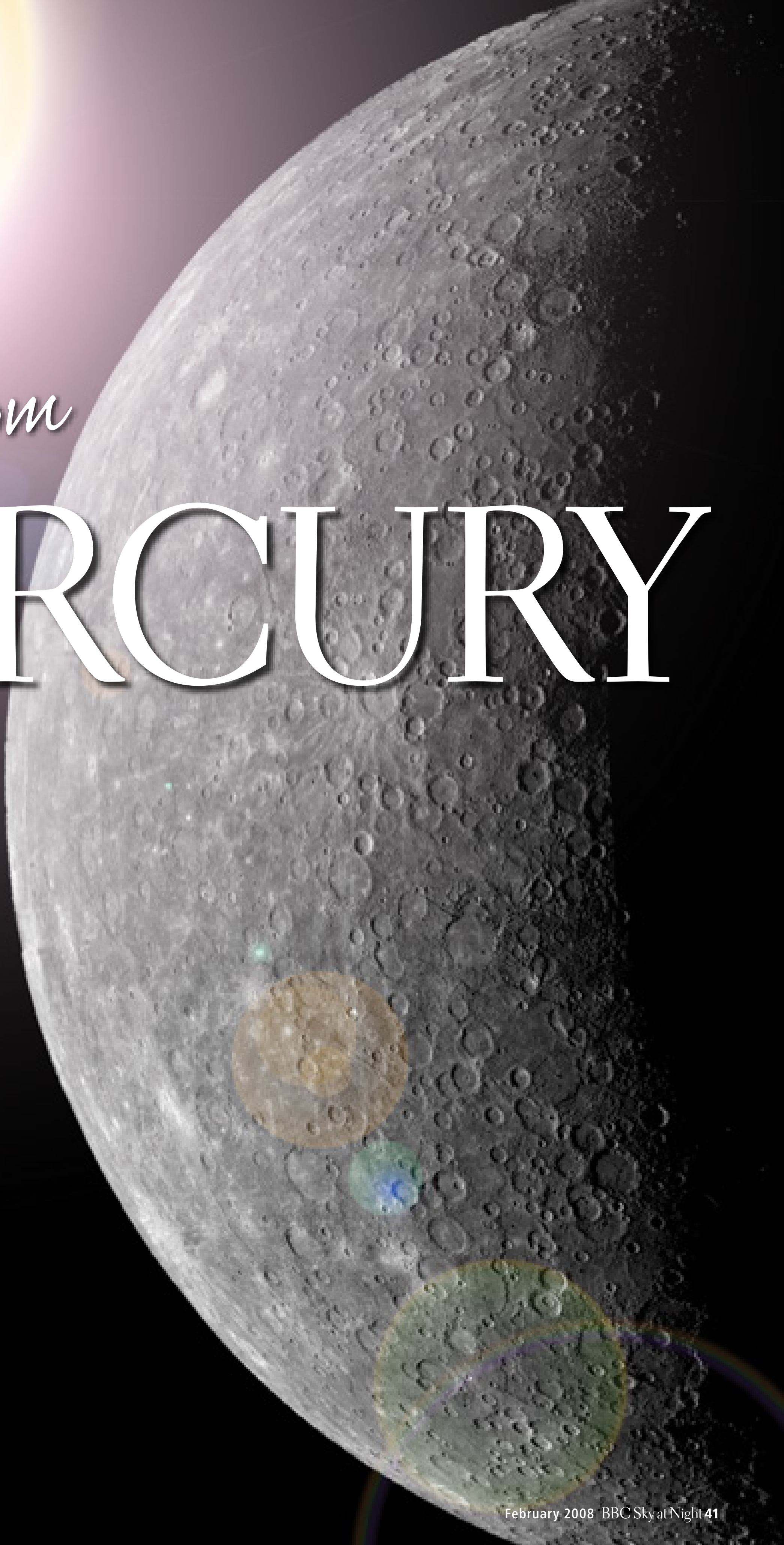


A message from

MERCURY

Little is known about the Sun's closest neighbour, but that's set to change as **David Rothery** discovers

On 14 January 2008, NASA's Messenger probe swung past the night side of Mercury at an altitude of only 200km (125 miles). By the time you read this article, you should have already seen the first images of the Sun's innermost planet since the Mariner 10 mission of 1974-5 and some of the first ever close-up images of Mercury's day side. Messenger will make two further flybys in October 2008 and September 2009 before being eased into orbit around Mercury on 18 March 2011. Systematic mapping will then begin, but ►

► the harvest of new information was due to start as soon as data from the first flyby had traversed the 1.08 million miles from Mercury to the Mission Operations Center, at the Johns Hopkins Applied Physics Laboratory.

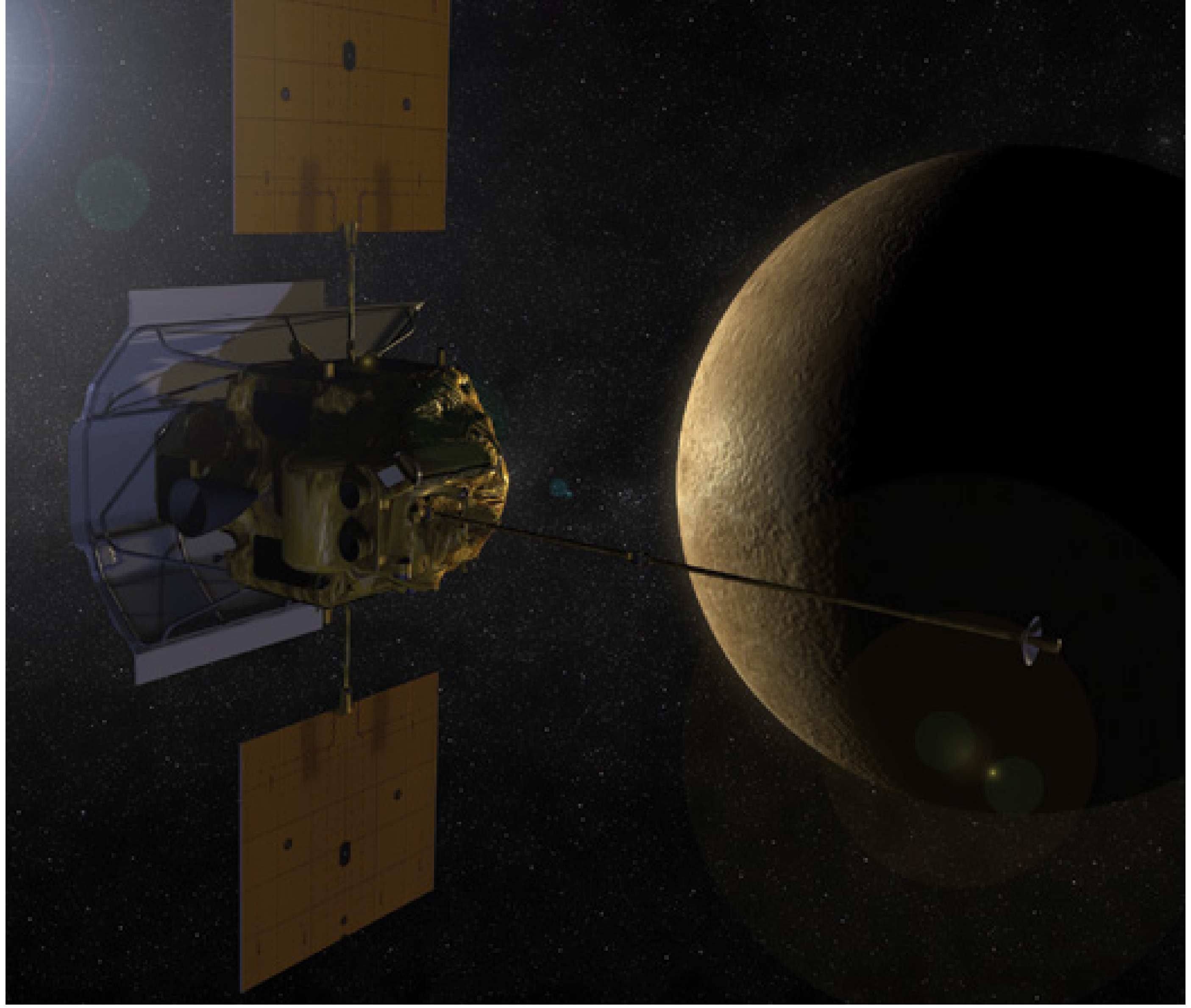
During the first flyby, Mercury was 32.5 million miles from the Sun, but its eccentric orbit carries it as far as 43.7 million miles and as close as 28.9 million miles. At such close range to the immense power of the Sun, Mercury's daytime surface temperature can reach a sweltering 450°C. To keep its sensitive electronics sufficiently cool, the 1.8m (6ft) wide Messenger spacecraft will take cover behind a 2.5m (8ft) sunshade of heat-resistant ceramic, and will only make a brief pass over Mercury's hottest terrain.

In the classical pantheon, Mercury was the messenger of the gods, and this is reflected by the craft's name, cumbersomely fabricated from MErcury Surface, Space Environment, GEochemistry and Ranging. Getting to Mercury isn't a problem, but you need an impossibly large fuel load to match velocities if you want to go into orbit around the planet upon arrival. Unless, that is, you take advantage of the 'free' change in velocity provided by carefully chosen gravity-assist flybys along the way. For this reason, Messenger, launched on 3 August 2004, made one gravity-assist encounter with Earth and then two with Venus, prior to its three with Mercury itself.

Viewed from Earth, Mercury is never more than 28° from the Sun in the sky. This means that when elongation occurs at perihelion – when Mercury appears furthest from the Sun in the sky but is closest to the Sun in its orbit – the separation is only 18°. Consequently, Mercury is an elusive object to see from your back garden. The best chance to see it from Europe in 2008 will be a few days before its favourable eastern (evening) elongation on 14 May.

Mercury can never be seen in a truly dark sky, so observations by ground-based telescopes have to be made in twilight through a large mass of air, or in daylight when Mercury is high in the sky and it is difficult to correct for the effects of light scattered in the atmosphere. The Hubble Space Telescope can't point at Mercury either, for fear of the Sun heating its tube and damaging the optics.

"Mercury's daytime surface temperature can reach a sweltering 450°C"

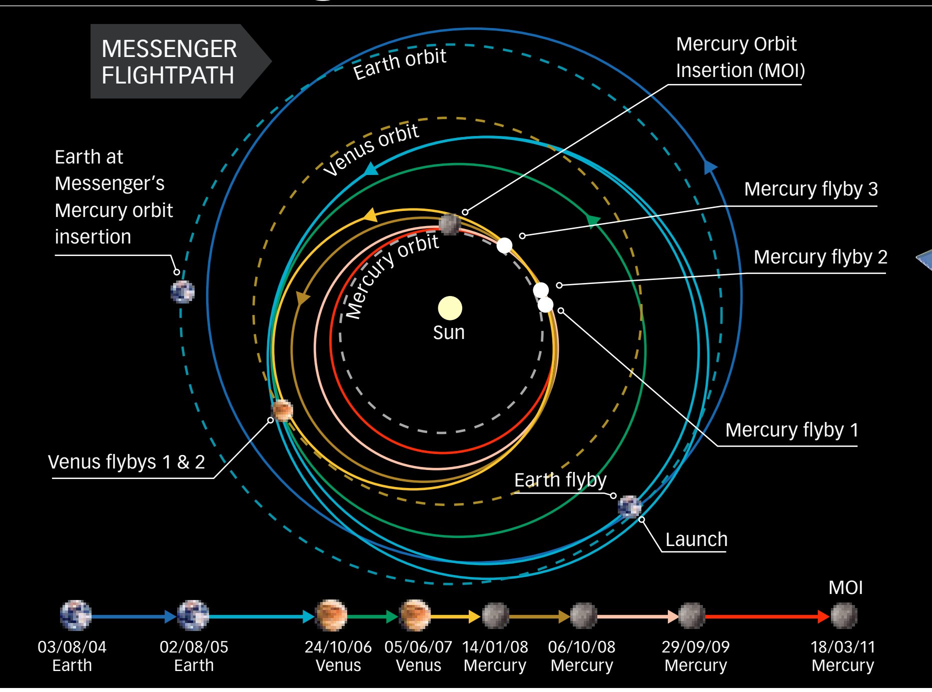


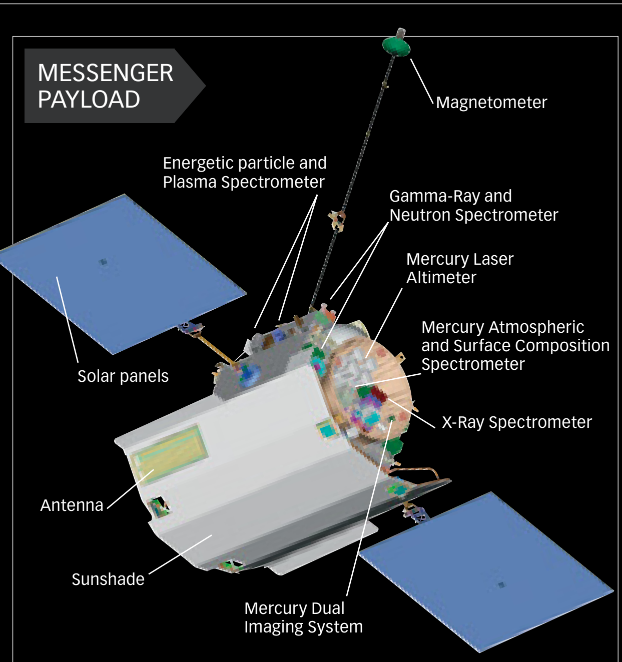
Mariner 10 mapped a little less than half of Mercury, and wasn't equipped to determine its surface composition, so the harvest of new knowledge from Messenger is expected to be immense. Not only will we learn about the rocky, Earth-like planet about which we know least (even Saturn's satellites are better known) we will also gain insights into the conditions experienced by the majority of known exoplanets. Like Mercury, these tend to be in very close orbits about their stars because of how they are discovered.

A world of mystery

The Messenger science team hopes to answer six key science questions. The first of these is why Mercury is so dense. The planet has almost the same density as the Earth, but this is a coincidence ►

Messenger in detail
The probe's intricate flightplan and payload

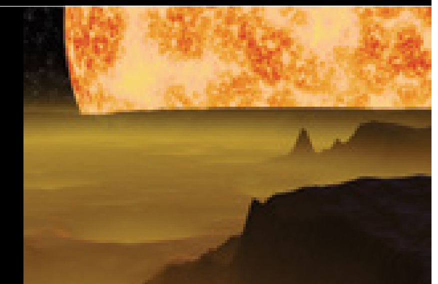


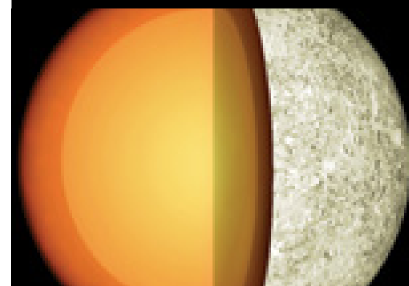


Messenger's journey to the innermost planet of the Solar System started in August 2004

Messenger's objectives
The NASA probe will study six key features of Mercury

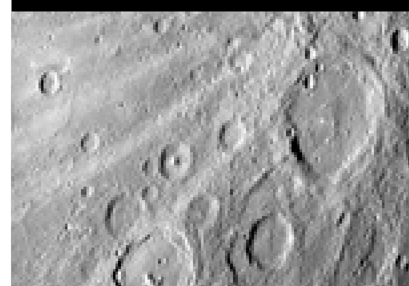
ATMOSPHERE ►
An ultraviolet spectrometer will measure atoms in the tenuous atmosphere. Combined with the distribution and energy of electrons and ions measured by Messenger's Energetic Particle and Plasma Spectrometer, this should give us a better understanding of the cause of the slow leakage of atoms into space.





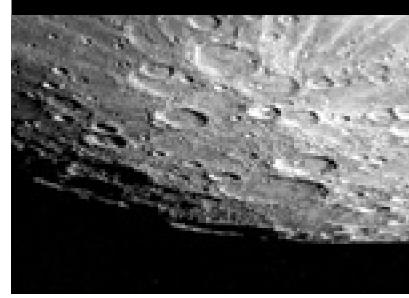
◄ CORE STRUCTURE
Mercury's internal density distribution will be studied by tracking tiny deviations of the Messenger craft in its orbit. Data collected by Messenger's laser altimeter will also determine the distortion in Mercury's shape resulting from the tidal pull of the Sun. This will be greater if the outer core is liquid, like Earth's.

DENSITY ►
We already know that Mercury has a strangely high density. The precise tracking of Messenger's orbit will reveal any local variations. Studies of the planet's geology, core and magnetic field will combine to help answer the question of how the high bulk density came about.



◄ GEOLOGY
Images showing features as small as 20m (65ft) across will reveal detailed landforms. Studies of the near infrared reflected spectrum will enable the distribution of the minerals in surface rocks to be mapped. X-rays and gamma-rays emitted by the surface will tell us the abundance of major elements.

MAGNETIC FIELD ►
Messenger's orbit will enable Mercury's magnetic field to be mapped in great detail. This should reveal if the field is internally generated, which could only occur if there is a convecting, electrically conducting zone in the core. Messenger will also measure how charged solar particles interact with the magnetic field.



◄ POLAR VOLATILES
Messenger's neutron and gamma-ray spectrometers may reveal the signature of hydrogen near the poles, which would imply the presence of ice in permanently shadowed regions. Also, its ultraviolet and plasma spectrometers may detect a faint whiff of hydroxyl or sulphur escaping from polar deposits.

Around 2km high, the escarpment known as Discovery Rupes clearly slices a path through craters

"It reflects radar pulses so strongly that it must have rather special properties consistent with water-ice or perhaps sulphur"

► masking a fundamental mismatch. Because it is a much smaller body, with only 5.5 per cent of the Earth's mass, the degree of internal compression within Mercury must be much less than inside the Earth. If Mercury were made of the same mixture as the Earth, then its density should be significantly less than Earth's. We know that Mercury's surface is a blanket of impact-fractured rock – or regolith – covering the bedrock. Minerals such as feldspar (common in the lunar highlands) and a general deficiency of iron are suggested by Earth-based spectroscopy, but its rocky exterior must hide a dense, iron-rich core that is exceptionally large relative to the planet's size.

There are various theories to account for this. One suggests that there was insufficient oxidation in the region of the solar nebula where Mercury formed, so that most of the iron ended up as metal, rather than being incorporated into silicate minerals. Another suggests that silicate dust was preferentially removed from this region by heat or radiation pressure. A third suggests that the young Mercury was initially more Earth-like, but was stripped of most of its rocky outer reaches when another planetary embryo slammed into it.

Measuring the elements and minerals on Mercury's surface is a vital first step to unravelling this mystery, but it will not be easy. We also need to understand the nature and origin of the planet's crust. Some parts of it could be 'primary crust' formed of crystals that rose to the surface of a global 'magma ocean' resulting from heat caused by a collision with another body. But other areas could be 'secondary crust' consisting of lava flows extracted from the mantle that partially melted.

Hot history

These two processes would produce a crust of significantly different composition even from the same starting material, so it is vital to know which we are dealing with before trying to infer the composition of the underlying mantle. This brings us to the second area Messenger will investigate: Mercury's geologic history. The craft will reveal features as small as 20m (65ft) across in the best-imaged regions and provide spectroscopic information on the composition. This should tell us how much volcanic activity has occurred in Mercury's history – a question not settled by Mariner 10 – and enable better mapping of tectonic features. These include Mercury's distinctive 'lobate scarps' (see 'Mercury's troubled past' on the next page).

Messenger will also look at the structure of Mercury's core. Is part of it really liquid, as suggested by the surprising magnetic field discovered by Mariner 10? Analysis of Earth-based radar measurements of Mercury's libration (its 'wobble'), published earlier this year, indicates that the crust and mantle are indeed de-coupled from the inner core by a fluid outer core. Messenger should provide fuller, and more convincing evidence.

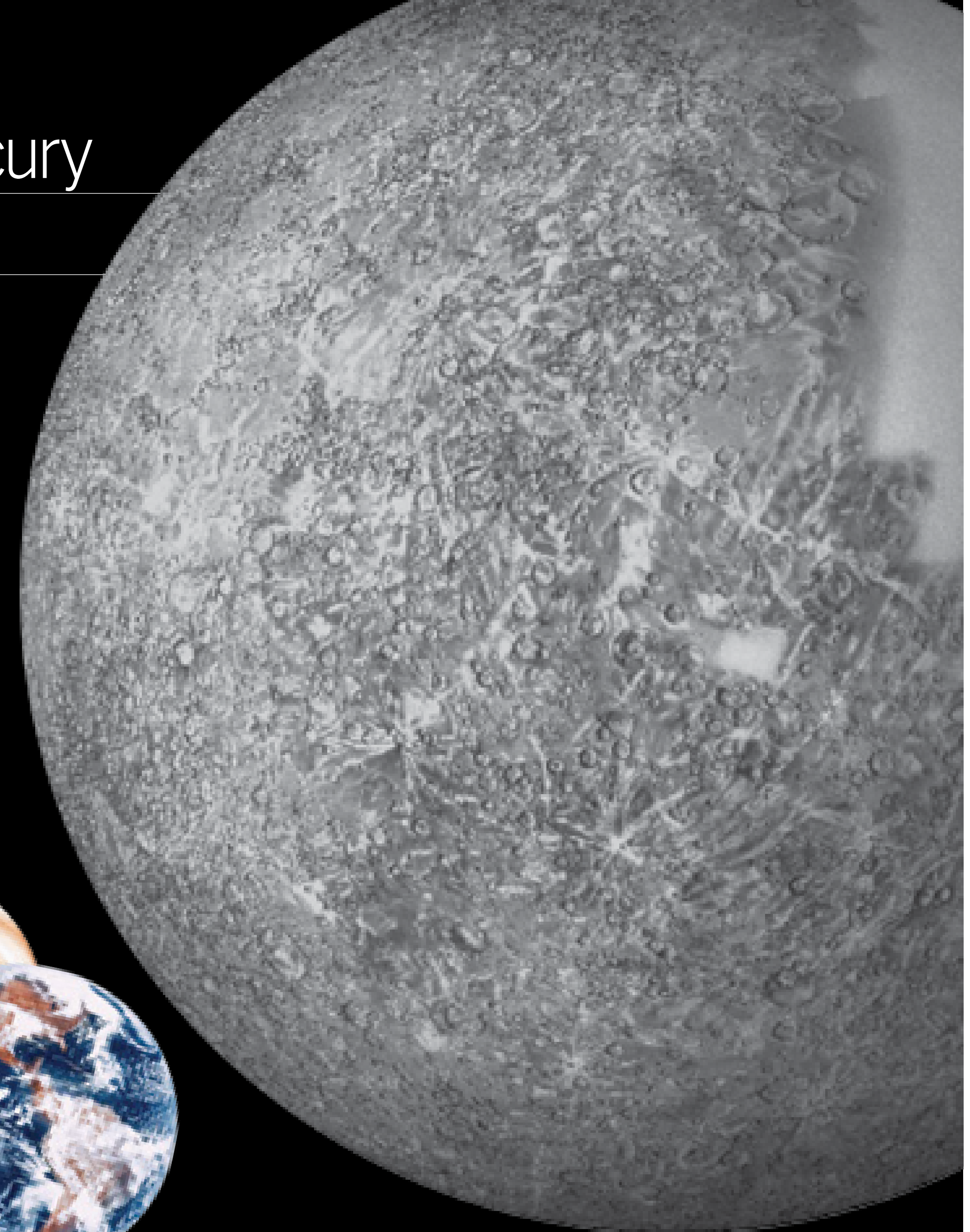
The nature of Mercury's core will contribute to Messenger's studies of its magnetic field. By mapping it from orbit over at least four Mercury years, Messenger will determine whether all of the field is generated internally in a convecting, electrically conducting core, or whether the surface rocks just happen to be magnetic. Just as importantly, the spacecraft will be able to observe how Mercury's field interacts with the solar magnetic field and with charged particles streaming out from the Sun. From time to time, some of these are expected to get through to the surface of the planet. Knowing how often, and where, this happens is important for understanding both the surface and the atmosphere.

Unidentified Mercury matter

Strange material revealed by radar in permanently shadowed regions of craters near Mercury's poles has baffled scientists. Another of Messenger's missions is to work out what this stuff is. It reflects radar pulses so strongly that it must have rather special properties consistent with water-ice or perhaps sulphur. Ice supplied by cometary impacts could perhaps survive in these polar 'cold traps' (as has also been suggested might have happened on the Moon). Alternatively, water or sulphur could have escaped from the interior because of volcanic activity.

Messenger's final task will be to study the precise nature of the atmosphere. This is more correctly called its exosphere because it is so diffuse that atoms within it are more likely to escape or hit the surface than to collide with another atom. The total pressure ►

All about Mercury

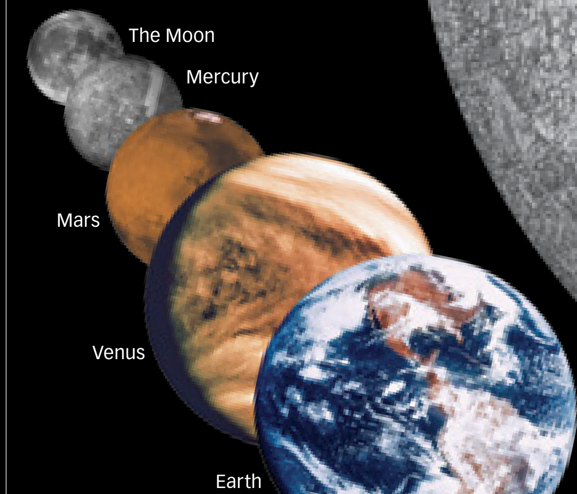


SURFACE FEATURES

At first glance, Mercury looks deceptively like the Moon. Craters abound, recording impacts by asteroids and comets during the past four billion years, although nowhere is it as heavily cratered as the lunar highlands. Mercury's 'smooth plains' are not so obviously volcanic as the lunar maria, nor do they stand out with such a clear contrast.

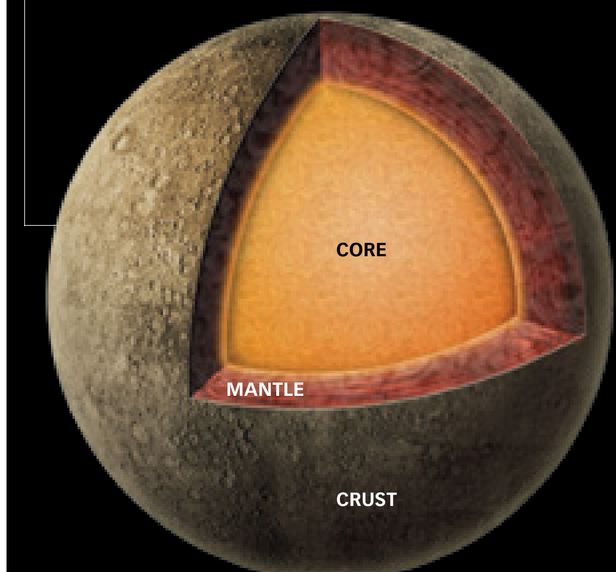
INNER PLANETS' RELATIVE SIZES

Mercury is the smallest rocky planet. Its diameter is only 40 per cent larger than the Moon's, but it has four and a half times the Moon's mass.



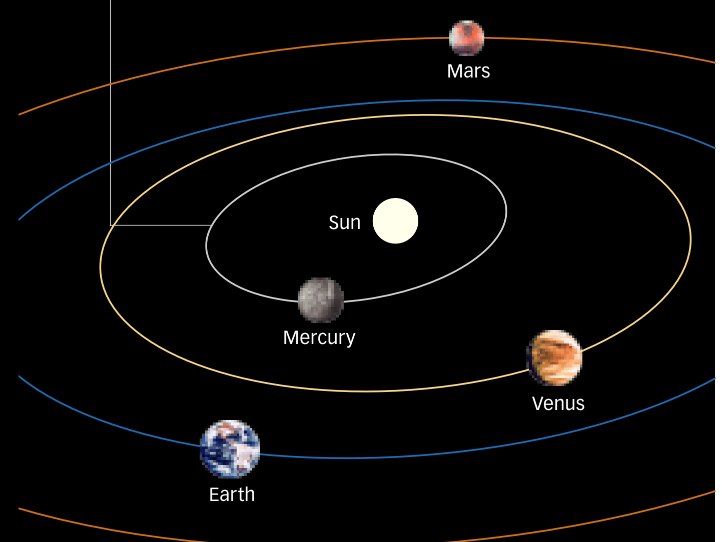
INTERIOR STRUCTURE

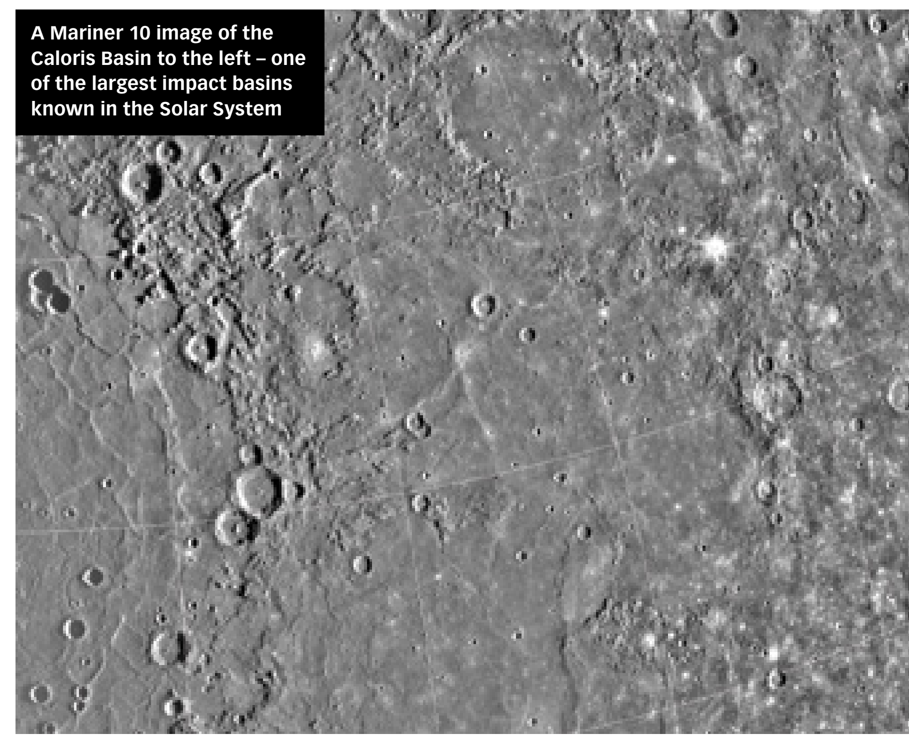
Mercury's iron core occupies about 42 per cent of its volume, and reaches within about 640km of the surface (for Earth the values are 16 per cent and 2,900km). The silicate (rocky) mantle above the core is likely to be capped by a differentiated rocky crust a few tens of kilometres thick.



ORBIT

Mercury has the most elliptical orbit of any planet, taking only 88 Earth-days to complete. Tidal forces make it rotate exactly three times for every two orbits. This strangely means that a day on Mercury is the length of two Mercury years.





A Mariner 10 image of the Caloris Basin to the left – one of the largest impact basins known in the Solar System

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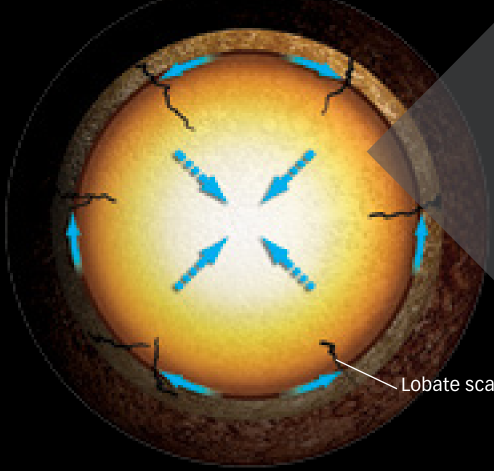
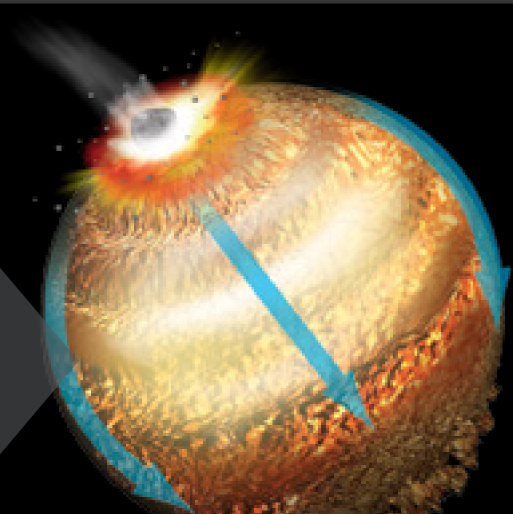
Mercury's troubled past



SHRINKING PLANET

Mercury's most distinctive features are 'lobate scarps' up to 500km (300 miles) long. These are kilometre-high steps in the terrain that wriggle across the landscape, just like the Mariner 10 image of Discovery Rupes on page 44. They appear to be 'thrust faults', where the ground on one side has been pushed over the other, recording a 3.8 billion-year-old episode of contraction when Mercury's diameter decreased by 1-2 km, possibly because of cooling and contraction of the core.



CALORIS BASIN FORMATION

Mercury has several multi-ringed impact basins. The 1,300km (800-mile) diameter Caloris Basin, only half seen by Mariner 10, is the largest and best preserved. It was made when an approximately 50km (30 mile) asteroid hit the planet at several tens of kilometres per second. Shockwaves from the impact formed the basin and converged on the opposite side of the globe to disrupt the surface into a chaotic array of blocky hills. Much of the basin is occupied by smooth plains, which may be lava flows. See an image of the basin on p45.

Ancient Mariner

Mariner 10 sent back a wealth of data

Mariner 10 had the most ambitious flight-plan of its era. It was the last of a family of Mariners previously sent to Mars and Venus, and was launched on 3 November 1973. It passed Venus on a gravity assist trajectory three months later and flew past Mercury at a range of 703km (430 miles) on 29 March 1974.

This nudged its trajectory into a solar orbit with a period exactly twice that of Mercury, enabling the craft to make repeat visits in September 1974 and March 1975 before it ran out of attitude control gas and lost the ability to keep its antenna pointed towards Earth.

It approached Mercury from the same direction each time, so only about 45 per cent of the surface was imaged, mostly at about 1km per pixel. Until Messenger arrives, these are the only close-up images of Mercury we have. The biggest surprise of the mission was the discovery that, unlike Mars and Venus, Mercury has a magnetic field, taken as evidence for a partly molten core, like the Earth's.

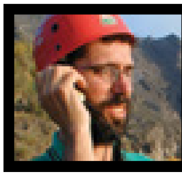
An image from Mariner 10 taken minutes after its closest approach

Mariner 10 was only able to map about 45 per cent of Mercury's disc

"Messenger probably won't fully answer these questions – no single mission ever could"

► is a million-millionths of the Earth's atmospheric pressure. Currently we know of six components there: helium (the most abundant) and hydrogen that probably come mostly from the solar wind; and sodium, potassium, calcium and oxygen that could be given off from surface rocks when they are bombarded by meteorites and charged particles from the Sun. Some of the hydrogen and oxygen could also originate from the mysterious polar deposits. To understand what is going on, we need to determine what other components there are, and how they are distributed over the planet and over time.

Messenger probably won't fully answer these questions – no single mission ever could – but further help is at hand. A joint European-Japanese mission to Mercury called BepiColombo will be launched in 2013, for arrival into orbit in 2019. This will be both bigger and better than Messenger, carrying more instruments and separating into two spacecraft upon arrival. A European one in a lower, more circular orbit will concentrate on the planet itself, while a Japanese craft in a higher, more eccentric, orbit will concentrate on mapping the magnetic field in three dimensions. Until then, Mercury should reveal some of its secrets to a well-equipped Messenger probe. It will keep scientists busy deciphering this hot planet's many secrets for years to come. ✪



Dr David Rothery will be appearing on February's *Sky at Night* TV programme to discuss the Messenger mission

NASA/JPL/NORTHWESTERN UNIVERSITY X 3, KEY EVENTS ILLUSTRATIONS BY PAUL WOOTTON