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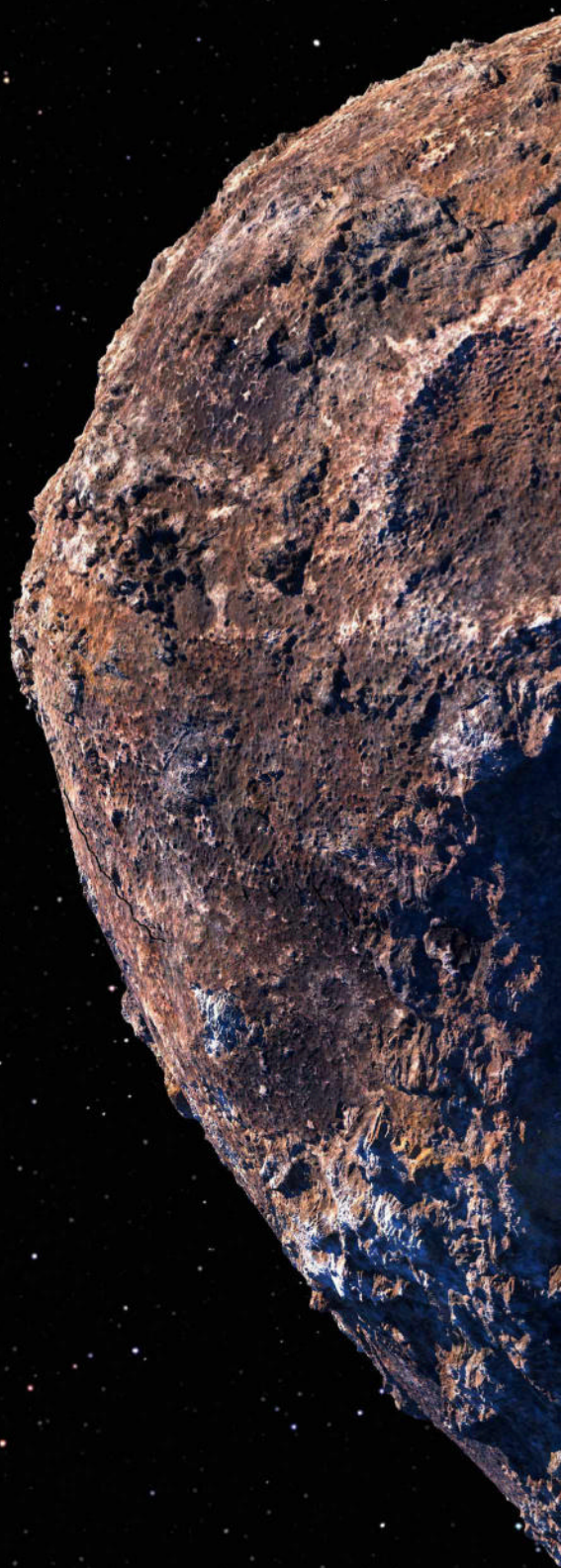
PSYCHE

Mission to a metal world

Govert Schilling explores the mystery of asteroid Psyche and how the mission to orbit it, launching this month, could unlock the secrets of the Solar System



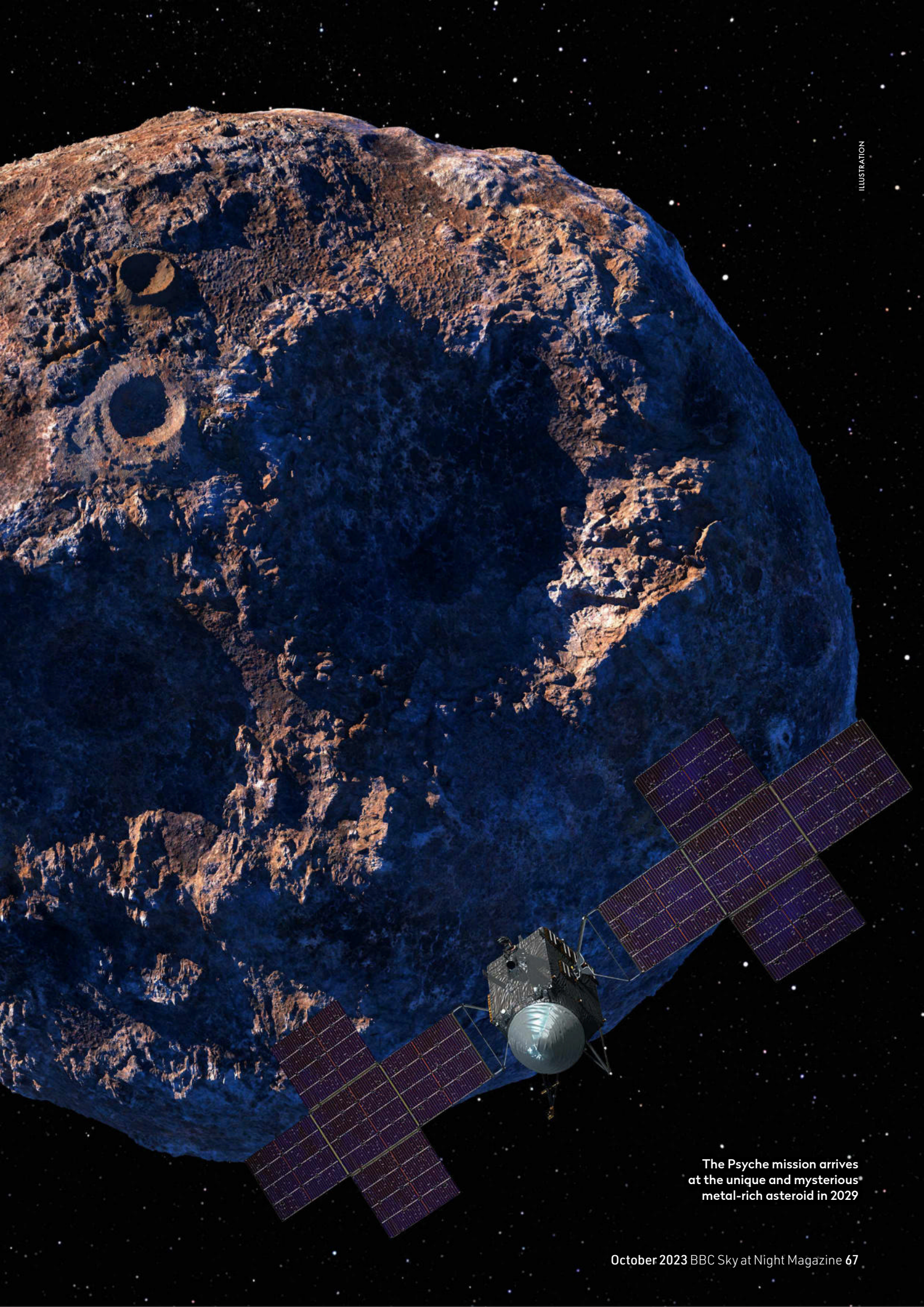
NASA/JPL-CALTECH/ASU

If the artist's impressions are anything to go by, we're in for spectacular images in August 2029, when NASA's Psyche spacecraft enters orbit around the asteroid with the same name. Psyche, slated for launch in early October, is the very first space mission to study an M-type (metallic) asteroid, and no one really knows what to expect. According to a number of recent studies, asteroid Psyche may sport volcanic 'lava' plains of pure iron or steep mountains of metal – something that has never before been seen in the Solar System.

One thing's for sure though: the Psyche mission (named after the asteroid, not the other way around!) will reveal the strange object's nature, composition and evolution, and shed further light on the origin of the Solar System. "It is our hope that Psyche teaches us about new and unexpected aspects of planet formation processes that have yet to be explored," says co-investigator Bill Bottke of the Southwest Research Institute in Boulder, Colorado. As for the asteroid itself, "we know it's metal-rich, but beyond that, its origin is an enigma."

Iron certain?

Psyche, named after the Greek goddess of the soul, was discovered 171 years ago in 1852, by Italian astronomer Annibale ▶

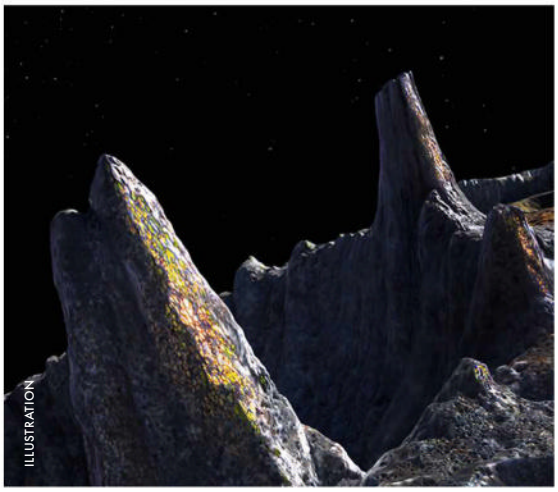


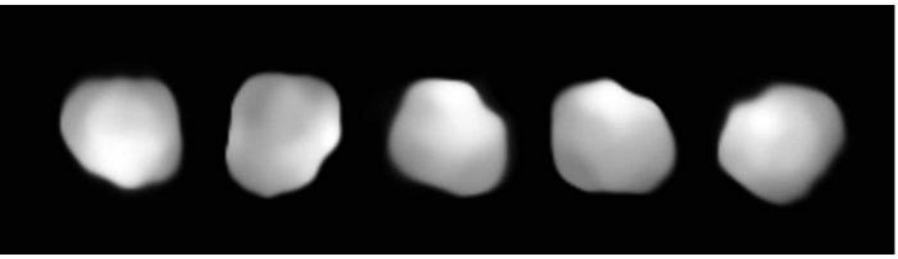
ILLUSTRATION

The Psyche mission arrives at the unique and mysterious metal-rich asteroid in 2029

◀ **Psyche could be the stripped-back metallic core left over from collisions in the early planet-forming phase of our Solar System or a remnant 'rubble pile' where metal is only scattered across the surface**

▼ **An artist's impression of Psyche's nickel-iron mountain peaks. Photos of the asteroid's true topography could be expected from August 2029**





▲ **Images taken by ESO's Very Large Telescope in 2018 gave us a sense of the asteroid's shape and size**

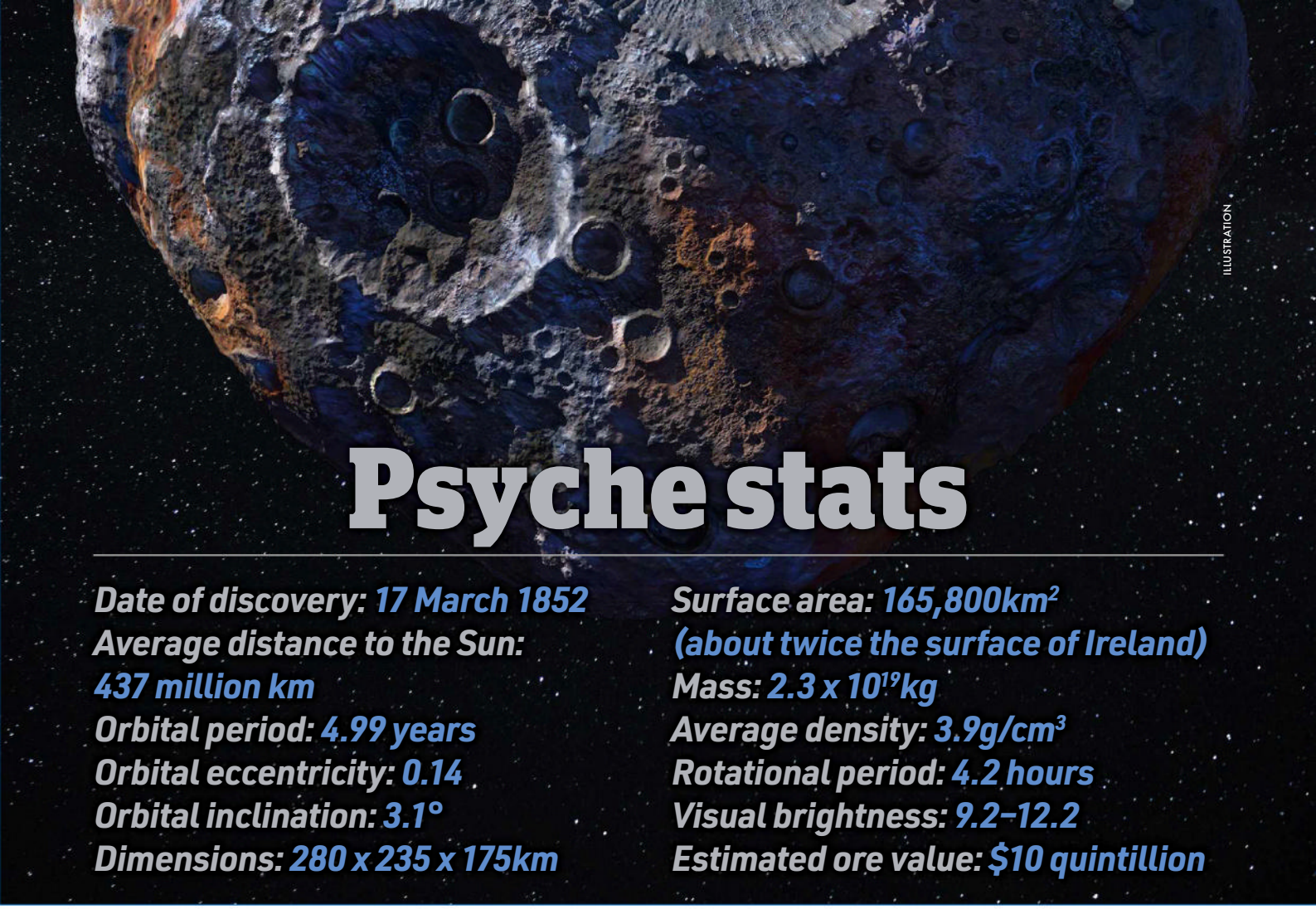
▶ de Gasparis. Back then, it was only the 16th asteroid known, and we now know it is among the 12 largest minor planets orbiting the Sun between Mars and Jupiter. With an average diameter of some 220 kilometres, Psyche contains about one per cent of the total mass of the entire asteroid belt. Moreover, spectroscopic studies and radar observations indicate its surface is very metal-rich. While astronomers have indeed discovered more of these M-type asteroids (including Lutetia, Kalliope and Kleopatra), Psyche is by far the largest and most massive one.

Astronomers have speculated that the large chunk of iron and nickel – if that is indeed what Psyche is – could be the exposed core of a larger proto-planet. During the smash-up and merging of smaller planetesimals (the building blocks of planets), the resulting larger bodies start out completely molten. Heavy metals sink to the core, while lighter rock floats to the top. Psyche may once have been such a 'differentiated' body. After it cooled down, a collision with another asteroid could have stripped the proto-planet of its rocky mantle, leaving a bare metal core.

While this scenario would provide a completely unique and unprecedented opportunity for scientists to study the core of a differentiated object, there are other possibilities as to the asteroid's origin. For example, if a differentiated body is completely shattered by a giant collision, part of the debris could reassemble into a huge 'rubble pile', with many metal-rich fragments ending up on the surface. Or maybe the iron on Psyche's surface is the result of a hypothesised geological process known as 'ferro-volcanism'. "The most important question we will answer is 'what is Psyche?'," says Lindy Elkins-Tanton of Arizona State University, principal investigator of the Psyche mission.

The main reason scientists started to doubt the exposed-core explanation is Psyche's relatively low density. The asteroid's dimensions are known from timing observations of stellar occultations and from high-resolution images obtained with the European Southern Observatory's Very Large Telescope in Chile. Meanwhile, studies of Psyche's gravitational influence on the orbits of other, much smaller asteroids, carried out by Finnish astronomer Lauri Siltala, have revealed the object's mass. From the known size and mass, Psyche's mean density turns out to be 3.9g per cubic centimetre – about half the value you would expect for a solid ball of metal.

The density measurements can mean two things. Either Psyche is mainly rock after all, with patches of iron on its surface – the 'lava' plains mentioned before – or the asteroid is a porous rubble pile, in



ILLUSTRATION

Psyche stats

Date of discovery: 17 March 1852
Average distance to the Sun: 437 million km
Orbital period: 4.99 years
Orbital eccentricity: 0.14
Orbital inclination: 3.1°
Dimensions: 280 x 235 x 175km
Surface area: 165,800km^2 (about twice the surface of Ireland)
Mass: 2.3 x 10^{19}kg
Average density: 3.9g/cm^3
Rotational period: 4.2 hours
Visual brightness: 9.2–12.2
Estimated ore value: $10 quintillion

which case the iron content could be substantially higher. In 2019, Francis Nimmo and Jacob Abrahams of the University of California Santa Cruz proposed the theory of (ancient) ferro-volcanism – a process you might expect when a newly formed and molten body is cooling down from the outside in. But a team led by David Cantillo of the University of Arizona carried out laboratory experiments indicating that Psyche's spectroscopic properties are best explained by a porous body containing up to 82.5 per cent metal, as they wrote in a 2021 paper.

Then there's the riddle about a possible link with iron meteorites. These are assumed to be fragments of disrupted differentiated bodies – in other words, bodies large enough to have ended up with an iron-nickel core. "The problem is that the asteroid belt shows limited evidence that so many bodies with cores actually disrupted," says Bottke. "This suggests that we are missing something important about Solar System evolution. Our investigation of Psyche may shed light on this mysterious issue."

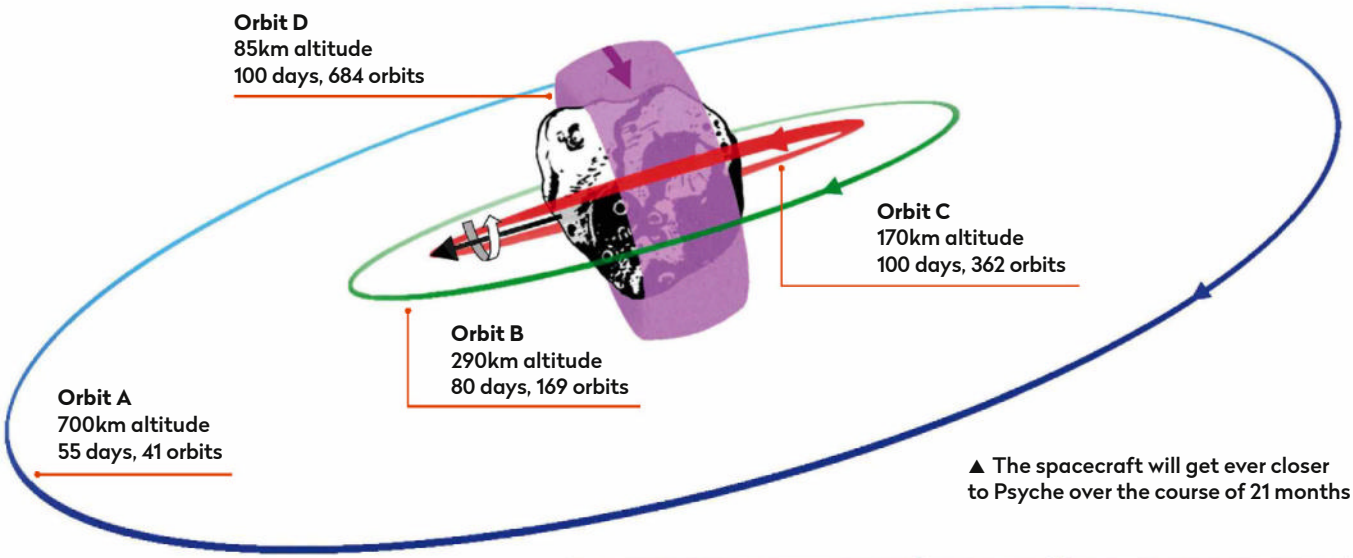
Long road to discovery

Given all of these mysteries, it's not surprising that Solar System researchers look forward to the launch of the Psyche mission on a SpaceX Falcon Heavy rocket from Kennedy Space Center in Florida. First proposed in 2014, Psyche was selected as a finalist in NASA's Discovery programme in 2015 and approved in January 2017 as the 14th entry in this series of focused, cost-effective science missions. A gravity assist fly-by of Mars in 2026, just 500 kilometres above the surface, will give the spacecraft enough energy to reach its target asteroid in the summer of 2029.

Psyche is a roughly cubic spacecraft about the size of a Smart car, built by Maxar Technologies. The mission is led by Arizona State University and will be operated by NASA's Jet Propulsion Laboratory in Pasadena. Two huge arrays of solar panels, with a total span of almost 25 metres and a surface area as large as a tennis court, will provide the power for the science instruments and for the spacecraft's solar electric propulsion thrusters, which are much more versatile than traditional chemical rocket engines.

> *"Psyche will orbit its namesake asteroid at four different altitudes above the enigmatic surface"*

Over a period of 21 months, Psyche will orbit its namesake asteroid at four different altitudes above the enigmatic surface. The first 55-day phase of the mission (orbit A, at 700 kilometres), focuses on general reconnaissance, mapping and magnetic field studies. Next, the craft enters orbit B (290 kilometres), to further study the asteroid's magnetic field and carry out topography measurements for a period of 80 days. Orbit C (170 kilometres, 100 days) will mainly be used to precisely map the asteroid's gravitational field, providing information about ▶



▲ The spacecraft will get ever closer to Psyche over the course of 21 months

▶ its interior structure. Finally, Psyche will lower itself to an altitude of a mere 85 kilometres (orbit D, also 100 days) to determine the chemical composition of the asteroid's surface.

Up close and personal

The mission's multi-spectral imager – basically two identical cameras with a suite of filters – is going to provide high-resolution images of Psyche's surface, and will certainly make the NASA artists' impressions obsolete, although everyone is curious about how realistic they will turn out to have been. A 2-metre boom carries a set of magnetometers, as well as a gamma-ray and neutron spectrometer, which will measure the abundances of various chemical elements on the asteroid's surface. Precise timing of the radio communication with the spacecraft – through its 2-metre-diameter antenna – enables mapping of Psyche's gravitational field.

Apart from its main science payload, with a total mass of just 30kg, the Psyche mission is also unprecedented in that it is tasked with testing a new method of spacecraft communication, using near-infrared lasers instead of radio waves. Known as Deep Space Optical Communications (DSOC), this technology demonstration project promises to achieve a substantially higher data rate. The laser signals from the craft will be collected by

▲ NASA engineers work on Psyche's innovative solar electric propulsion thrusters

NASA/JPL-CALTECH X 2, STOCKTREK IMAGES/ISTOCK/GETTY IMAGES, MEL STOUTSENBERGER/ALAMY STOCK PHOTO, NASA/JPL-CALTECH/UCLA/MPS/DLR/IDA X 2

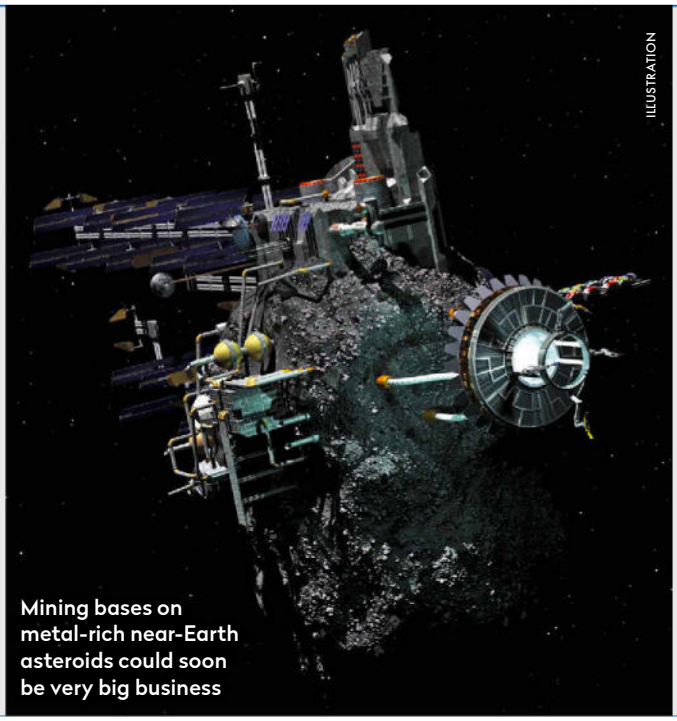
A cosmic colliery?

Some argue that asteroids like Psyche could be mined for their valuable metals

Metal-rich asteroids like Psyche are scientifically interesting, but they may also have large economic value. According to some estimates, Psyche could well contain a staggering 10 quintillion dollars' worth of iron, nickel and other precious metals. But even if this were true, would humans actually be able to extract such metals and return them to Earth?

"The potential of asteroid mining has made entrepreneurs excited around the world," says Bill Bottke (Southwest Research Institute). But, he adds, "asteroid mining is hard and Psyche is far away. It may be a long time before the world suggested by *The Expanse* TV show becomes a reality. When that day arrives, though, Psyche would make an excellent target, depending on what we want to do with its metals."

Other M-type asteroids, like the near-Earth objects 1986 DA and 2016 ED85, are much smaller but also much easier (and less costly) to exploit. Small-scale asteroid mining may well become a reality before the end of this century.



ILLUSTRATION

Mining bases on metal-rich near-Earth asteroids could soon be very big business

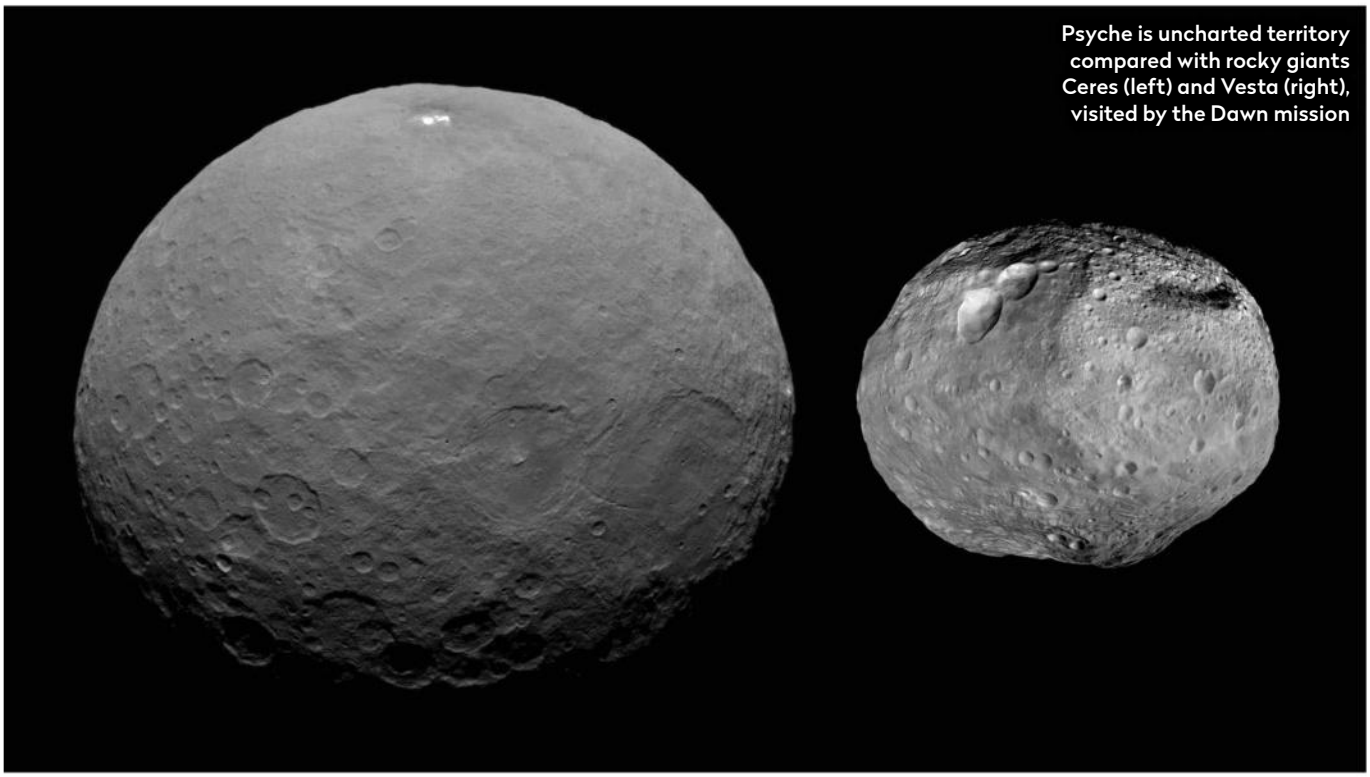
▲ **The 200-inch (5-metre) Hale Telescope will receive the craft's communications via laser**

the venerable 5-metre Hale Telescope at Palomar Mountain in California. Engineers expect to use this form of laser communication more often in future missions to Mars.

Psyche is a vitally important mission in the exploration of our Solar System, and is more or less comparable to NASA's Dawn mission, which orbited the two largest main belt asteroids Ceres and Vesta between 2011 and 2018. "But this mission differs from Dawn in the sense that Psyche is a different kind of object than has been visited thus far," says Bottke. While Psyche (like Ceres and Vesta) is likely to be a primordial object, Bottke emphasises that very little is known about the metal-rich asteroid with much certainty. "For example," he says, "it is still an open question whether Psyche formed in the inner or outer Solar System, or whether any of our known meteorites are a good match to its surface."

Scientists are likely to have a lot of answers within a few years. But then again, Psyche may also provide them with new questions and unexpected results. "Secretly, I am hoping that Psyche is something really strange," says principal investigator Elkins-Tanton. "Not a core, not a recognisable kind of unmelted meteoritic material. Maybe it's a metal-rich remnant of the material that was near the Sun in the earliest history of the Solar System. My secret hope is to be really surprised!"

Govert Schilling's book *The Elephant in the Universe* is published by Harvard University Press



Psyche is uncharted territory compared with rocky giants Ceres (left) and Vesta (right), visited by the Dawn mission