Journey to a metal world

Benjamin P. Weiss and Linda T. Elkins-Tanton

A mission en route to the unusual asteroid Psyche may be humanity’s only opportunity to visit the core of a planetary body.

Jules Verne almost had it right back in 1864. In *Journey to the Center of the Earth*, a geologist and his team descend into a volcano in Iceland to explore Earth’s hidden metal core. But it turns out that visiting our planet’s center is and will remain an impossible feat for many human lifetimes: The core is hotter than the surface of the Sun and its pressure more than 3.5 million times that on Earth’s surface (see Physics Today, October 2023, page 12).

Just 12 years before Verne wrote his book, Annibale de Gasparis, an astronomer in Naples, Italy, discovered the 16th known asteroid, which he named Psyche. Since that time, astronomers have been observing how strongly Psyche’s gravity tugs on passing asteroids, bouncing radar waves off it, and measuring the spectrum of light reflected from its surface. Collectively, these observations now tell us that Psyche is weirdly dense—so dense that, like Earth’s core, it must be made mainly of iron–nickel metal. To understand how that came to be, on 13 October 2023, NASA launched a robotic mission to investigate Psyche up close.

For 50 years astronomers have been sending probes to investigate our solar system. They have visited rocky bodies like Mercury, Venus, the Moon, and Mars; icy bodies like Europa and Enceladus; and gas-rich bodies like Jupiter and Saturn. But they have never traveled to a body with a metal surface.

The main reason is that the bodies are rare: Only about 10% of known asteroids seem to be largely metallic. Psyche is by far the largest, with an effective diameter of about 220 km. Even so, in our highest-resolution images of the asteroid, it is just a few pixels wide.

Studying Psyche will help us learn about a previously unobserved building block of Earth and the other rocky planets—the metal-rich materials that form their cores. Furthermore, if Psyche is the remnant of an early-formed metal core, it may give us the only glimpse of one that we will ever have.

How to make a metallic world

Our best guess is that Psyche formed as the metallic core—the iron-rich central region—of a planetesimal, a tiny planetary body the size of a city or a continent (see schematic). As the building blocks of the planets, planetesimals were ubiquitous during the first few million years of our solar system’s 4.5-billion-year history. Because radioactive isotopes with short half-lives were abundant in the early solar system, many planetesimals were largely molten. As a result, metal in those bodies sank under gravity to form a dense, central core surrounded by lighter silicate rock, similar to the structure that rocky planets have today. Such metal-silicate differentiation was the primary process that concentrated metal on a planetary scale in the solar system.

Psyche may be the battered remnant of one of those planetesimals. Impacts may have removed much of its silicate-rock exterior, revealing the metal core. Current models of the formation of Earth and the other rocky planets require the accumulation of many planetesimals and their larger descendants, planetary embryos. Many of those bodies were already differentiated, such that their metal cores merged to form Earth’s core. The Psyche asteroid, therefore, may be an example of a primary, original metal–silicate differentiation event.

Although our fiducial model of Psyche is that it formed as a planetesimal core with residual rocky material, we may well be wrong. The asteroid might instead be material that never melted. In particular, it may have somehow formed from the preferential aggregation of materials that are much more iron rich than the bulk composition of the solar system.

Determining how Psyche became so metal rich is important because it could point the way to understanding how other metal-rich worlds formed. For example, although it has a rocky surface, the planet Mercury also has a mysterious abundance of metal. Furthermore, we know of a dozen or so Earth-sized planets around other stars with similarly high densities.

Measuring an unknown object

Because Psyche is unlike any object previously explored in situ, our team faced a fascinating challenge in designing a spacecraft that is prepared for the unknown. To determine
whether Psyche is indeed part of a core, the spacecraft carries a multispectral imager to detect spectral absorption signatures of metal and rock, a gamma-ray and neutron spectrometer to measure the elemental composition of the surface, and a magnetometer to detect any remanent magnetic field emanating from the asteroid. We will also track the spacecraft’s velocity by observing Doppler shifts of radio waves from the spacecraft’s telecommunications antenna to measure Psyche’s gravity field.

If Psyche is a core, we will be able to learn things that are largely unknown for most planetary cores, including Earth’s. We will be able to determine the minor elements it contains and how they relate to its interior structure; that’s important because it could tell us about the conditions under which metal-silicate differentiation occurred and how the body later solidified. We could also find out whether and how the churning of Psyche’s metallic liquid once generated a magnetic field 4 billion years ago like Earth’s core does today. And if the asteroid is not a core, there may exist processes that can build primordial iron-rich planets without requiring later stripping by impacts.

**Looking ahead**

Psyche lies in the outer asteroid belt, about three Earth–Sun distances from the Sun. To reach the asteroid, the spacecraft first has to go through three phases of propulsion. The first was the big boost it received from its launch vehicle, the SpaceX Falcon Heavy. It now is gently but efficiently being propelled by ionized xenon sent through thrusters that convert the solar panels’ electrical currents into thrust. The final step will be a slingshot following a flyby of Mars in 2026. After the spacecraft arrives at Psyche in 2029, it will orbit the asteroid at various altitudes and eventually approach within 75 km of the surface.

The history of planetary exploration tells us that when a spacecraft visits a new kind of planetary object, the unexpected awaits. The Voyager probes found that Jupiter’s moon Io, despite being just a quarter the size of Earth, is a hellish world of erupting volcanoes. The Galileo spacecraft discovered that Europa, despite its frigid, roughly −225 °F surface, contains a vast, global subsurface ocean. And Cassini was showered by geysers erupting from Saturn’s moon Enceladus.

For now, Psyche is a dark and blurry smudge on a photograph and a playground for our imaginations. It could, like Io, have a surface stained yellow from sulfurous volcanoes that erupted more than 4 billion years ago as it first cooled. It may, like rare metallic meteorites called pallasites, be studied with bottle-green olivine crystals that could be the remnants of Psyche’s overlying silicate proto-mantle or the mantles of early impactors. The metal lips of craters created by meteor impacts might have frozen in mid-splash, leaving spires and cups on the asteroid’s surface. Psyche might have one of the strongest magnetic fields observed around a body in our solar system, or it may have none at all.

The Psyche mission is also a stepping stone in exploration. A hundred years from now, landers may probe the innards of asteroids with seismometers, and commercial missions may mine the vast riches of nearby metallic asteroids. For now, the next milestone comes in 2029, when we get our first up-close glimpse of a metal world.

**A METAL-RICH PLANETESIMAL, UP CLOSE.** Rocky–iron materials (left) melt by radiogenic heating and may be stripped by mantle-abrading impacts. Differentiated bodies could generate a magnetic field, but only a planetesimal that crystallized from the inside out could have recorded the magnetic field in its outer layers, as shown at bottom left. The late formation and preferential accretion of iron-rich materials (right) could produce a metal-rich, unmelted body. It would not have generated a magnetic field.

**Additional resources**