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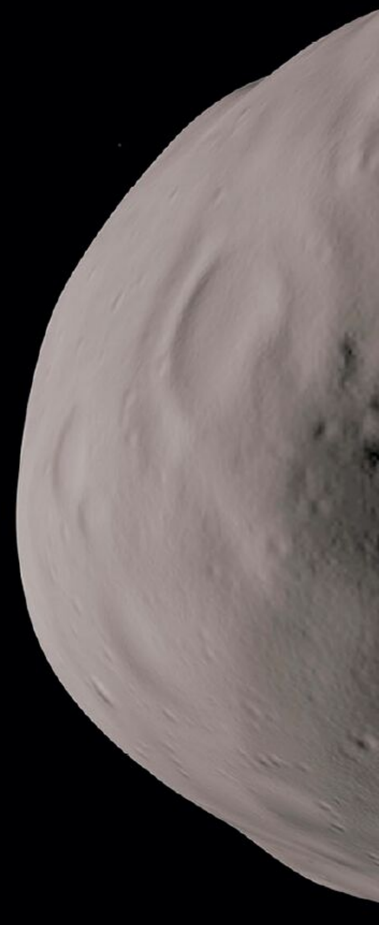

The origin of Mars's bizarre moon is still a mystery, but an imminent mission is set to finally provide answers, reports **Nadia Drake**

NEXT to Earth, Mars may be the most-studied world in our solar system, currently home to a fleet of orbiters, landers and rovers. But above the red sands on which the rovers trundle, a strange moon rises twice each day. And despite all the scrutiny that Mars itself receives, this moon, Phobos, remains shrouded in mystery.

Phobos and its smaller neighbouring moon, Deimos – both discovered in 1877 – are two of the most perplexing worlds in the solar system. "They're the only objects at this stage, in the solar system, for which we have pretty much no idea what they are," says Pascal Lee at the SETI Institute in California. "We know what other moons are. We know asteroids and comets. Phobos and Deimos? No idea."

The Martian moons might be captured asteroids, or they could have formed from the same disc of primordial planet-stuff as Mars. Perhaps they were forged from a fiery cataclysm like the collision that crafted Earth's moon. Or maybe their origin story is something else entirely. "What the heck are they?" asks Abigail Fraeman at NASA's Jet Propulsion Laboratory in California. "I think this is one of the great mysteries of planetary science."

Now, there is hope we might finally solve that puzzle, thanks to a new mission to Phobos that is in the works. Doing so would offer more than just a satisfying answer: it could also open a new window on the history of the inner solar system, and perhaps point to the source of life's building blocks on Earth.

It is fair to say that figuring out the origins of Mars's moons – or indeed learning anything conclusive about them – hasn't been much of a priority. So far, most of what we know about the pair comes from Mars-focused missions that happened to spare some time to observe the rusted world's little moons. "Phobos and Deimos have always been these sort of neglected worlds because they're attached to such an interesting world – Mars," says David Minton at Purdue University in Indiana. "They've always been afterthoughts."

By the 1950s, astronomers had calculated that Phobos circles Mars every 7.5 hours and that Deimos, the outer moon, completes an orbit every 30 hours. They had also figured out roughly how big the moons are – which is to say, tiny. Phobos, the larger of the two, is just 27 kilometres across at its widest point.

More oddly, Phobos is spiralling inwards, falling towards Mars at a rate of nearly 2 centimetres per year. For the dynamics of that descent to work out, astronomers calculated that the moon's density must be astonishingly low, a conjecture that has been tough to explain by nature alone.

So strange is Phobos that one Soviet scientist even seriously wondered if it might be of alien construction. "Could Phobos be indeed rigid on the outside – but hollow on the inside? A natural satellite cannot be a hollow object," astrophysicist Iosif Shklovskii wrote in *Intelligent Life in the Universe*, the 1966 book he co-authored with astronomer Carl Sagan (who, perhaps not-coincidentally, drove an orange Porsche with the licence plate "PHOBOS"). "The idea that the moons of Mars are artificial satellites may seem fantastic, at first glance," he wrote. "In my opinion, however, it merits serious consideration." ›

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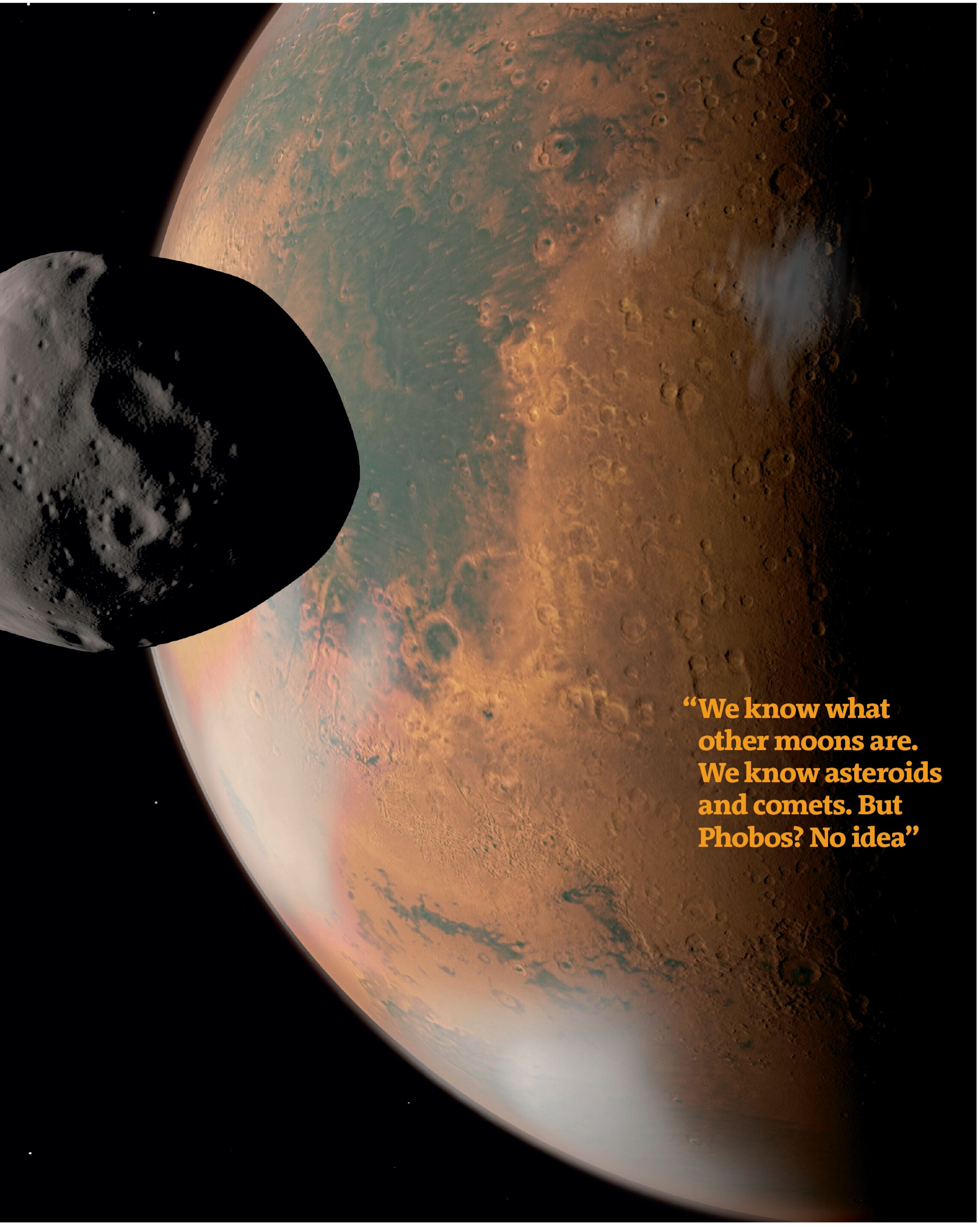


“We know what other moons are. We know asteroids and comets. But Phobos? No idea”

Revealing the origin of Phobos
Learn about the 2026 mission to Mars's bizarre moon at newscientist.com/video

Today, we know with certainty that Phobos isn't an alien space station. Astronomers have discovered that many asteroids are what are known as "rubble piles": loose agglomerations of debris that contain multiple internal cavities. The measured density of Phobos is consistent with a rubble pile, too. But it is still true that the moon is falling towards Mars and that, within the next 100 million years, it will either smash into the planet or be ripped apart to form a ring that will rain down on Mars over millennia. "Phobos is kind of a quirk," says Minton. "If it's 4.5 billion years old, like everything else in the solar system, we just happen to be watching it during the last tiny percentage of its life."

From decades of observation, we have learned little more than the following: Phobos is deeply weird (as is Deimos). It rises in the west and sets in the east, twice each Martian day. It is much darker than the peachy Martian surface – in fact, it is one of the least reflective bodies in the solar system. Unusual, unexplained grooves disrupt its pockmarked surface, along with a gargantuan crater named Stickney.

Impossible moons

Not only do Phobos and Deimos look nothing like Mars, but their surface composition is different too. We have found as much from spectral analysis, where astronomers study the precise wavelengths of light the moons absorb to get a handle of what they are made of. This has shown that the moons' surfaces closely resemble a type of dark asteroid rich in water and organic compounds that lives near the outer edge of the main asteroid belt, between the orbits of Mars and Jupiter. As a result, many scientists think the moons are captured objects, primordial bodies loosed from their natal grounds during a period of upheaval in the early solar system and snared by Martian gravity.

They could also be from even further out. A recent analysis by Sonia Fornasier at the Paris Observatory in France and her colleagues suggests that, spectroscopically, Phobos and Deimos look more like two parts of a dead comet that broke apart when it was pulled into Mars's orbit. "I'm really intrigued by the idea that they are a captured body," says Fornasier. "From where? I don't know."

The big problem is that the moons orbit Mars in exactly the wrong way for those capture stories to make sense. Their paths are tidy – nearly circular around Mars's equator – but we expect to see this alignment when moons form from the same cloud of stuff as their planet. It can also happen when they coalesce within a debris ring produced by a giant impact, perhaps the collision that carved the mammoth Borealis basin at the Martian north pole. "It's incredibly difficult to get a spacecraft to achieve that orbit when you have rockets on it, let alone a lump of rock," says Minton.

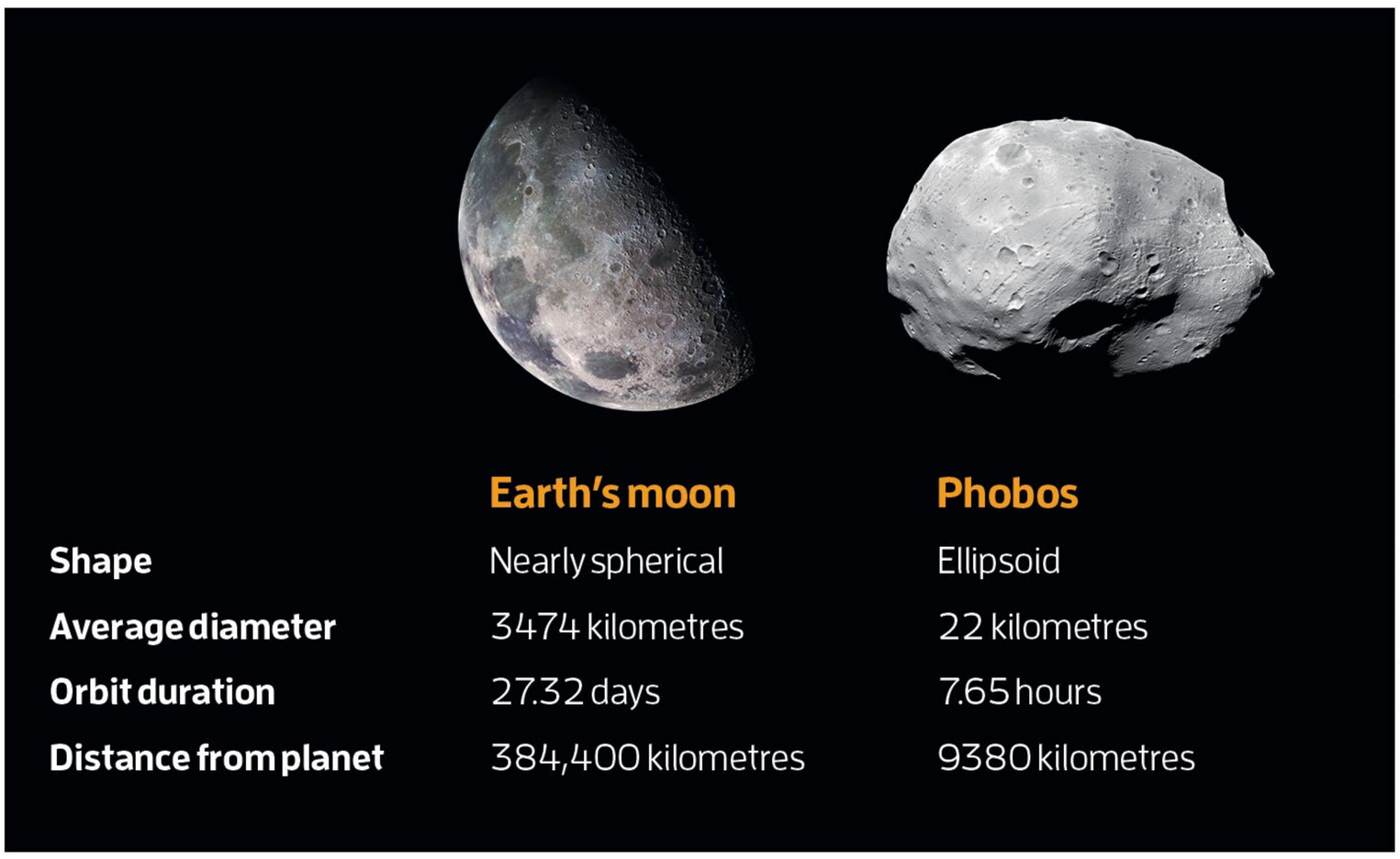
"On one side of Phobos, Mars would forever be in the sky; on the other, you would see endless stars"

Captured objects, conversely, tend to trace irregular orbits: their paths are oval, tilted relative to a planet's equator and, in some cases, take them in the opposite direction to the planet's spin. In other words, it is vanishingly improbable that Mars captured both Phobos and Deimos and set them on their current routes. But if they formed at Mars, from the same ingredients as the planet, how can they look so different to the planet itself? "I think one thing one day and another thing another day," says Fraeman. "My favourite hypothesis right now is that they are from an impact, but what remains is mostly impactor that's mixed with a little bit of Mars."

One thing that would help us solve the mystery would be to actually send a dedicated mission to Phobos. But though a number of such programmes have been considered over the years, the only previous attempts – all Soviet and Russian craft – failed. The first, Phobos 1, was lost on its way to the Mars system in 1988. Phobos 2 successfully reached Mars the next year, but malfunctioned shortly after arrival. And the third, a 2011 sample-return mission called Phobos-Grunt, never escaped Earth's atmosphere. "It was a gorgeous midnight launch into a clear and frosty Kazakhstan sky," recalls Leonid Gurvits, an astronomer and expert in Russian space history at Delft University of Technology in the Netherlands. "But it was the only nice thing about that launch. The rest of the story was very sad."

Now, it is time to try again. In 2026, the Japan Aerospace Exploration Agency (JAXA) is due to launch the Martian Moons eXploration (MMX) probe to surveil Phobos up close – and, if all goes well, to collect samples from its surface and return them to Earth.

The mission's scientific instruments will make detailed 3D maps of Phobos and the composition of its surface and collect reams of data. But the true treasure will be the trove that MMX brings back to Earth. Over just 2.5 hours, the craft will scoop up what it can before lifting off and leaving the Mars system in 2030,



	Earth's moon	Phobos
Shape	Nearly spherical	Ellipsoid
Average diameter	3474 kilometres	22 kilometres
Orbit duration	27.32 days	7.65 hours
Distance from planet	384,400 kilometres	9380 kilometres

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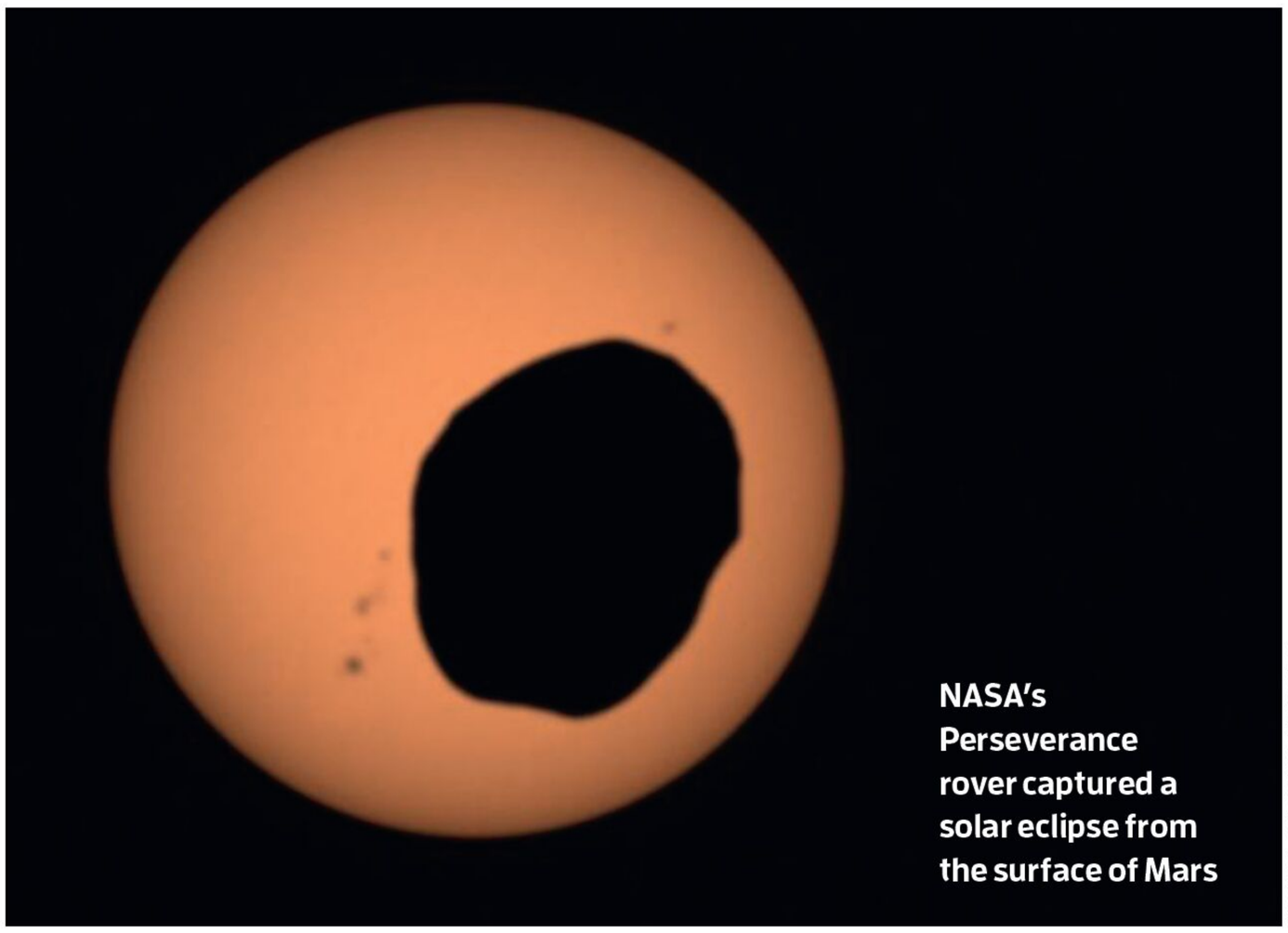

NASA's Perseverance rover captured a solar eclipse from the surface of Mars

NASA/JPL-CALTECH/ASU/MSSS/SSI

returning to Earth in 2031. And then the real fun begins, because no instrument we have yet launched into space has the analytical power of our labs back home.

"It's the first sample-return mission from the Martian gravity field and the Martian satellite Phobos," says JAXA's Tomohiro Usui, a cosmochemist on the MMX team. The samples are expected to conclusively solve the mystery of Phobos's origins, he says, even if that means going through them grain by grain. "With laboratory experiments or real samples, you can investigate in detail the elemental composition, see if it is a captured body, maybe a comet, or if it was formed in situ," says Fornasier.

If Phobos was once an asteroid – or even a more comet-like body that was born even further from the sun – it would add to our story about how habitability evolved in the inner solar system. "That will tell us something very important about mechanisms that deliver these very important ingredients to the inner planets," says Fraeman.

For now, the origin of Earth's water and organic chemicals is somewhat mysterious. But the prevailing idea is that those vital compounds formed far from the sun, where temperatures are cold enough for them to condense on small, icy bodies such as asteroids. Then, the thinking goes, the giant planets shuffled around in the early days of the solar system and the gravitational turbulence prompted the icy bodies to pinball in all directions, including inwards on a collision course with Mars and Earth. The resulting impacts could have been responsible for bringing water and carbon-based molecules to our planet.

If, on the other hand, Phobos turns out to look like a lopped-off chunk of Mars, then we will learn something more about the history of Mars itself. We will find out what the building blocks of primordial Mars were like and which materials were floating around in the early inner solar system. That information can then be fed into simulations of how Mars evolved, says Fraeman, which will help us better understand its inner workings.

We would equally be able to use the MMX samples to figure out when the Phobos-forming impact occurred, if it indeed happened, says Usui. Depending on its precise timing – whether this took place before or after the Jupiter system coalesced – we will learn more about how giant planet formation and migration affected Mars, Earth and the rest of inner solar system. In a scenario where Mars snared Phobos from further afield, scientists could pin an age on the time of capture. That would be a harder date to work out, says Usui, but it can be done and it should tell us "whether that was because of Jupiter's turbulence, or not".

A way station to Mars

There could be an additional bonus prize to be won from a trip to Phobos, too. For all our studies of Mars, one thing we have never yet done is scoop up and return home a piece of the Red Planet. NASA's Perseverance rover has been collecting and storing samples with just this goal in mind, and the agency had planned to send a mission to bring those samples to Earth. However, the plans have been hit by delays and budget problems.

The MMX mission might offer us another chance because, regardless of Phobos's origins, it has accumulated dust from its host planet, potentially for billions of years, along with bits of Mars that have been launched into space by impacts. "It could have collected Martian meteorites throughout Martian history, or for as long as Phobos has been what it is," says Lee. "You could have samples of Mars sitting on Phobos that are better preserved than you would be able to find on Mars today." If we are really lucky, those samples could help us learn whether Mars was habitable – or even inhabited.

"We are going to get more than 10 grams of Phobos's materials... and maybe 10 milligrams of Martian samples. Ten milligrams is so huge for a cosmochemist," says Usui. "That is my kind of realistic dream. It's going to be real."

Even beyond that, MMX could be a stepping stone towards establishing a human presence in Mars orbit, perhaps with Phobos as an outpost. Despite the general focus on sending humans to Mars, there have been plenty of calls to head to Phobos instead. Being smaller, it is much easer to land on and take off from, and it would serve as a perfect place from which to operate robots on the Martian surface.

Life on Phobos would be strange. As is the case with our moon, it is tidally locked, meaning it always points the same face towards Mars. On one side of Phobos, Mars would forever be in the sky; on the other, endless stars. Its gravity is extremely weak, only about one-thousandth that of Earth's. If you jumped with enough oomph, you might rise some 350 metres and then gently descend over the course of many minutes. In any sort of structure, "you'd be forever bumping your head on the ceiling", says Lee. Even travelling in a vehicle at as little as 45 kilometres an hour would be enough to launch you from the moon entirely. "That's both the wonder and challenge of Phobos," he says.

Rather than establishing a permanent outpost on Phobos, Lee argues that it would be smarter to pull into Mars orbit, strap on a jetpack and make a short trip to the bizarre moon's surface. Just a short jaunt from Mars, Phobos could be a logical place to store Martian samples for humans to retrieve.

But those ideas will change, says Lee, if the gravity instrument on MMX reveals that Phobos is cavernous and filled with large amounts of ice – the raw material needed to manufacture rocket fuel in orbit. "That could be a game changer," he says. "If Phobos and Deimos are volatile-rich or water-rich, then all bets are off in terms of their human future." ▮

Nadia Drake is a science journalist based in the US, specialising in astronomy, planetary science and space exploration