New Scientist

WEEKLY 2 March 2024

QUANTUM ENGINE POWERED BY A SINGLE ATOM

REVEALED: LARGEST VOLCANIC ERUPTION IN RECORDED HISTORY

NEW HOPE IN THE HUNT FOR ELUSIVE ALIEN MOONS

HEALTHY *SKIN* HEALTHY *YOU*

How caring for your skin could protect you from Alzheimer's, heart disease and much more

HAPPINESS HACK

Why a fresh perspective helps you get more joy from everyday life

No3480 £6.95 CAN$9.99

Features

The hunt for alien moons

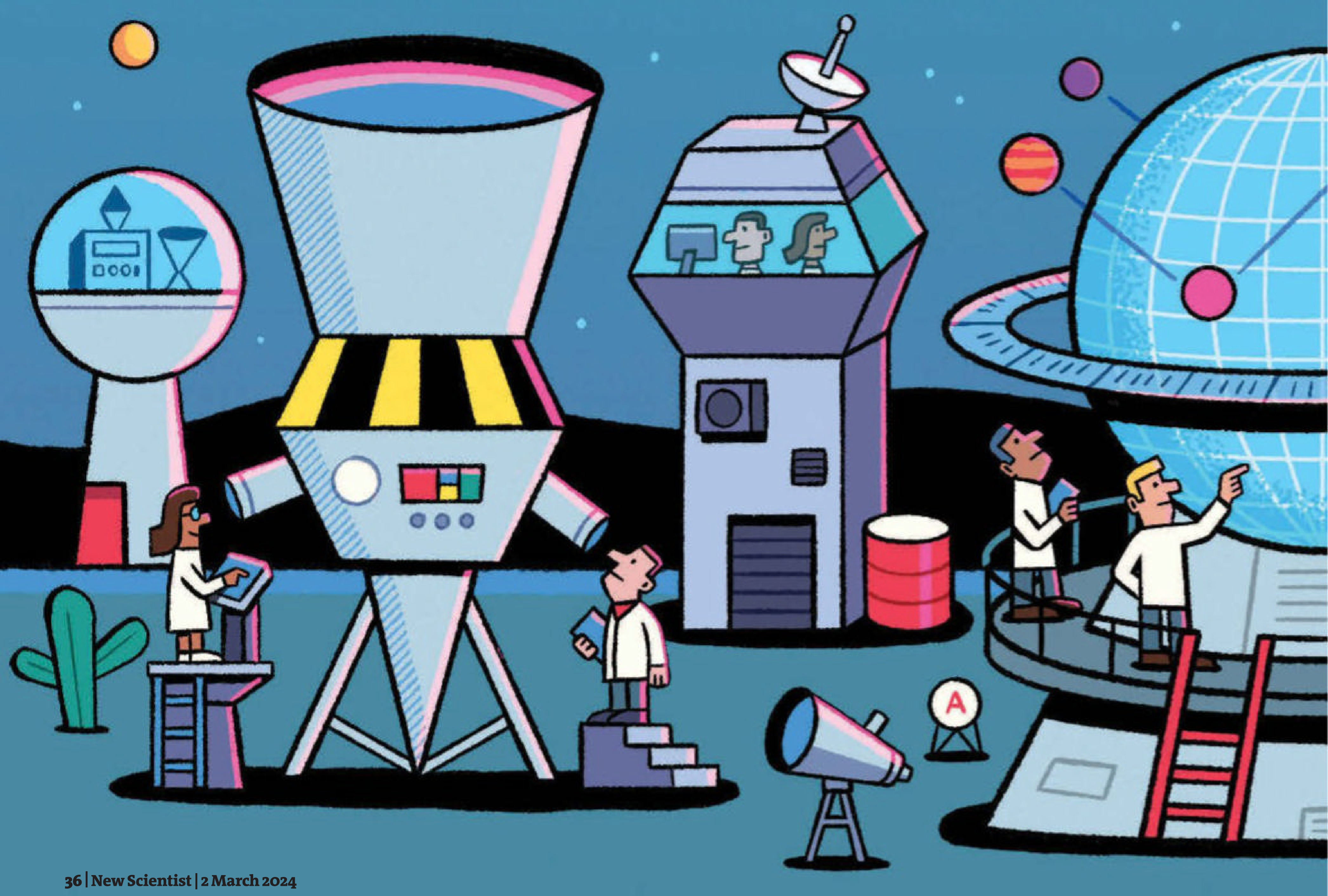
Planets orbiting other stars could host all manner of exotic moons, some of which may be habitable – and we are finally on the cusp of finding them, says **Jonathan O'Callaghan**

ALLAN SANDERS

YEARS ago, when David Kipping lived in London, he would walk home through the city and look up at the moon. As an astronomer, its faintly glowing presence served as a nightly source of inspiration. "It was a reminder that moons were waiting for us around exoplanets," he says. "It just made sense that we should look for them."

Finding exomoons – natural satellites of worlds beyond our solar system – would be thrilling. For a start, they may play a key role in determining the habitability of host planets by damping their wobbles, fostering a stable climate in the same way that our moon has done for Earth. They might also come in weird and wonderful configurations, such as rings of moons and moons with their own moons. But most excitingly, it is possible that some of them are more hospitable to life than exoplanets.

Kipping, now at Cornell University in New York, is part of a small community of astronomers who search for exomoons.



The statistics, at least, are on their side: we have found some 5500 exoplanets so far, and some of these could have dozens of moons. The trouble is, proving their existence isn't straightforward. The two sightings Kipping has made so far are hotly disputed.

But now, hope is on the horizon, with a host of new ways to search for these objects – from watching rogue planets that have abandoned their stars to monitoring the gravitational wobbles of exoplanets. Armed with these new techniques, and with new telescopes on the way, the moon hunters are on the cusp of discovering a whole new class of alien worlds.

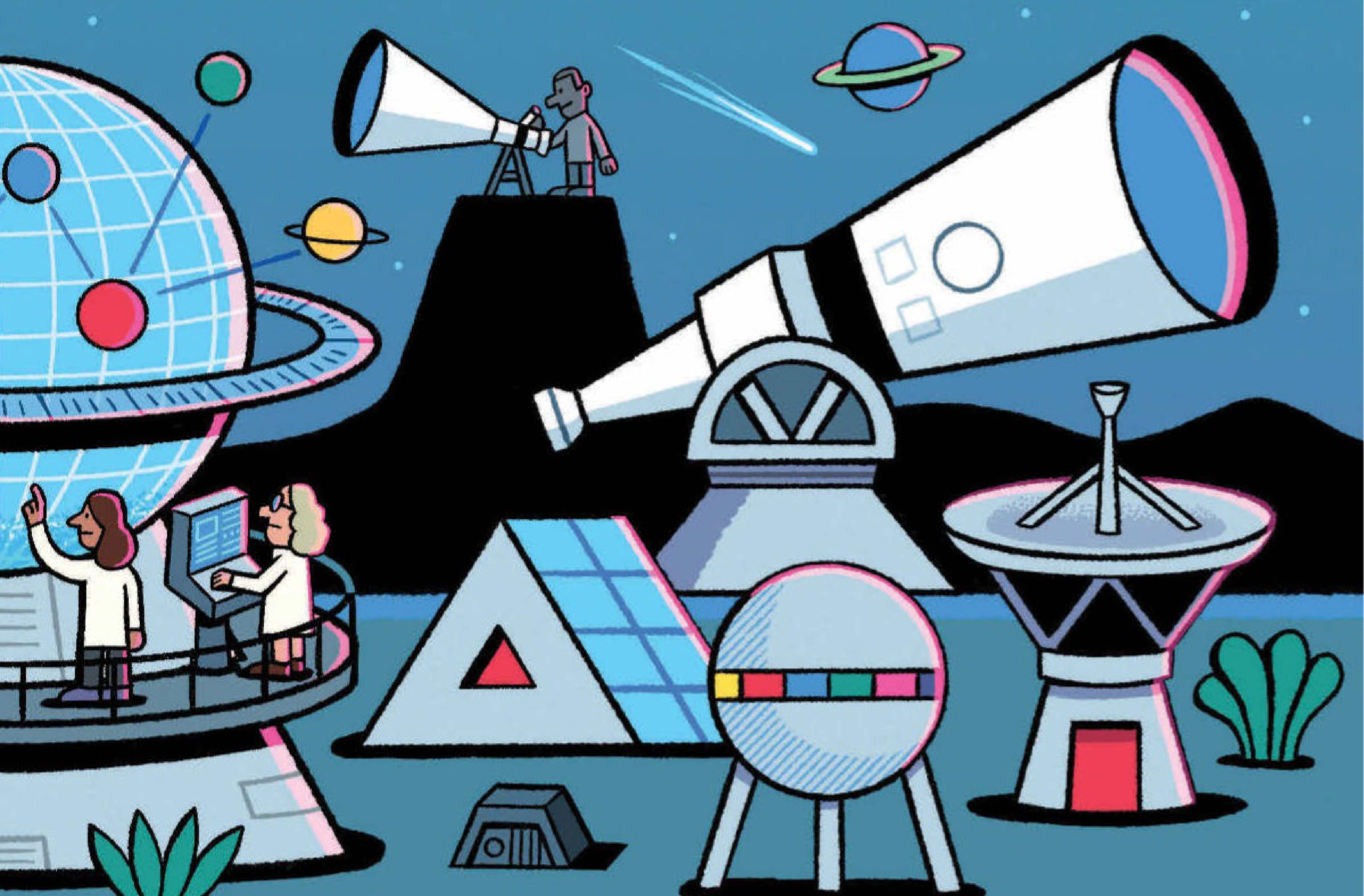
If our solar system is anything to go by, moons are everywhere – six of our eight planets have them. Earth has a solitary and sizeable one, while Mars has two small asteroid-like companions. The four giant planets host the most extensive satellite systems, with Saturn currently holding the record at around 150 known moons.

There isn't just one way to make a moon, either. Our own appears to be the result of a chance event that saw a Mars-sized object slam into us 4.5 billion years ago, its tidal effects playing a key role in the evolution of life on Earth since. The moons of Mars, on the other hand, are probably captured asteroids, while Jupiter and Saturn's may have formed in discs of debris around the planets.

Moons can come in all manner of configurations, too. Two of Saturn's – Janus and Epimetheus – almost share an orbit. But it could get weirder than that. "In principle, you could have crazy things like rings of moons around planets, like Saturn's rings but moons instead of tiny little particles," says Sean Raymond at the University of Bordeaux in France. Along with Juna Kollmeier at Carnegie Observatories in California, Raymond has even postulated that, under the right conditions, moons could have their own moons. These are called moonmoons.

Astronomers started thinking about exomoons in earnest when the first exoplanets were discovered in the 1990s. Darren Williams, now at Pennsylvania State University, was a graduate student around this time. "Very quickly, the number ballooned from zero to 10," he says. "All of these planets were giant Jupiters. I said they're going to have moons, and some of the moons are going to be big enough to support life."

Moons could be intriguing locations to look for life if they are large enough to hold onto sizeable atmospheres. The cut-off for this is surprisingly small, barely one-tenth the mass of Earth, says Lisa Kaltenegger at Cornell University. "There is no reason why an exomoon couldn't be inhabited," she says. And while planets are likely to need to orbit in a star's habitable zone to host liquid water and life, a moon could be heated by a planet in a much wider orbit around a star. "These moons could be much further out to be warm enough for life," says Kaltenegger. "It's much easier to keep them from freezing in the interior ›



"In the exoplanet game, people are really used to slam dunk discoveries"

because of the tidal heating from the planet."

Take our solar system as an example. We know that Jupiter's tidal forces keep its four largest moons warmer than they would otherwise be, by squeezing them, which generates heat through friction. Saturn's atmosphere-laden moon Titan, meanwhile, is the only known place besides Earth with lakes and seas on its surface, albeit ones filled with liquid hydrocarbons instead of water.

A habitable moon orbiting a gas giant might have an amazing sky, especially if the moon were tidally locked – with one face always pointing towards the planet – like our moon is to Earth. One side of such a satellite would live under permanent planet-shine and never experience full night. "You could walk on that moon [from the far side to the planet side] and the planet would start to come into view," says Kaltenegger.

All of which is to say that exomoons are wondrous places. So how do we find them? And why are we yet to confirm a sighting?

Jean Schneider at the Paris Observatory was the first to tackle one of those questions. In 1999, astronomers had broken fresh ground by spotting an exoplanet using a new technique called the transit method – noticing the dip in a star's light as a planet passes in front of it – which has since become our predominant way of finding these worlds. In theory, thought Schneider, the same technique could reveal exomoons. He worked out that an exomoon should cause a slight shift in a planet's transit depending on whether it is in front of or behind the planet as it crosses the star's face. These are now called transit timing variations. "It gives you the revolution period of the moon around the planet, and the amplitude of the variation gives you the mass of the moon," he says.

The first real attempt to search for a moon around a transiting exoplanet was made with the Hubble Space Telescope in 2001, with no luck. But the field of transiting exoplanets was revolutionised in 2009 with the launch of NASA's Kepler telescope, a wildly successful mission that found more than 2700 transiting worlds in its nine years of observation. It was as a result of these sightings that Kipping began to think seriously about the possibility of finding exomoons.

As the Kepler discoveries poured in, he and his colleague Alex Teachey at the Academia Sinica Institute of Astronomy and Astrophysics in Taiwan went through the data with a fine-tooth comb to look for exomoons. The problem was that many of Kepler's discoveries were hot Jupiters, gas giants on tight orbits around their stars. This appeared to rule out exomoons because the gravitational pull of the stars in such locations would be likely to rip away any moons.

As such, from an initial look at 300 Kepler planets in 2016, Kipping and Teachey came up almost empty-handed. "I remember being very depressed," says Kipping. "I went to Alex's office and I said, 'Is there anything in here at all?'" There were no clear exomoon signals.

The only potential hit the pair found was around a gas giant called Kepler-1625 b, which is 8200 light years from Earth and about the same size as Jupiter, but with a much greater mass. The pair were given time on Hubble in 2017 to observe the planet in more detail and they found a transit timing variation suggesting the presence of an exomoon, which they dubbed Kepler-1625 b I. To cause the signal, the moon would have to be huge, with a radius on a par with that of Neptune.

Unfortunately, upon further inspection, the data turned out to be inconclusive. No amount of analysis could unequivocally confirm the signal the pair had seen. "There's been some controversy," says Kipping. "I remain very sceptical myself."

Super-moons

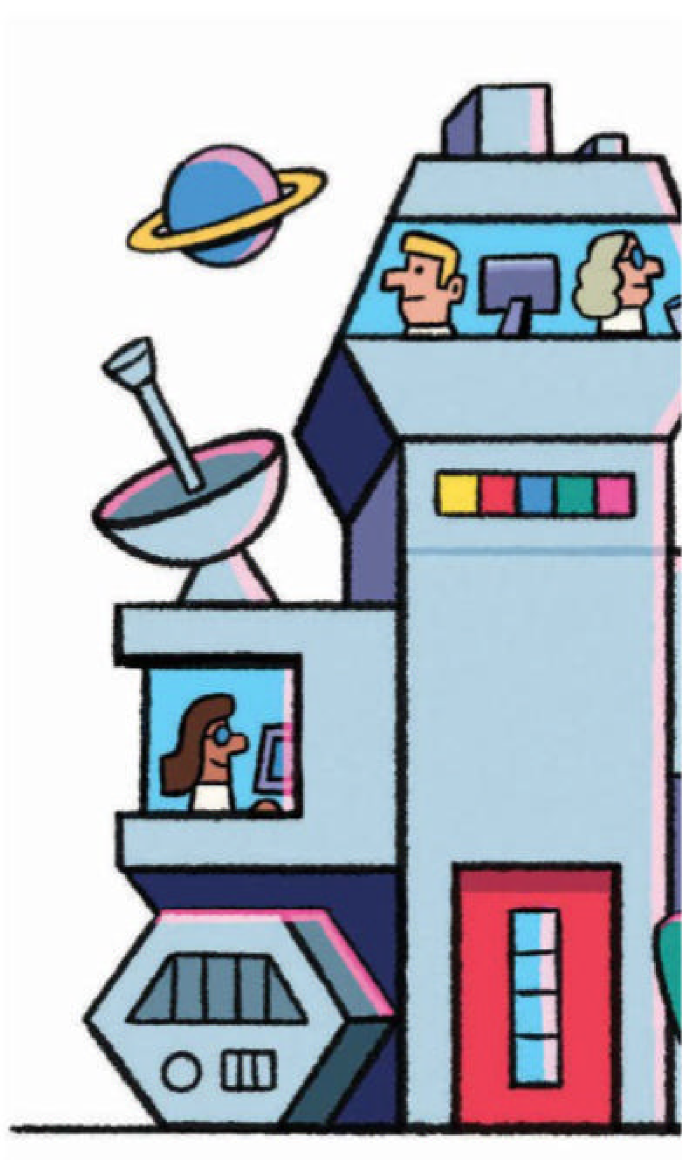
Then, in 2022, Kipping and Teachey revealed a second exomoon candidate around a Jupiter-sized planet about 5600 light years away called Kepler-1708 b. This moon would be much smaller than the first candidate, but still huge compared with any in our solar system: a mini-Neptune or super-Earth-sized object more than twice the size of our planet. Kipping describes the candidate as "basically something we just couldn't kill... a persistent signal of an exomoon that we can't get rid of".

Not everyone agrees, however. In December 2023, René Heller at the Max Planck Institute for Solar System Research and Michael Hippke at the Sonneberg Observatory, both in Germany, published a paper refuting the existence of the two exomoons. Reanalysing the original data, Heller and Hippke said they couldn't find the same evidence as Kipping and Teachey. "We conclude that neither Kepler-1625 b nor Kepler-1708 b are likely to be orbited by a large exomoon," they wrote.

But Kipping says there were flaws in Heller and Hippke's analysis. "We've used their exact dataset they published and we can still recover the signal," he says, having penned a rebuttal to the pair's work in January. "To me, there's no doubt their algorithm has missed this solution somehow."

This back and forth shows how difficult it is to confirm an exomoon detection using Kepler and Hubble data, and Kipping's detections remain tentative at best. "They're not slam dunks, and in the exoplanet game, people are really used to slam dunks," says Teachey.

Finding out if the moons exist for certain would require further observations over many hours. Instead, a better bet may be to look elsewhere – around free-floating planets, for instance. Also known as rogue planets, these worlds have been spotted drifting through our galaxy by the likes of the James Webb Space Telescope (JWST), glowing from their residual heat – which could also provide



energy for potential life. These wandering objects, likely to have been ejected from orbits around young stars, could perhaps be acting as roaming oases of habitability.

If these rogues have any large moons in orbit, spotting their transits should be possible. “You can monitor them in much the same way you would monitor a star for a transiting exoplanet, but instead of an exoplanet, you are seeing moons,” says Melinda Soares-Furtado at the University of Wisconsin-Madison.

A NASA observatory set to launch in 2027 aims to do just that. The Nancy Grace Roman Space Telescope, known simply as Roman, will stare at portions of the sky for long periods. Its primary goal is to seek transiting planets, and it is expected to find as many as 100,000 of these. But Soares-Furtado and Mary Anne Limbach at the University of Michigan and their colleagues calculated in 2022 that the telescope will also be particularly sensitive to exomoons orbiting free-floating worlds in the Orion nebula. This is the closest region of intense star formation to Earth, where there are thought to be rogue planets. More than a dozen transiting exomoons are likely to be detectable there if they exist, the researchers found, right down to the size

GSFC/SVS

Artist’s impression of NASA’s Nancy Grace Roman Space Telescope

of Jupiter’s moon Callisto or Saturn’s Titan.

Such discoveries would also give us a good handle on how prevalent exomoons are likely to be. “You can do large-scale statistics,” says Soares-Furtado. If these moons turn out to be as numerous as we think, it could dramatically increase the number of locations where we might one day look for life. “It increases the number of places to look by around a factor of 100 if our solar system is not unique in the number of moons that we find here,” says Soares-Furtado. This estimate is based on the fact that, in our solar system, there is around a factor of 100 more moons than planets.

The majority of exoplanets Roman is hoping to discover will be in orbit around stars. It will find them using yet another technique, one called microlensing, which looks for the bend in light from a distant star when a closer star and any accompanying planets pass between it and our line of sight. That method should be able to detect exomoons, too, “all the way down to about twice the mass of the moon, or the mass of Jupiter’s moon Ganymede”, says Scott Gaudi at the Ohio State University, who leads Roman’s exoplanet team. It could even spot some moons comparable to our own around Earth-mass planets. “We’re not going to get thousands of exomoons with Roman,” he says. “But we’re going to start to detect how common these things are.”

The cadre of scientists looking for exomoons is small, probably because of how hard it is. But they are determined and innovative. Andrew Vanderburg at the Massachusetts Institute of Technology, for example, wants to detect exomoons in a totally different way, by noting the slight gravitational wobble in a planet caused by the presence of a moon. Upcoming big, ground-based telescopes, like the Extremely Large Telescope – expected to finish construction in Chile around 2028 – would be particularly suited to this technique. “If you can take observations of the planets themselves, getting light using direct imaging, you can look for moons,” he says.

There are also grounds for optimism in new telescopes designed to look for exoplanet transits, only this time with enough accuracy to make an exomoon detection in a star system. An upcoming European Space Agency (ESA) instrument called Plato, set to launch in 2026, might be sensitive to moons down to the size of Earth, says Ana Heras at ESA in the Netherlands, who is the project scientist for the mission. NASA’s Habitable Worlds Observatory, a proposed successor to JWST intending to launch in the 2040s to image Earth-like planets and hunt for life, might go even further – picking out the reflected light of exomoons as small as our moon in the light of those planets. “Habitable Worlds is absolutely incredible for exomoons,” says Limbach.

All those plans are exciting, but they mean waiting years, if not decades, for any sightings. Luckily, there is a telescope already in use that could find moons as small as Europa, which is about 90 per cent of the size of Earth’s moon. “JWST is the first telescope humanity has ever built that can find those moons,” says Kipping.

To their frustration, he and others have submitted multiple proposals to the Space Telescope Science Institute (STScI) in the US, which runs JWST, to use the instrument to hunt for exomoons, but they have had no luck so far. Scientists peer-review proposals to use JWST and advise STScI on what programmes to approve, but Vanderburg says that the exomoon ones are “consistently getting trashed in the reviews because they’re unproven science. Until we have that first detection, that’s how it’s going to be.”

But the moon hunters won’t give up. Kipping and his colleagues will find out in March if their latest STSci proposal to hunt for exomoons has been successful. His team has identified three planets that could be prime locations for this: two gas giants and one super-Earth. “Those moons really, really should be there,” says Kipping. But only one existing telescope can find them. If one of their JWST proposals is finally selected, they will be able to do one of the most advanced searches for exomoons yet. We are almost certain they exist. But it is “not good enough to say they’re out there,” says Teachey. “Somebody’s got to go find them.” ▮

Jonathan O’Callaghan is a freelance writer based in London