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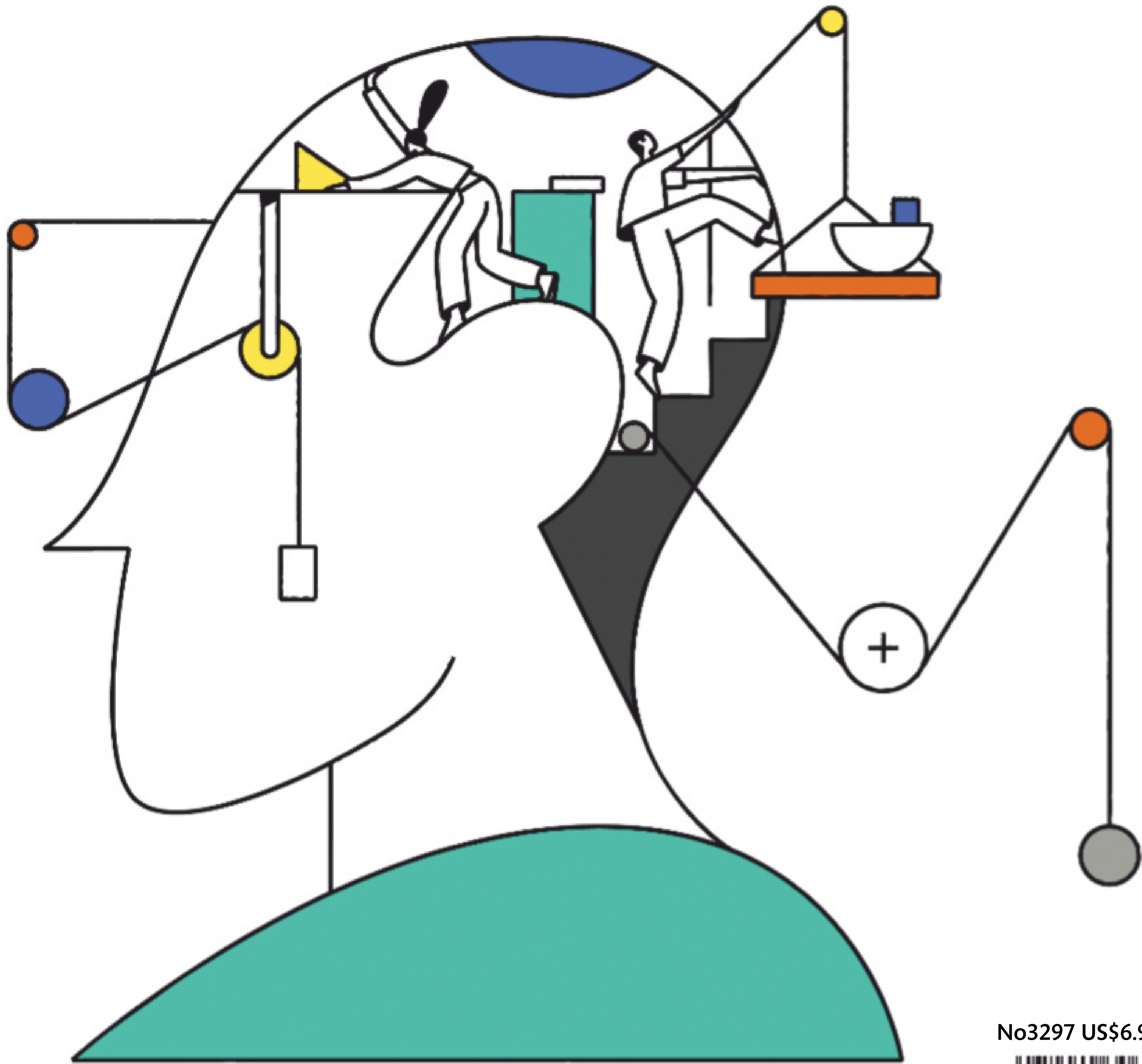

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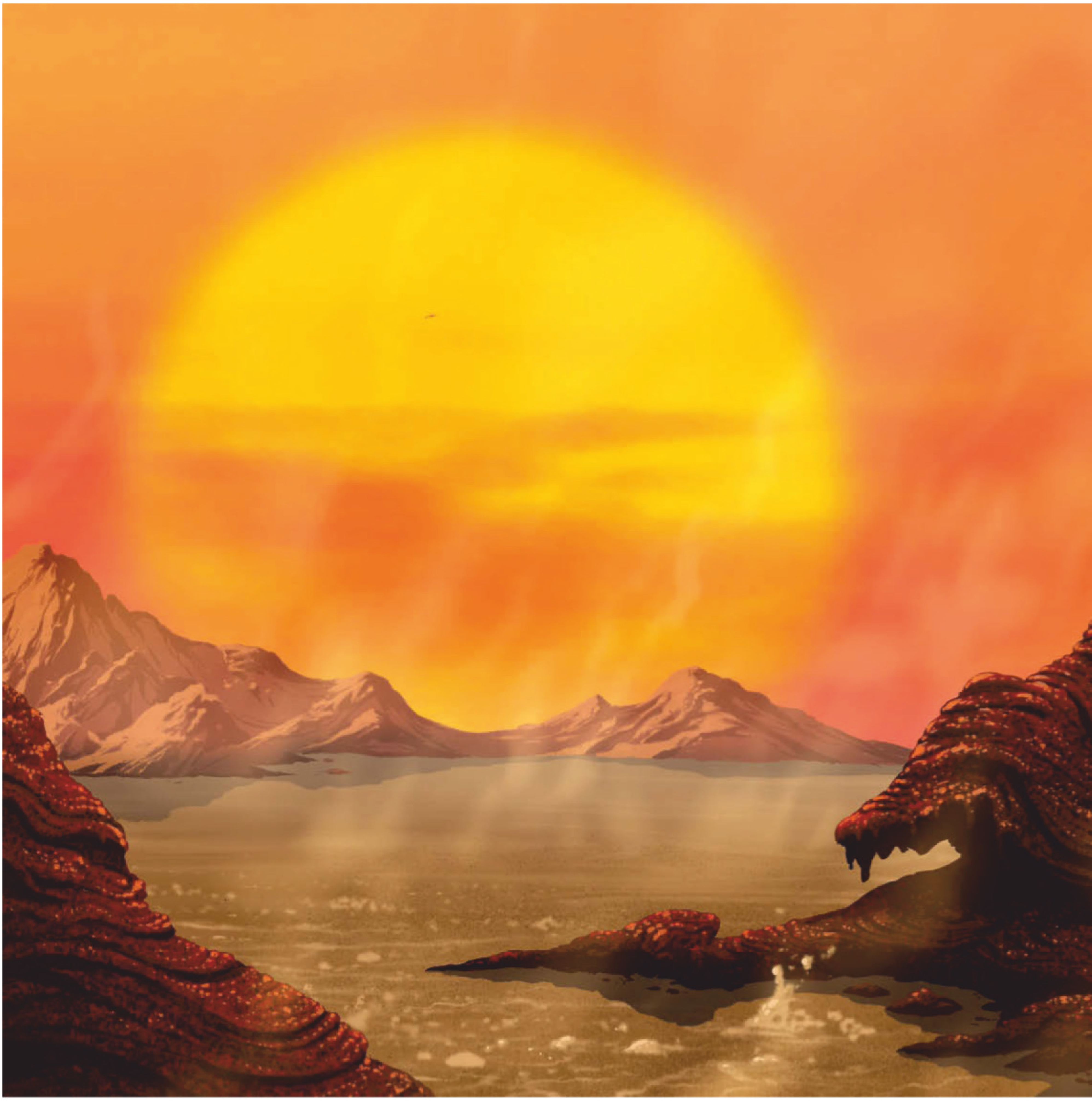

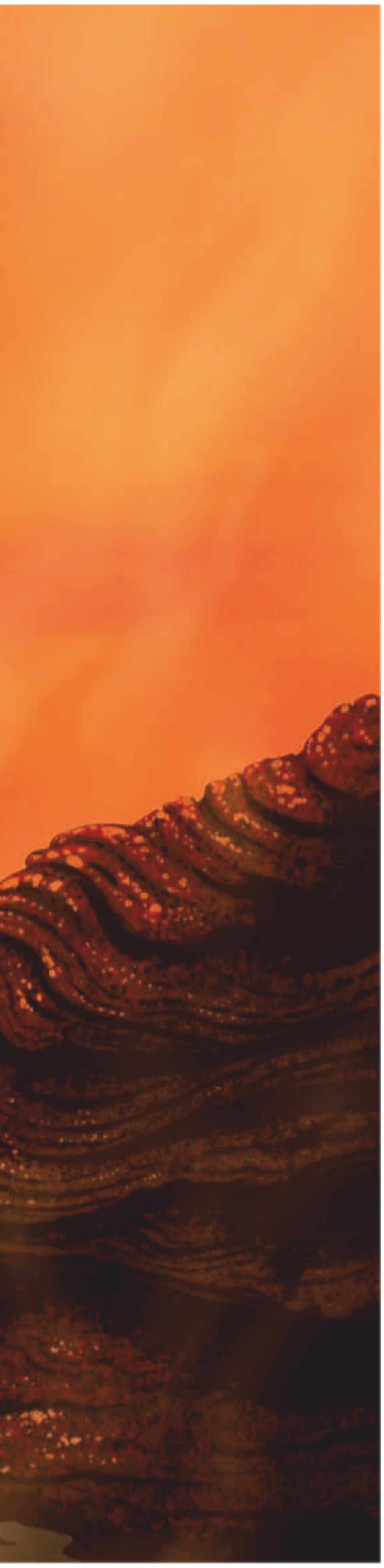

ARIK ROPER

# Brave new worlds

The hunt for extraterrestrial life has always focused on Earth-like planets. It is time for a radical rethink, reports **Colin Stuart**

IN A dark and seemingly barren universe, our pale blue dot of a world is a beacon of hope that life is possible. The confluence of factors that help sustain life here are astonishing: from the planet's rocky crust, broken into tectonic plates that help maintain a breathable atmosphere by releasing and trapping gases, to its distance from the sun. Earth orbits at the inner edge of a Goldilocks region called the habitable zone: a narrow ring that is neither too hot nor too cold to allow liquid water to exist. Every living thing we know of, from a bacterium to a blue whale, needs water to survive.

Given this, it is no surprise that our efforts to find life elsewhere have focused on spotting a carbon copy of our world. Frustratingly, these seem to be few and far between. Of the thousands of exoplanets discovered to date, only a handful are thought to have conditions remotely like ours. Most orbit either scorchingly close to their host star or keep a frosty distance. Others move in loops around two stars, circle long-dead suns or wander the cosmos alone, without the benefit of stellar heat at all. Life on such planets would once have been considered impossible – but that view is changing.

Recent research suggests that these weird and wonderful worlds could be capable of sustaining life after all. It is time to tear up the rulebook and go on an incredible interplanetary journey.

## HELL OR HEAVEN?

### Planets in searing proximity to their stars

**Evidence that planets very different from Earth could nevertheless be balmy havens for life might not be too far away. Leave the safety of our planet and travel towards the sun, where Venus and Mercury orbit, and conventional wisdom says that soaring temperatures would make liquid water and life impossible. Today, Venus is a hellscape with temperatures in excess of 400°C. Yet data collected by NASA's Pioneer Venus project in the 1970s hints at a much wetter past. "Venus could have been temperate for billions of years," says Michael Way at NASA's Goddard Institute for Space Studies in New York.**

**Until now, the issue has been how to reconcile that liquid past with Venus's proximity to the sun. Way believes the answer may lie in the planet's long days, each of which lasts for nearly eight Earth months. According to Way's climate model of Venus, published in March, the planet's slow rotation allowed a large cloud to settle directly under the sun's glare, making it capable of reflecting back much of its heat.** ›

"That means Venus spent much of its life with surface liquid water," he says. If true, that has profound consequences for which planets should be considered habitable. "For slowly rotating planets like Venus, the habitable zone is much further in towards the star," says Way.

If one interpretation of recent observations is correct, this might even extend as close as Mercury. Our solar system's furthest-in planet is dominated by an ancient impact scar known as the Caloris basin, which is more than twice the size of France. In 1974, a fly-by mission discovered so-called "chaotic terrain" on the other side of the planet. The usual explanation is that the impact generated seismic waves travelling in opposite directions around Mercury, which crumpled the surface as they met on the other side of the planet.

## VOLATILE PLANET

Alexis Rodriguez at the Planetary Science Institute in Arizona has another idea. Based on data from the more recent Messenger mission to Mercury, he says "the basin is 2.5 billion years older than the chaotic terrain". In other words, they can't be connected.

Rodriguez's work, published in March, suggests a different reason for the jumbled terrain: a collapse triggered by the evaporation of materials such as salts and sulphates, collectively known as volatiles. The process would have resembled the formation of a sinkhole, "except that we are talking about entire mountain ranges collapsing", he says.

Crucially, those volatiles could have included the building blocks of life and even water, says Rodriguez. "We've been too hasty ruling out planets like Mercury as not habitable." And this matters, because we know that there are plenty of these kinds of worlds out there.

**"We have been too hasty in ruling out planets like Mercury as not habitable"**

## TWIN SUNS

Planets orbiting two stars

Imagine a world with two sunrises and two sunsets, in which you would have two shadows. That would be the reality of living on a circumbinary planet – one that orbits a pair of stars. NASA's Kepler space telescope has found a handful of these unusual worlds, and the new Transiting Exoplanet Survey Satellite found another in January this year. Some have been in the habitable zone, but so far they have all been gas planets, with no chance of the plate tectonics so essential to life on Earth. We are yet to find a rocky circumbinary planet.

Othon Winter at São Paulo State University in Brazil thinks he can change that. He is part of a team of astronomers that has recently modelled terrestrial planet formation in the habitable zones of known circumbinary systems. Their calculations suggest that if a circumbinary planet has already been found, then there is a fifty-fifty chance that a terrestrial planet also exists in the system's habitable zone. Winter is keeping an eye on two systems in particular that have had rocky planets forming in every simulation he and his team have run. Even more tantalisingly, their simulations suggest that such planets may have remained habitable for billions of years. "They are stable for a very long time," says Winter, "enough time for life to develop".

Signs of habitable circumbinary planets may already be hiding in existing observations, just waiting to be identified. "There could be 30 or 40 lurking in existing Kepler data," says David Martin at Ohio State University. Kepler looked for the telltale dip in the brightness of a star as a planet passed in front of it, an event known as a transit. For an Earth-sized planet circling a sun-like star, the brightness dips are so small – just 0.01 per cent – that astronomers use a technique called folding to firm up their finds. This involves stacking the various transits on top of each other in order to make the dips more obvious. With two suns, however, the process isn't quite so simple. Martin is working hard to hone an algorithm to do the job, in the hope of recovering habitable circumbinary planets from the Kepler data archive over the coming months.

**"Planets with two suns could remain habitable for billions of years"**

## ZOMBIE WORLDS

Planets circling dead stars

**The sun isn't going to last forever. In around 5 billion years, it will have expanded to engulf the inner planets and belched its outer layers into space, leaving behind a small core called a white dwarf. This hardly seems like an ideal environment in which to find a habitable planet, but Thea Kozakis at Cornell University in New York thinks otherwise. "It's actually a pretty stable environment," she says. According to calculations published in April, she believes planets could exist in the habitable zone of a white dwarf for up to 8.5 billion years – longer than Earth's residence to date in the sun's habitable zone. The catch is that as white dwarfs kick out less heat than normal stars, the habitable zone would be much closer in. "The planet would orbit in a matter of days," she says. Unless the planet's orbit was almost perfectly circular, that would lead to tidal forces far greater than those on Earth.**

**Such planets would be easier to find than those in circumbinary systems – a combination of a**

small star and a close planet would lead to transits where up to 50 per cent of the white dwarf's light would be blocked, compared with 0.01 per cent for the sun and Earth. The trouble is that no one has really been looking for them. That could soon change, says Kozakis. "It may be possible to find them with Hubble and the upcoming James Webb Space Telescope."

Other people believe life around white dwarfs may be discovered another way: by seeking signs of a civilisation dealing with the demise of its star. John Gertz is on the board of the Search for Extraterrestrial Intelligence Institute, a US research organisation. In a paper published last November, he explored the dilemma an alien world would face as its star began to die. "I wanted to look at it from ET's point of view," he says. His ultimate conclusion is that fleeing a dying sun would be too difficult, forcing an advanced civilisation to undertake unprecedented engineering projects that Gertz thinks may be detectable. "White dwarfs have been added to the target list of Breakthrough Listen," he says, a $100 million project to scour the skies for alien signals. "We need to shift our entire paradigm of looking at stars for signs of life."

## LONE SURVIVORS

Planets without a star to orbit

If we are throwing out the established rules, then why bother with a star at all? Joseph Glaser at Drexel University in Pennsylvania studies rogue planets – orphan worlds ejected from their birth solar system to roam space alone. Glaser's modelling work, published in February, found that 38 per cent of solar systems lose a planet at some point. This suggests the universe is full of lone wanderers, with potentially hundreds of billions of them in the Milky Way alone.

Smaller planets like ours are the most likely to be ejected, especially those with rocky crusts. It also takes time for a planet to become unstable. "It can take half the lifetime of the star," he says. So what are the chances of an Earth-sized rocky planet in the habitable zone going rogue? According to Glaser, "it's hard for it to happen, but it is definitely possible".

In fact, we have already found Earth-mass rogue planets thanks to a technique called gravitational microlensing. If planets pass in front of a distant, unrelated star, their gravity acts as a lens that temporarily magnifies its light. The duration of these events, which can last from hours to weeks, depends on the mass of the planet. "We recently found several events that lasted a few hours," says Przemek Mróz at the California Institute of Technology. "These events are caused by Earth-mass planets."

Mróz estimates that there are between one and three Earth-mass rogue planets for each star in the Milky Way, which itself contains at least 100 billion stars. We could

## LUNAR LIFE

Moons where the conditions are just right

**Maybe we shouldn't only be considering planets as places where life might exist. "The largest amount of habitable real estate in the universe could be in the form of moons," says Jesper Tjoa at the Max Planck Institute for Solar System Research in Germany. We already know that some satellites of Jupiter and Saturn – including Europa and Enceladus – harbour subsurface oceans of liquid water, despite being far outside the habitable zone of the sun. "If this is replicated around other stars, then habitable moons would vastly outnumber habitable planets," says Tjoa.**

**In research published in April, he discussed a "subsurface habitable zone". By modelling the interiors of small, icy moons, he found that the gravity of the planet they circle is more important than heat from the sun. Moons are stretched and squeezed as they orbit, and those distortions inject enough tidal energy to melt the subsurface ice. "It is, in principle, possible to have a habitable moon a thousand times further from the sun than Earth, as long as you have the right planetary environment," says Tjoa. The more the moon's orbit deviates from a circle, the better. Upcoming telescopes such as PLATO, a space-based observatory due for launch in 2026, should be able to find moons the size of Ganymede, the solar system's largest satellite, which orbits Jupiter and has a diameter almost half that of Earth's.**

### NEW MOONS

**Not all habitable moons have to exist in such far-flung locations, however. Gas planets in a sun's habitable zone could possess warm, rocky moons not dissimilar to Earth. José Caballero at the Spanish Centre of Astrobiology was part of a team that recently looked at moons in the habitable zone of smaller, cooler and very long-lived stars called red dwarfs. They started by looking at more than 100 red dwarfs already known to have exoplanets orbiting them, before modelling the long-term stability of hypothetical moons. Out of all of these systems, "four planets in the habitable zone could host stable moons", says Caballero. The number is relatively low because you need a very big planet to prevent the moon from being pulled out of orbit. "It would be similar to the planet Polyphemus and its moon Pandora in the movie *Avatar*," says Caballero.**

**According to the study, published last December, these four moons – if they exist – would range in size from that of Earth's own satellite up to Saturn's largest moon, Titan. Crucially, the team's calculations predict that this quartet of moons could remain in orbit around their gas giant planets for a period equal to the current age of the universe, plenty of time for life to emerge and evolve.**

**"The largest amount of habitable real estate could be in the form of moons"**

soon be finding a lot more of them thanks to the Nancy Grace Roman space telescope that will launch in 2026 and observe microlensing events. "It will be a revolution similar to Kepler 10 years ago," says Etienne Bachelet at Las Cumbres Observatory, referring to Kepler's discovery of thousands of exoplanets orbiting stars. Bachelet co-authored a paper last year on the impact the new mission will have on finding rogue planets. "It's going to detect a lot of them and we'll have a better understanding of how many there are in the galaxy," he says.

The big question is whether primitive life can persist on a once-habitable planet if it no longer has a star as its primary energy source. To survive, it might have to rely on heat from within, partly due to radioactive decay below the surface. For Earth, this is 15,000 times less than the energy we receive from the sun. "The planet will freeze unless it has a thick atmosphere," says Mróz, "but you never know – nature is unpredictable." ▮

Colin Stuart is an astronomy author and speaker. You can follow him on Twitter @skyponderer