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WEEKLY May 8–14, 2021

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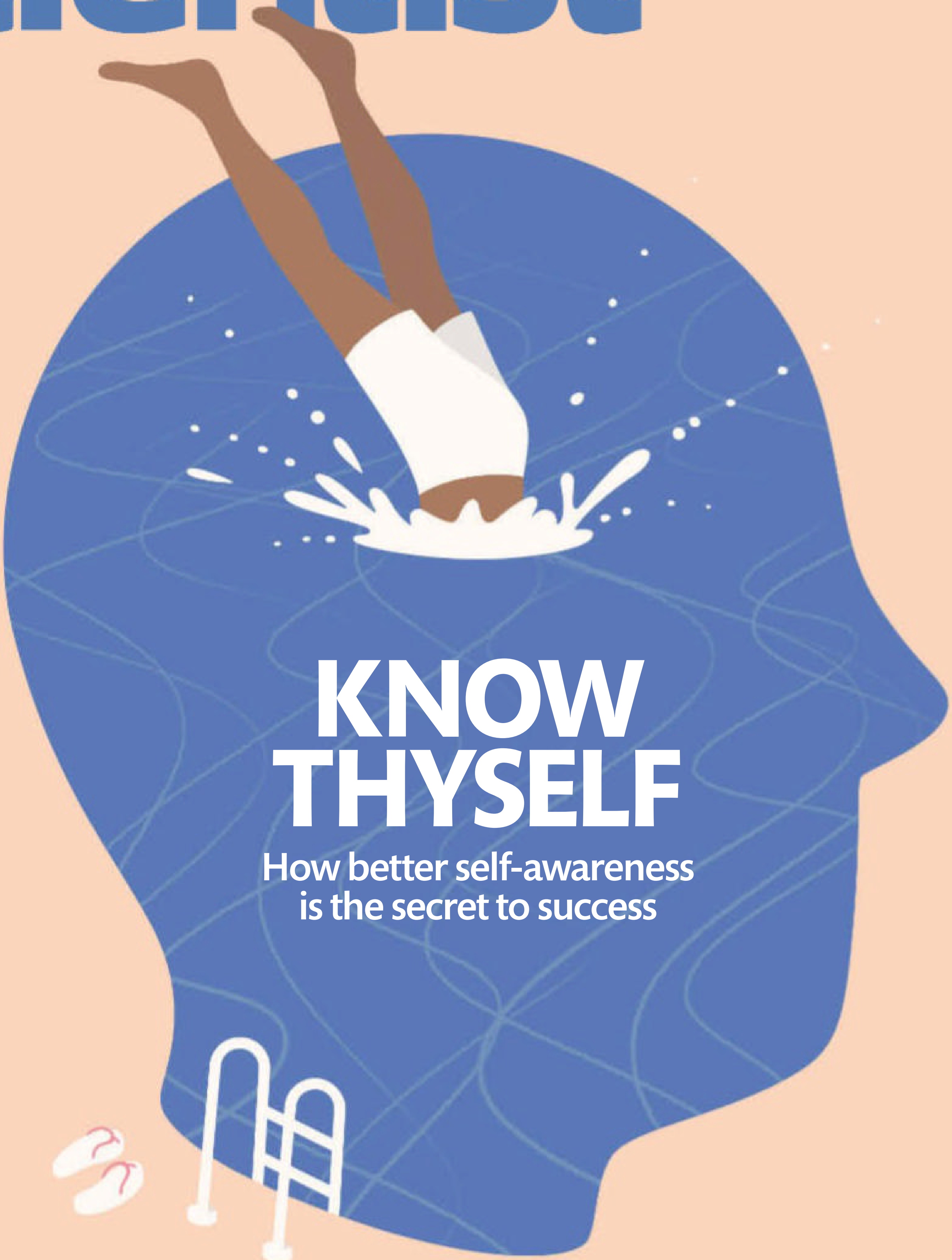

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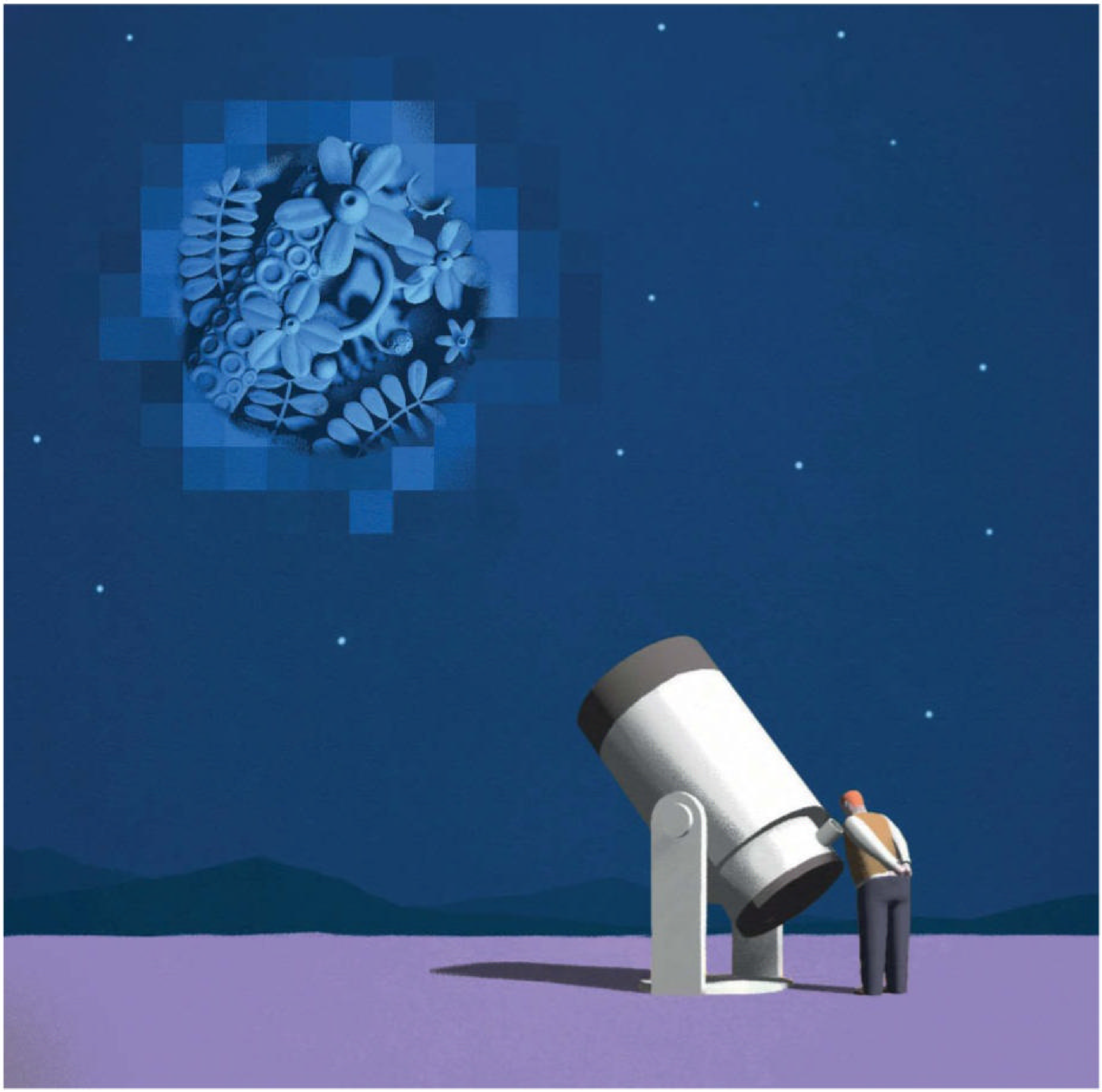

STUART MCREATH

Far-flung flora

A new way to decipher the light from distant worlds could give us unmistakable evidence of extraterrestrial photosynthesis, and maybe alien plants, finds **Colin Stuart**

PALM trees with crimson fronds sway in the breeze as waves lap at a shore warmed by an alien sun. Rock pools are lined with something kelp-like, blue lichens carpet every boulder and strange flowers spring from the dunes beyond.

Astronomers are in little doubt that a plant-filled planet exists beyond our solar system, even if they aren't entirely sure what the flora would look like. The universe isn't short of worlds that could host life. Extrapolating from the 4000 or so exoplanets we have identified so far, NASA researchers recently estimated that there could be around 5 billion habitable planets in our galaxy alone. The challenge is to show that one of them is indeed inhabited.

A small army of astronomers are devoted to the task, scouring light that passes through alien atmospheres for hints of bacteria or plants. It is a vibrant enterprise, but at best it provides circumstantial evidence. Astronomers have long known there is a better way – that searching for light reflected off the surface of an exoplanet offers greater chances of success. "It gives you the chance to look directly for living material itself," says William Sparks at the SETI Institute in Mountain View, California.

The problem was that it was impossible. But recent breakthroughs suggest we can finally tease out the portion of reflected light that would betray unambiguous signs of photosynthesis from other worlds. The telescopes we need are already under construction. In the meantime, the race is on to figure out just what to look for. Astronomers are now working to identify the reflected signatures of verdant vegetation on Earth as a guide to what they should seek on alien worlds.

When it comes to searching planets beyond our solar system for signs of life, astronomers have focused primarily on atmospheric biosignatures. There is a huge amount of oxygen in Earth's atmosphere, for example, produced by plants, trees and photosynthesising microorganisms adrift on the open ocean. It is a similar story with methane, which is produced by bacteria, rotting vegetation and ruminant beasts.

But teasing out traces of these gases on other worlds is fraught with difficulty. As light from the host star passes through the planet's atmosphere, different colours are absorbed depending on which gases are present. The resulting gaps in the spectrum we see from Earth tell us what the planet's atmosphere is made of. You need a big telescope to separate the light into its constituent parts with sufficient resolution, however, and for the most part that means you are limited to ground-based instruments. The snag there is that the starlight then has to pass through Earth's atmosphere, too, where terrestrial oxygen leaves its own mark. This is just one of many ways to get a false positive.

"We've been waiting two decades for a breakthrough like this"

We could remove the complicating effects of our atmosphere with a large space telescope like the James Webb observatory, due to launch in October. Even then, though, these signatures are far from clear cut. Oxygen could be coming from water being broken into its constituent parts by sunlight, for example, and methane could be billowing from volcanic vents rather than decaying plants. "The growing consensus is that we won't be certain of anything we find," says Sara Seager at the Massachusetts Institute of Technology. "For every scientist who can find a way for life to produce that gas, there's another who can find a way it can be produced without life."

Twenty years ago, Seager was among the first to explore an alternative way to study exoplanets using light. To understand it, think about light as an electromagnetic wave. Usually the light we encounter from the sun or a light bulb is unpolarised – the wave vibrates in various directions. Polarised light, on the other hand, is restricted to vibrating only in certain directions. It just so happens that starlight is polarised when it reflects off a planet's surface, and the way it is polarised should contain clues about exactly what is doing the polarising – including life.

This is what attracted Seager and others to polarimetry, or the measurement of polarised light. Whereas atmospheric biosignatures are ambiguous, signatures coming directly from the surfaces of alien worlds – encoded in polarised light – would provide more reliable clues.

Polarised light might make it possible to nail down the presence of liquid water on other planets, for example. Looking for signatures in atmospheres will only show water as vapour in the highest layers of the air. Polarimetry can detect clouds of liquid water droplets and maybe even oceans, as sunlight glinting off water is strongly polarised. "You can even analyse wind speeds and wave heights," says Michael Sterzik at the European Southern Observatory in Chile, because they alter the way the ocean reflects newly polarised sunlight back into space. "Polarisation is the most promising technique for characterising Earth-like exoplanets," says Sterzik.

But it might get even better than that. In the best-case scenario, polarised light could dazzle us with unmistakeable evidence of biology. This would come in the form of signature oscillations in light waves that can only be caused by the chemical structure of the chlorophyll molecules involved in photosynthesis, the process by which plants and some bacteria on Earth convert sunlight into sugars.

The catch is that polarised light reflecting off distant planets is extremely difficult to observe. For starters, it is dimmer than light coming directly from a star via an ›

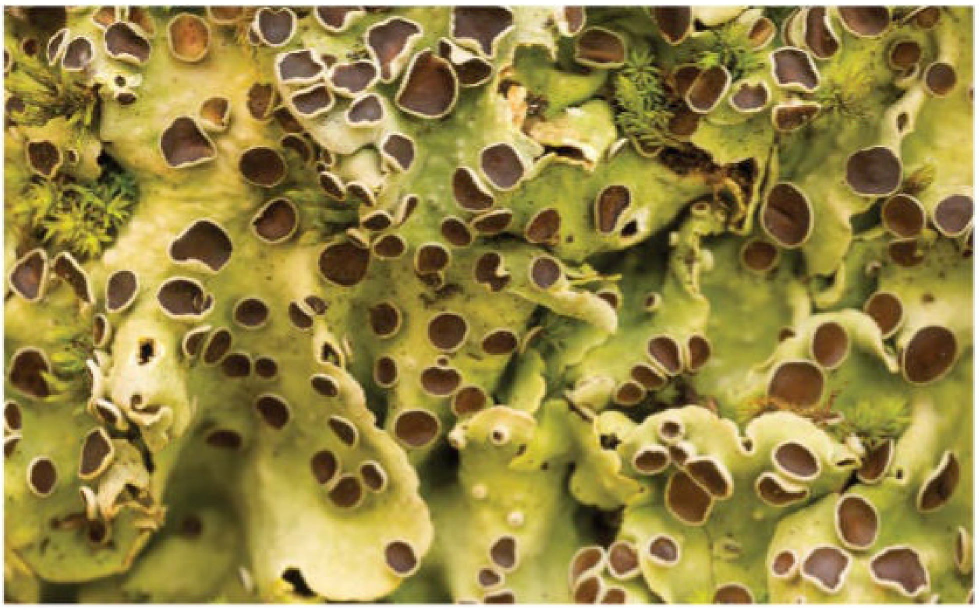
Black grass, blue leaves

If there are plants on other planets, what might they look like? We don't know. But astrobiologists have offered some informed speculation.

Plant life on Earth evolved to suit the conditions provided by the unique properties of our sun and our planet's atmosphere. Most of the light that reaches Earth's surface is in the red part of the visible spectrum, which is thought to explain why chlorophyll, the cellular machinery behind photosynthesis, absorbs mostly red light and reflects green. That is why plants are green.

Evolution is very sensitive to environment, so plant life on worlds unlike ours could be quite different to the flora we know. Many of the exoplanets that we consider the most habitable orbit red dwarf stars, which are smaller and cooler than our sun. Researchers have speculated that plants in these systems could have photosynthetic pigments that render their leaves red, yellow, purple or even blue. It all depends on the dominant colour of the light hitting a planet's surface.

If the host star is particularly dim or distant, plants might even appear black to human eyes because they would need to absorb more parts of the visible spectrum to photosynthesise. Researchers have also suggested that plants on worlds subject to serious solar flares might secrete some sort of natural sunscreen.



CHRIS MATTISON/NATUREPL.COM

Lichen on other planets would twist light in a particular way

atmosphere. Then there is the fact that only one per cent of the reflected light is polarised, making the signal fainter still. "We've tried several times and failed," says Seager. "I never thought we'd see it."

Now, finally, we have. In January, two separate teams announced they had detected polarised light from an exoplanet. A group led by Rob van Holstein at Leiden University in the Netherlands was first, using the Very Large Telescope in Chile to capture polarised infrared light from a disc of dust and gas surrounding the exoplanet DH Tau b. Less than a fortnight later, a team led by Jeremy Bailey at the University of New South Wales in Australia announced the detection of polarised starlight reflected off 51 Pegasi b – the first exoplanet discovered around a sun-like star.

Neither planet is Earth-like – both have masses greater than Jupiter. But the detections are a big breakthrough. "We've been waiting two decades for this," says Bailey.

The challenge now is twofold. First, astronomers have to refine the detection techniques so that we can repeat the feat for smaller, Earth-like planets. The smaller a planet and the further away it is from its star, the fainter the light reflected off its surface will be. Second, and most importantly, we have to figure out what signatures plant life would leave in any polarised light we can detect.

That isn't going to be easy, but polarimetry does at least make it possible because there is something unique about the way life – and plants in particular – polarise light. The reflected light from clouds and oceans is linearly polarised, meaning the wave vibrates in line with the direction in which it is travelling. Plants, on the other hand, impart circular polarisation: the reflected light wave rotates in a plane at right angles to the direction of travel.

There are non-living things that can produce this signal, but the chlorophyll in plants does it in a unique way. Whether the rotation of polarisation is clockwise or anticlockwise depends on the chirality, or handedness, of the molecules doing the polarising. Look at your hands for a moment. They are mirror images of one another, but you cannot perfectly superimpose one on top of the other. This is what chiral means.

In chemistry, molecules also exist in similar left-handed and right-handed orientations. When non-biological materials impart circular polarisation, each handedness is produced in equal quantities. But life on Earth only uses amino acids that are left-handed and sugars that are right-handed. This exclusivity is called homochirality and it is something Sparks thinks we could see in the polarised light from an Earth-like exoplanet. Seeing at least a 60:40 split between the two orientations would be enough to suggest life, he says, as there is nothing else we know of that could be behind a divergence from 50:50. "It's a more unique biosignature," says Sparks.

It was long thought that circular polarisation signals would be thousands of times weaker than their linear counterparts, and therefore

"There is something unique about the way life, and plants in particular, polarise light"

far too faint to see. But Sparks has recently called that assumption into question. His experiment involved shining unpolarised light at cultured bacteria that photosynthesise without producing oxygen. In October 2020, Sparks and his colleagues showed that up to 1 per cent of the light reflected off these bacteria was circularly polarised – about the same as the linear polarisation signal. "It's stronger than we thought," he says.

In a further twist, they found the signal was highest when the bacteria broke down and released raw pigments into their environment. "It means we're not looking for life," says Sparks. "We're looking for death." The result backs up an earlier find from Lucas Patty at the Institute of Plant Biology in Hungary, who is one of Sparks's co-authors. In 2019, he showed that the circular polarisation signal linked to brown algae can be as high as 2 per cent.

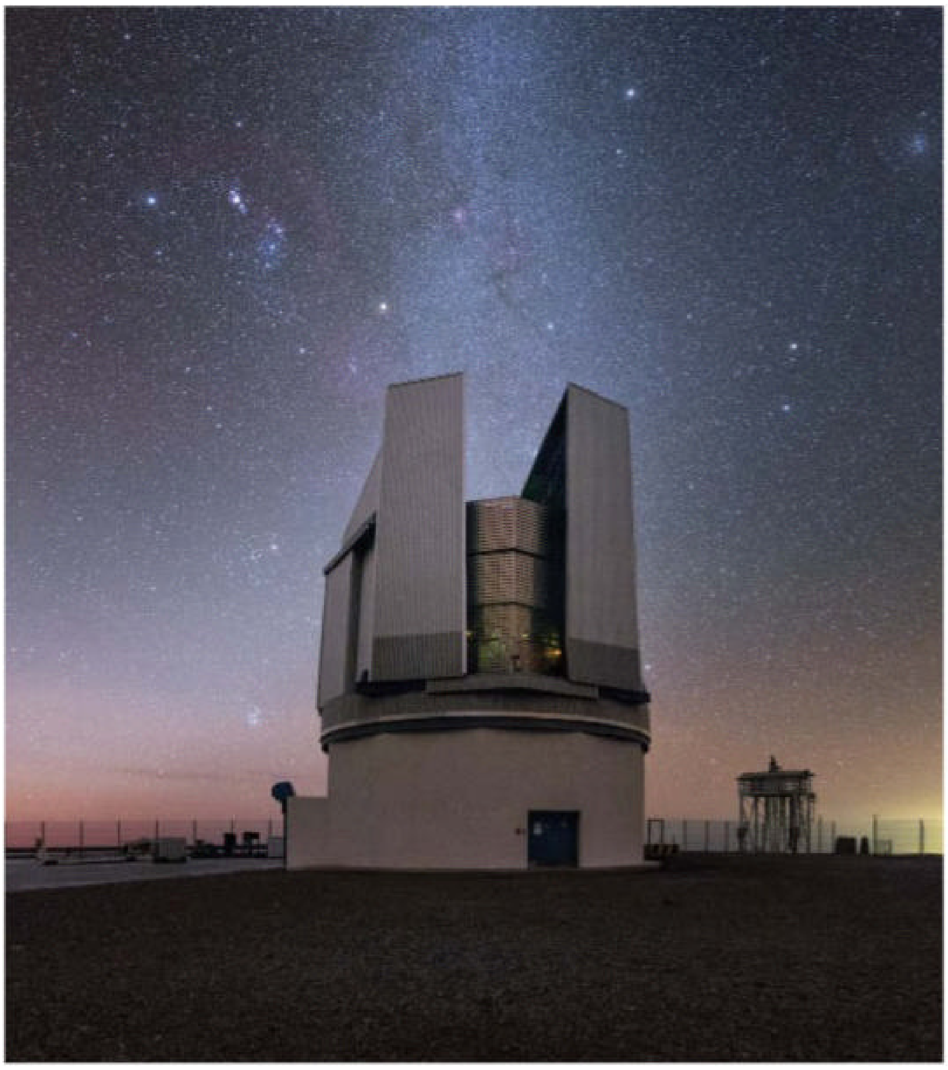
But even if the polarisation signal from alien photosynthetic life is stronger than we would expect, would we really be able to detect it across the vast swathes of space? "There's no denying it's going to be difficult," says Sparks. "We're just beginning to understand the interaction between light and life."

Fortunately, we live on a perfect test planet. Sterzik has been using the Very Large Telescope to look at the light of our own planet reflected back to us by the moon, known as earthshine. This includes some of the polarised light bouncing into space from plants on Earth, and Sterzik was able to distinguish visible areas of vegetation in the signal. "It is surprisingly straightforward to use polarimetry in this way," he says.

Sterzik also noticed something else that surprised him. "We saw more polarisation in the red part of the spectrum than expected," he says. Leaves of deciduous plants are particularly good at reflecting light at the crossover between the visible and infrared parts of the spectrum. This so-called red-edge is also a potential biosignature. If it turns out to be even stronger when observed by its polarisation, that could offer us another robust way of looking for plants on distant planets.

But we can do better still. With earthshine, you have to disentangle the effect of the lunar surface on the signal. Strapping a polarimeter to the International Space Station could get around this issue, but you still can't see the whole planet at once. "We can't do this properly until we step away from the Earth and take a selfie from the moon," says Dora Klindžić, part of the team at Leiden University involved in spotting the polarisation signal from DH Tau b.

Klindžić is the driving force behind the Lunar Observatory for Unresolved Polarimetry of Earth (LOUPE) mission. Last November, she outlined her idea to piggyback a polarimeter onto a future trip to the moon and drink in the polarised light from Earth as it hits the lunar surface. Rather than capturing a beautifully focused image of Earth, like the famous ones taken by the Apollo astronauts, LOUPE would cram all of Earth's light into a single, unresolved pixel. The idea is to mimic the way we see the light from distant exoplanets.



ESO/Y.BELETSKY

The Very Large Telescope in the Atacama desert, northern Chile

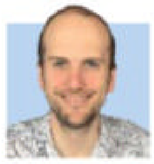
Moonshot

By untangling the polarisation signals LOUPE detects, we can match them to known features of Earth's biosphere. That way, when we turn to the wider universe, we know exactly the kind of polarisation biosignatures we are looking for. There is a chance it could help us tell the difference between signatures from photosynthetic bacteria and more conventional plant life – something that both Sparks and Patty say is currently beyond us.

We shouldn't have to wait too long, either. "Within a year or so we may have the first prototype to test," says Klindžić. With the moon the subject of growing interest both from government space agencies and private companies, there will be no shortage of missions on which to hitch a ride.

The other big project in the pipeline is the Extremely Large Telescope, which is currently under construction in the Atacama desert in Chile. Its primary mirror will be a whopping 39 metres in diameter – compared with 8.2 metres at the Very Large Telescope – and it will come equipped with a next-generation spectropolarimeter. "I definitely believe that detecting rocky exoplanets and characterising them is possible with the ELT," says van Holstein.

All of which adds yet more impetus to the race to understand how life on Earth – and plants in particular – polarise sunlight. "What we're doing now is something we're really going to cash in on once the next generation of telescopes comes out," says Klindžić. It could well herald the dawn of a new era in our search for life elsewhere, one that gives us the best chance yet of answering that age-old question: are we alone in the universe? ■



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