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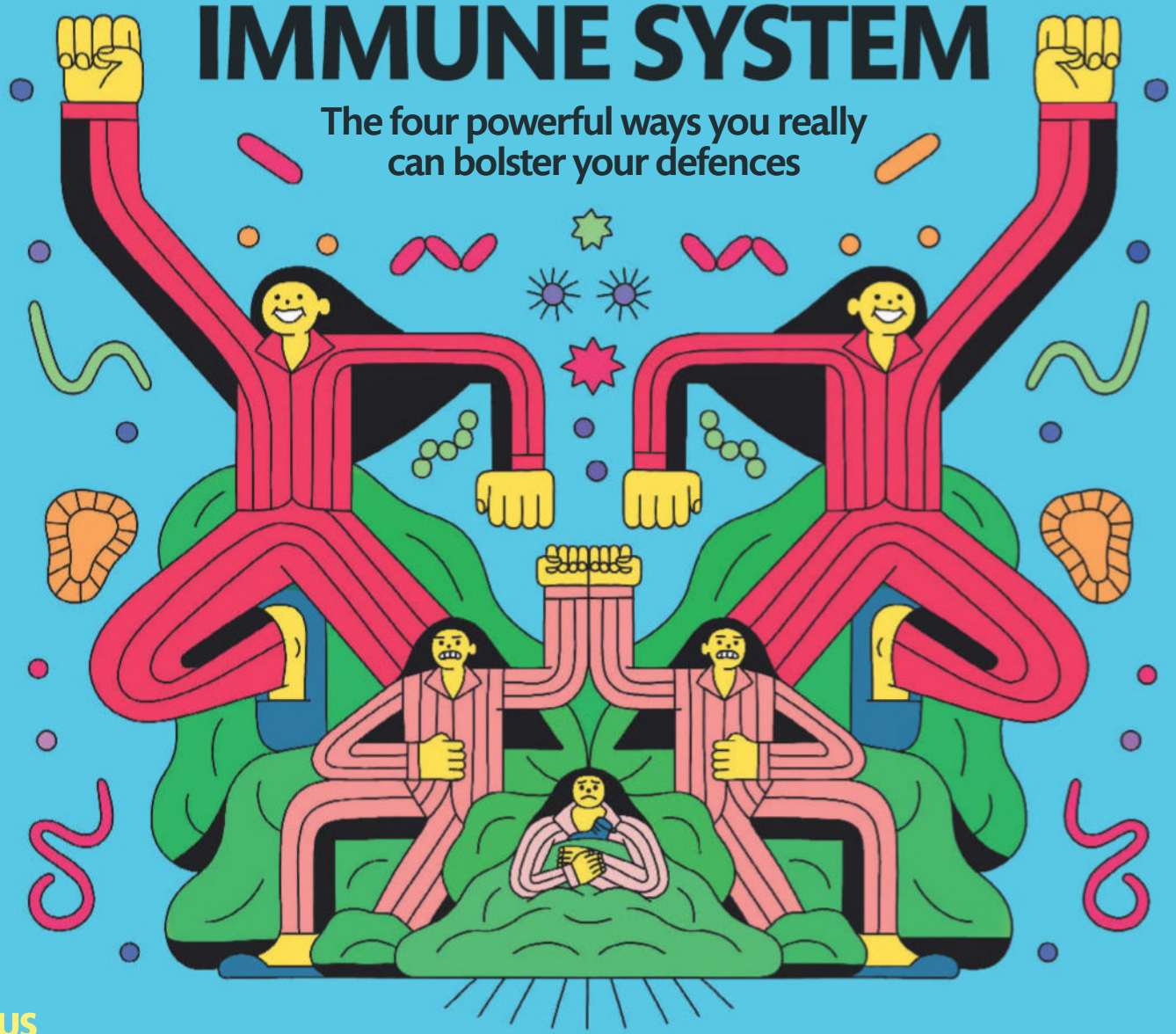

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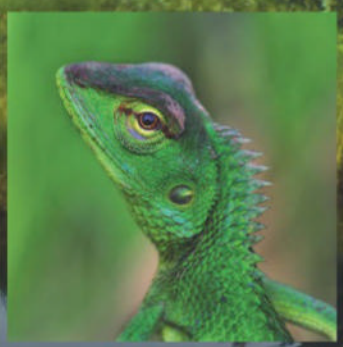

Insect and ecosystems safari: Sri Lanka

30 March 2026 | 11 days

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Alaskan brown bear, ecology and wilderness adventure: US

9 August 2026 | 6 days

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5 September 2026 | 16 days

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Yellowstone National Park and Grand Teton wildlife safari: US

28 July 2026 | 5 days

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- Track elusive wolf packs, witness vast herds of bison and elk and spot grizzlies and eagles in their natural habitat, all while gaining insight into the ecology, behaviour and predator-prey dynamics that shape this extraordinary landscape
- From sweeping sagebrush valleys to geyser-dotted plains, each day is crafted to maximise wildlife encounters

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The four powerful ways you really can bolster your defences

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Cover image: Cristina Spanò

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"For long-term immune power, we must look to our microbiome"

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MIKEBAGLEY64/GETTY IMAGES

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The back pages

Health by numbers

New Year's resolutions work only if you know what to measure

AS 2025 draws to a close, it is traditional to look back at the year that was and forward to what may come next. Many of us will be considering New Year's resolutions, such as getting fitter, eating better and boosting our immune system – but how do you know if your new habits are truly working?

To start with, "boosting" your immune system is a misnomer, since an overactive immune defence would be a bad thing, but as new research is revealing (see page 26), it is possible to assess our ability to fend off infection by measuring levels of certain immune cells. From this, your "immune grade" can reveal if you are fighting fit.

Tests alone aren't very useful, though, if you don't know what you are measuring. We are increasingly aware of the need to have a diverse gut microbiome, with numerous DIY faecal tests now for sale. The trouble is, no one agrees which microbes give you a high score. That should soon change, thanks to a study using the Zoe health app, which can now score the overall health of your microbiome from 0 to 1000 (see page 11).

"Boosting your immune system is a misnomer, as an overactive immune defence would be bad"

That said, it is important not to be blinded by statistics. Body mass index (BMI), for example, is one of the most commonly used measures of health, but it is heavily flawed. It remains popular because it is a simple calculation of a person's weight relative to their height, yet this fails to take into account whether a person's weight is high because of excess fat, which can reflect poor health, or more bone and muscle mass. This is why researchers proposed a whole new definition of obesity earlier this year.

There are two things we can take from all of this. The first is that if you are trying to make a change in your life, be sure that you have the right numbers to measure that change. It's no use pledging to get up early to exercise each day if you measure success by what time your alarm goes off. The second is that the science of what works is always changing, and you should aim to keep up with the best evidence available. Of course, if you're reading this, you are already off to a good start. ▮

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Zoology

Tiny toadlet catches the eye

This miniature frog, less than 14 millimetres in length, is barely bigger than a pencil tip. Found in the forests of Serra do Quiriri, Brazil, this new-to-science species of pumpkin toadlet frog has been named *Brachycephalus lulai*, after the country's president, Luiz Inácio Lula Da Silva. Researchers spotted the frog thanks to its unique mating call, and later confirmed it was a new species using DNA analysis.

LUIZ F. RIBEIRO/SWNS

Space

Black hole stars really do exist

Mysterious 'little red dots' seen by the James Webb Space Telescope can be explained by a new kind of black hole enshrouded in an enormous ball of glowing gas, finds **Alex Wilkins**

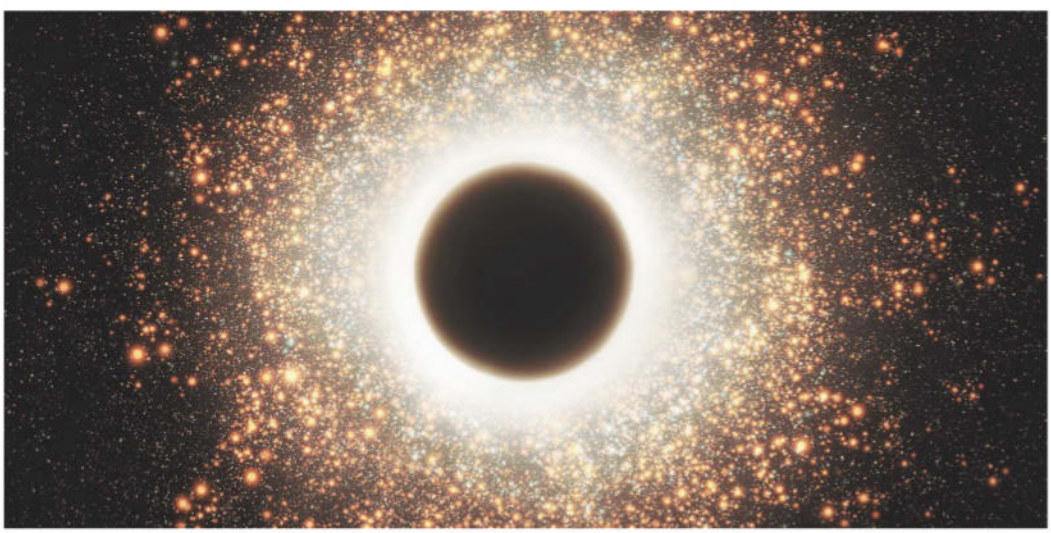
THE early universe appears to be littered with enormous, star-like balls of gas powered by a black hole at their core, a finding that might solve one of the biggest mysteries thrown up by the discoveries of the James Webb Space Telescope (JWST).

When JWST first began peering back to the universe's first billion years, astronomers found a group of what looked like extremely compact, red and very bright galaxies unlike any we can see in our local universe. The most popular explanations for these so-called little red dots (LRDs) were supermassive black holes with dust swirling around them, or galaxies very densely packed full of stars – but neither one fully made sense of the light JWST was detecting.

Earlier this year, astronomers proposed instead that LRDs were dense spheres of gas with a black hole at their centre, called black hole stars. "When material falls into the black hole, a lot of gravitational energy is released, and this could make the whole ball of gas around it glow like a star," says Anna de Graaff at Harvard University. Although the energy doesn't come from nuclear fusion, as in a regular star, the effect is a similar glowing ball of dense gas, just on a far bigger scale, says de Graaff. However, while some LRDs supported this interpretation, it was still controversial.

"The black hole star model was thought to be so weird and out there, but it does seem to work"

Now, de Graaff and her colleagues have analysed the widest sample of LRDs since JWST began its observations, including more than 100 galaxies, and concluded they are best explained by star-like objects, or black hole stars (arXiv, doi.org/qjdp).



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Balls of gas with black holes at their centre could glow like stars

"The name black hole star is, for sure, still controversial, but I do think that there is now a decent consensus in the community that we are looking at an accreting black hole that's enshrouded in dense gas," says de Graaff.

When the team looked at the brightness of light at different frequencies, called a spectrum, coming from the LRDs, the patterns best matched light coming from a single, relatively smooth surface, called a blackbody. This is also how stars appear, in contrast to the more complicated and spiky spectra seen from galaxies, which produce their light from a combination of stars, dust, gas and a central black hole.

"The black hole star model has been around for a while but was thought to be so weird and out there, but it actually does seem to work," says Jillian Bellovary at the American Museum of Natural History in New York.

In September, de Graaff and her colleagues also found a separate, single LRD that had an extremely sharp peak for a frequency of light coming from galaxies, which they nicknamed "The Cliff". "We saw certain features in the spectrum that truly could not be explained by any of our existing models," says de Graaff.

Shine a light

While many astronomers agree LRDs appear to function like vast stars, it will be difficult to prove that what is powering them is a black hole, says de Graaff. "The centre of this object is embedded in this envelope that is very, very dense, or optically thick," she says.

One way of proving they are black holes is by looking at how the light coming from them alters over time, and seeing if they vary like we know black holes do in our local universe, says Xihan Ji at the University of Cambridge. "You see the brightness changing on relatively short timescales, like months or even days, but for these little red dots, there seems to be very little evidence of this variability most of the time."

It can be difficult to look for evidence of longer variations in light from LRDs because JWST has only a limited time to make its observations, but another recent study could give some indication. Fengwu Sun at Harvard University and his colleagues found an LRD whose light had been bent around a very massive galaxy sitting between it and Earth, called a gravitational lens. The lens produced four images of the original LRD, but because the light for each image had travelled different distances to reach us, each one was equivalent to looking at the LRD at different snapshots over a 130-year period.

The four snapshots appear to show a variability in brightness similar to known pulsating stars, but hinting at a far greater width, consistent with the black hole star hypothesis. Sun and his team declined to speak with *New Scientist* for this story.

While using a gravitational lens to measure the LRD at different times is clever, there could be other explanations for this variability, says Bellovary. ▮

Physics

Qubits break quantum limit to encode information for longer

Karmela Padavic-Callaghan

THE odd phenomenon of quantum superposition has helped researchers break a fundamental quantum mechanical limit – and given quantum objects properties that make them useful for quantum computing for longer periods of time.

For a century, physicists have been puzzled by exactly where to draw the line between the quantum world of the small and the macroscopic world that we experience. In 1985, physicists Anthony Leggett and Anupam Garg devised a mathematical test that could be applied to objects and their behaviour over time to diagnose whether they are big enough to escape quantumness. Here, quantum objects are identified by the unusually strong correlations between their properties at different points in time, akin to their behaviour yesterday and tomorrow being unexpectedly related.

Objects that score high enough on this test are deemed to be quantum, but those scores were thought to be limited by a number called the temporal Tsirelson's bound (TTB). Even definitively quantum objects, theorists thought, couldn't break this bound. Now, Arijit Chatterjee at the Indian Institute of Science Education and Research in Pune and his team have devised a way to dramatically break the TTB with one of the simplest quantum objects.

They focused on qubits, which are the most basic building blocks of quantum computers and other quantum information processing devices. Qubits can be made in many ways, but these researchers used a carbon-based molecule that contained three qubits. They used the first qubit to control how the second "target" qubit behaved for some amount of time. Then, they used the third qubit to extract the properties of the target.

A three-qubit system is expected to be limited by the TTB, but Chatterjee and his colleagues found a way for the target qubit to break the bound in an extreme manner (*Physical Review Letters*, doi.org/hbcnxs). In fact, their method produced one of the biggest violations that seems mathematically plausible. Their secret was making the first qubit control the target qubit with a quantum superposition state. Here, an object can effectively embody two states, or behaviours, that seem mutually exclusive.

"This finding fundamentally expands our understanding of how quantum objects behave over time"

A qubit normally falls victim to what is known as decoherence as time goes on – meaning its ability to encode quantum information erodes. But when the target qubit had broken the TTB, decoherence came later and it maintained its ability to encode information for five times as long, because its behaviour across time was being controlled by a superposition.

Chatterjee says this robustness is desirable and useful in any situation where qubits must be precisely controlled, such as for computation.

Le Luo at Sun Yat-Sen University in China says that, in addition to having clear potential for improving quantum computing protocols, the new study also fundamentally expands our understanding of how quantum objects behave over time. ▮

Climate change

Some Arctic warming may be 'irreversible'

LOOK-FOTO/IMAGE PROFESSIONALS GMBH/ALAMY

High ocean temperatures could keep the Arctic warm, even with lower emissions

THE Arctic may retain about 1.5°C of warming even if the carbon dioxide in the atmosphere returns to pre-industrial levels.

"These findings highlight the irreversible nature of Arctic climate change even under aggressive CDR [carbon dioxide removal] scenarios," wrote Xiao Dong at the Institute of Atmospheric Physics in Beijing and his colleagues in their study.

This is because the ocean, which has absorbed 90 per cent of the heat from global warming, will continue heating the Arctic for centuries even if the atmosphere cools down.

"Even if you get the atmosphere cooling, the ocean will be lagging behind that," says Michael Meredith at the British Antarctic Survey.

Dong and his colleagues predicted the Arctic's potential to retain heat using 11 independent climate models. They analysed an abstract scenario where atmospheric CO_2 quadruples from pre-industrial levels over 140 years, declines for 140 years and then remains at pre-industrial levels for 60 years.

They also analysed a potential real-world climate scenario in which humanity immediately slashes emissions, as well as one in which we continue high emissions but then ramp up CDR starting in 2070. In these two scenarios, they found the Arctic is about 1.5°C warmer and receives an extra 0.1 millimetres of precipitation per day in 2100, which is the same as in the abstract scenario (*Environmental Research Letters*, doi.org/qjdq).

The models also predict that, unlike the rest of the far north, temperatures and precipitation will decrease over a swathe of ocean just south of Greenland and Iceland. This suggests the Atlantic Meridional Overturning Circulation (AMOC) will transport less warm water there. Research suggests the AMOC is already slowing as the global ocean warms, a trend that could eventually bring colder winters to Europe. ▮

Alec Luhn

Health

Ejaculation timing is key for IVF

Men should abstain from ejaculation for less than two days before providing a sperm sample

Helen Thomson

MEN should ejaculate less than 48 hours before in vitro fertilisation egg collection to maximise the chances of it leading to an ongoing pregnancy, according to the first clinical trial to test how different ejaculation abstinence intervals affect the success of the fertility treatment.

Towards the end of an IVF cycle, the woman takes a "trigger" drug that pushes developing eggs to maturation. This is injected 36 hours before the eggs are collected and fertilised.

To ensure the healthiest possible sperm for fertilisation, men are usually advised to ejaculate within a window of between two and seven days before providing the sample that will be used for IVF. "There is an optimal period between ejaculations when sperm are at their best," says David Miller at the University of Leeds, UK, who wasn't involved in the trial.

But two to seven days is a wide range. On the one hand, the longer sperm are stored in the testes, the longer they are exposed to various toxins, most notably free oxygen radicals, which form naturally during metabolic processes. This can cause DNA damage and impair sperm quality, says Richard Paulson at Keck School of Medicine of USC, Los Angeles, who also wasn't involved in the trial. But too short a time between ejaculations reduces sperm numbers.

"There is an optimal period between ejaculations when sperm are at their best"

Until now, there hasn't been any robust clinical data that shortening the ejaculation interval translates into improved pregnancy outcomes, but there have been hints. For instance, a 2024 meta-analysis found that leaving less than four days between ejaculations improved semen quality in men who are infertile. Another study reported that an interval of less than 4 hours reduced the amount of sperm that had DNA damage and improved sperm motility.

To test the idea directly, Yang Yu at First Hospital of Jilin University in Changchun, China, and his team asked 226 men undergoing conventional IVF to ejaculate around 36 hours before producing their final sample. Another 227 were asked to ejaculate between 48 hours and seven days beforehand.

The group with the shorter abstinence interval had higher ongoing pregnancy rates – 46 per cent compared with 36 per cent (*Preprints with The Lancet*, doi.org/qjc7). "The better pregnancy rate looks encouraging," says Miller, "but of course, this doesn't necessarily reflect, fully, the final treatment outcome, which is live birth rate." Nevertheless, he says because the miscarriage rate was lower (although not statistically so) in the shorter abstinence group, he would expect more live births, too.

Paulson says that while the study makes an interesting observation, it has weaknesses, such as including both fresh and frozen embryos, when IVF success rates may vary between the two. He also points out that the data shows a decreased fertilisation rate but an increased number of ongoing pregnancies in the shorter interval group, suggesting fewer couples conceived, but of those who did, more continued past 12 weeks, which needs more careful analysis. ▮

Marine biology

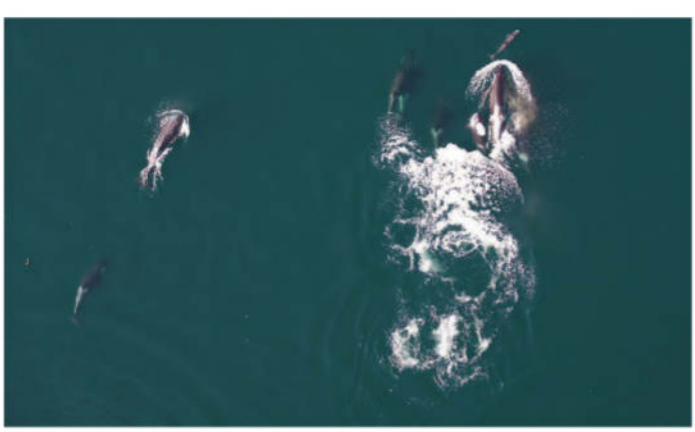
Dolphins seen scouting salmon for their orca 'friends'

KILLER whales and dolphins have been working together to hunt salmon in the northern Pacific Ocean, an unexpected finding that further reveals the complex social lives of marine mammals.

Video cameras and sensors attached to nine killer whales – also known as orcas – showed four of them diving with numerous Pacific white-sided dolphins towards Chinook salmon hiding in the depths off northern Vancouver Island. Three more whales were observed by drone. The orcas ate the salmon, while the dolphins scavenged the scraps (*Nature Scientific Reports*, doi.org/hbfgfz).

"They were cooperatively foraging," says Sarah Fortune at Dalhousie University in Canada. "You could anthropomorphise it and say that they're being friends."

Also known as king salmon, Chinook salmon can grow more than a metre long and are often too big for dolphins to eat.



UBC (A. TRITES), DAL (S. FORTUNE), HAKAI I. (K. HOLMES), IZW (X. CHENG)

A dolphin joins a pod of killer whales off the coast of British Columbia, Canada

But northern Vancouver Island whales are messy eaters and often tear fish apart to share with family, leaving blood, scales and fragments for dolphins to consume. The dolphins help whales "scout" out salmon, the researchers believe.

Six out of the 12 whales interacted with the dolphins, orienting to face them a combined total of 102 times in the videos. Four dived with dolphins as deep as 60 metres, where salmon can take cover among rocks and crevasses.

While both species emitted clicks and buzzes, the sensor data revealed that whales often reduced their echolocation – apparently to "eavesdrop" on the dolphins. Since echolocation is narrowly focused like a spotlight, a large number of dolphins scanning the water may improve a whale's chances of finding fish, says Fortune.

"It's like turning on the high beams" on a car, she says, "and the light is the sound." ▮

Alec Luhn

Gene editing

Trick to block the spread of malaria passes key test

Michael Le Page

A GENETIC technology known as a gene drive could help prevent malaria by spreading genes in wild mosquitoes that stop them transmitting the parasite. Tests in a lab in Tanzania have now confirmed that one potential gene drive should achieve this if it were released in the country.

"It would be a game-changing technology, that's for sure," says George Christophides at Imperial College London.

A specific piece of DNA in the genome of an animal is normally passed on to only half its offspring, because a parent's DNA is divided in half among egg or sperm. Gene drives increase this proportion, meaning a bit of DNA can spread rapidly through a population even if it provides no evolutionary benefit.

There are many natural gene drives that work via all kinds of mechanisms. In 2013, biologists developed artificial gene drives using CRISPR gene-editing technology, which works by copying pieces of DNA from one chromosome to another.

The idea is to use these drives to spread bits of DNA that block malaria transmission – but which bits? Christophides reported in 2022 that the development of malaria parasites inside mosquitoes can be greatly reduced by two tiny proteins, one derived from honeybees

Anopheles gambiae mosquitoes transmit malaria

APURV JADHAV/ALAMY

and the other from the African clawed frog. The added genes for these antimalarial proteins can be linked to the gene for an enzyme that helps mosquitoes digest blood, so the antimalarial proteins are made after a mosquito feeds and get secreted into its gut.

But these tests were done using lab strains of mosquitoes and malarial parasites collected decades ago, so it wasn't clear if this approach would work in affected African countries today.

Now, researchers including Christophides and Dickson Lwetoijera at the Ifakara Health Institute in Tanzania have modified local *Anopheles gambiae* mosquitoes to produce the components of a gene drive

> "The hope is that this technology could help eliminate malaria from certain areas"

based on this approach (*Nature*, doi.org/qh66). The components were kept separate, meaning the gene drive cannot spread, and the mosquitoes were housed in a secure facility.

Tests show robust inhibition of malaria parasites taken from infected children, and also effective copying of the genes for the antimalarial proteins. "So we are now able to say that this technology could work in the field," says Christophides.

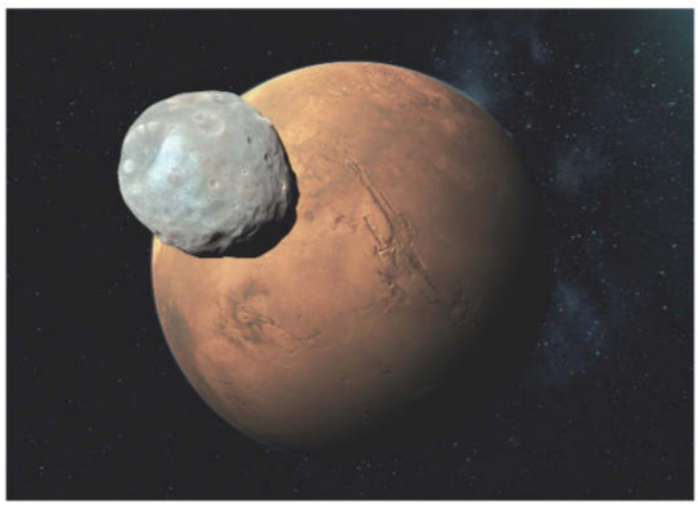
The next step is to see how mosquitoes that produce the antimalarial proteins behave in the wild.

The hope is that the gene drive could help eliminate malaria from areas where *A. gambiae* is the only species spreading malaria, says Christophides. ▮

Solar system

Mars may once have had a larger moon

Bas den Hond



DETLEV VAN RAVENSWAAY/SCIENCE PHOTO LIBRARY

Mars now has two moons, of which Phobos is the largest

A MARS crater may have once contained water that sloshed back and forth as a tide came and went. If that is true, Mars must have had a moon that was massive enough to exert a gravitational pull on the planet's seas sufficient enough to create tides – one that was bigger than either of its current moons.

Suniti Karunatillake at Louisiana State University and his team saw that traces of tidal activity seem to be preserved in thin layers within sedimentary rocks in Gale crater.

They analysed the layers to obtain the period of the tides and the properties of the moon that helped cause them. If it existed, it was 15 to 18 times as massive as Phobos, Mars's largest moon.

Karunatillake presented the results at the annual meeting of the American Geophysical Union in New Orleans, Louisiana.

The rocks the researchers base their conclusions on were imaged by NASA's Curiosity rover. They contain alternating layers of different thickness and colour. Such layers are called rhythmites, because they are a sign material was brought in by a wind or current with a regularly varying strength. In the case of tides, the incoming tide brings sand, which is covered with fine mud when the tide turns and the water is at a standstill.

The Gale rhythmites contain thin, dark lines suggesting such "mud drapes", which "show a very close similarity with Earth tidal patterns", says team member Priyabrata Das, also at Louisiana State University.

To strengthen their hypothesis, team member Ranjan Sarkar at the Max Planck Institute for Solar System Research in Germany used a mathematical technique called a Fourier transform to analyse the pattern of layering. This identified additional periodicities in the layer thicknesses, suggesting both the sun and a moon were once driving the tide, just like on Earth.

But not everyone is convinced. The lake inside Gale crater, which is 154 kilometres in diameter, was too small to have tides, says Nicolas Mangold at the Laboratory of Planetology and Geosciences in Nantes, France, and a member of NASA's Perseverance Mars team. ▮

Archaeology

Roman rule may have brought new diseases to Britain

Chris Simms

HISTORIC ENGLAND/HERITAGE IMAGES/SCIENCE PHOTO LIBRARY

The negative health impacts were most felt in urban areas

THE health of populations in Britain declined under Roman occupation, particularly in more urban areas.

There is a widely held belief the Romans brought civilisation to those they conquered, perhaps best exemplified in Monty Python's *Life of Brian*, in which John Cleese's character asks "What have the Romans ever done for us?"

Yet researchers are aware that there was a decline in the health of the population in Iron Age Britain after the Romans conquered the territory in AD 43 – and that populations thrived after they left.

Now, Rebecca Pitt at the University of Reading, UK, has studied 646 ancient skeletons, 372 belonging to children who were less than 3.5 years old when they died, and 274 from adult females aged between 18 and 45 years old. These came from 24 Iron Age and Romano-British sites across south and central England, dating from four centuries before Roman rule up until the fourth century AD, when they withdrew.

Pitt estimated the ages of the individuals from features of the pelvis in adults and from the teeth of the children. Looking at the experiences of potential mothers and infants together, she says, should give a better impression of the stressors affecting different generations.

Pitt examined the bones and teeth, looking for abnormalities such as lesions or fractures that could indicate tuberculosis, osteomyelitis or dental disease. She also used X-rays to look at the internal structures of bones, which can reveal changes to development caused by malnutrition or deficiencies in vitamin C and D.

Bone analysis suggests people had vitamin D deficiencies

REBECCA PITT

This revealed that the negative health impacts of the Roman occupation were concentrated in the two larger urban centres in the study – the Roman administrative towns of Venta Belgarum, now Winchester, and Corinium Dobunnorum or Cirencester (*Antiquity*, doi.org/qh75).

Overall, 81 per cent of the urban Roman adults had bone abnormalities compared with 62 per cent of people dating from the Iron Age, but the Iron Age and rural Roman cohorts didn't differ significantly. And just 26 per cent of Iron Age children featured such effects compared with 41 per cent of those in rural Roman settlements and 61 per cent in urban Roman sites.

"One of the things that was really apparent in the urban non-adults was rickets, which means that people weren't getting enough access to vitamin D from sunlight," says Pitt.

She suggests these health effects were down to new diseases the Romans brought with them as well as the class divides and infrastructure they introduced.

Martin Millett at the University of Cambridge says the finding is interesting, but he doesn't think it's necessarily an urban effect.

"These urban centres are not huge medieval towns with deep poverty and huge densities," he says. "What we may be seeing is an increasing differentiation between the rich and the poor." ▮

Solar system

There could be more Earth-like planets than we think

Alex Wilkins

EARTH may owe some of its properties to a nearby star that blew up as the solar system was forming – a pattern that could be ubiquitous across the galaxy.

The solar system used to be filled with heat-producing radioactive elements that quickly decayed. The heat from these elements drove off large amounts of water from the space rocks and comets that came together to form Earth, ensuring the planet had the right amount of water for life to develop.

It is unclear how these elements reached the solar system. Many are found in supernova explosions, but simulations of close-by supernovae struggle to produce the exact ratios of elements needed.

Now, Ryo Sawada at the University of Tokyo in Japan and his colleagues have found a supernova slightly further away, around 3 light

"The recipe for Earth is likely not a rare accident, but a process happening all over the galaxy"

years from the solar system, could produce the required elements in a two-stage process (*Science Advances*, doi.org/qh63). Some, such as radioactive aluminium, would be produced directly in the supernova and travel on shock waves to reach the solar system.

Then, high-energy particles called cosmic rays emanating from the supernova would follow and hit other atoms in the solar system's still-forming disc of gas, dust and rocks, to produce the rest.

Sawada and his team estimate between 10 to 50 per cent of sun-like star and planetary systems could have been seeded with radioactive elements in this way. "The recipe for Earth is likely not a rare accident, but a universal process happening all over the galaxy," says Sawada. ▮

What a healthy gut looks like

A map of the gut microbiome has identified the species of bacteria most associated with good health outcomes, as well as the ones that aren't, reports **Chris Simms**

WE OFTEN hear talk of things being good for our microbiome, and in turn, good for our health. But it wasn't entirely clear what a healthy gut microbiome consisted of. Now, a study of more than 34,000 people has edged us closer towards understanding the mixes of microbes that reliably signal low inflammation, good immunity and healthy cholesterol levels.

Your gut microbiome can influence your immune system, rate of ageing and your risk of poor mental health. Despite a profusion of home tests promising to reveal the make-up of your gut community, their usefulness has been debated, because it is hard to pin down what a "good" microbial mix is.

Previous measures mainly looked at species diversity, with a greater array of bacteria being better. But it is difficult to identify particular communities of organisms that are implicated in a specific aspect of our health, because microbiomes vary so much from person to person.

"There is a very intricate relationship between the food we eat, the composition of our gut microbiome and the effects the gut microbiome has on our health. The only way to try to map these connections is having large enough sample sizes," says Nicola Segata at the University of Trento in Italy.

To create such a map, Segata and his colleagues have assessed a dataset from more than 34,500 people who took part in the PREDICT programme in the UK and US, run by microbiome testing firm Zoe, and validated the results against data from 25 other cohorts from Western countries.

Of the thousands of species that reside in the human gut, the researchers focused on 661 bacterial species that were found in more than 20 per cent of the Zoe participants. They used this to determine the 50 bacteria most associated with markers of good health – assessed via markers such as body mass index and blood glucose levels – and the 50 most linked to poor health.

"Our body and microbiome are two complex systems that make one even more complex system"

The 50 "good bacteria" species – 22 of which are new to science – seem to influence four key areas: cholesterol levels; inflammation and immune health; body fat distribution; and blood sugar control.

The participants who were deemed healthy, because they had no known medical conditions, had about 3.6 more of these species than people with a condition, while people at a healthy weight hosted about 5.2 more of them than those with obesity (*Nature*, doi.org/qh8c).

The researchers suggest that good or bad health outcomes may come about due to the vital role the gut microbiome plays in releasing chemicals involved in cholesterol transport, inflammation reduction, fat metabolism and insulin sensitivity.

As to the specific species that were present, most microbes in both the "good" and "bad" rankings belong to the Clostridia class. Within this class, species in the Lachnospiraceae family featured 40 times, with 13 seemingly having favourable effects and 27 unfavourable.

"The study highlights bacterial groups that could be further investigated regarding their potential positive or negative impact [on] health conditions, such as high blood glucose levels or obesity," says Ines Moura at the University of Leeds, UK.

The link between these microbes and diet was assessed via food questionnaires and data logged on the Zoe app, where users are advised to aim for at least 30 different plants a week and at least three portions a day of fermented foods, with an emphasis on fibre and not too many ultra-processed options.

The researchers found that most of the microbes either aligned with a generally healthy diet and better health, or with a worse diet and poorer health. But 65 of the 661 microbes didn't fit in.

"These 65 bacteria are a testament to the fact that the picture is still more complex than what we saw," says Segata, who also works as a consultant for Zoe.

Good versus bad bacteria

This sorting of "good" versus "bad" bacteria has enabled the researchers to create a 0 to 1000 ranking scale for the overall health of someone's gut microbiota, which is already used as part of Zoe's gut health tests.

"Think of a healthy gut microbiome as a community of chemical factories. We want large numbers of species, we want the good ones outnumbering the bad ones," says team member Tim Spector at King's College London, co-founder of Zoe.

This doesn't mean the ideal healthy gut microbiome has been pinned down, though.

"We really need to think about our body and our microbiome as two complex systems that together make one even more complex system," says Segata. "When you change one thing, everything is modified a bit as a consequence."

Bigger studies are needed to tease out these links and cover more of the global population, says Segata. However, once we have established the baseline of your health and microbiome, it should become possible to recommend specific foods to tweak your gut bacteria, he says.

There are thousands of species of bacteria that reside in the human gut

DESIGN CELLS/SCIENCE PHOTO LIBRARY/ALAMY

For more on the gut microbiome and the immune system, turn to page 26

Environment

How best to use hydrogen power

With supplies of low-carbon hydrogen limited, researchers say we should prioritise the areas where it could have the biggest impact, finds **Alec Luhn**

HYDROGEN, the most abundant element, gives off energy when combined with oxygen, and the only by-product is water. That is why politicians have touted it as the Swiss Army Knife of climate change, able to power a huge array of vehicles and industrial processes that currently run on fossil fuels.

However, 99 per cent of the hydrogen supply today is "grey" hydrogen, produced by breaking down methane or coal gas, which releases carbon dioxide. To reach net-zero emissions, many countries plan to rely on "blue" hydrogen, where this CO_2 would be captured at the smokestack and injected underground, or "green" hydrogen, which is produced by splitting water with renewable electricity.

The problem is that low-carbon hydrogen is at least twice as expensive as grey hydrogen. Ramping up production to make it cheaper will require government subsidies. While places like the European Union are supporting the industry, President Donald Trump has begun to cancel the low-carbon hydrogen hubs planned under a $7 billion programme in the US.

Because of these headwinds, analyst firm BloombergNEF has halved its low-carbon hydrogen production forecast to just 5.5 million tonnes by 2030, roughly 5 per cent of current grey hydrogen consumption. With supply limited, it is important to focus on the clean hydrogen uses that make the most sense for the climate and the economy, experts say.

"Hydrogen can pretty much do everything, but that doesn't mean it should," says Russell McKenna at ETH Zurich in Switzerland.

In a recent study, McKenna and his colleagues analysed the CO_2 that would have to be emitted to produce and transport low-carbon hydrogen in 2000 planned projects worldwide, comparing this with the CO_2 emissions this hydrogen could displace. They found hydrogen could have the biggest impact in the steel, biofuels and ammonia industries

VCG/VCG VIA GETTY IMAGES

Green hydrogen plants split water with renewable electricity

"Hydrogen can pretty much do everything, but that doesn't mean that it should"

(*Nature Energy*, doi.org/qfhs). In contrast, using hydrogen for road transport, power generation and domestic heating wouldn't reduce emissions as much.

Steel is emissions-heavy when produced in a blast furnace, as coke made from coal provides not only heat to melt iron oxide ore, but also carbon for a reaction that strips the oxygen away from that ore. So it isn't enough to heat the metal with renewable electricity, as you need something to stand in for carbon in the reaction, which hydrogen can do, emitting water rather than CO_2.

Stegra, a green steel start-up, is building a facility in northern Sweden that plans to produce steel with an electric arc furnace and green hydrogen produced from river water on site by late 2026, becoming the first carbon-free steel plant. There are also projects under way elsewhere in Europe, Asia and North America.

But cheap renewable electricity has to be available to make the green hydrogen and power the arc furnaces. ArcelorMittal, a multinational steel-making corporation, says it turned down €1.3 billion in subsidies this year to convert two steel plants in Germany to hydrogen because of high electricity prices.

Feeding the world

The production of ammonia, which can be converted into a variety of fertilisers, involves another crucial chemical reaction in the form of the Haber-Bosch process, which makes the nitrogen in the air react with hydrogen.

This enabled a revolution in agriculture and a boom in global population, and hydrogen today is largely consumed for ammonia production and oil refining. About 70 per cent of all ammonia goes towards fertiliser, while the rest helps manufacture plastics, explosives and other chemicals.

"We can't electrify that... because it's a chemical reaction that needs this input," says McKenna. "But it needs to be decarbonised hydrogen."

Countries like Saudi Arabia have begun building factories to produce hundreds of thousands of tonnes of green ammonia with solar and wind energy, mostly for export.

Finally, there is transport. McKenna and his team found that producing hydrotreated vegetable oil was one of the most impactful uses of hydrogen. This involves treating used cooking oil with hydrogen to break down the fats into hydrocarbons that can be burned.

Both ammonia and hydrotreated vegetable oil are being considered as replacements for heavy fuel oil in shipping, which accounts for 3 per cent of global emissions. Aviation, with its similar carbon footprint, could switch to ammonia as well.

In the long term, researchers at institutions like Cranfield University in the UK are designing aircraft with ultra-strong tanks to hold compressed hydrogen. While hydrogen or ammonia produce nitrogen oxide pollution when burned, they can instead combine with oxygen in a fuel cell to produce electricity and water. Fuel cell aircraft are the ultimate goal, says Phil Longhurst at Cranfield University. ▮

Health

Timing cancer drug delivery around our body clock could boost survival

Linda Geddes

THEY say timing is everything, and treating cancer may be no exception. Researchers have found that simply shifting when people receive immunotherapy drugs could improve their survival.

Our cells operate on 24-hour cycles known as circadian rhythms, which coordinate everything from hormone release to the timing of cell division and repair. These rhythms are often disrupted in cancer cells, which tend to divide continuously, rather than at set times.

This has prompted efforts to reduce the side effects of chemotherapy, which targets rapidly dividing cells, by administering it when healthy tissues are least active. Increasingly, however, researchers are exploring whether the effectiveness of cancer drugs might also be improved by giving them at particular times.

One such group of drugs is immune checkpoint inhibitors, which help immune T-cells recognise and attack tumours more effectively. Earlier this year, Zhe Huang at Central South University in Changsha, China,

"Those treated before 3pm had significantly longer progression-free survival and overall survival"

and his colleagues reported that giving the checkpoint inhibitor pembrolizumab alongside chemotherapy to people with advanced non-small cell lung cancer (NSCLC) before 11.30am was associated with nearly double the survival rate seen in those who received most of their treatment in the afternoon.

To investigate whether timing treatments around circadian rhythms – known as chronotherapy – might also benefit people with small cell lung cancer, a faster-growing and more aggressive form of the condition, the same team analysed data from 397 people treated with the checkpoint inhibitors atezolizumab or durvalumab alongside chemotherapy between 2019 and 2023.

"Compared with patients treated later in the day, those treated before 3pm had significantly longer progression-free survival and overall survival," says team member Yongchang Zhang, also at Central South University.

After adjusting for multiple confounding factors, earlier administration was associated with a 52 per cent lower risk of cancer progression and a 63 per cent lower risk of death over the study period (*Cancer*, doi.org/qh3q).

Zhang believes this effect probably exists for other tumour types, pointing to hints from studies of renal cell carcinoma and melanoma. As to why this dosing regimen has this effect, the NSCLC trial showed that morning administration boosted circulating T-cell numbers and activation, while late-day dosing had the opposite effect.

But could hospitals realistically implement this? Compared with new treatments, changing treatment time has almost no cost, says Zhang. Still, treating everyone early in the day isn't practical, says Robert Dallmann at the University of Warwick, UK, and individuals' internal clocks differ. "The difference in biological time between 'early birds' and 'night owls', for example, can be many hours." ▮

Palaeontology

Diplodocus may have been as colourful as birds

MICROSCOPIC structures seen in the fossilised skin of a sauropod suggest these giant dinosaurs may have been as brightly coloured as some birds.

Tess Gallagher at the University of Bristol, UK, and her colleagues examined sauropod skin fossils thought to be around 145 million years old, collected in 2019 and 2022 from Mother's Day Quarry in Montana. Although the fossils couldn't be definitively identified, it is thought they were probably *Diplodocus*.

The researchers took tiny pieces off the four scales from the fossils using a scalpel, then studied them with a scanning electron microscope, to see details at a cellular level.

MARK TURNER/ALAMY

The grey depiction of *Diplodocus* in palaeoart could be due an update

The skin was three-dimensionally preserved, not just an impression, says Gallagher. It also showed evidence of diverse melanosomes, the structures inside cells that store melanin, creating colour in skin, hair, eyes and feathers (*Royal Society Open Science*, doi.org/qh3n).

"I was expecting to find traces of melanin at the bare minimum," she says. "What we did find was evidence that sauropods could have diverse melanosome shapes, which ultimately means the potential for diverse colours."

Every specimen the team studied had melanosomes and they came in two main types: oblong- and disc-shaped. However, it isn't yet possible to say exactly which colours the skin of these sauropods would have been – only that the variety in the structures suggests multiple possible shades.

The closest comparisons that can be made to the disc-shaped structures are the platelet melanosomes found in modern bird feathers. Gallagher says these may be evidence that *Diplodocus* had the potential to create a variety of colour using their melanosomes. "These animals could have more striking colour patterns, as opposed to being grey like we see in old palaeoart." ▮

James Woodford


WATERLOO
SPARKLING WATER
WATER DOWN NOTHING
O SUGAR
WATERLOO
SPARKLING WATER
GUAVA BERRY
0 CALORIES
SUGAR
SWEETENERS
SODIUM
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Views

Comment

A little alone time

The festive season is a period of social connection for many of us, but making space for solitude is also important, says **Thuy-vy Nguyen**

SIMONE ROTELLA

WE tend to imagine the holiday season as universally joyful and social, full of family gatherings, sparkling lights and shared traditions. But people's experiences at this time of year are far from uniform, and stepping outside the usual norms can come with its own perks.

In a recent survey of more than 300 adults in the UK by our Solitude Lab, most respondents said they would still spend Christmas with family this year – either in larger gatherings or smaller households with partners and children. But social time, even positive time with loved ones, can be demanding. Gift buying, travel, disruptions to normal routines, hosting or simply the general sensory rush of the holiday season can all build up and drain us. When asked which feelings they associate with the season, people most often chose words related to love and togetherness, but a large proportion of people in our survey also chose calm and relaxation. This suggests people expect both connection and rest. Brief moments of solitude can help balance it all out.

Research from our lab shows that around 15 minutes of alone time can bring down heightened emotions. In several lab experiments, we consistently observed drops in strong emotions like excitement or frustration after people had spent just 15 to 30 minutes alone. In those studies, participants were often asked to spend the time browsing on their phone, reading or simply sitting with their thoughts. We also found physiological evidence that solitude helps the body come down from stress more quickly. That makes it a useful counterbalance during weeks when stimulation runs high.

These small pockets of time don't need to be dramatic. A quiet cup of tea before everyone wakes up or a short solo errand can create space to breathe, reset and steady yourself before rejoining the group. Solitude in this case isn't avoidance, but instead a way to regulate.

Not everyone spends the holidays surrounded by people, though. In our survey, about 9 per cent of adults said they expect to spend Christmas day on their own. Many participants in this solo Christmas group associated the holidays with calm and rest, and joy and happiness still appeared in their responses. Loneliness and boredom were mentioned less often – more commonly by older adults, often because they spent Christmas alone due to circumstances out of their control.

Choice is a big factor in shaping the experience of solitude, and it can take different forms. Social norms – especially after the covid-19 pandemic – have shifted towards spending time alone. More people now embrace it rather than fear it, and our mindset plays a large part in how solitude feels.

Having options for how we spend time alone helps, too. Solitude lends itself to introspective activities like looking back on positive moments from the past year or low-key activities such as taking a walk through a local park. Being out of the house for solitude can also create chances for small chats with strangers – moments that can lift your mood and strengthen your sense of belonging over the holiday, a benefit that is often underestimated. And while physical solitude means being on your own, it doesn't mean you are cut off. Reaching out to someone, writing a card or simply keeping others in mind can remind us of connections we have built, making solitary time feel more enriching.

Whether your Christmas season is spent with others or alone, solitude offers a simple resource: a brief space to settle yourself, reflect and approach the holidays with a bit more ease. It isn't about choosing isolation over connection, but about allowing both to have their place during a season that often asks a lot of us. ▮

Thuy-vy Nguyen is the principal investigator of the Solitude Lab and author of *Solitude: The science and power of being alone*

This changes everything

How not to misread science fiction

Focusing on the futuristic tech that appears in sci-fi without paying attention to the actual point of the story is a big mistake, says **Annalee Newitz**

Annalee Newitz is a science journalist and author. Their latest book is *Automatic Noodle*. They are the co-host of the Hugo-winning podcast *Our Opinions Are Correct*. You can follow them @annaleen and their website is techsploitation.com

Annalee's week

What I'm reading
404 Media, an incredible online publication for investigative journalism about tech.

What I'm watching
Heated Rivalry, *a gay ice hockey romance series that is extremely Canadian.*

What I'm working on
Planning the European tour for sci-fi anthology We Will Rise Again.

This column appears monthly. Up next week: Rowan Hooper

WE ARE approaching the Gregorian New Year, and it's a great time to ponder what's coming next. Are we about to use CRISPR to grow wings? Will we all be uploading our brains to the Amazon cloud? Should we wrap the sun in a Dyson sphere? If, like me, you are a nerd who loves science and engineering, sci-fi is the place you turn to imagine the answers. The problem is that most people are getting the wrong messages from these visions of tomorrow.

As a science journalist who also writes science fiction, I am giving you an end-of-year present: a quick guide to not misreading sci-fi stories. Pay attention, because all our civilisations depend on it.

There are two main ways that people misread sci-fi. Let's start with the simpler one, known as the Torment Nexus Problem. It appears most often in tech conferences and business plans, and gets its name from an iconic social media post by the satirist Alex Blechman. In 2021, he wrote:

"Sci-Fi Author: In my book I invented the Torment Nexus as a cautionary tale

Tech Company: At long last, we have created the Torment Nexus from classic sci-fi novel Don't Create The Torment Nexus".

You get the idea. The Torment Nexus Problem crops up when people read, watch or play a sci-fi story and focus on its futuristic tech without paying attention to the actual point of the story.

As a result, you get billionaire Peter Thiel co-founding a company that specialises in data and surveillance called Palantir, named after the fantasy tech of the "seeing stones" in *The Lord of the Rings* that drive their users to evil and madness. Palantir's products have been used by the Israel Defense Forces to strike targets in Gaza. Earlier this year, the firm signed a contract with the US government to build a system for tracking the movements of certain migrants. J. R. R. Tolkien would not be amused.

There are less disturbing examples as well. When Mark Zuckerberg decided to pivot Facebook to virtual reality, he renamed it Meta, after the metaverse in Neal Stephenson's *Snow Crash*. But this fictional metaverse isn't something you would want to emulate, if you paid attention when reading the story. It's a hostile corporate space that unleashes a mind virus that causes people's brains to "crash" like computers.

> **"Zuckerberg and Thiel overlooked the fact that a palantir and the metaverse destroy people's minds"**

You might be sensing a theme here. Thiel and Zuckerberg wanted to make fictional tech real and appear to have overlooked the fact that a palantir and the metaverse destroy people's minds. That's a profound misreading of sci-fi.

The second major way people misread science fiction could be called the Blueprint Problem. Essentially, it's the mistaken idea that sci-fi provides an exact model for what is coming next and if we replicate what happens in sci-fi, we will arrive in a glorious future.

The Blueprint Problem inspired a lot of early space programmes in the 1950s, which prioritised putting humans into space rather than exploring it remotely with robotic spacecraft. Generations of people had watched *Flash Gordon* and read Edgar Rice Burroughs, and had been promised that people would fly spaceships to colonise alien worlds. Today, we have robots discovering incredible things on Mars and space probes grabbing chunks of asteroids for analysis. But the media are still more likely to make a fuss over Katy Perry riding in Jeff Bezos's rocket than to celebrate when the autonomous Voyager spacecrafts hit the termination shock that marks the edge of our solar system.

Most of the hype around AI products can also be blamed on the Blueprint Problem. We were promised AI servants and savants in so much sci-fi over the past century that robocops and holographic doctors have come to feel inevitable. But they aren't.

Science fiction isn't a map, a recipe book or a prescription. Instead, it is a world view, a way of approaching problems with the underlying assumption that things don't have to be the way they are. This conviction inspired the book *We Will Rise Again*, a sci-fi anthology about social change that I co-edited with Karen Lord and Malka Older. We collected stories and essays intended to dislodge people's preconceptions about where human civilisations are headed. In our book, the future isn't predestined; it's a process, and people are actively shaping it.

The more you appreciate this process, the weirder the present-day world starts to seem. Why do we build machines to fold tissues into boxes? Why do we believe in invisible lines called borders? Why do we assume there are only two immutable genders? Asking those kinds of questions is the real point of science fiction. They are the gateways to new worlds.

If you want to build a better future, you cannot merely replicate something you read. You must imagine it yourself. ▮

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Ancient artists

Christoph Baumer & Therese Weber
Bloomsbury Academic

IN 1954, Pablo Picasso told his secretary that for all the artistic developments in the millennia since humans first engraved images into rock, these works of ancient art had still "never been surpassed", such was their "purity of expression". It is easy to see why Picasso was so enamoured. In their book *Rock Art and its Legacy in Myth and Art*, historian Christoph Baumer and artist Therese Weber catalogue a vast array of petroglyphs, which are made by etching into rock.

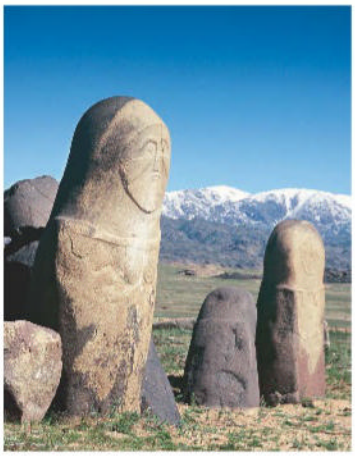
"Many of these petroglyphs are masterpieces," says Baumer. "They are very simple, and just with a few strokes you very clearly recognise not just an animal, but its main attributes."

The rock art photographed for the book, some of which is shown here and on the following pages, comes from a large area, ranging from Mongolia in the east to the Sahara in the west. The oldest dates back at least 8000 years.

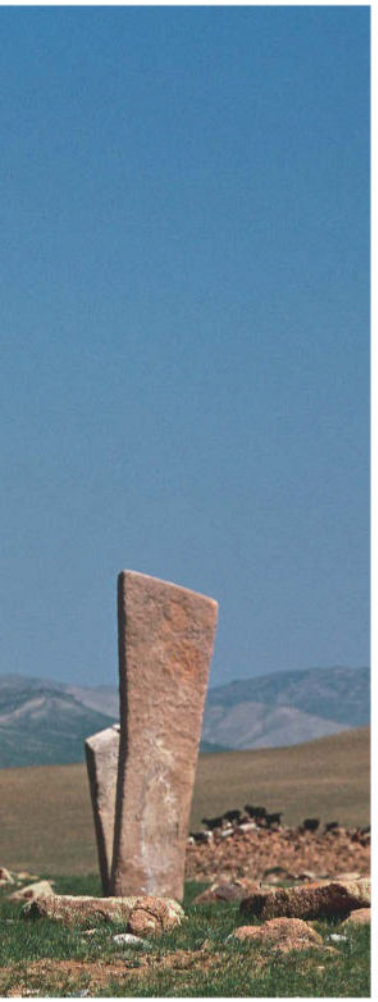
This wide swathe of territory means there is remarkable variety, both between and within images, such as in this Bronze and Iron Age tableau of ancient humans and animals seen in a horizontal limestone rock from the desert in northern Saudi Arabia (left). But there is also remarkable similarity, given the low populations and enormous separation between them.

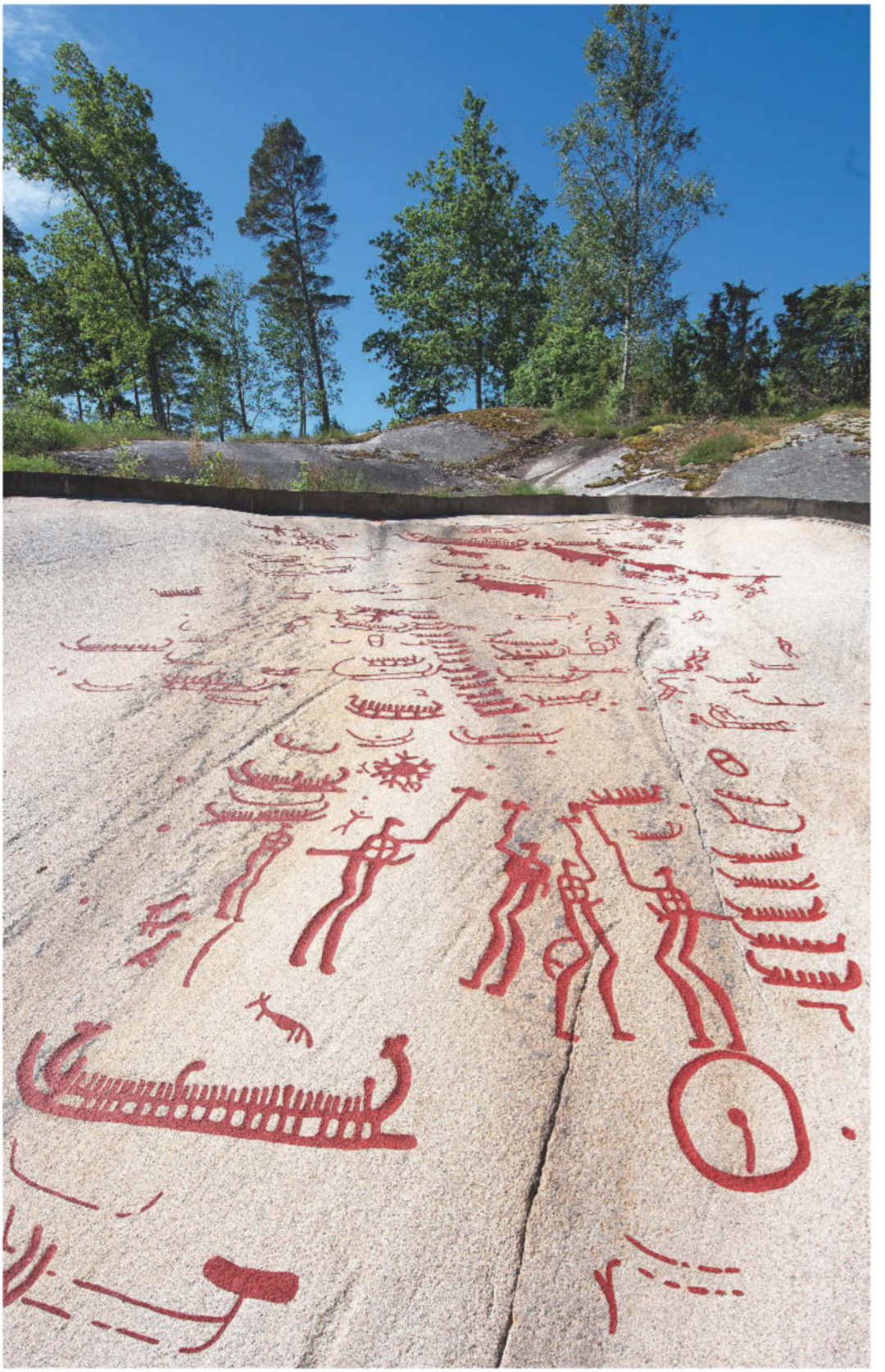
Picasso might disagree, but these drawings are still deeply mysterious, in part because they are difficult to accurately date. But Baumer is enthusiastic about how much they can explain: "It tells us something about the beliefs, habits and economy of very ancient peoples, which we otherwise know of very little."

Alex Wilkins



Clockwise from above: human-like stone slabs from a burial site in Xinjiang, China, dated to the start of the second millennium BC; a so-called deer stone from a burial site in northern Mongolia, dated to 1400-850 BC; a large petroglyph found in Aspeberget, Sweden, showing warriors, ships, farm scenes and a sun-like disc (these Bronze Age images have been painted red for tourists, but would have originally been the colour of the rock); sun-like figures and deer images found in Kyrgyzstan, from the Bronze Age; one of the largest petroglyphs in southern Saudi Arabia, showing a dromedary camel, from the Iron Age.





‘I was terrible at science at school’

With the human family tree now more like a hedge, **Bill Bryson** told the *New Scientist* podcast about updating his 2003 bestselling book on science – and why he wrote it in the first place

Rowan Hooper: Bill, when I mentioned in the office that you were coming in, people reacted like I’d said Ryan Gosling or David Beckham was visiting.
Bill Bryson: It’s my looks.

RH: Your 2003 book, *A Short History of Nearly Everything*, became one of the best-selling non-fiction books of the 21st century. And now you’ve revised it.
It was over 20 years old. And, obviously, science has moved on a great deal. Take the Denisovans. When I wrote the book, nobody had a clue about these archaic peoples. Same with *Homo floresiensis*, the hobbit. So I thought I’d bring it up to date. It became a real pleasure for me because I got to go back and reinterview a lot of the people that I spoke to first time around.

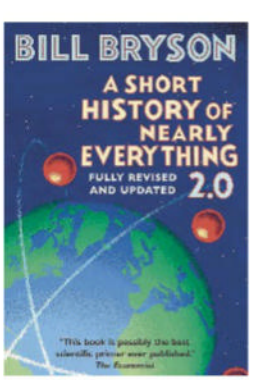
DAVID LEVENE/EYEVINE

RH: It’s one of the joys of being a science reporter, isn’t it? The time that scientists give you, the privilege of getting the time of world experts.
I think for a lot of scientists, nobody’s ever really expressed much interest in what they do. And the more technical the work, the less likely that people in a pub are gonna say: “Oh, tell me more.” But here am I saying: “This is amazing. Tell me all about it.”

And the question I always ask them was: what got you started in that field, what was the magic moment that made you want to spend your life studying lichens or whatever?

RH: Let me turn that question on you: what was the magic moment for you and science?
I was terrible at science at school. Bored out of my mind. There was a tendency when I was a kid growing up in America in the 50s and 60s that when they taught you physics, it was to make you into a physicist, or if they taught you chemistry, it was like they were trying to create new generations of chemists.

And there’s loads of people like me that are never going to be scientists, but ought to be able to engage with science at some level. Obviously, science explains everything there is to know. It tells us who we are, where we’re going and what we have to do if we want to get there. I thought there’s got to be some level at which I can engage with science and marvel at the wonder of it without having to go into lots of equations and all that sort of blackboard-type stuff.



And I put this to my publishers and they all said, “No, that’s just a really dumb idea, you’re not qualified, you just shouldn’t be doing this. Leave that to Stephen Hawking.” But they let me do it.

And, luckily, it turned out that there are lots of people like me in the world who want to know about science. The whole idea of the book was: how do we know what we know? How do scientists figure these things out?

One of the things that I hadn’t expected was that the amount of things we don’t know is actually exciting. It would be awful if we knew everything.

You know, there is a lot we could do with knowing, just the very fact that we don’t know how many insect species there are on Earth.

RH: They’re going extinct before we even know how many there are. That leads me to climate change, which isn’t in the book, and I wondered why you decided to leave that out?
Yeah, it was a tough call, but the idea of the book is really to try to understand how we got to where we are now, our current state of knowledge in so far as I’m capable of understanding it. So the book is a lot about the history of science.

Penny Sarchet: One thing that’s changed between the original and the new version is that, in 2003, a long human life lasted about 650,000 hours or 74.2 years, but now it’s 700,000 hours, 80-odd years. That’s quite a boost in longevity over that time.
The point I was making originally was that we only live for 650,000 hours. If you think about the number of hours of your life you’ve wasted, fooled around doing idle things, just watching *Coronation Street*.

> **“One of the things that I hadn’t expected was that the amount of things we don’t know is actually exciting”**

PS: Was there anything that stood out when you were revising the book that was an unexpected delight?
The one that rocked me on my heels was discovering that there are twice as many known moons in the solar system. I thought, “How hard is it to identify a moon? Where were they all?”

The number of moons of Jupiter has trebled in 20 years. Of course, a lot of these moons are very small. And, apparently, the definition of a moon is anything rocky that orbits a planet.

RH: Another thing that is very different is the proliferation of the human family tree – it's more like a hedge! Did that surprise you? It was starting to look quite straightforward, wasn't it?
Yeah, it was. Not just to me, but I think to people in the field. They were pretty confident that they had kind of figured things out. And then, the Denisovans, also the hobbits of Flores. And other archaic human groups that have been found since then.

The thing that fascinates me as a complete outsider is, how did these people all get around? I mean, how did they disperse and what happened when they came upon each other? There's a tendency to think there would have been fighting, but actually there was a lot of interbreeding. I think it's kind of heartwarming, the idea that these people were living side by side for long periods. Because we modern *Homo sapiens* don't do that very well at all.

Alec Luhn: Twenty years ago, there was a more benign kind of atmosphere. Now, in the US, people talk about a war on science. Was it daunting to do a 2.0 version of your book in the world in which we live?
The whole idea of the book is that, because [the first one has] been out there for 20 years, I'm hoping I've done it for another 20 years. And I'm hoping, with this current US administration, we will look back on it some years from now and just see it as a kind of a blip.

It would just be tragic if those sorts of policies and that kind of vindictiveness and institutionalised anger became a permanent feature of the US.

This is an edited version of an interview broadcast on *New Scientist*'s podcast *The world, the universe and us*

In our own image

Humans project our thoughts and feelings onto everything from dogs to hurricanes. **Elle Hunt** finds out why in a fascinating book

Book
Human-ish
Justin Gregg
One World

IN THE late 19th century, a strange debate raged in the journal *Nature* about the "reputed suicide of scorpions". They had been seen stinging themselves in the head and deliberately self-destructing when trapped by fire. Did this "scorpionic suicide" (if it happened as described) amount to existential hopelessness, as credible men of science argued?

Zoologist Conwy Lloyd Morgan was so energised by all this that he experimented on scorpions himself, declaring it his "duty", given the implications for the emerging theory of natural selection. Morgan surrounded scorpions with fire, heated them in glass jars and coated them with acid. None attempted suicide; they did, however, burn to death.

Today, this may register as an oddity, but we still cling to ideas about non-human life and minds that say more about us than them. In *Human-ish: How anthropomorphism makes us smart, weird and delusional*, Justin Gregg explores the baggage we bring to our engagement with other animals.

Gregg is a dolphin cognition researcher and an author whose last book, *If Nietzsche Were a Narwhal*, looked at what animal intelligence says about human stupidity. Here, his focus is our tendency to attribute human-like thoughts, feelings and intentions to non-human beings.

Through many entertaining examples, Gregg reveals the mind-boggling lengths to which we take this projection, such as in the existence of "neuticles": prosthetic testicles for neutered dogs to counter perceived emasculation and "loss of dignity". He also tells us about the couple who contacted him about an "ocean birth", dissuaded only when he pointed out they would attract sharks as well as dolphins.

Despite his genial tone, Gregg is serious in exposing how animals suffer due to our chronic anthropomorphism, for example in our lop-sided relationship with pets, increasingly treated as substitute children. Bulldogs, pugs and Persian cats – inbred to satisfy our love of large eyes, small noses and baby faces – are plagued with health issues, even struggling to breathe. And the plot of the film *Jaws* turned sharks from rarely seen ocean-dwellers into public enemies facing official culls, to the detriment of ocean ecosystems.

Irrational as Gregg reveals our anthropomorphism to be, he is sympathetic to the inclination: we are hard-wired for it, and it's fun. But it can rebound: projecting human needs and desires onto other beings (even ones as unlike us as scorpions) affects which species we study. For instance, "mammalcentrism" means we know relatively little about insects.

Like another recent book, *The Arrogant Ape* by primatologist Christine Webb, *Human-ish* also examines "human exceptionalism" and our tendency to place ourselves at the centre of nature. This even extends to natural phenomena: it is known, for example, that hurricanes tend to kill more people if they have feminine names, because they are perceived as less dangerous, meaning people are less likely to take adequate precautions.

In *Human-ish*'s final third, Gregg shows how projecting human characteristics onto machines and products (think cars and bottles) leaves us vulnerable to marketing. It is also increasingly leading us astray in tech as people project human-like sentience onto AI. Anthropomorphism may seem like a low-stakes diversion, even a natural impulse, but Gregg shows it is worth taking seriously – and keeping in check.

Humans bring plenty of emotional baggage to their relationship with other animals

RYAN J. LANE/GETTY IMAGES

Elle Hunt is a writer based in Norwich, UK

How we think

Could an expanded idea about physical metaphors crack one of neuroscience's toughest questions? It's compelling, says **Michael Marshall**, but the writing setting it out is far less so

Book

The Neural Mind

George Lakoff and Srini Narayanan

University of Chicago Press

THIS is a book review in two parts. The first is about the ideas presented in *The Neural Mind: How brains think*, which are fascinating. The second is about the actual experience of reading it.

The book tackles one of the biggest questions in neuroscience: how do neurons perform all the different kinds of human thought possible, from planning motor actions to composing sentences and musing about philosophy?

The authors have very different perspectives. George Lakoff is a linguist and cognitive scientist, based, until his retirement, at the University of California, Berkeley. He studied the role of metaphors in thought. Srini Narayanan is a senior research director at the AI company Google DeepMind in Zurich, Switzerland. His work focuses on how artificial intelligences learn language.

The book's central idea is that the brain uses the same processes for motor functions, language and abstract thought. Similar neuronal circuits and pathways, Lakoff and Narayanan argue, have been co-opted by evolution to perform all these types of thought – which seem radically different on the surface, but have profound core commonalities.

This is easiest to understand if we think about human babies, or other animals without language. While each animal's experiences are different, there are concepts they will almost inevitably learn: ideas like up and down, motion and rest, force and resistance. Somehow, these must be represented in the brain.

CATHERINE FALLS/GETTY IMAGES

A simple drink of water is actually a complex neurological action

In books like *Metaphors We Live By* (co-written with his then colleague Mark Johnson in 1980), Lakoff argued that these concepts recur in metaphors we use to convey ideas. Happiness and success are "up", metaphorically, while sadness and failure are "down". We use this up-down construction to describe musical notes, even though pitch is determined by the frequency of sound waves and has nothing to do with altitude. Likewise, communication is often described as a physical transfer, in phrases like "getting through to you".

"In the first animals, brains were mostly for motor control. Things like language are recent innovations"

The trivial reading of this is that physical metaphors help us grasp tricky abstract concepts. But Lakoff and Narayanan are arguing something deeper: these physical metaphors are literally how we think. This makes sense, they write, if you consider how brains evolved. In the first animals, they were mostly for motor control. Things like language and abstract thought are recent innovations. Since evolution is naturally thrifty, often reusing existing structures in new ways, it is reasonable to imagine neuronal circuits that evolved for motor control were co-opted for language and thought.

Suppose you want to drink from a glass of water. Most of us can do this with little difficulty, but it is a strikingly complicated action. You must reach out with your arm, then use your hand to grasp the glass. Next, you must move the glass to your mouth, and drink. You must decide how many sips or swallows to take, iterating until your thirst is quenched. Finally, you must put the glass down.

This, say Lakoff and Narayanan, is mirrored in our language and grammar. We break complex behaviours and language into chunks. Think about sentences, with their words and syllables, nouns and verbs. A subject performs an action on an object. Or think about past, present and future tenses, reflecting whether we did something, are doing something or will do something.

These physical metaphors also shape abstract thoughts. Lovers "drift apart"; regimes "fall". If we apply the same metaphorical framing to a phenomenon, we can get stuck – and we often make creative leaps by applying a new metaphor. Instead of that regime "falling", maybe it is "swept aside" to make way for something new.

It is hard to know how to test all of this. Lakoff and Narayanan propose circuit models that might exist in the brain and underpin these patterns of thought. But we are nowhere near a neuron-by-neuron map of the human brain, so I think true tests of their hypothesis are many years away.

Still, Lakoff and Narayanan do enough to convince me their ideas ought to be taken seriously. What they didn't do, however, is write a readable book. *The Neural Mind*, I am sorry to say, is painful to read. It is repetitive and disjointed, leaping from one thought to the next in a way that is exhausting. Ideas that need careful unpacking are dispatched in a paragraph and trivial concepts are expounded at length. And there is no excuse for ending chapter 2 with a sentence spanning 130 words. Basically, I read this so you don't have to. ▮

Michael Marshall is a writer based in Devon, UK

Editor's pick

A different way of looking at Schrödinger's cat

29 November, p 28

From David Longhurst, Haslemere, Surrey, UK

Before Christmas, I was trying to explain quantum theory to the grandchildren and mentioned Schrödinger's cat, where the cat is both alive and dead before the box is opened. The children were sceptical. "Surely," they said, "if you carefully observe the box from the outside, sooner or later the 'cat' will interact with one or more walls of the box and you would be able to infer its state without having to directly observe it." So, I pointed to the Christmas tree, and said: "Under the tree is a carefully wrapped present for each of you. The present may be the gift of your dreams, or a pair of Grandma's knitted socks. But you won't know until you take off the wrapping and look inside." Now that got their attention.

From James R. Meyer, Toome, County Antrim, UK

I have always found it strange when physicists say that they repeat quantum experiments. They repeat only certain parameters – they cannot ever repeat precisely the total physical environment. All they can do is repeat part of that physical environment. And that being the case, how can they be sure that aspects of the overall changing environment don't affect the outcome?

If the total environment does affect the outcomes of such partial tests, then it could be that quantum outcomes aren't random, but determined by the environment. And if that is the case, then all the mystery surrounding quantum theory simply disappears. There is no need for a many-worlds theory, there is no need for Schrödinger's cat. What is measured doesn't depend on an observer; the observer simply observes what is the case.

The sweet spot between indifference and apathy

29 November, p 7

From Martin van Raay, Culemborg, The Netherlands

Regarding why climate action is stalling while Earth gets hotter: perhaps the disaster takes too long to hit. We have been hearing about it for years now, and while it is getting worse, it doesn't have the urgency that, say, covid-19 had. Most people believe there is still time to act, so they stall. On the other hand, saying it's five past midnight might drive people to apathy: "We're doomed, so nothing helps now." Is there a sweet spot between indifference and apathy?

In defence of the trend towards SUVs

22 November, p 19

From Guy Cox, St. Albans, New South Wales, Australia

The trend towards SUVs that Anthony Laverty writes about is also evident here in Australia. But is it really bad for the planet? These SUVs tend to be diesel and therefore much more economical on fuel. I drive such a vehicle, a 15-year-old Audi Q5 SUV, and it delivers around 60 miles per gallon. That is as good as a Toyota Prius hybrid. (The Prius would do better in the city, the Q5 on the motorway.) In comparison, I have had, in my younger days, two original Minis, which couldn't remotely approach this figure.

Let's say a big hooray for the hoverfly

29 November, p 34

From Terry Klumpp, Melbourne, Australia

Oh, how we all too often underestimate the amazing abilities of insects. So, thank you for the excellent and informative article, "Heroes in disguise", on the fabulous hoverfly.

Delving into the search for dark matter

29 November, p 20

From John Woodgate Rayleigh, Essex, UK

In response to Chanda Prescod-Weinstein's article on the research into dark matter: dark matter seems to me to be "aether with mass". It can't have any viscosity, for example, because if it did, normal matter passing through it would lose energy, which we would be able to detect. This applies at the cosmic scale even if dark mass particles are very loosely distributed.

To help the climate, it's better to look down not up

Letters, 29 November

From Wai Wong, Melbourne, Australia

While John Tons's idea of painting every roof white is effective at cooling the home and reducing the urban heat island effect, it has a negligible effect on a global scale, because the total area of roofs of buildings is minute compared with Earth's surface area.

Antarctica's surface area alone is equivalent to the roofs of about 100 billion medium-sized homes, far more than the number of roofs that can potentially be painted white. That is why the drawback of photovoltaic solar panels' dark colour is dwarfed by their benefit in reducing fossil fuel consumption. On the other hand, road surfaces cover a much larger area than roofs, and trials of light-coloured road surfaces are happening around the world.

Giving mosquitoes their proboscis back

29 November, p 14

From David Aldred, Brough, East Riding of Yorkshire, UK

I was fascinated to read that a mosquito's proboscis can act as a surprisingly hardy 3D printer nozzle. I wonder if they can also manufacture a replacement mosquito proboscis?

Mice and heavy metal don't get along

29 November, p 48

From Ian Simmons, Westcliff-on-Sea, Essex, UK

With regard to Feedback's musings on what kind of music mice like, I was once party to an accidental experiment on this when I worked in Newcastle. Our education department shared a wall with an adjacent lab's mouse facility, where the animals were suffering from unexpectedly poor fertility.

Suspecting noise to be behind the problem, the lab was engaged in lengthy negotiations with a nightclub that shared the building. However, during the Newcastle Science Festival that year, we held a 24-hour hackathon in the education department and came to realise that the mouse lab's night shift technician, who worked alone, livened up the lonely hours by playing thrash metal at ear-splitting volume. A word was had, the metal music ceased and fertility was restored.

Cats are the ones calling the shots

6 December, p 9

From Jon Fanning, Wilberfoss, East Riding of Yorkshire, UK

Your article on when our feline friends spread around the world was very strange in repeating the long-debunked theory that cats have ever been domesticated. As every scientist, and indeed individual, who has ever met a cat with its servant knows, it is humans who were domesticated.

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Letters sent to New Scientist, 9 Derry Street, London, W8 5HY will be delayed

Improve your immunity

You can upgrade your immune system to help fight off infection, but not in the way you think, discovers **Helen Thomson**

CRISTINA SPANÒ

I AM lying under a blanket, feeling rough, staring at a bowl of oranges. Every fibre of my being is urging me to devour the lot. I can hear my mum – and medical friends at university – insisting that a megadose of vitamin C will head off my oncoming cold.

The thing is, I know it isn't true. Despite the common belief, vitamin C doesn't prevent colds. At best, it may shave a few hours off your symptoms. Still, the myth endures, because who wouldn't want an easy way to supercharge their immune system?

Over the past weekend, friends have also suggested I drink ginger tea and gobble down some turmeric. It got me thinking: what, if anything, really helps strengthen the immune system to aid it in warding off potential invaders? To find out, I decided to take stock of my own immune health and find an evidence-based approach to improving it. Along the way, I learned how absent bacteria, the contents of my spice rack and even my outlook on life play a critical role in enhancing my immune defences – and uncovered the one thing that might harm immunity more than anything else.

We often talk about "boosting" our immune system, but, taken literally, that would be a terrible idea. Immunity isn't a dial you can just turn up, says immunologist Daniel Davis at Imperial College London.

Your immune system is made up of a diverse network of cells, proteins and organs that must be powerful enough to attack invaders but restrained enough not to target healthy cells or harmless molecules – overreactions that underlie autoimmune conditions and allergies. "You don't want to boost your immune system. You want to help it respond appropriately," says Davis. "That's a lot harder to do."

But before I start tinkering with my immunity, I need some idea of what shape it is in. According to immunologist Jenna Macciochi at the University of Sussex, UK, a rough gauge is simply counting your colds. "An average person experiences a few mild illnesses a year," she says. "More frequent or severe illness can indicate an underlying immune dysfunction or heightened susceptibility."

By that measure, my immune system is worse than average: I had a couple of colds at the beginning of the year, plus a recent

throat infection and a bout of covid-19 in the past three months.

A more sophisticated assessment comes from Sunil Ahuja at the University of Texas Health Science Center at San Antonio, who has developed an "immune grade" that reflects your immune resilience – the ability to neutralise threats while minimising collateral tissue damage.

When immune resilience is low, you get increased inflammation, the immune system's brute-force response to any kind of threat. Immune cells also become senescent – where they stop dividing but don't die. The accumulation of senescent cells causes the release of chemicals that accelerate ageing processes, independent of chronological age. "Low immune resilience opens the door for disease states," says Ahuja.

To find out your immune grade, you need a T-cell test, sometimes called a lymphocyte subset test, which in the UK costs around £199 (it is generally a little cheaper in the US). This measures two types of immune cell: CD4 "helper" T-cells, whose job it is to coordinate immune responses, and CD8 "killer" T-cells, which destroy infected cells. ›

FREDERICK FLORIN/AFP VIA GETTY IMAGES; R. KELLY SIKKEMA/UNSPLASH

Sauerkraut and fresh ginger are tasty ways to help your immunity

A high CD4 count is good: it means plenty of generals to organise any potential immune battle. High CD8 is helpful if you are currently fighting an infection, but chronically high levels indicate an overactive immune system and increased inflammation, which is linked with several serious health problems. CD8 levels increase with age and with lifestyle factors like smoking, heavy drinking and lack of physical activity.

Making the immune grade

These numbers are inadequate on their own. Instead, you need to work out their ratio by dividing CD4 by CD8. A ratio above 1 suggests CD8 levels are being kept in check, or "restrained", as Ahuja calls it. A ratio below 1 suggests they are "unrestrained", something you want to avoid. Combine this result with your CD4 level, which ideally should be above 800 cells per microlitre, and you have your grade (see "Immunity score", right). My ratio was 2.66, meaning my CD8 levels are being kept in check, but my CD4 count was 691 per µL, which translates to a grade of 2a. Respectable, but could do better.

Immune grade is a meaningful measure: over the past decade, Ahuja's team has tracked the immune grade of more than 10,000 people. Those with better scores respond well to vaccines, are less susceptible to infections and have lower rates of hospitalisation from infections. "During the pandemic, we found that 80-year-olds with a good immune grade were less likely to be hospitalised with covid-19 than people of any age with the lowest immune grade," says Ahuja. Having a bad grade also puts your mortality on the fast track: 40-year-olds with grade 4 – the weakest grade – face the same mortality risk at that age as healthy 55-year-olds with a grade 1 result.

"For long-term immune power, we must look to our microbiome"

Immunity score

For a high immune grade, you need good levels of CD4+ cells, and you also need your CD8 cells to be kept in check, or "restrained"

	Score	CD4+ T-cells (cells/mm3)	
Immune Health Grades	I	≥800	Restrained
	IIa	≥500 <800	
	IIb	>200 <500	
	IIc	≤200	
	III	≥800	Unrestrained
	IVa	≥500 <800	
	IVb	>200 <500	
	IVc	≤200	

So, how do I move from 2a towards grade 1? I don't smoke, which has a negative impact on almost every type of immune cell studied, so my first instinct is diet.

Here, our mass ignorance about vitamin C is a cautionary tale – particularly as we live in a world where inaccurate health advice spreads so easily on social media. This myth actually began in the 1970s with Nobel prize-winner Linus Pauling, whose book *Vitamin C and the Common Cold* spread the message that high doses could prevent colds. "He was always on TV, always on the radio, everyone was listening to him," says Davis. Later analyses suggested that his data was flawed and cherry-picked, but the message stuck.

There is something that might give me a quick fix, however. A 2013 review concluded that 75 milligrams of zinc taken daily within 24 hours of getting your first sniffle reduced the duration of a cold, with significantly fewer people still experiencing symptoms on day 7 than those who took placebos.

For long-term immune power, though, we need to look to our microbiome. The trillions of bacteria inhabiting our gut influence the action of all the main cell types in our immune army. Vitally, they maintain the integrity of the gut lining, preventing leakiness and inflammation, and churn out beneficial chemicals such as short-chain fatty acids, which can modify T-cells' response to viruses like influenza or HIV.

The simplest way to build a healthy microbiome is to ensure microbial diversity by feeding them plenty of whole foods, plus at least 30 grams of fibre per day. Another easy intervention is gardening. Healthy soil is teeming with beneficial bacteria that get transferred directly from our hands to our guts and are linked to better immune health. Amish communities who farm manually, for instance, tend to have stronger immune systems than similar Hutterite groups who use industrialised farming.

Then there are probiotics – live microorganisms – that you can drink or consume through fermented foods like natural yogurt, kimchi or kefir. During the covid-19 pandemic, Tim Spector, co-founder of the nutrition app Zoe, and his colleagues

"Your immune system must be powerful enough to attack invaders but not target healthy cells"

surveyed almost half a million people and found those taking probiotics or eating fermented food regularly had less severe covid-19 symptoms than those taking vitamin C, zinc, garlic or nothing.

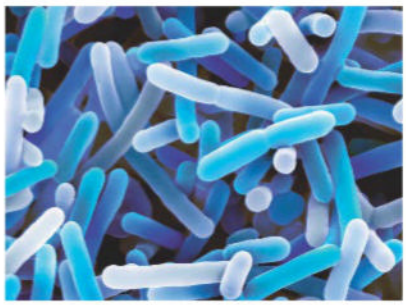
Of course, correlation isn't causation, but other studies add to its weight. In a 2021 trial, 36 people were randomly assigned to eat five to six daily portions of fermented foods or a high-fibre diet for 10 weeks. The fermented food group saw bigger shifts in immune cells and a significant decrease in inflammatory proteins in just a few weeks, compared with the fibre group.

I have recently started eating around three portions of kefir and the like each day. The Zoe researchers tell me that fewer servings of fermented food should still be beneficial , though specific doses haven't been tested. For the sake of my immune system, I am motivated to try more. Five to six servings of fermented food a day sounds excessive, but each serving doesn't need to be large, it is about 300 calories altogether, says Christopher Gardner at Stanford University in California, who led the trial. "[It] isn't as much as it might sound."

While it also seems a little excessive to delve much deeper into your microbiome, I recently happened to be approached by researchers at the Functional Gut Clinic in London, the first microbiome clinic in the UK, with the offer of being their first patient to receive a full gut MOT. So, over a few days, I took a battery of stool, breath and glucose tests. Alongside some interesting revelations about bad bacteria that had taken up residence in my small intestine, giving me insight into some recent health issues, the results also offered a surprising window into my immune health. It turned out that my gut was completely devoid of four types of beneficial bacteria that are normally a significant part of the adult gut microbiome.

Their absence was concerning. For instance, one of the missing bacteria, *Bifidobacterium bifidum*, supports immune health by preventing over-inflammation and boosts the activity of immune cells that kill pathogens, as well as increases the production of certain antibodies. Anthony Hobson, clinical director at the Functional Gut Clinic, suggests that it could be my childhood dairy intolerance that led to these helpful bacteria – which are often consumed first through breast milk, then in other dairy products – failing ever to find a niche.

Most people with a healthy, balanced diet shouldn't need to take probiotic supplements – or, for that matter, spend £900 ($1180) on advanced microbiome tests unless they have significant gut issues. But armed with this information, I have refocused my diet and now take daily probiotics to feed my gut its missing microbes. Reseeding the microbiome is challenging after the first five years of life, but I'm hoping that topping up with bacteria-rich foods will help my immune health in the long run.



DENNIS KUNKEL MICROSCOPY/SCIENCE PHOTO LIBRARY

***Bifidobacterium* in the gut helps prevent over-inflammation**

MINT IMAGES LIMITED/ALAMY

Gardening can expose you to more beneficial bacteria

Spice up your diet

As I cast a thankful eye on some homemade sauerkraut in need of burping, I consider what else might earn its space in my store cupboard. I drink fresh ginger and turmeric tea daily, vaguely aware of supposed immune benefits. But is this, like vitamin C, largely wishful thinking?

Perhaps not. A recent review suggests that ginger does have anti-inflammatory properties, triggering the release of chemicals called cytokines that help regulate immune responses. "I do recommend people eat ginger in order to improve the health of their immune system," says Fitriyono Ayustaningwarno at Diponegoro University in Semarang, ›

Indonesia, lead author of the review. He adds, however, that its anti-inflammatory properties will only be effective when consumed in adequate amounts. "The best way to get the bioactive compounds in the ginger is by eating it fresh," he says.

Turmeric also has a wealth of research on the immune benefits of its active compound, curcumin – in animals at least. The molecule that gives the spice its distinct orange colour protects against pneumonia by regulating immune responses and dampens inflammation. It also boosts the immune system's ability to fight a range of cancers.

In humans, however, results are limited. Curcumin may improve symptoms of rheumatoid arthritis by influencing the activity of macrophages, immune cells that digest pathogens, and there are trials testing whether it can improve the efficacy of chemotherapy. But strong evidence is severely lacking. The problem – and it's a big one – is its bioavailability. When we eat turmeric, barely any curcumin is actually absorbed.

Researchers are currently exploring ways around this. Taking curcumin alongside piperine, found in black pepper, prevents the body from metabolising it so quickly, for example, and other formulations are being developed to improve absorption.

"You wouldn't use curcumin to prevent getting the flu or other infectious disease," says Claus Schneider at Vanderbilt University in Nashville, Tennessee. But he says there is good evidence that its breakdown products can act on pathways crucial for regulating immune response and inflammation. He points to a small study of people on haemodialysis, which showed that 2.5 g of turmeric added to a daily fruit juice for three months reduced inflammatory proteins in their body compared with a placebo.

So my fresh ginger and turmeric tea is no miracle cure, but it is probably doing more good than harm.

While diet is a powerful but complex modulator of immune health, exercise is more straightforward. A wealth of evidence shows that moderate, regular physical exercise is one of the most effective ways to improve your immune system.

Moderate exercise is anything that raises your heart rate and makes you a bit sweaty: brisk walking, swimming, gentle running. These activities improve immune surveillance – increasing the number of circulating immune cells that scan for abnormal cells and pathogens – boost antibody production and help the body return to normal after an immune response. In July, Yang Li at Beijing Normal University in China and her colleagues performed a large-scale review of all the evidence of exercise on the immune system and their conclusion was frank: "Exercise minimises the chance of becoming sick... Exercise is considered a naturally built-in immune booster."

But more isn't always better. High-intensity training can raise levels of the stress hormone cortisol, which temporarily suppresses our immune system. When mice infected with a parasitic infection swam for 60 to 90 minutes, five times a week, it exacerbated symptoms by 50 per cent, whereas those that did so for 30 minutes, twice a week boosted helper T-cells and improved clearance of the parasite. In people with depression, spending 40 minutes walking, four times a week has been found to lower markers of inflammation in the brain by up to 25 per cent, whereas more intense exercise increased them.

Because of this, some advice has warned against daily exercise, arguing it could have negative effects on immune function. In 2018, however, John Campbell and James Turner at the University of Bath, UK, disproved this idea, showing that daily exercise increased T-cell production by up to 25 per cent and decreased inflammatory markers by up to 35 per cent.

So, how much is too much? Li and her colleagues concluded that negative effects on immune health are particularly noticeable in athletes who engage in high-intensity interval training, which involves short

MCKAY ANDY/MILLENNIUM IMAGES, UK

A brisk walk is one way to raise antibody production

"Exercise is considered a naturally built-in immune booster"

CHRIS STEELE-PERKINS/MAGNUM PHOTOS

"The thing that has the most clearly proven impact on our immune health is long-term stress"

Your daily commute could be increasing your levels of inflammation

bursts of exercise that raise your heart rate to 80 to 90 per cent of its maximum rate, followed by short recovery periods. Proper rest, appropriate nutrition and stress management can mitigate these risks, they say.

But given the majority of us don't train at such punishing levels every day, it is unlikely we will experience the negative side of exercise. So, if you are serious about boosting your immune health, moderate daily exercise is probably the sweet spot.

Attitude check

And keep in mind that consistency is key: in unpublished work, Ahuja's team gave adults a regular exercise regime for 24 weeks and showed that everyone's immune grade had improved by the end. But after just two weeks of no exercise, their grades slid back to baseline. "We sit on our asses and it's not good," says Ahuja.

Ahuja reminds me that, alongside diet and exercise, there is a third pillar of immune health that we often overlook: the brain. "What do all these 100-plus-year-olds, sitting there smoking, drinking, have in common?" he asks. "They have a great attitude to life!"

He points to a study published in *Nature* in July that showed we can influence our immune system simply by the way we think. In the study, volunteers were exposed to virtual-reality avatars displaying clear signs of infection as they moved close to them. Merely anticipating contact with infected avatars activated brain changes that altered immune cell activity in the participants' blood, in ways that mirrored what is seen when the body encounters a real infection.

It is a vivid demonstration of how powerfully the brain affects our immune health. And it isn't just the thought of being ill that can trigger the response: being on edge in general affects the state of our immune health. "The thing that has the most clearly proven impact on our immune health is long-term stress," says Davis. One of the reasons we are so confident in stating this is because we have a molecular level understanding of what happens when we are stressed, he says.

When the body senses a threat, it releases hormones such as adrenaline and cortisol to initiate a fight-or-flight response. This response triggers signalling pathways aimed at promoting survival, temporarily increasing inflammation and certain immune cells in preparation for injury or infection. Meanwhile, it suppresses things like digestion – no need to digest your lunch when you are facing a tiger.

But when cortisol levels remain high due to chronic stress, these signalling pathways are impaired, weakening your immune system, making you more susceptible to infections and autoimmune diseases, and reducing your response to vaccines. When human immune cells are mixed with virus-infected cells, those that have cortisol added to the blend are weakest at responding, says Davis.

Of course, telling yourself to be less stressed to improve your immune health is easier said than done. At the very least, says Davis, knowing that negative cognitive states have real impacts on your immune system might motivate you to take steps to seek support and solutions that help you decompress.

If only there were a tablet that could do all of this for us, I thought. "That's what everyone wants," says Ahuja, a magic pill that supercharges the immune system. He wonders whether in time, GLP-1 drugs like Wegovy or Mounjaro might prove to be something of a contender for this role, given their effects on metabolism and mood. But that is still speculation.

For now, as I burrow deeper under the covers, I am glad I have discovered that zinc, rather than oranges, might help me recover a little quicker. But it is the slow fixes that will make a difference over the long term: nourishing my microbes with fermented foods, challenging myself to daily workouts and finding ways to keep long-term stress in check. It isn't a magic pill, but if it nudges my immune grade towards a 1, perhaps I will be less of a target for whatever challenges next year brings. ▮

Helen Thomson is a science journalist specialising in life sciences, health and biotech

How to spot an alien

Tentative evidence for alien life sometimes hits the headlines, but how can we ever know for sure? **Miriam Frankel** has your essential guide

THE afternoon of 7 August 1996 isn't a time that sticks in many people's minds. But if things had worked out differently, it might have been etched into our collective memory. At 1.15pm, US President Bill Clinton stepped onto the White House's verdant South Lawn to speak about the possible detection of life in a Martian meteorite. "If this discovery is confirmed, it will surely be one of the most stunning insights into our universe that science has ever uncovered," he said.

But it wasn't: it joined a list of inconclusive claims about alien life. We don't, of course, have to go all the way back to the 1990s to find other such claims – just a few years ago, the discovery of phosphine gas in the atmosphere

GIULIA CALISTRO

of Venus got scientists excited. And in 2017, Avi Loeb at Harvard University said the interstellar object 'Oumuamua was a piece of alien technology.

With a slew of new missions poised to return data from alien worlds, the pace of these potential discoveries is likely to accelerate. So, what questions should we ask ourselves when apparent evidence of alien life inevitably arrives? In this guide, we'll walk through the most plausible ways it might first show up, from faint chemical signatures to fossilised microbes. Think of it as a scientific gut-check – a sliding scale of how close different scenarios come to proving alien life exists the next time headlines proclaim we're not alone.

Scenario 1
We detect biosignatures in the atmosphere of a distant exoplanet

News breaks that a planet light years away from Earth has an atmosphere seemingly laced with gases we associate with life. Headlines trumpet a "breathable world", and the internet goes wild. But what should we make of such a claim?

This is one of the most plausible ways we might first see signs of alien life – not through little green men, but via telltale molecules in the air. On Earth, life has radically altered the atmosphere: microbes, plants and people all leave chemical traces. If the same is true elsewhere, then telescopes trained on exoplanets could pick out radiation absorbed and emitted by gas molecules exhaled by alien organisms that's present in the exoplanets' atmospheres.

Some gases are more suggestive than others. Carbon dioxide and water vapour, for instance, can come from both biological and geological processes. Others, known as biosignatures, are harder to explain without the presence of life. But identifying them – and proving they truly point to biology – is trickier than it sounds.

Take K2-18b, a planet about 120 light years away from us. In 2023, Nikku Madhusudhan at the University of Cambridge and his team discovered tentative signs of dimethyl sulphide (DMS) in data from the James Webb Space Telescope (JWST). On Earth, DMS is produced only by marine plankton and bacteria.

Madhusudhan also found a second, similar gas, dimethyl disulphide (DMDS), in data from a different instrument, supporting his team's original findings. This year, a paper found similar, though slightly weaker, evidence of DMS, also via the JWST. "It is still not at a level that we want for claiming a robust detection," says Madhusudhan. "But the signal has increased, so we're going in the right direction. We need more data."

Madhusudhan, for one, is optimistic. "We are seeing tentative signs of molecules that have been predicted to be biomarkers well before the observations, and that's the important bit," he says.

Others argue that data like this is too flimsy to support a claim of life. Andrew Rushby at Birkbeck, University of London, builds atmospheric models to test how reliable such detections really are. One of his students, Ruohan Liu, is currently investigating alternative explanations for Madhusudhan's findings. For example, many scientists assume that K2-18b has liquid water, which makes biological processes more likely but which may ultimately fail to be true. "Maybe it is more like a mini Neptune," says Rushby, pointing out that a gas-rich planet could also produce the same spectra.

Rushby and his colleagues have even proposed a framework for evaluating potential signs of life based on probability. Instead of just asking "Could life make this?", it asks "What else could?", weighing different explanations by likelihood and context. That includes the planet's temperature, chemical balance and the type of star it orbits.

Madhusudhan acknowledges the need for caution, but pushes back against the idea that gas signatures are always insufficient for proving alien life exists. Treating life as an extraordinary claim requiring extraordinary evidence stems from human bias, he says. After all, how are claims of life different from those of astrophysical objects that we can't see directly? "How do we know there is a black hole at the centre of our galaxy?" he asks.

Ultimately, no single observation is likely to clinch the case for life. Proof, if it exists, will come in stages, and we do have some guidelines for how such a process would work (see "Seven steps to proving alien life exists", page 34).

But to make a truly convincing case out of hot air, Rushby says the detection of more biologically produced gases from the same exoplanet could strengthen the findings, highlighting oxygen and methane as crucial. And we will need several observations, he says: "The more independent lines of evidence we can have, the better we can rule out systematics like problems with a specific telescope that might be fooling us."

So if, in the not-too-distant future, an exoplanet's atmosphere sets the internet ablaze, keep your cool. A few whiffs of something fishy in the air don't yet mean life is out there. But they do mean it's worth looking harder.

Potential for detecting alien life: 1/10

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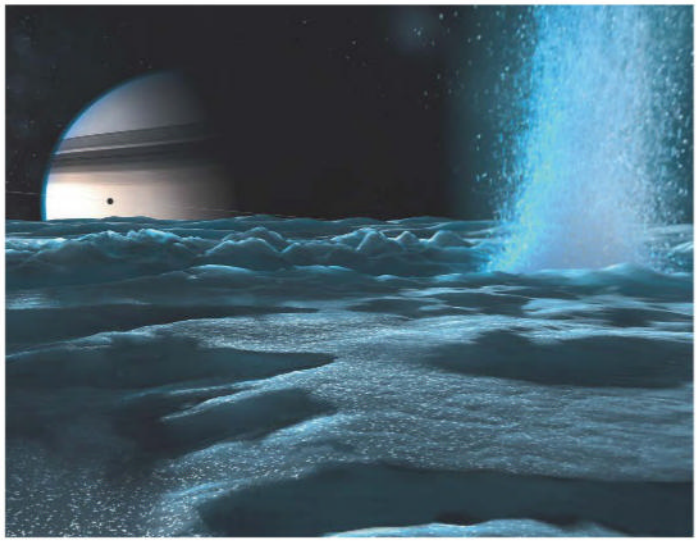
Seven steps to confirming alien life exists

One of the earliest attempts to make a framework for detecting life was in 2021, when NASA astrobiologists proposed the Confidence of Life Detection Scale (CoLD). It involves seven basic steps, or "levels". Here's their checklist:

1) **Detect a signal, like light emitted from an extraterrestrial atmosphere or a rock with protein fragments**
2) **Rule out contamination**
3) **Ensure it comes from a habitable environment**
4) **Show it can't be produced by known non-living processes**
5) **Look for further, independent biological signals**
6) **Rule out alternative hypotheses with additional observations**
7) **Make observations of predicted, additional signals with another observatory or instrument**

So far, nothing we've seen has made it past step 3.

"Mars remains our best shot at finding signs of ancient alien microbes"



SCIENCE PHOTO LIBRARY/ALAMY

Signals of life may be seen in jets of water on Saturn's moon Enceladus, shown in this artist's impression

Scenario 2
Water samples from the ocean of an icy moon contain biological molecules

In the next 50 years, humanity will probably see its first reconnaissance mission to Jupiter's moon Europa or Saturn's moon Enceladus. These icy worlds are special to scientists because they hide vast underground oceans beneath their frozen crusts, potentially teeming with life. There is energy, too – molecular hydrogen formed when rock and water interact could feed alien microbes just as it does on Earth. A lander armed with a drill could mine for water samples and potentially fly them back to Earth.

Peering down the microscope, we might then see unfamiliar creatures swimming in our Petri dishes – ideally, ones strange enough to rule out the possibility of contamination.

But a round trip isn't exactly easy: our latest mission, the Jupiter Icy Moons Explorer, will take eight years to reach Europa. So, what if we didn't need to bring back a sample from an icy world? What if we could detect life in situ?

That's what Nozair Khawaja at the Free University of Berlin is trying to do. He and his colleagues are designing an instrument for NASA's upcoming Europa Clipper mission. It builds on earlier work: in 2018, Khawaja and his team reported the first-ever discovery of massive and very complex organic compounds from the plumes of Enceladus.

They weren't able to pin down exactly what the molecules were, but it appeared to have a round structure, with nitrogen, oxygen and hydrocarbon chains.

"When we put that together, search candidate compounds appeared. And one of them is humic-acid-like," he says, referring to an organic substance in Earth's soil that clings to nutrients and helps feed microbes.

But there is a snag: some organic molecules can also be formed when ice is zapped by radiation, and the surface of Enceladus gets plenty of that. The molecules might be biological, or they might just be chemical noise, though Khawaja's latest work suggests they are unlikely to be the latter, since they emerge from the moon's interior, which is protected from radiation.

It is unclear whether Europa has active plumes like Enceladus does, but if so, the Europa Clipper spacecraft will fly through them. If not, it will skim areas where micrometeorites have punched into the ice and thrown up buried material from below. This time, the onboard instruments will be more sensitive. Khawaja's team is designing them to detect combinations of amino acids and fatty acids that show matching chirality – essentially, a molecule's left- or right-handed orientation. In nature, life tends to favour one-handedness over the other, producing patterns that rarely arise on their own. All these signals, in combination, would show beyond doubt there's "potential for life", he says.

There's another challenge: speed. Previous missions like Cassini zipped through plumes from Enceladus at 18 kilometres per second, many times faster than a bullet, a pace that can damage molecules such as DNA. "Stuff can break up in instrument chambers and things like that," says Andrew Coates at University College London. But Khawaja says Europa Clipper will aim for a lower speed of 3 to 6 km/s. "This is the speed which, through our experiments, we think can give us the whole DNA molecule intact, in addition to some fragments."

Of course, after all this, we would still be left with only a tentative detection of life, which would need to be backed up by further missions.

Research on Earth will also be crucial.

Khawaja is working on an experiment to determine whether the core of the icy moons could support life and how material from below can be ejected in plumes, strengthening future findings and making predictions that we could test.

The bottom line? If there is life beneath the ice, we may not know for sure for decades, but molecular fragments are a strong starting point.

Potential for detecting alien life: 4/10

Scenario 3
We find the imprint of ancient life in rocks from Mars

Right now, a piece of Mars sits waiting in a sealed titanium tube on the dusty floor of Jezero Crater, having been cached by the Perseverance rover in late 2024. Just 6 centimetres long, with pale, bleached spots, it looks unremarkable. But within decades, this mudstone could be returned to Earth and offer some of the most convincing evidence of life beyond our planet.

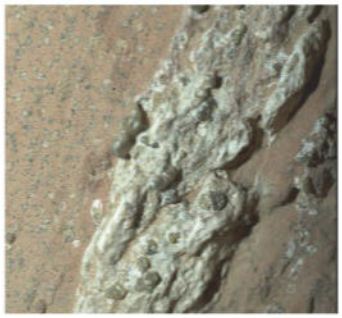
Of all the planets in the solar system, Mars remains our best shot at finding signs of ancient alien microbes. It is relatively nearby and, in its youth, was wet with rivers, lakes and groundwater, all of which could have supported life. That is why the campaign to bring samples back to Earth is being treated as one of the most consequential science efforts of the coming decades.

Even so, once precious cargo from Mars reaches Earth – probably in the 2030s – we will still face tough questions. Take the Jezero sample, nicknamed Cheyava Falls. It was discovered in an ancient riverbed and drew attention for its bleached specks. On Earth, similar spots can form when microbes use ferric iron to generate energy through iron reduction.

"We have several lines of evidence to indicate that these kinds of bleached spots in red rocks are probably biological at least most of the time. But it's a bit unclear, to be honest, even on Earth," says Sean McMahon, an astrobiologist at the University of Edinburgh, UK. Geochemical reactions can also produce them, though typically with heat – something Mars, being icy nowadays, lacks. But alien worlds also have alien chemistries that might make such reactions possible. The spots won't amount to proof.

Organic molecules – the building blocks of life – have also been found in the Cheyava Falls sample. But Perseverance can't determine exactly what they are. Only once samples are studied in Earth-based labs will we be able to tease out the details.

One thing scientists will be looking for are polycyclic lipids, fatty molecules from cell membranes made of carbon, hydrogen and oxygen. These are more likely to survive than fragile molecules like DNA. Even the number of carbon atoms in fatty acids might be telling: life tends to favour even numbers. While Martian organisms might not follow this rule, living and non-living processes are still likely to leave different patterns.



NASA/JPL-CALTECH/MSSS

Bleached spots on Martian rock could have been made by microbes

Still, nothing would be definitive. After all, amino acids have been found in uninhabitable environments like comets and interstellar space. To be confident, we would need multiple lines of evidence from different missions.

Coates thinks the European Space Agency's upcoming Rosalind Franklin rover could provide just that. "I think the combination of bringing stuff back and Rosalind Franklin could be the two things we need to actually detect it," he says.

Launching in 2028, the rover will be able to drill 2 metres beneath the ground, where there is a better chance of finding life, since the surface is bombarded with radiation. Unlike Perseverance, it will carry a mass spectrometer capable of detecting amino acids and complex molecules, and it will assess their chirality.

From there, it will be able to exclude Earth-based signals, since we know that the chirality and ratios of isotopes – elements with a different number of neutrons in the nucleus – of nitrogen and carbon are different on Mars.

If signs of life are found, the next step would be making predictions that we could test. "It follows that you should find these [biological] features only in parts of the environment that were habitable," says McMahon. It would be enough to warrant more sample return missions, maybe from elsewhere on the planet in places once shielded and flooded with water, such as the Hellas Planitia plain, or Martian neighbourhoods that we think are completely hostile to life, such as the top of massive volcanoes like Olympus Mons.

So when it comes to Mars, we might have our first real clues within a decade. But a press conference on the White House lawn? That could still be 20 or 30 years away. ▮

Potential for detecting alien life: 6/10

The only place we'll find little green men is on Earth

JOE RAEDLE/NEWSMAKERS/GETTY IMAGES

Miriam Frankel is a science journalist specialising in space and physics

A daily dose of creativity

Exercise, diet… and art? Epidemiologist **Daisy Fancourt** reveals the powerful but overlooked health benefits of creative expression

CUT your sugar, get some exercise, stop smoking, eat your vegetables, take supplements, don't stress, sleep well. Every day, we are bombarded with information about how to live longer, healthier, happier lives. But there is one piece of advice I bet you have never been given. It's probably the most enjoyable health tip you could be told, but the data supporting it has – to date – remained a bizarrely well-kept secret: engage in the arts.

Over the past few decades, evidence has been accumulating to suggest that being more creative works wonders for our health. Programmes being developed around the world are starting to integrate the arts into healthcare, with astonishing results, from music in surgery reducing the amount of sedatives, opioids and anti-anxiety meds needed, to dance programmes helping people with Parkinson's disease to walk.

But the arts aren't just there for us when we are sick. Crafts, singing, theatre, dance, reading, writing and drawing are inherently good for us as part of our day-to-day lives, even if thoughts about our health are far from our minds. In my forthcoming book, *Art Cure*, I argue that they are a "health behaviour" akin to exercise, diet and sleep. Here's why, and how, you should get more art into your life in 2026.

As an epidemiologist, I spend my days looking at data from cohort studies – massive datasets that contain thousands of individuals who have completed questionnaires, had nurse interviews, donated blood samples and undergone brain imaging every few years of their lives. Many of these studies in countries around the world contain buried questions on arts engagement. Using complex statistical methods, we can look at the long-term relationship between everyday arts engagement and dozens of health outcomes.

The results are remarkable. People who participate more frequently in the arts, watch artistic performances and visit cultural venues are happier and feel more satisfied with their lives over the years and decades that follow. Children who engage more with the arts have a reduced risk of developing problems like depression by the onset of adolescence. Among adults over the age of 50, those who regularly go to live music events, the theatre or museums and exhibitions have nearly half the risk of developing depression over the next few years.

You might be wondering if this isn't about

FOTOGRAFIA INC./GETTY IMAGES

People who paint have brains that appear younger than their chronological age

SEAN GARDNER/GETTY IMAGES

Live events are a great way to get more creativity into your life

the arts at all. What if people who are creatively engaged are wealthier, healthier or engaging in other behaviours that might be responsible for these effects? The statistics underpinning these analyses are sophisticated – we can not only take account of potential confounding factors like these, but also consider other factors like genetics, family environment and childhood experiences, and the results still hold.

The benefits aren't just psychological either. Toddlers who engage in music activities have increased prosocial skills as they head into primary school. Adolescents who are involved in bands, dance and editing school newspapers are less likely to get involved in antisocial behaviours or crime. And older adults who go to cultural events have a 32 per cent lower likelihood of being lonely 10 years later.

The results are particularly strong as we age. Looking at data from nearly 100,000 people across 16 different countries, my team at University College London and I have found that having hobbies – things like gardening, baking and journalling – is related to higher self-reported health as we get older. Better balance, reduced pain levels, better sleep, longer preservation of cognition, reduced frailty, even a reduced risk of certain diseases like diabetes – the benefits accumulate the more we engage.

On a par with exercise

Notably, many of these studies have compared arts with better-known health behaviours like physical activity and found that the effect sizes are surprisingly similar. In fact, multiple studies have now found that people who spend more time reading books, making music, dancing and attending artistic events actually live longer than people who don't engage with the arts.

How are all these effects happening? There are psychological, social and behavioural mechanisms at play. But, personally, the mechanisms I find most exciting are the biological ones. Increasing numbers of studies show that people who regularly engage in the arts have lower blood pressure and heart rate, lower cholesterol, reduced inflammatory markers, better regulation of immune function and lower body-mass index.

In the past few years, major developments in the calculation of biological clocks – which compare if our bodies are ageing faster or slower than our chronological age – have enabled scientists to consider how health behaviours influence our "pace" of ageing. And various studies that combine data from our cardiovascular, respiratory, circulatory and musculoskeletal systems and even patterns of our gene expression suggest that engaging in the arts could even help you to stay biologically younger. People who dance, make music and paint have brains that appear younger in age.

I want to be clear: I am not suggesting the arts are any kind of panacea. Arts can be inaccessible to people because of cost, and there are a whole host of myths about purported health benefits, from the improbable to the downright ridiculous. But the evidence remains that engaging regularly in creative activities that you enjoy is an investment in your health that is worth making. And doing so would be an altruistic act too – economists working with the UK government have estimated that the health benefits of arts engagement in the UK are worth over £18.6 billion each year to society.

So how can we all increase our arts consumption? It's a question I come back to across every chapter of *Art Cure*, giving a "daily dose" of recommendations for how you can use the arts to achieve your health goals. Overall, my advice is to think about the arts as you think about food. Avoid the temptation to go out and binge on arts – in the same way that crash dieting doesn't work, you aren't going to experience long-term benefits from short-term engagement that then fizzles out. Instead, try to figure out what your arts equivalent of "five-a-day" fruit and veg is. Maybe that's just 10 minutes of creative writing before you start work each day or putting aside 15 minutes for a crafts activity each evening. Make easy creative substitutions – swap a date-night dinner for a gig, a gym session for a dance class and reading the news on the train for reading a poetry book.

Mix up your ingredients, too. Diversity of arts experiences is actually just as important as frequency of engagement. Each creative encounter brings different sensory treats for our brains and bodies that have their own health benefits. Experiment with new flavours of creative experience, heading for "moderate novelty" – something that is outside your comfort zone, but still something you think you will enjoy. Make your engagement real life, not virtual – screen-based arts activities tend to be the ultra-processed foods of the arts world.

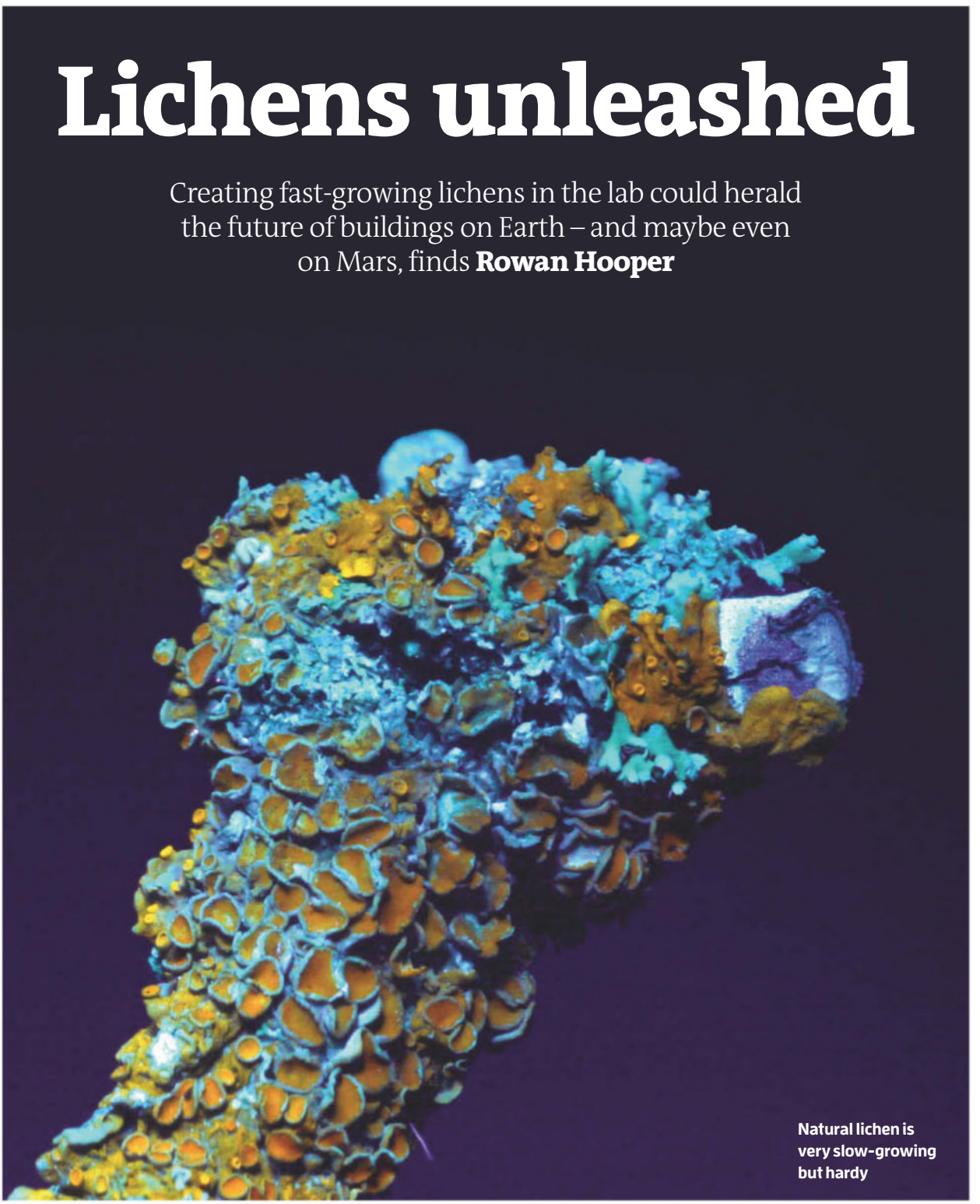
Most of all, be a mindful chef. In our busy lives, it's easy to want to distil the arts down to a pill that we can pop and then forget about. But the very beauty of the arts is that they aren't a pill. They are one of the most diverse, complex and personal behaviours we can engage in. So we should all give the arts the time in our lives they deserve. And we should revel in our engagement – allow art to make us feel exhilarated, intoxicated, elated. Because it is fundamentally, measurably good for us. ▮

"Screen-based arts activities tend to be the ultra-processed foods of the arts world"

Daisy Fancourt is professor of psychobiology & epidemiology at University College London and author of *Art Cure*

Lichens unleashed

Creating fast-growing lichens in the lab could herald the future of buildings on Earth – and maybe even on Mars, finds **Rowan Hooper**



DR KLAUS SCHMITT

Natural lichen is very slow-growing but hardy

WHEN I usually examine lichens, I am in a forest, peering at frilly growths on tree branches with my hand lens. Or on exposed rocks high in the Alps, or old gravestones, or the rocky seashore, in the zone where the seaweed stops growing but before bigger land plants take over. I have been looking at a lot of lichens during research for a book on symbiosis, but where I have never seen them before is in a lab flask swirling in an incubator. And while I often think about what lichens tell us about the past, I hadn't until recently thought about what they tell us about the future.

The green cloudy fluid I am looking at in the incubator is not at all what we think of as a lichen, which is a symbiotic partnership between a fungus and an alga. "That's because this is a synthetic lichen," says Rodrigo Ledesma-Amaro, who is the director of the Bezos Center for Sustainable Protein here at Imperial College London. The fluid is a co-culture of two species, a fungus (yeast) and a cyanobacterium. Like a natural lichen, the fungus provides a scaffold, a host structure for the bacterium, and the bacterium makes sugars through photosynthesis using light, water and carbon dioxide, and feeds them to the fungus.

Why would you want to make such a potion? Because, Ledesma-Amaro tells me, we can gene-edit yeast to get it to create all sorts of useful products – food, fuels, chemicals, materials, pharmaceuticals – and if we can drive that production through photosynthesis, then we can make those things sustainably. For that reason, synthetic lichens are sparking excitement not only in the biotech industry but also beyond. Lichens, it transpires, could be harnessed to repair buildings, fight the climate crisis and even build habitations on Mars.

"Synthetic lichens recreate the symbiosis of natural lichens, but grow much faster, and using yeast as a partner allows us to sustainably produce a whole range of high-value compounds," says Ledesma-Amaro. Yeast is a well-known, industrialised organism that is "programmable" and easily grown at scale.

In the synthetic lichen I see, Ledesma-Amaro and his team use yeast that is genetically engineered to make caryophyllene, which has applications in the pharmaceutical, cosmetic and fuel industries. In the near future, he foresees a range of useful products: antibiotics, biofuels and synthetic palm oil. Another form of synthetic lichen might be engineered to capture and store carbon dioxide. Other scientists see lichens being deployed to repair ageing concrete structures around the world.

The ambitions for lichens are high, even reaching beyond our own planet. On the moon and on Mars, NASA and private space companies plan to use synthetic space lichen – properly known as an engineered living material – to grow on regolith and make material for constructing buildings and furniture.

Synthetic symbionts

Modest in appearance and slow in growth, lichens are the archetypal demonstration of symbiosis, which means "living together" and refers to the cohabitation of two different species. In the case of lichen, the textbook explanation is that a fungal partner hosts an individual of another species, known as the photobiont. Usually, this is algal, but sometimes bacterial, and it makes food through photosynthesis and shares it with its host. The fungal partner provides, among other things, superb protection from the elements, such that the lichen can survive in extreme conditions where little else can make a living. This is why some scientists are repurposing lichens and making synthetic versions of their own.

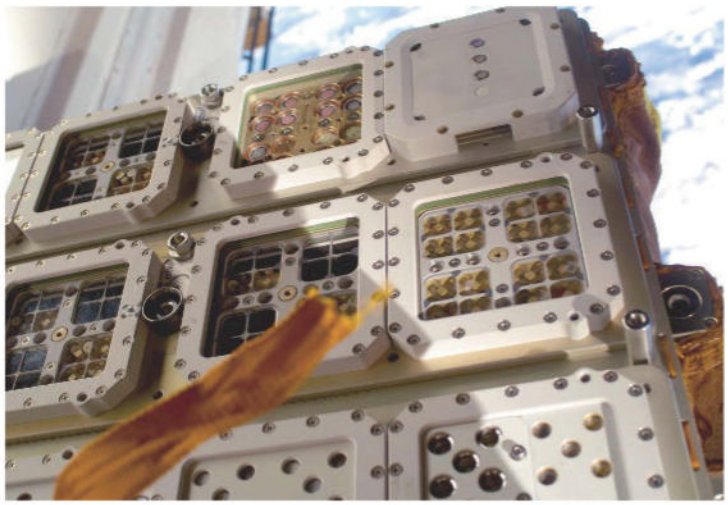
Lichens have two qualities in their favour. First, as a symbiotic organism, the whole is greater than the sum of its parts. In other words, each lichen can do things that the fungus alone or the photobiont alone cannot do. From afar, lichens may be modest in appearance, but up close, they are complex, luxuriant, charismatic organisms. Natural lichens are also far more than the textbook two-species partnership of fungus plus alga. Often, there are these two organisms, plus a secondary fungus in the form of yeast and an extra bacterial species, making a community of four. But even that is an underestimate. "In nature, what we call a 'lichen' colloquially is actually a community of many – tens to hundreds – of different microbes," says Arjun Khakhar, a biologist who makes synthetic lichens at Colorado State University. "Two lichens that look identical and are right next to each other can have hugely different members." Various analyses of fresh lichen tissue have found that they contain between 1 million and 100 million bacteria per gram.

The second thing lichens have going for them is that they are robust. They can live and photosynthesise in the harshest of conditions. In Svalbard, far within the Arctic circle, there are around 700 species of lichen. They cope with low temperatures, aridity and high ultraviolet radiation. On the seashore, they tolerate repeated immersion in saltwater – an experience that most other land plants can't cope with. Some species grow inside rock ("endolithic" lichen, literally "inside rock"). It is an open question as to just what aspect of their biology allows them to cope with desiccation and extreme temperatures.

Khakhar suggests lichens' resilience comes from biomolecules the filamentous fungus produces, which protect the entire community in the lichen. "The unique molecules it is able to make are potentially due to lichens' capacity to leverage both bacterial and fungal biochemistries via distributing tasks across the community," he says. For example, components in the photobionts can make various pigments with chlorophyll, and the fungus can make sunscreen by synthesising compounds such as carotenoids (the pigments in carrots, ripe tomatoes and autumn leaves) and melanins (which colour our skin).

Together, the symbiotic lichen community has access to a greater range of compounds than a single organism can hope to produce, and this unlocks the lichen's superpower. Physically, too, the fungal component helps buffer the community from swings in temperature and humidity. Then there's its slow growth, which allows it to live with minimal resources.

These attributes have been enough to get NASA excited. Lichens can survive exposure to both simulated and real space conditions. Starting in 2014, a lichen species called *Circinaria gyrosa* lived – or at least, didn't die – on a shelf on the exterior of the International ›



ESA

A lichen lived for 18 months on the exterior of the ISS

Space Station for 18 months. When it was brought back inside and given water, it started growing. The fact that lichens can grow inside rock and tolerate the conditions of space excites proponents of lithopanspermia, the idea that microbes could travel between planets in asteroids.

Congrui Jin, an engineer specialising in living materials at Texas A&M University, started thinking about the potential of lichens for a forward-thinking NASA project aimed at finding efficient ways to build places to live and work on Mars – whenever we eventually get there. Some proposals for off-planet housing rely on inflatable structures, the idea being that fewer materials are needed to make air-filled housing. But every item of prefabricated material transported there by rocket is still expensive. A cheaper alternative to hefting such items up from Earth is to find a way to produce building materials from the regolith already on the planet. For Jin, lichens are the perfect solution. But a naturally occurring species may not necessarily work.

"We want to pair the fungi with some photosynthetic species like cyanobacteria. They can convert sunlight and water into organic nutrients and precipitate calcium carbonate," she says. "It acts as glue to bind the soil particles on Mars into a cohesive structure." This biomaterial can then be used in a 3D printer to produce building materials – floors, partitions, walls, furniture, you name it. The bulk of what you need, whether sunlight, carbon dioxide, water, nutrients or vast supplies of basalt rock, is already there on Mars.

Jin's work has recently shown that lichens are promising candidates for turning Mars regolith into building material and for producing other biominerals and biopolymers. Lichens are tough, and some eager futurists consider them good candidates for helping to terraform the Red Planet. But even if there weren't planetary protection measures to abide by, lichens can't grow on the surface of Mars, exposed to the elements. Mars has no magnetic field, and any life on the surface needs to be shielded from the harsh radiation. So, Jin envisions her Mars lichens growing in shelters.

However, colonising other planets is a long way off, and Jin realised her lichens had a more immediate role on Earth. There are many occasions when it would be useful to bind rubble together and make a usable building material. Think about the wrecked buildings left by natural and human-caused disasters. As well as that, a way to sequester carbon during the concrete-making process would help moderate its huge carbon footprint. And what if we could produce self-healing concrete? Buildings and structures would be cheaper to maintain and would have a longer life, too. Previous attempts to use microbes to perform these functions have faltered because concrete is an inhospitable place in which to live. But if lichens can cope in space, Jin reasoned, surely they can cope with concrete.

Jin and her colleagues showed that a lichen-based approach, pairing fungi with cyanobacteria, makes a co-culture that can grow on concrete. Not only that, her synthetic lichen precipitates calcium carbonate – the mineral that forms chalk, limestone and marble – healing cracks in the structure. "We tried filamentous fungi and cyanobacteria and found that they have better survivability [than other microbes] under the dry and nutrient-poor conditions in concrete," she says. "They get along with each other and the process is autonomous, and they also have [a] very good capability to precipitate calcium carbonate." Unlike single-species approaches, the co-culture doesn't require the addition of external nutrients, because the synthetic lichen extracts nitrogen from the air and makes its own fertiliser.

Khakhar is also attempting to make fast-growing lichen by selecting microbes that are already fast growers, before tweaking them and pairing them to become lichen-like. His lab, in work similar to Jin's, has made a synthetic lichen in which the fungal component becomes mineralised. "Filamentous fungi are fed by the cyanobacteria embedded in them and grow a mycelium that has a stone exoskeleton," he says. "In the future, this will enable the sustainable biomanufacture of building materials." He calls the engineered product mycomaterials.

My investigations of symbiosis have deepened my appreciation of lichens as dynamic mini ecosystems, a living lesson in the reality of interdependence, as has understanding their sci-fi potential in crafting the materials of tomorrow. So the next time you see those frilly growths on a tree, a gravestone or an old bench, perhaps take a moment to pause – and consider what a future-shaping marvel you are beholding. ▮

Lichen is a community of many different microbes

JOSE B. RUIZ/NATUREPL.COM

Rowan Hooper is podcast editor at *New Scientist*. His book *Togetherness* will be published in 2026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The back pages

Mathematics of life

Beware the snow-fake!

Mathematician **Katie Steckles** admits to a fit of festive pedantry over one particular seasonal decoration

Katie Steckles is a mathematician, lecturer, YouTuber and author based in Manchester, UK. She is also adviser for *New Scientist*'s puzzle column, BrainTwister. Follow her @stecks

AT THIS time of year, everything seems to be decorated with some kind of seasonal design – trees, holly, jolly Santas and so on. One shape you often see is a snowflake. Yes, they are beautiful and intricate, but I can find their proliferation deeply annoying.

The shape of snowflakes is an artefact of the chemical structure of ice, and even though (as they say) every snowflake is unique, there is actually a surprisingly regular mathematical pattern in there too. We often use the language of symmetry to describe shapes. If something has reflection symmetry, we can draw a line across it, and the shapes on each side will be mirror images of each other.

A shape can also have rotational symmetry – we can partially rotate it and get the same shape. The number of different positions on the way round that result in the same shape is called the order of the symmetry: a shape like a square has order 4 rotational symmetry, while an equilateral triangle has order 3.

Some shapes just have rotational symmetry (like the three-legged emblem of the Isle of Man) and some just have reflection symmetry (like a stick figure, which has a single line of reflection down the middle).

Regular polygons have both rotation and reflection symmetries – called dihedral symmetry – and we can combine these symmetries to get others. For example, reflecting a square vertically then horizontally equals a rotation by 180 degrees. In the same way we add together numbers, there are also ways to "add" symmetries to describe what happens when you combine them – part of an area of maths called group theory.

ANDRII OLEKSIENKO/SHUTTERSTOCK

The snowflake is a perfect example: it has the structure of a hexagon, which can be reflected along six different lines passing through the centre of the shape, and rotated by 60 degrees six times. This symmetry arises due to the chemical structure of water and ice. The angle between the bonds is such that when the water freezes, the molecules – held together by hydrogen bonds – arrange themselves into a rigid hexagonal lattice.

This chemistry means that the vast majority of ice structures, including snowflakes, have an underlying hexagonal shape. The exact form of the snowflake depends on the conditions under which it forms, including temperature, humidity and pressure – meaning they all have tiny differences, but the same underlying structure.

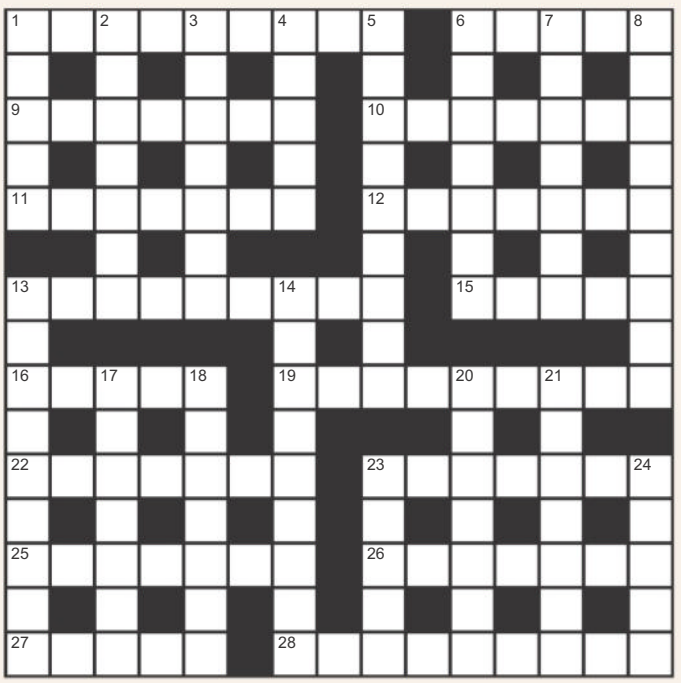
As a mathematician, I am very pleased in the winter to be surrounded by shapes with such an elegant structure, even if it's too small to see. But I am also deeply frustrated by decorations (not the one shown!) depicting snowflakes with eight (boo) or five (ugh) branches. Be vigilant, readers: beware the seasonal snow-fake! ▮

Mathematics of life appears monthly

Next week
Debunking gardening myths

These articles are posted each week at newscientist.com/maker

Quick crossword #198 *Set by Richard Smyth*



Scribble zone

Cryptic crossword next week

ACROSS

1 Stellar explosion (9)
6 Additional on-screen window (3-2)
9 Automated (7)
10 Eight-sided shape (7)
11 Tungsten, formerly (7)
12 O, H, K or S, say (7)
13 $CaCO_3$ deposit (9)
15 Prefix denoting 4 (5)
16 Sightless (5)
19 First of its kind? (9)
22 Whole number (7)
23 Sea life unintentionally trapped by fishing vessels (2-5)
25 Memory loss (7)
26 Peewit (7)
27 13-19 (5)
28 Rubbery polymer (9)

DOWN

1 Threaded fastener (5)
2 Pap (7)
3 Laboratory stands (7)
4 ___'s razor, logical principle (5)
5 >0 (5,4)
6 One receiving medical treatment (7)
7 Colouring agent (7)
8 Enter; pierce (9)
13 Oil, perhaps (9)
14 Artificial sweetener (9)
17 Strong (7)
18 Processes (food) (7)
20 Back of the head (7)
21 Y (7)
23 Lightweight timber (5)
24 ___'s sign, pregnancy indicator (5)

Our games are now playable online
newscientist.com/games

Quick quiz #322
set by Tom Leslie

1 In November, researchers extracted the oldest ever RNA sample from a frozen mammoth. What does the "A" in both RNA and DNA stand for?

2 Also last month, physicists uncovered a universal law to describe how objects what?

3 What asteroid was the target of the OSIRIS-REx mission that returned to Earth with samples of the space rock in 2023?

4 Which firm is reportedly in talks to sell its tensor AI processing units to other tech companies?

5 What is the name of the deadly fungus that has devastated amphibian populations around the world?

BrainTwister
set by Alison Kiddle

#106 Indices behaving oddly

What is $3^3 + 7^3$?

For which values of n will $3^n + 7^n$ be a multiple of 10?

Which number shares the same relationship with 6 as 3 shares with 7 in this pattern?

Answers to this week's puzzles on page 47

Music in the wild

Animals seem to respond to music when it is played to them, but what do they hear?

Chris Daniel
Conwy, UK
We don't know for certain what causes these responses. Many experiments have been done to investigate the mechanisms of the calming effect of music in animals, but conclusions have been difficult to reach. While some studies have shown that music produces stronger effects than non-musical sounds, they don't explain the reason for the responses or what aspects of the music enrich or modulate behaviour, as random sounds or white noise also have a beneficial effect in some animals.

One hypothesis is that within captive settings, the music masks more stressful ambient sounds such as human activity, ventilation systems, etc. However, it may also provide sensory stimulation by increasing the complexity of the auditory environment, which may not otherwise be as rich and varied as it is in the wild. It may be that acoustic features in music that

"Cats seem indifferent to most music but do respond to pieces written for them with tempos similar to that of purring"

cause emotional arousal overlap with those contained in animals' vocalisations and other naturally meaningful sounds.

Experimenters have tried to determine if animals perceive music in the way that humans do by breaking it down into melody, rhythm and spectral features such as amplitude, frequency and dynamic range. However, this doesn't reveal anything about animals' preference for particular sound features.

Animals have a variety of rhythmic elements in their natural behaviour and some animals, such as parrots and a certain captive Californian sea lion, are able to move to a beat when certain music is played to them. One study found that playing slow music (under 100 beats per minute) to dairy cows increased milk yield by 3 per cent. In another, kennelled dogs responded to a variety of music, but soft rock had the most relaxing effect. Cats, on the other hand, seem indifferent to most human music, but do respond to pieces written specially for them that have a tempo similar to that of a purring or suckling sound while feeding.

Robert Checchio
Dunellen, New Jersey, US
The American rock band the Beach Boys already gave us the answer to this question with their 1966 album, *Pet Sounds*.

INCAMERASTOCK/ALAMY

Do birds actually sleep more during the short, cold days of winter?

This week's new questions

Branching out **In winter, birds often sit quietly on a branch for hours. Do they actually sleep more or is it just a way to conserve energy?** ***Caroline Deforche****, Lichtervelde, Belgium*

Scream if you know the answer **Why do we scream in fear? It doesn't help and it makes us more vulnerable to predators.** ***Chadi Ajaj****, Ottawa, Canada*

Wake-up call

My partner says he wakes up in the night as he needs to urinate. But could it be that he needs to urinate because he has woken up? (continued)

Maria Gardani
University of Edinburgh, UK
Surprisingly, both explanations can be true. Waking up at night was traditionally attributed to nocturia – frequent nighttime urination. That certainly happens: many people produce more urine at night than their bladder can comfortably hold, especially as levels of the hormone that normally suppresses nighttime urine production decline with age.

But recent research suggests the reverse can be just as common. If something else wakes you first, which can happen at the lighter stages of sleep – a noise, stress, reflux or disrupted sleep cycles – you become aware of your bladder in a way you wouldn't during deep sleep. Even a moderately full bladder can suddenly feel urgent once you are awake.

This means nocturia isn't always the root of the problem; sometimes it is a sleep problem in disguise. Sleep apnoea, for instance, can repeatedly disturb sleep and indirectly prompt nighttime trips to the loo. On the other hand, if someone gets up to pass a large volume of urine, the bladder was probably the reason.

In practice, the simplest way to tell is to note what wakes you. If you are aware of waking first and only then deciding to pee – and especially if little urine comes out – broken sleep may be to blame. If the urge itself gets you to wake, the bladder is to blame.

Antero Ranne
Helsinki, Finland
Sometimes I perceive the need to urinate before waking up. I know this because, often, I have been dreaming about trying to find a toilet. On other occasions, I may wake up because of a leg cramp, for instance, and then notice the need to urinate only after getting up.

Gill Elliott
St Albans, Hertfordshire, UK
James Hardy suggests that waking up to wee can be caused by poor daytime choices, such as excess fluids in the second half of the day. However, if I restrict my fluid intake in the evening in order to try to circumvent the 1.30am wee (and the regularity of this suggests a certain amount of habit), I am awoken anyway by

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Tom Gauld
for New Scientist

a horrendous cramp. It seems I cannot win.

Keith Marwood
via email
For over 30 years, a friend of mine has woken up two or three times in the night to urinate. However, he generally has a dream in which he needs to urinate and goes looking for a toilet, often unsuccessfully. When he finds one, the toilet is bizarrely inadequate in some way. He always needs to urinate badly when he wakes up. Make of that what you will, but I should say that I don't, er... that is, my friend doesn't, seem to suffer any adverse effects from this routine.

Listen up

What part, if any, do my ears or auditory system play when I generate a tune in my head? (continued)

Mike Follows
Sutton Coldfield, West Midlands, UK
Imagining a song is an example of a phantom perception – the conscious awareness of a sensory experience without an external stimulus. When you imagine a tune, many of the same regions of the brain (particularly the secondary auditory cortex in the superior temporal gyrus) activate as if you were actually hearing the sound, but without involving your ears. This capacity is shaped by a lifetime of listening. I imagine that at least some composers can hear the music they are creating before it is ever played.

"If you wake first and then decide to pee, broken sleep may be to blame. If the urge itself wakes you up, it's the bladder"

While earworms – songs that replay in our heads – can be irritating, tinnitus is a far more unpleasant phantom perception: a ringing or buzzing sound that affects about 15 per cent of the population and can be continuous and debilitating for some.

Neuroscientist Linus Milinski and his team at the University of Oxford's Sleep and Circadian Neuroscience Institute suspect that tinnitus is associated with poor sleep. They propose that the large, spontaneous waves of brain activity occurring during deep, non-rapid eye movement (non-REM) sleep might normally suppress the activity that gives rise to tinnitus. Their research may ultimately lead to better understanding – and possibly a cure.

We are highly sensitive to extremely quiet sounds, which suggests that our auditory system must amplify the incoming signal. Stochastic resonance is a phenomenon in which adding an optimal level of noise can amplify a weak signal, improving its detection or processing. I wonder whether tinnitus might be the noise our brains naturally introduce to enhance the signal – but that modern living disturbs our sleep to the extent that, in some people, this internal noise becomes audible. ▮

Answers

Quick quiz #322 *Answer*

1 Acid
2 Shatter
3 Bennu
4 Google
5 Chytrid

Quick crossword #198 *Answers*

ACROSS 1 Supernova, **6** Pop-up, **9** Robotic, **10** Octagon, **11** Wolfram, **12** Element, **13** Limescale, **15** Tetra, **16** Blind, **19** Prototype, **22** Integer, **23** By-catch, **25** Amnesia, **26** Lapwing, **27** Teens, **28** Elastomer

DOWN 1 Screw, **2** Pabulum, **3** Retorts, **4** Occam, **5** Above zero, **6** Patient, **7** Pigment, **8** Penetrate, **13** Lubricant, **14** Aspartame, **17** Intense, **18** Digests, **20** Occiput, **21** Yttrium, **23** Balsa, **24** Hegar

#106 Indices behaving oddly *Solution*

The answer to $3^3 + 7^3 = 370$.

If you raise 7 to an odd power, the number will end in either a 7 or 3, alternating between the two, and if you raise 3 to an odd power, it will end in a 3 or 7. So $3^n + 7^n$ is always a multiple of 10 when n is odd.

The number 4 shares these properties when paired with 6. $6^n + 4^n$ is always a multiple of 10 when n is odd. Expanding $(10 - a)^n$, every term is a multiple of 10 except for $(-a)^n$, which is $-a^n$ for odd n. So $(10 - a)^n + a^n$ is always a multiple of 10.

A gift of a headline

Feedback is a sucker for a truly spectacular headline. One where the first few words are utterly bizarre and you think it can't get any weirder, only for the header to go ever further off the deep end with every subsequent word, until you are left wondering if you're reading a news source or a lost novel by James Joyce.

On 29 November in the online music magazine *Stereogum*, there appeared a fine example of the form: "Grimes DJing immortality influencer's shroom trip with special guest Mr. Beast". If you are baffled, fear not: we will now spend the next few paragraphs explaining what is going on.

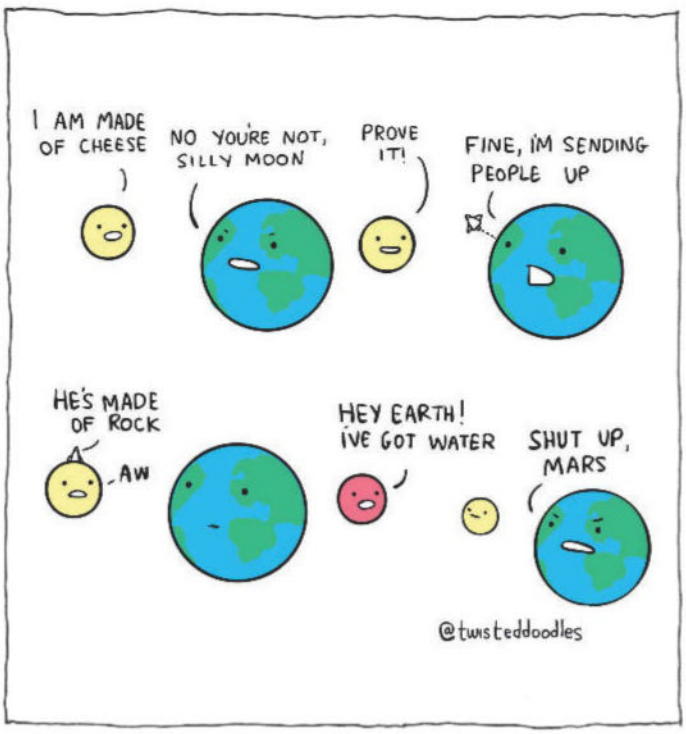
Let's start on the left. Grimes is a musician whose albums often have sci-fi themes. A climate-themed 2020 release was called *Miss Anthropocene*, and her debut *Geidi Primes* was a tribute (albeit misspelled) to Frank Herbert's *Dune*.

Meanwhile, Bryan Johnson is a tech millionaire who has decided he wants to live forever, devoting a large chunk of his time to experimenting with ways to extend his lifespan. This has included exercising (OK), changing his diet (fine), taking an immunosuppressant drug called rapamycin, normally used for people who have received organ transplants (he stopped this one) and ultimately planning to upload his mind into an AI (of course).

The story is that Johnson took hallucinogenic mushrooms and had a bunch of biomarkers measured, all while being livestreamed. Grimes was brought in to play music while he did this. While YouTuber MrBeast didn't make an appearance in the end, others did, including Salesforce CEO Marc Benioff and tech journalist Ashlee Vance. If we were ever to trip out of our minds on psilocybin-laced fungi, we would rather have a trained therapist and a loved one in the room. But we are sure Johnson knew what he was doing.

The video of the event is available online. It is a little over five and half hours long. Feedback should have watched the whole thing, in the spirit of due diligence, but unlike Johnson we know we will die one day, and we aren't going to waste all that time.

Twisteddoodles *for New Scientist*



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Consideration of items sent in the post will be delayed

Unthinkable questions

This may be the start of a new recurring theme for Feedback: "questions we never thought to ask". Reader Keith Edkins spotted our first such item, and all we can say to everyone who tries to follow this up is: good luck.

Keith saw a 2014 paper in *Folia Parasitologica*, which as the title implies is devoted to parasites. One such parasite is *Toxoplasma gondii*, a single-celled organism that infects cats and is present in many people, and which may be linked to psychiatric conditions such as intermittent explosive disorder. Hence the question in the paper's title: "Does the prevalence of latent toxoplasmosis and frequency of Rhesus-negative subjects correlate with the nationwide rate of traffic accidents?"

As Keith says, "The answer appears to be 'No, if you control the statistics properly'." But what a question. Can anyone top it?

Graphics from hell

Sometimes explanatory graphics aren't. In our long and undistinguished career in science journalism, Feedback has spent a lot of time trying to figure out what on earth researchers were trying to convey in the complicated graphics they provide. Flowcharts that loop back on themselves, bar graphs with colour-coded shading in monochrome – you name it, we have been mildly confused by it.

However, a graphic in a recent paper in *Scientific Reports* takes the biscuit, and in fact the whole biscuit tin. Reader Jim Santo flagged it, noting "this one's a doozy", but we had already seen it. Published on 19 November, the study purported to describe an AI-based system for assisting with the diagnosis of autism spectrum disorder. Feedback has no particular opinion on the study itself, and it wouldn't matter if we did, because the journal retracted it on 5 December.

Feedback anticipated this, having seen scientists discussing the paper on social media, so we hastily downloaded a copy. The key issue is figure 1, which claims to be the "Overall working of the framework presented as an infographic". It must be seen to be believed.

At the centre is a woman with a small child on her lap. Her legs appear to be encased in concrete. The child is pointing to a speech bubble, which reads "MISSING VALUE &runctional features". To the right is another speech bubble, which says "Historical medical frymblal & Environental features".

Elsewhere there is a pink blob that could be a damaged kidney bean, which apparently represents "7 TOL LIne storee". There is also a mention of "Factor Fexcectorn", and an inexplicable bicycle with spikes.

As the journal notes in its retraction, the whole thing is AI-generated, but Feedback found ourselves staring in ever-growing fascination. Towards the bottom of the graphic there is a mention of "Totalbottl", and we wondered if the explanation might be found at the bottom of one. As for the bicycle, we can only suggest someone has been taken for a ride.

Feedback will say this for *Scientific Reports*: this is one of the fastest retractions we've ever heard of. It's quite common for journals to take years to retract faulty papers. Retraction Watch reported on 3 December that dozens of papers by the psychologist Hans Eysenck may need to be retracted due to "questionable data" and other issues, not least weird claims that some people have "cancer-prone personalities". To drive home the glacial pace at which this is all happening: Eysenck died in 1997.

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