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This was Sylvia's promise to you...

A generation ago, a woman named Sylvia made a promise. As a doctor's secretary, she'd watched stroke destroy the lives of so many people. She was determined to make sure we could all live in a world where we're far less likely to lose our lives to stroke.

She kept her promise, and a gift to the Stroke Association was included in her Will. Sylvia's gift helped fund the work that made sure many more of us survive stroke now than did in her lifetime.

Sylvia changed the story for us all. Now it's our turn to change the story for those who'll come after us.

Stroke still shatters lives and tears families apart. And for so many survivors the road to recovery is still long and desperately lonely. If you or someone you love has been affected by stroke – you'll know just what that means.

But it doesn't have to be like this. You can change the story, just like Sylvia did, with a gift in your Will. All it takes is a promise.

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or visit stroke.org.uk/legacy

Rebuilding lives after stroke

Stroke Association

FROM THE EDITOR

Could you imagine watching an Earthrise? It would feel like a dream: a glowing, blue-green gem of a planet creeping up over a grey horizon. The chance to see Earth from space is just about the only thing that could convince me to set foot onto a rocket pointed at the Moon. But let's be honest, unless Elon Musk slides into my DMs, "should I go to the Moon?" is not likely a question I'll ever have to answer. But for some, it seems like a trip to the lunar surface and back might not be totally out of the question in our lifetime.

Over the next decade, an armada of probes, rovers and satellites from national and private space agencies will descend upon the Moon. For the most part, they will all ultimately ask the same question: is it worth putting humans back on the Moon? And by 2030, a new space station, called the Lunar Gateway, will set up shop permanently in the Moon's orbit, from where scientists can conduct experiments at a lower cost and without the pesky delay of having to send signals to Earth and back.

It all adds up to an almost inevitable conclusion: in the next 50 years there's bound to be a permanent base on the Moon, which seems likely to be funded, in part, by space tourism. Find out how we'll get there on p52.

If you haven't already, check out our podcast, *Instant Genius*, on your favourite podcast app. This month you'll find episodes on the neuroscience of grief, numeracy in the animal kingdom and the strange biology of hyenas. Don't miss out!

Daniel Bennett, Editor

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ON THE BBC THIS MONTH...

H_2O: The Molecule That Made Us
How does our most precious resource tie the planet together? This brilliant series is now available on iPlayer for the next six months.
Available on iPlayer

Freeze The Fear
Wim 'The Iceman' Hof seemingly has the ability to control his body temperature, allowing him to do things like run a barefoot marathon in the Arctic. In this show, he'll put celebs to the test and hopefully we'll learn a little of the science behind his feats.
BBC One
Check *Radio Times* for details

Space Tourism – What's The Cost To The Climate?
As Jeff Bezos and Richard Branson invite tourists to join them on a rocket into space, this programme addresses the elephant in the room. How much harm does space tourism do to the climate?
BBC World Service
Monday 11 April, 8pm
Also available on BBC Sounds

If my brain can't feel pain, why do we get headaches? →p79

CONTRIBUTORS

JULES HOWARD
As it turns out, huffing and puffing can be quite useful in the animal kingdom. Zoologist Jules explores how and why evolution led to animals that can blow themselves up like balloons. →p44

PROF TURI KING
Turi and her team were the scientists who identified the remains of Richard III. Now she's appearing on BBC Two to help solve family mysteries using DNA tech. →p66

DR ALEKS KROTOSKI
As presenter of *The Digital Human* on BBC Radio 4, Aleks has spent much of her career navigating sea changes in tech. Who could be better to guide us through the strange new world of the metaverse? →p70

CERI PERKINS
A former employee at CERN, Ceri takes us on a deep dive into operations and discoveries, and talks to a CERN physicist about what the future holds. →p86

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EYE OPENER

A far-out way in

RIYADH, SAUDI ARABIA

Imagine arriving at an event, joining the queue to get in, and finding yourself standing in the world's largest kaleidoscope.

That's what visitors to 2022's LEAP: One Eye On the Stars tech conference found when they arrived at the venue in Saudi Arabia. The installation, made by London-based architecture studio STUFISH, stood six metres high, three metres wide and covered a 40-metre path into the exhibition.

"The ambition was to achieve an endless horizon for people to walk towards," says MAciej Woroniecki, a partner at STUFISH. Scenes from Saudi Arabia's natural environment, across the land, sea and sky, were shown on LED tiles, which were then reflected by specially designed foil mirrors to achieve the kaleidoscope effect.

But could the world's largest kaleidoscope have been even bigger?

"The effect within the kaleidoscope only gets better the bigger it is. The limiting factor was the space in which it was installed," says Woroniecki.

STUFISH/COVER IMAGES

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EYE OPENER

Open wide

MONTEREY CANYON,
CALIFORNIA

Thanks to its delicate, translucent appearance, *Megalodicopia hians* has been nicknamed the 'ghostfish'. Although it's not actually a fish, it's a type of invertebrate called a 'tunicate'. Tunicates are interesting as they belong to a group called chordates, which means they are more closely related to vertebrates than to other invertebrates like octopuses or sponges.

But don't be fooled by its squishy appearance, this tunicate is a predator. It waits, anchored to a deep-sea canyon wall or seafloor, until an unlucky shrimp or amphipod swims unknowingly into its cavernous hood. Then its 'mouth' slams shut, trapping the prey until it's digested.

Living at depths of around 200m to 1,000m, *M. hians* is a hermaphrodite. It produces both eggs and sperm that drift off in the water in search of another tunicate. But if there are no others nearby, then it can reproduce by itself. Handy.

NORBERT WU/MINDEN PICTURES

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EYE OPENER

The wrong type of snow

PIAU-ENGALY, FRANCE

The slopes of the Piau-Engaly ski resort in southern France are coated in a thick layer of sand following the Saharan dust storm in March.

Several times a year, strong winds carry dust and sand high up into the sky above the Sahara. When the dust cloud reaches altitudes of between 900 to 2,100m (3,000 to 7,000 feet), it can be carried thousands of kilometres around the world. Southerly winds bring it towards mainland Europe and the UK.

When the dust cloud arrives, the sky appears to turn orange, but not because that's the colour of the sand. Sunlight is scattered by molecules in the atmosphere, and long-wavelength blue light is scattered most strongly. When there is dust in the air, there's more scattering of blue light, which means that more of the shorter-wavelength red and orange light makes it through.

GETTY IMAGES

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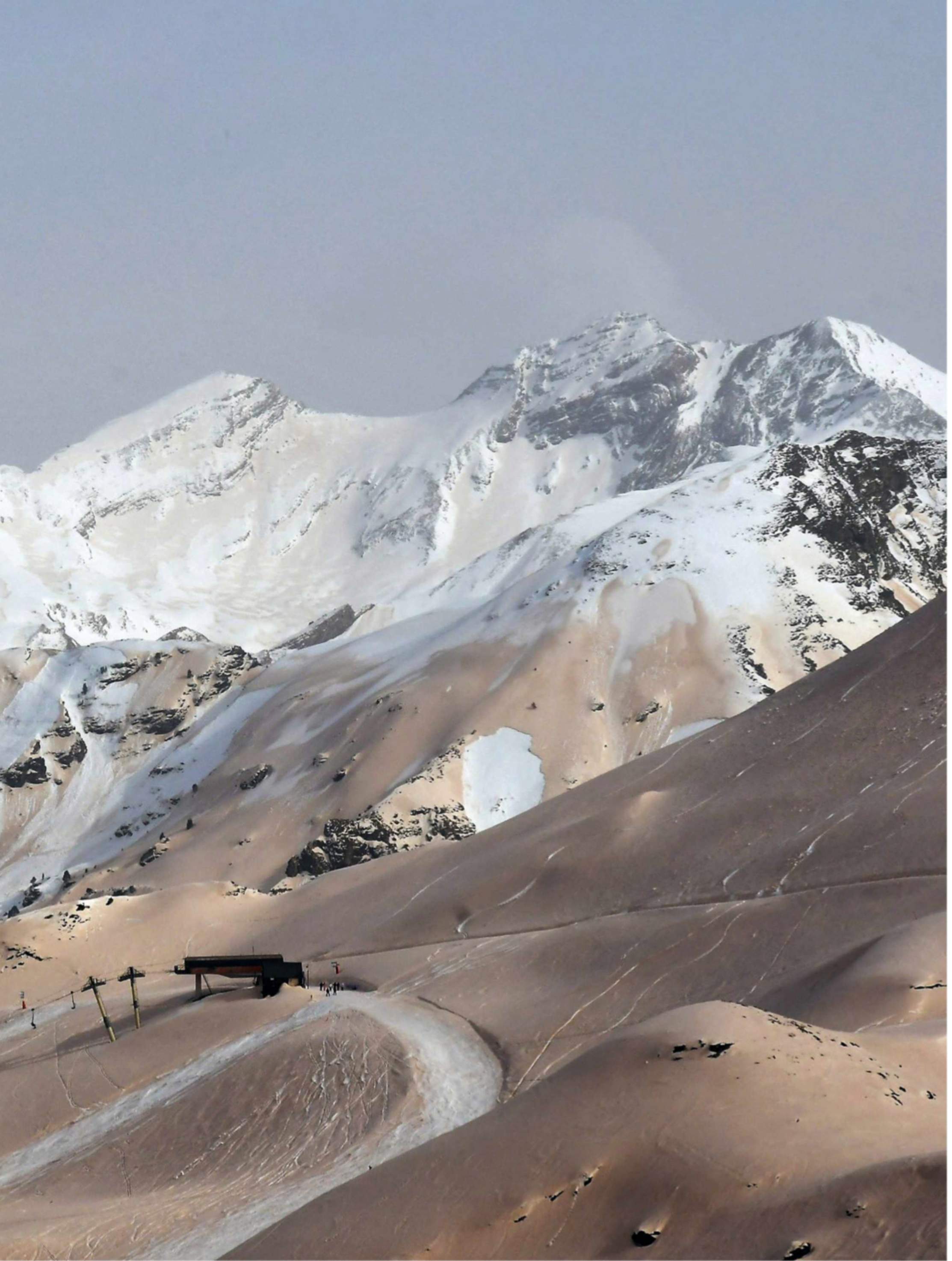

CONVERSATION

YOUR OPINIONS ON SCIENCE, TECHNOLOGY AND *BBC SCIENCE FOCUS*

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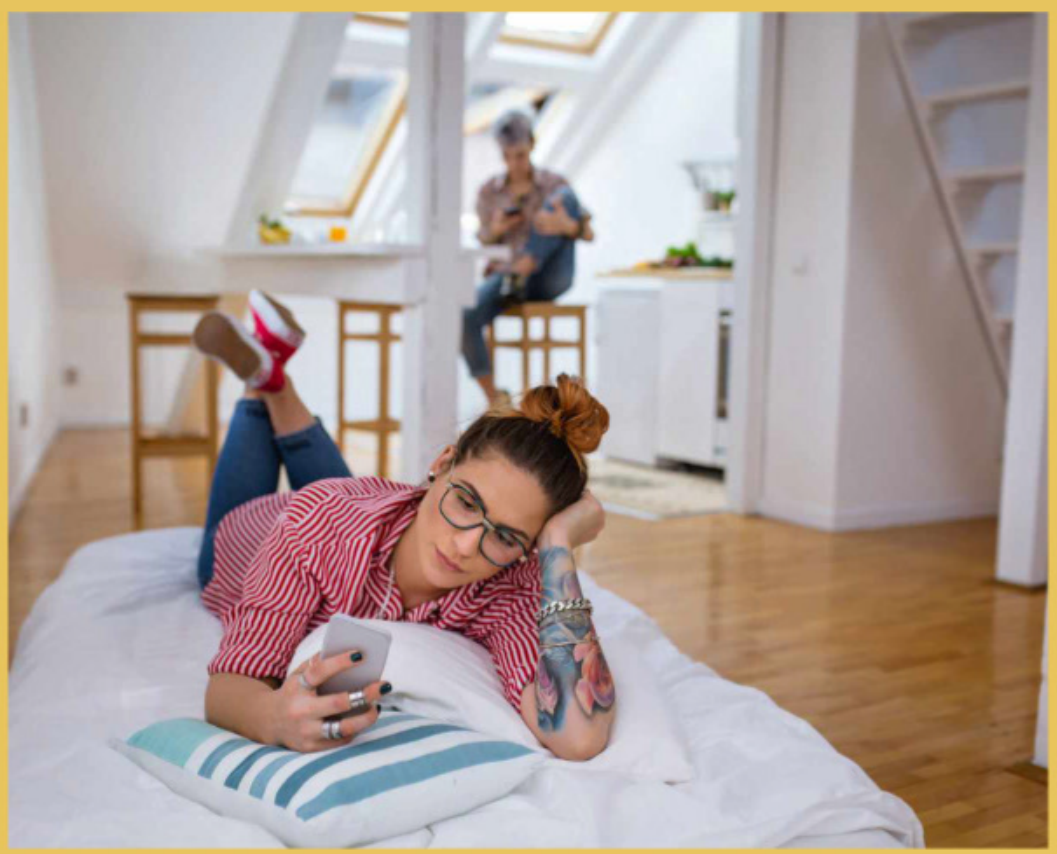
LETTER OF THE MONTH

Technoference

Your article about intimacy (February, p66) really hit home with me on a deeply emotional level. My husband has often said to me that my social media use, internet surfing and messaging on my phone is deeply intrusive and has created a barrier between us. So the phrase 'technoference' really stuck a chord with me. We've worked hard as a couple to put aside technology-free moments, and this has worked for us. While technology has helped us reach out to more people, over time, I believe it's made us more isolated. We should all seek out face-to-face relationships and physical contact with others, as a way of boosting our mental health and making us happier people.

Natasha Russell-Carr



WRITE IN AND WIN!

The writer of next issue's *Letter Of The Month* wins a **WiZ Hero table lamp.** Dim or brighten this colourful smart light with the accompanying app, or use pre-set light modes to set the mood in your home. If you prefer to go hands-free, the light can be voice controlled via Amazon Alexa, Apple Siri or Google Assistant. **wizconnected.com**

Save our skies

As a pilot, the idea of the skies being full of small aircraft scares the hell out of me (January, p44). Small aircraft – like the little bubble helicopters – are difficult to see and they tend to be where you don't expect them to be. If all of these people are talking to air traffic control, the frequencies will become jammed and you won't be able to get a word in edgeways, never mind keep track of what everybody is saying. I hope they rethink this whole idea. I do not want to share the sky with hundreds of little hornets.

Emily Johnston

Tardigrades in space

I was fascinated to read your article about blasting tardigrades into space in 2040 (February, p26). Then later in the same issue, the main feature talked about the new direction of looking for alien technology (p52). You also mention wormholes, potential shortcuts to other parts of the Universe. But then I thought, what if this search could be reciprocated by unknown civilisations? Having crossed through a wormhole, they intercept the interstellar tardigrades. Won't the aliens

Tardigrades: confusing for aliens

"IN A FUTURE LUNAR MINING COLONY, EMPLOYERS WILL LITERALLY CONTROL THE AIR THEIR WORKERS BREATHE"

DR EVIE KENDAL, P61

Plant-based fast food might be better for us, but could it have unintended consequences?

GETTY IMAGES X2, ALAMY

wonder how these creatures were able to get into space? And how do they communicate with them? Our alien visitors may well just turn around in disappointment and book a revisit in two billion years!

Might it be an idea to send another gold LP with the tardigrades?

John Pawson

Is vegan the future?

Having read your article about vegan fast food (February, p30), I have no arguments in the benefits derived by having plant-based burgers. However, will there be unintended consequences? Will red meat animals still be kept (for example, in a zoo), if there is no market for them?

A change to vegan burgers should, in theory, lower the cost of living, but I will not hold my breath. It will be interesting to see how this scenario eventually pans out. Hopefully before climate change gets us all.

John Williams

Stop using 'trendy' units!

I am fed up with authors using trendy units to express physical quantities. For example, areas given in terms of football pitches, instead of in m^2 or km^2. Masses in terms of elephants, instead of kilograms. Volumes of water in terms of Olympic swimming pools, instead of litres.

Now, I have no idea what the area of a football pitch is, or the volume of an Olympic swimming pool, or the mass of an elephant (is it an African or Asian elephant? Do elephants come in standard sizes?). The use of these silly and nebulous units just dumbs down articles.

I recently read an article, in a popular science magazine, which stated that, "in two seconds the number of solar neutrinos that pass through your finger will exceed the number of all of the human beings that have ever lived." Really?! And how many might that be?

I think it is high time that editors censored and banned the use of these ridiculous trendy units in articles for publication.

Dr Ron Barnes

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There are many reasons to leave a gift in your Will to medical research

The most important calls you Grandma

Medical research isn't just about scientific discovery – it's about protecting the health of the people we care about for years to come. So if you're hoping that your Will can provide a better, happier, healthier life for those you love, would you consider supporting medical research?

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MORE SALAD?
GM lettuce may keep bones strong in space p17

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DISCOVERIES

REPRODUCTION

MALE CONTRACEPTIVE PILL ONE STEP CLOSER

The researchers behind the drug hope it will start human clinical trials later this year

ALAMY

Brain damage Shrunken brain region may hold clues for dealing with dementia sufferers' confusion p21 **Eat like a Viking** The health benefits of a Nordic diet p23 **Lost ship found** Shackleton's sunken *Endurance* located 3,000m below Antarctic ice p26

A contraceptive pill for men may be just around the corner. Researchers at the University of Minnesota in Minneapolis have created an oral, non-hormone-based pill that's 99 per cent effective in preventing pregnancies in mice.

"So far, the compound … shows really promising results without any observable side effects in mice," said Md Abdullah al Noman, the graduate student who presented the research at the spring meeting of the American Chemical Society in San Diego.

The compound, named YCT529, works by shutting off a protein called retinoic acid receptor alpha (RAR-α), which binds to vitamin A and plays an important role in cell growth, including sperm formation.

The researchers gave male mice one dose of YCT529 every day for four weeks. They found that it dramatically reduced the rodents' sperm counts and was 99 per cent effective in reducing pregnancies in the test group. They also found that the mice were able to sire pups again four to six weeks after they stopped taking the drug.

When the female contraceptive pill was approved for use in the 1960s, it revolutionised women's lives. For those who could take it, 'the pill', as it became known, was convenient, affordable and effective.

ABOVE The long sought-after 'male pill' would need to offer a reliable, reversible and safe way to shut down sperm production

But attempts to create a male equivalent in the decades since have, so far, been unsuccessful. The lack of a 'male pill' has left men who want to play their part in birth control limited to condoms, which are single-use and prone to failure, or vasectomies, which require surgery and are largely irreversible.

Complicating matters further is the fact that most male contraceptive drugs currently undergoing clinical trials target the male sex hormone testosterone. Artificially altering someone's testosterone levels can potentially lead to unpleasant side effects, such as depression, weight gain and increased cholesterol.

"The facts say that men produce 1,500 sperm per heartbeat, but for women there is usually one ovum per cycle. So, to stop this large amount of sperm production we need a really effective method," said Noman.

He and the rest of the team behind YCT529 hope that human clinical trials for the compound will begin later this year. But they have already started working on another version of it.

"We're trying to make a newer, second-generation compound that would be effective in a lower dose," said Noman. "Sometimes a lower dose could mean higher toxicity – I have to give that caveat. But in most cases a lower dose is better. Now we're trying to make a compound that will hit two targets at the same time – RAR-α and retinoic acid receptor gamma (RAR-γ).

"RAR-γ is also essential for sperm production, so if we could selectively hit these two targets, we hope that we could get the same effect with a lower dose."

"They found that YCT259 dramatically reduced the rodents' sperm counts and was 99 per cent effective in reducing pregnancies"

SCIENCE PHOTO LIBRARY, KEVIN YATES, UC DAVIS

SPACE

Astronauts could grow super lettuce to keep bones strong in space

The genetically engineered salad leaf produces a hormone that stimulates bone growth and could be cultivated aboard a space station

A team from the University of California, Davis, has developed a genetically modified strain of lettuce that could help prevent astronauts losing bone density during long space journeys.

Regular lettuce has already been grown successfully aboard the International Space Station (ISS), so the team decided to see if they could create a strain of the plant that produces a bone-stimulating chemical called human parathyroid hormone (PTH), which would help counter the bone-depleting effects of spending extended periods in the microgravity of space.

"The higher we can boost the expression [of PTH], the smaller the amount of lettuce that needs to be consumed"

Recent NASA studies carried out on Scott Kelly and Christina Koch (the first two astronauts to spend a year on the ISS) found that they lost more than 1 per cent of their bone density during each month of their stay. With a mission to Mars likely to last around three years, scientists are searching for ways to counter these effects. Medicine is one possibility and food is another, which may be more practical.

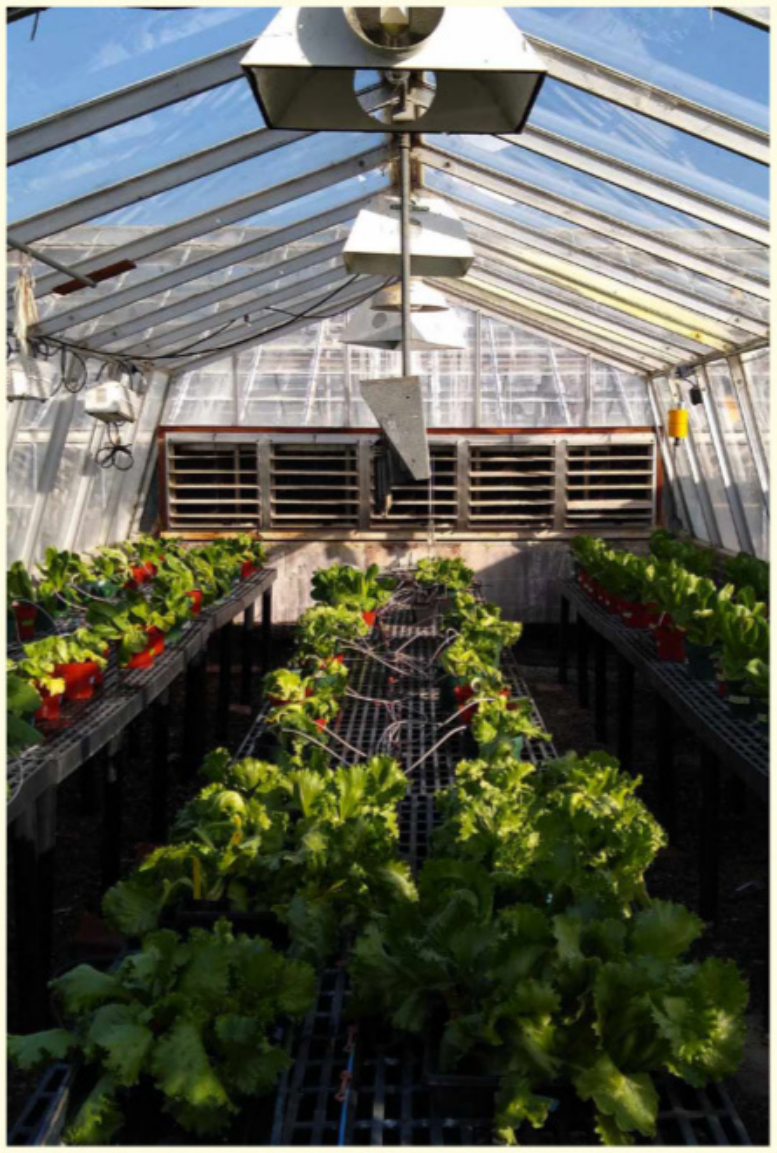
Growing lettuce that contains PTH on a space vessel would take up far less room than storing large quantities of medicines to counter the bone-depleting effects of microgravity.

"Astronauts can carry [genetically modified] seeds, which are tiny – you can have a few thousand seeds in a vial about the size of your thumb – and grow them just like regular lettuce," said Dr Somen Nandi, one of the scientists behind the genetically modified lettuce. "They could use the plants to synthesise pharmaceuticals, such as PTH, and then eat the plants."

Initial tests show that 1kg of the GM lettuces contains around 10mg of PTH, making the daily portion of the salad leaves required to counter the effects of microgravity about 380g.

"We've looked at a few [lettuces] so far and the average [PTH content] was 10-12mg per kg, but we think we might be able to increase that," said Prof Karen McDonald, another member of the team. "The higher we can boost the expression [of PTH], the smaller the amount of lettuce that needs to be consumed."

The team hasn't taste tested the GM lettuce, as it hasn't been confirmed as safe for human consumption yet, though they say it's likely to taste much the same as regular lettuce. They now want to test the lettuce's effectiveness in animal models and see how well it grows on the ISS before moving on to human trials.



ABOVE It's not rocket science... it's lettuce science. GM lettuce could help astronauts avoid bone-mass depletion

The HR 6819 system is made up of two stars. One star (in the foreground) has sucked the atmosphere off the other

SPACE

‘Vampire’ star system spotted 1,000 light-years from Earth

In this binary system, one of the stars sucks gas and dust away from the other star

Back in 2020, researchers based at the European Southern Observatory (ESO) made an exciting announcement – they had found the closest-ever black hole to Earth.

It was, according to the team led by Thomas Rivinius, lurking just 1,000 light-years away in a triple system dubbed HR 6819. According to the ESO team, it comprised one star that was orbiting a black hole in a tight, 40-day orbit and another one much further out.

However, not everyone was convinced. Particularly Julia Bodensteiner, a PhD student based at KU Leuven, Belgium. She thought it was more likely that HR 6819 was a two-star system in which one star was ‘feeding’ on material from the other – a so-called vampire system.

To get to the bottom of the mystery, the two teams joined forces to gather more data on the mysterious system using ESO’s Very Large Telescope (VLT) and Very Large Telescope Interferometer (VLTI).

“The scenarios we were looking for were rather clear, very different and easily distinguishable with the right instrument,” said Rivinius. “We agreed that there were two sources of light in the system, so the question was whether they orbit each other closely, as in the stripped-star scenario, or are far apart from each other, as in the black hole scenario.”

> “One of the stars had sucked the atmosphere off its companion star”

After careful analysis, they were able to rule out the possibility of there being a star out in a wider orbit and so the most likely conclusion is that HR 6819 is a binary system.

“Our best interpretation so far is that we caught this binary system in a moment shortly after one of the stars had sucked the atmosphere off its companion star. This is a common phenomenon in close binary systems, sometimes referred to as ‘stellar vampirism’ in the press,” said Bodensteiner, now a fellow at ESO in Germany. “While the donor star was stripped of some of its material, the recipient star began to spin more rapidly.”

The researchers are planning further observations of HR 6819 in the hope that they will be able to shed further light on the properties and evolution of vampirism in other binary star systems.

ESO/DSS2/DAVIDE DE MARTIN, ESO/L CALCADA, BANANA ART STUDIO

PALAEONTOLOGY

168-million-year-old fossil suggests stegosaurs originated in Asia

The fossil is one of the oldest ever discovered and could shed light on the evolution of one of the world's most instantly recognisable groups of dinosaurs

With their jutting armoured backplates, intimidating spiked tail, long neck and almost comically small head, the stegosaurs are some of the most instantly recognisable dinosaurs.

The hulking, plant-eating dinosaurs roamed the Earth during the Jurassic and early Cretaceous, more than 150 million years ago. Fossils of the animals have been found on every continent except for Antarctica and Australasia.

So far 14 distinct species of stegosaur have been identified, including *Huayangosaurus*, a more primitive species that had large spikes protruding from its shoulders, and *Miragaia*, a species known for its extremely long neck.

But thanks to the incomplete nature of many of the fossils, palaeontologists have struggled to piece together a complete stegosaur family tree. Now, though, researchers from the Chongqing Bureau of Geological and Mineral Resource Exploration and Development in China have discovered the fossil of a stegosaur that features bones from the back, shoulder, thigh, feet and ribs, along with several armour plates. It dates back 168 million years to the Bajocian stage of the Middle Jurassic, making it the oldest ever found in Asia.

They named the stegosaur *Bashanosaurus primitivus*. 'Bashan' refers to the ancient name for the area of Chongqing in southwestern China where it was found, and 'primitivus' is Latin for 'first'.

At around 2.8 metres in length, *Bashanosaurus* was small for a stegosaur, though the researchers are unable to confirm if it was fully grown or not. It also had smaller shoulder blades and slimmer armour plates compared to other known species.

"All these features are clues to the stegosaurs' place on the dinosaur family tree," said research leader Dr Dai Hui from Chongqing Bureau of Geological and Mineral Resource Exploration and Development.

"*Bashanosaurus* can be distinguished from other Middle Jurassic stegosaurs, and clearly represents a new species," Hui added. "What's more, our analysis of the family tree indicates that it is one of the earliest diverging stegosaurs, along with the Chongqing Lizard *Chungkingosaurus*, and *Huayangosaurus*. These were all unearthed from the Middle to Late Jurassic Shaximiao Formation in China, suggesting that stegosaurs might have originated in Asia."

Artist's impression of *Bashanosaurus primitivus*, the oldest stegosaur found to date

ENVIRONMENT

The Amazon rainforest may be approaching a tipping point

The rainforest is losing its ability to recover from fires and droughts and is nearing a critical time that would see much of the land turned into savannah

The Amazon rainforest's ability to recover from damaging events such as droughts and fires has consistently declined across more than three-quarters of its landmass over the last 20 years.

The figure was calculated by researchers based at the University of Exeter, the Potsdam Institute for Climate Impact Research (PIK) and the Technical University of Munich, who analysed satellite data. They were investigating the claim that the Amazon is reaching a tipping point that could see the loss of many of its trees.

It is as yet uncertain when this critical point may be reached, but as the Amazon covers an area of 6.7 million square kilometres and is home to 1 in 10 species on Earth, the loss would have a major knock-on effect on biodiversity, climate change and global carbon storage.

The team used a technique that had previously been used to measure the health of the Greenland ice sheet. Its aim is to predict how close a given system is to an abrupt change by identifying a slowing down of its attributes, such as its reaction to changes in weather.

They analysed two satellite data sets on biomass and the greenness of the forest and found that there was a slowing down in the restoring forces that usually bring the system back to its equilibrium after suffering damage.

"The Amazon rainforest is a highly complex system, so it's very difficult to predict if and when a tipping point could be reached," said Dr Chris Boulton, at the University of Exeter.

"We now have satellite data on the Amazon that covers a sufficiently long timespan to observe changes in resilience.

"Our study looked in detail at month-to-month changes as the forest responded to fluctuating weather conditions. We studied metrics that are theoretically related to the rate of recovery after perturbations – external events that affect the forest – to see how the resilience of the Amazon ecosystem has changed in recent decades.

"Resilience dropped during the major droughts of 2005 and 2010, as part of an ongoing decline from the early 2000s to the most recent data in 2016."

The team found that although average rainfall hasn't changed significantly in recent years, dry seasons have become longer and droughts more severe.

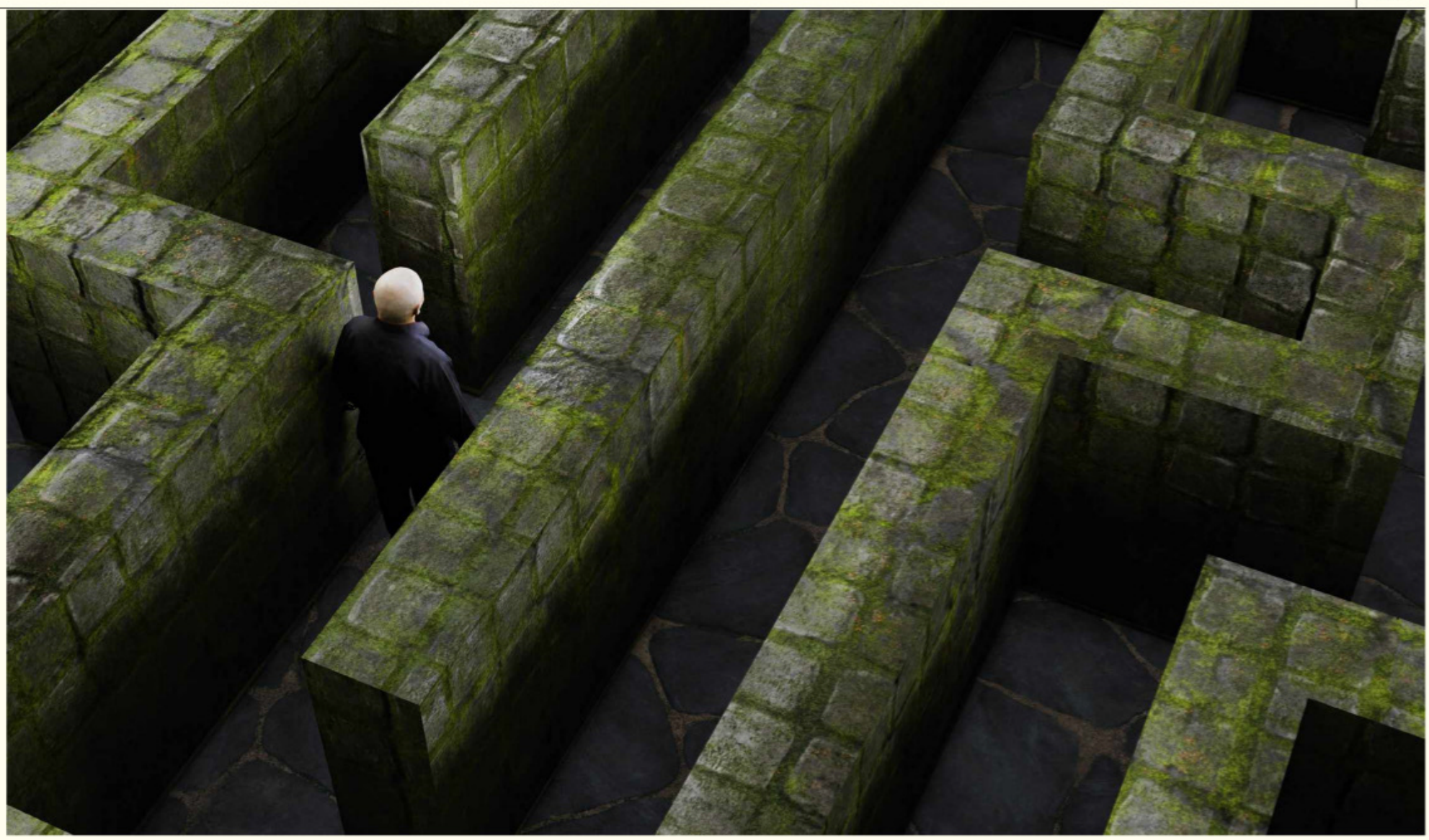
They also discovered that although the overall amount of biomass has only declined slightly, the rainforest's ability to recover from damaging events has declined much more.

"The rainforest can look more or less the same, yet it can be losing resilience – making it slower to recover from a major event like a drought," said Prof Tim Lenton, at the University of Exeter.

"This gives new compelling evidence to support efforts to reverse deforestation and degradation of the Amazon to give it back some resilience against ongoing climate change."

"The rainforest can look more or less the same, yet it can be losing resilience – making it slower to recover from a major event like a drought"

It is getting harder for the Amazon to recover from events like droughts and fires



BRAIN

Damaged areas of the brain could explain confusion in dementia patients

Researchers have found dementia patients have damage in the 'highly evolved' areas of the brain that usually help us to recognise new information

The cause of the confusion that people with dementia experience when something unexpected happens could be down to a specific network in the brain, according to a study carried out by researchers at the University of Oxford and the University of Cambridge. The finding could help patients and their loved ones better manage potentially upsetting situations, the researchers say.

The team scanned the brains of healthy participants and those with dementia using a technique called magnetoencephalography, which can take 1,000 snapshots of the brain per second.

They then played them a sound that changed in pitch or rhythm, to mimic a real-life surprise event such as a shift in conversation topic or a switch in the position of furniture in a room, and then monitored the response in the participants' brains.

In a healthy brain, the response occurs in two phases. The first correlates with the auditory system 'noticing the sound', while the second correlates with another area of the brain recognising the difference.

ABOVE The confusion experienced by dementia patients may be explained by damage in a particular region of the brain

But in the patients with dementia, the researchers found there was a reduced response in the second phase. Their brains weren't telling them that there had been a change or what to do about it. This could be why they struggle when unexpected events occur.

"If people with Alzheimer's disease are in their home environment and they're surrounded by things they are used to, they're alright really," said Dr Thomas E Cope, one of the study's authors at the University of Cambridge.

"They can muddle along. But then if one day something small changes – the kettle's broken, say – and they need to respond differently, they can't. They just can't work out what to do."

Using magnetoencephalography combined with MRI scans, the team showed that this second phase was located in an area of the brain called the multiple demand network, which is a region involved in attention, problem solving and working memory.

"In dementia syndromes, at least one of the areas in the multiple demand network is damaged or shrunk," said Cope. "And we know those patients also have this reduced ability to respond to change."

At present, there is no treatment available to repair or replace a person's multiple demand network, but Cope said that the findings will help patients better understand what is happening to them, and so help them to cope with change more easily.

GETTY IMAGES X2

MEDICINE

Revolutionary heart transplant carried out on a toddler could lower the risk of organ rejection

Along with the heart, the child received a donation of thymus tissue, which is a key part of the immune system

A baby born with severe heart defects is recovering well after becoming the first recipient of a pioneering new transplant technique carried out at Duke University in North Carolina, USA.

Easton Sinnamon was born with several heart defects as well as a deficiency in his thymus. The thymus is a gland found behind the breastbone that plays a key role in the immune system by creating white blood cells known as T-cells. His condition left him in need of a heart transplant and a thymus tissue transplant.

Under currently available procedures, transplanted hearts have an average lifespan of between 10 and 15 years, due to the damaging effects caused by the immunosuppressant drugs used to prevent them from being rejected.

However, researchers at Duke have been pioneering a technique of using donated thymus tissue to increase the possibility of a transplanted organ being accepted.

The thymus gland stimulates the production of T-cells, which attack foreign substances that enter the body. Therefore, implanting tissue taken from the thymus gland of the same donor as the transplanted organ could help the body to accept it.

The approach has shown promise in animal studies, but Easton's rare combination of conditions led to the researchers attempting it on him.

"This has the potential to change the face of solid organ transplantation in the future," said Joseph W Turek, Duke's chief of paediatric cardiac surgery and a member of the surgical team.

"If this approach proves successful – and further validation is contemplated – it would mean transplant recipients would not reject the donated organ and they would also not need to undergo treatment with long-term immune-suppression medications, which can be highly toxic, particularly to the kidneys.

"This concept of tolerance has always been the holy grail in transplantation, and we are now on the doorstep," said Turek.

Easton received both procedures in August 2021 when he was six months old. At the time of writing, it was 172 days since the operation, and he is said to be doing well.

"It was one of those things where it could help him, and if it works, it not only helps him, but it could help thousands of other people as well with their children who need transplants," said Easton's mother, Kaitlyn.

"When we talked about it, it was like, 'Why would we not do it when we can make a difference for all these other people?'" she said.

TOP Easton Sinnamon after receiving the heart and thymus donations

MIDDLE Easton gets to go home with his family following the operation's success

BOTTOM Easton on his first birthday

SINNAMON FAMILY/DUKE UNIVERSITY X3, ALAMY

The Nordic diet includes lots of fruit, vegetables and fish

HEALTH

Switching to a Nordic diet could help us to stay healthy

The diet, which focuses on produce available in the Nordic countries, could help to reduce the risk of cardiovascular disease, type 2 diabetes and high blood pressure

The health benefits of eating a Mediterranean-style diet have long been touted, but it seems that eating more like our northern neighbours could also produce similar results.

Researchers at the University of Copenhagen have found that the Nordic diet can provide significant health benefits such as lower cholesterol, lower blood pressure and a reduced risk of blood clots, even for those people who are overweight.

The Mediterranean diet can be challenging for people in colder regions to follow, where produce like peppers, tomatoes and olives are not locally grown. The Nordic diet is based on ingredients that grow in Denmark, Sweden, Norway, Finland, Greenland, the Faroe Islands and Iceland, and includes foods like apples, potatoes, carrots, berries, cabbage, rye, oats, nuts and fish, along with oils made from rapeseed, sunflower or flaxseed.

The team took 200 volunteers from Finland, Norway, Sweden and Iceland, all over the age of 50. They all had high BMIs that put them at an increased risk of diabetes and cardiovascular disease. They asked half of the volunteers to stick to their regular diet and asked the other half to switch to the set of Nordic Nutrition Recommendations put together by dietary experts in 2012.

Blood and urine samples were taken at the start of the study and again after six months to check key markers of health.

"The group that had been on the Nordic diet for six months became significantly healthier, with lower cholesterol levels, lower overall levels of both saturated and unsaturated fat in the blood, and better regulation of glucose, compared to the control group," said co-author Dr Lars Ove Dragsted, at the University of Copenhagen.

"We kept the group on the Nordic diet weight-stable, meaning that we asked them to eat more if they lost weight. Even without weight loss, we could see an improvement in their health."

The team are as yet unsure why they saw such positive results, though they suspect it was in part due to the composition of fats in the Nordic diet, which are high in omega-3 and omega-6.

"By analysing the blood of participants, we could see that those who benefited most from the dietary change had different fat-soluble substances than the control group," said Dragsted.

"These are substances that appear to be linked to unsaturated fatty acids from oils in the Nordic diet. This is a sign that Nordic dietary fats probably play the most significant role for the health effects seen here, which I hadn't expected."

MATERIALS

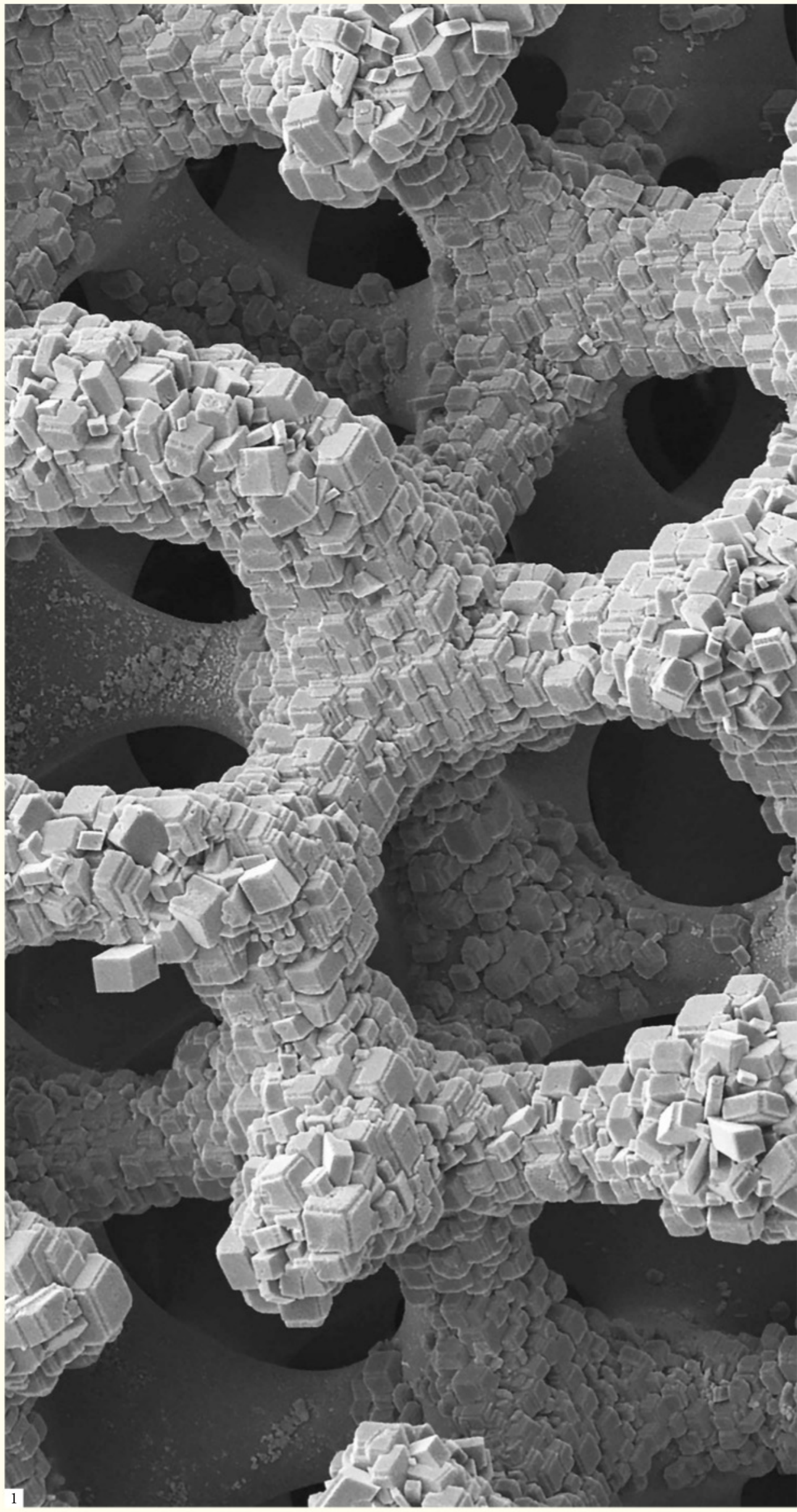
Knobby starfish could inspire super-light, super-strong materials

When it comes to engineering, nature knows best. Researchers at Virginia Tech have found that the exoskeleton of a starfish (*Protoreaster nodosus*) found in the Indo-Pacific region has a never-before-seen structure that makes it incredibly strong and lightweight. It is thought that the starfish evolved its unique skeleton to fend off predators.

If successfully recreated, the structure could help engineers to create a new class of synthetic materials that could be used in everything from aviation to construction.

Though it is made from calcite, a crystalline form of calcium carbonate that is usually brittle like chalk, the skeleton's complex pattern makes it extremely durable, but flexible and lightweight at the same time.

"This nearly perfect microlattice has not been reported in nature or fabricated synthetically before," said mechanical engineer Ling Li, the assistant professor who led the study. "Our overall goal is to learn and take inspiration from nature to develop novel porous materials that are both strong and damage-tolerant."



LING LI/VIRGINIA TECH X2, ALEX PARRISH X2

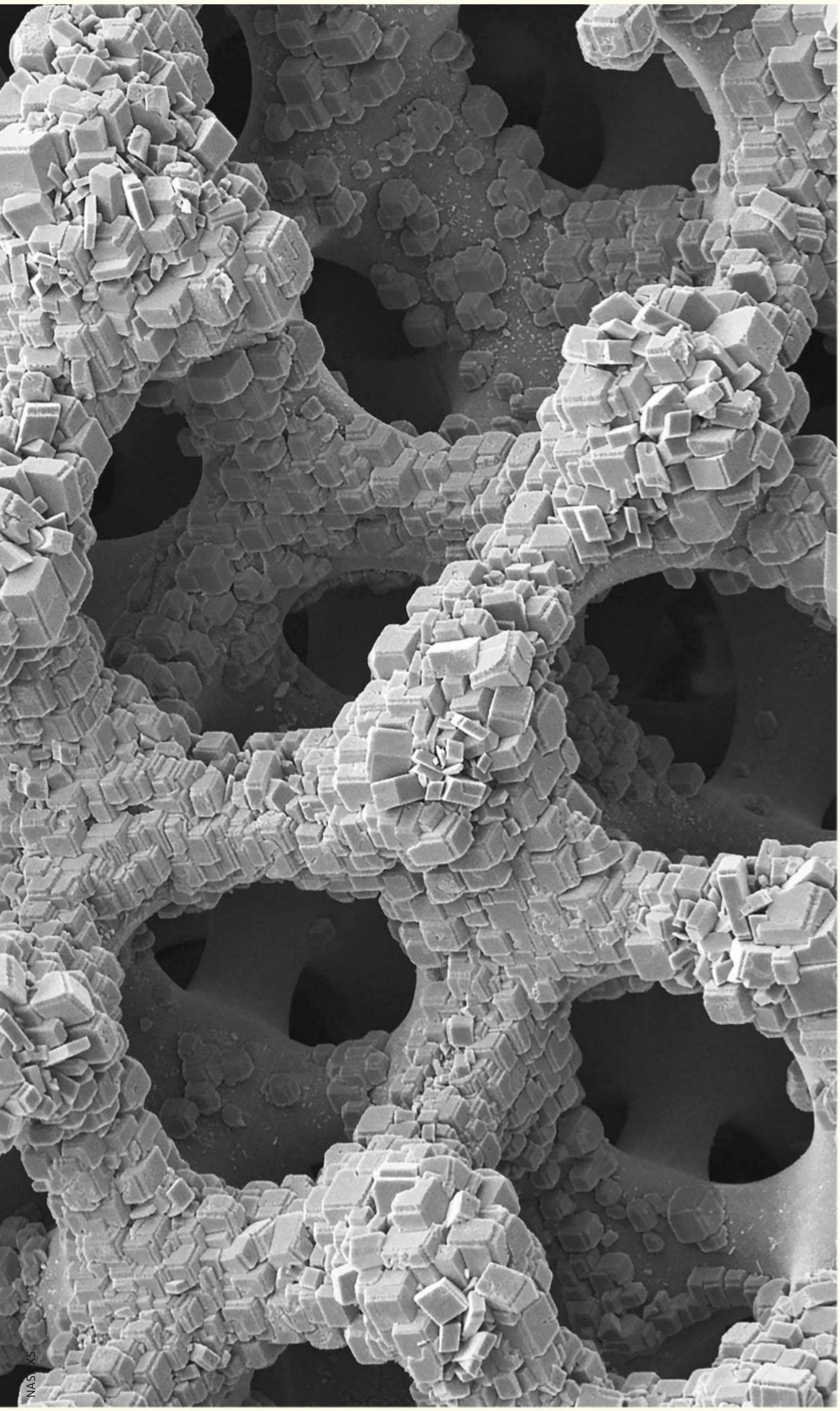
1

1. This image, taken by a scanning electron micrograph, shows the intricate structure of the starfish's exoskeleton. Each of the holes is around 10 micrometres in diameter (one micrometre = 0.001 millimetres)

2. This second image shows a zoomed out view of the starfish's skeleton.

3. Assistant professor Ling Li holds an example of a real knobby starfish exoskeleton.

4. In the flesh, knobby starfish look pretty intimidating. They grow up to 30 centimetres across and are covered in rows of black horns. They are also known as chocolate chip starfish, which makes them seem much less threatening.



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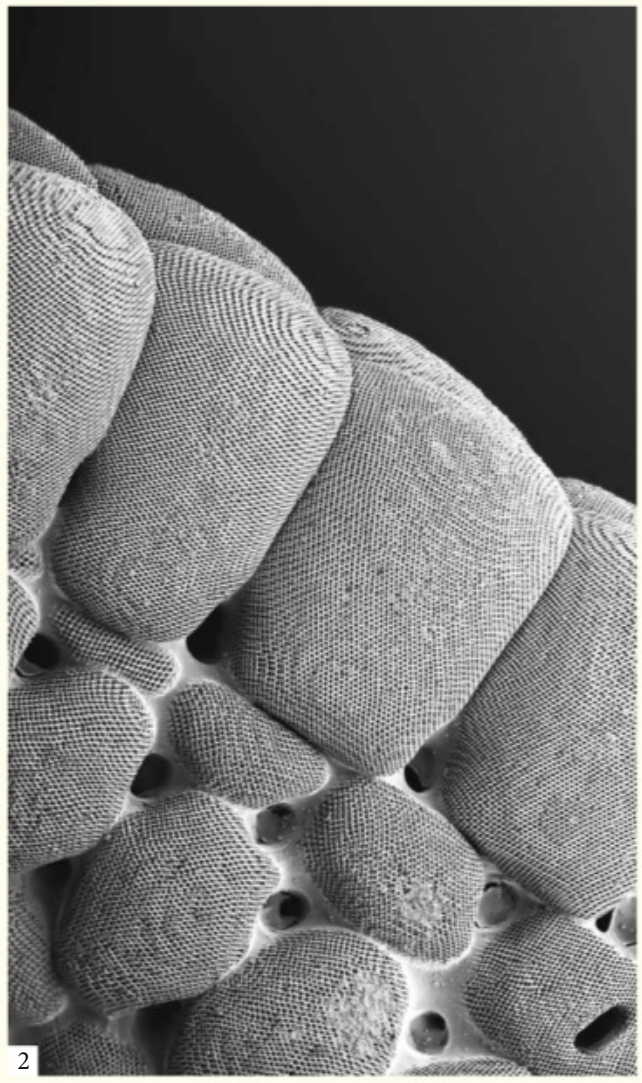

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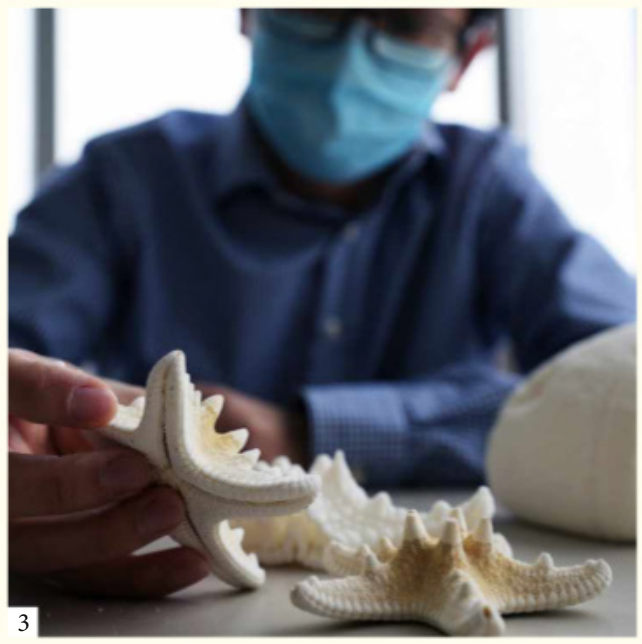

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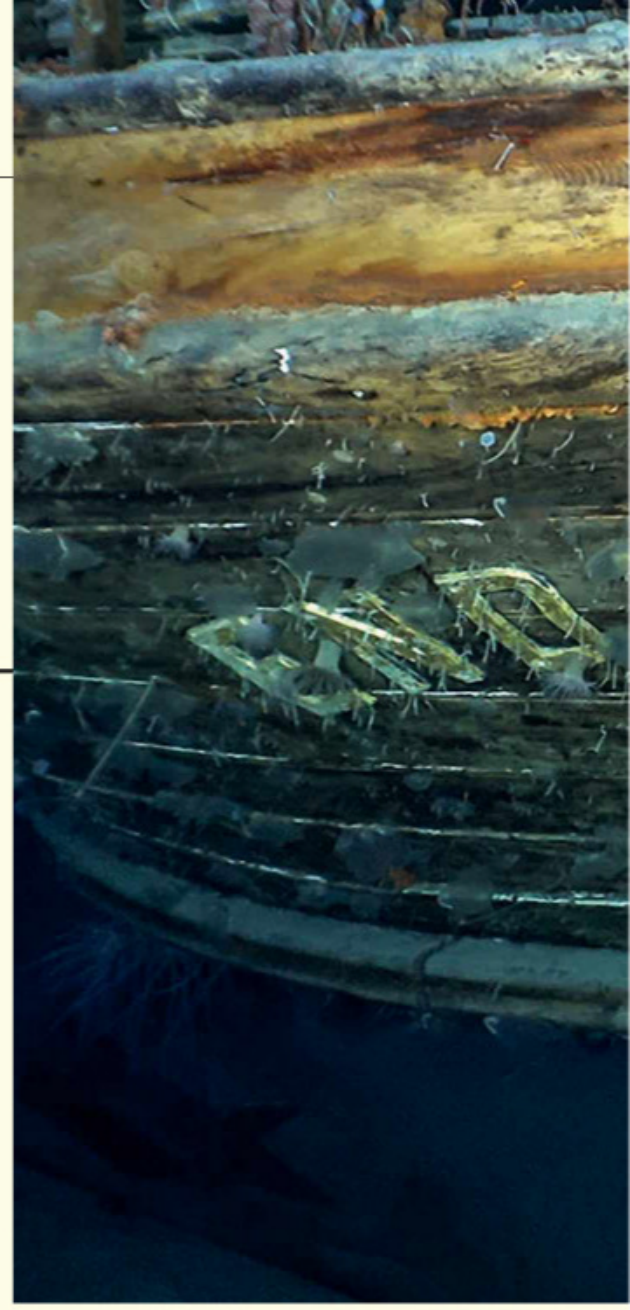
LASSE RABENSTEIN AND NICO VINCENT
Endurance22 team members



Horizons

What's next for the team that found Shackleton's sunken ship?

Huge headlines were made when the Endurance22 research team discovered *Endurance* at a depth of 3,008m. Now they've found it, how will they study it? Expedition members Nico Vincent and Lasse Rabenstein spoke to us from their research vessel...

WHY IS THE DISCOVERY OF *ENDURANCE* SCIENTIFICALLY IMPORTANT?

Lasse Rabenstein: If I'm honest, when I first heard about this expedition, I asked that exact question. We knew a lot about the ship already from the history books. But getting scientific instruments to the Weddell Sea is a rare opportunity, as there aren't many icebreaker ships in the southern hemisphere that can make it into the ice. It is no coincidence that Shackleton's expedition got stopped in the Weddell Sea, as it has really heavy ice conditions. Therefore, every chance to get in-situ data samples from the Weddell Sea should be taken.

Finding the wreck itself was motivating, and people were really creative in their way of thinking. We combined all the different fields of science – research, navigation, subsea technology, archaeology – to work together to achieve that goal. Without this expedition, we wouldn't have developed new technologies for observing and navigating the ice. It was the first to use Sabertooth underwater vehicles, made by Saab.

HOW DID THE SABERTOOTH VEHICLES HELP YOU FIND *ENDURANCE*?

Nico Vincent: We identified and built several solutions to find the ship. No divers could be deployed, as the wreck is too deep for humans. The deepest a diver has reached is 700m, but the wreck is at 3,000m. Only robots can dive to that depth.

Accessing that depth in open water is extremely complicated and requires advanced technology and a strong, experienced team. However, to make it to that depth under drifting ice is harder than landing on the Moon was in 1969.

Sabertooth's main advantage is that it is a hybrid vehicle: it is both an Autonomous Underwater Vehicle (AUV) and a Remote Operated Vehicle (ROV). That means we can switch Sabertooth from following a dedicated task plan in full autonomous mode to a real-time manual remote drone. Keeping real-time control on the vehicle allows us to record real-time data and also make fast decisions. As soon as *Endurance* had been detected in autonomous mode, we switched to manual and proceeded towards our target for formal identification.

YOU MENTIONED OTHER SCIENTIFIC OPPORTUNITIES PRESENTED BY THE EXPEDITION. WHAT DID YOU LEARN?

LR: Scientists study the sea ice in the Arctic and the Antarctic because this ice is very important for the global climate. Sea ice acts as a gigantic mirror for the Sun's rays, reflecting solar energy back into the atmosphere and space. This has a cooling effect on the global climate.

If ice disappears, due to warming or another effect of climate change, then there will be open ocean in its place, which absorbs a lot of this solar energy and heats up the planet even more. This is also called the 'ice-albedo feedback mechanism'.

So it's important for us to understand how the sea ice reacts to global warming. Normally, people study this ice from space, using satellite missions and imagery to take measurements of ice thickness, sea temperatures and ice temperatures.

[Scientists] have super complex numerical models running that can simulate sea ice processes and the effect on global climate. But this is only trustworthy if you can get to the Weddell Sea and other ice-covered regions into the world, and actually check if what your models or your measurements from space tell you is true. That means we have to collect so-called in-situ data.

WHAT'S NEXT FOR THE EXPEDITION?

LR: Of the 15 scientists on the ship [*Agulhas II,* an icebreaking polar

The researchers want to revisit the *Endurance* with biologists, who can help to record the marine life living around the wreck

FALKLANDS MARITIME HERITAGE TRUST/ESTHER HORVATH X2, FALKLANDS MARITIME HERITAGE TRUST/NATIONAL GEOGRAPHIC

“To access that depth [of 3,000 metres] under drifting ice is harder than landing on the Moon was in 1969”

supply and research ship], we had no biologist. When we saw the images of the wreck and we saw the marine life there, we decided it was very important to involve deep-sea marine biologists and see what kind of life forms could be observed on the wreck. It will also be interesting for subsea geologists and deep-sea sedimentologists to learn more about the Weddell Sea.

Navigating through ice is challenging, but there is a lot of potential to improve it with technology, and this expedition was really the start of a new future for shipping.

I run a spin-off from the German Polar Research Institute and we’re trying to set up what you could call the Google Maps of polar regions. We’ve established the software, and it was used for the first time on the Endurance22 expedition.

Using satellite Earth observation images, the captain on the bridge could navigate through the ice, even in the dark hours or during snowfall. We could use it like a street map to direct us through the ice. Ice is changing continuously, it drifts 20 kilometres or more in a day. Leads open up – which are the ‘streets’ or paths between ice for the ship – or they can close.

This is the future of ships, shipping 4.0, I would say. It’s a smart ship interconnected with the internet, exchanging data with the outside world. All of the satellite imagery that served as a street map for the ship, and also the data from sensors on the ship, are transmitted to a data cloud for the development of a kind of a Google Maps for the Arctic and Antarctic.

WHAT WILL HAPPEN TO *ENDURANCE* NOW?

NV: The wreck is protected as historical heritage through the Antarctica treaty. No samples have been taken and the ship remains untouched.

We have produced a LIDAR survey, obtained 4K footage, and undertaken photomosaic and geophysical surveys to allow archaeologists to produce meteorology and accurate studies for scientific publication. There are plans to construct a 3D model of the wreck, for both temporary exhibitions and permanent museum display. The data will be recorded to a level of accuracy comparable to that of an archaeological survey on land.

WHAT CAN WE CONTINUE TO GAIN FROM THE STORY OF *ENDURANCE*?

LR: The story is truly inspiring. Shackleton had courage, and although the *Endurance* failed, Shackleton was successful in a way because he became a polar hero. He never stretched the risk so it became deadly. He never lost a single man’s life, throughout everything that he did. I think for many people, Shackleton is a positive inspiration.

Our work is getting real media attention, which is a good thing. There is this phrase that ‘you can only protect what you know’. If people start to read this story and get interested in it, then they might read more about the nature, geology and climate of the Arctic and Antarctic regions. These regions, especially the Arctic, are the ones changing fastest due to global warming. But [with more] awareness, we have a better chance of protecting them and our climate in the long term.

NICO VINCENT
Nico is the expedition sub-sea manager for the Endurance22 exploration.

DR LASSE RABENSTEIN
Lasse is the chief scientist for the Endurance22 expedition.

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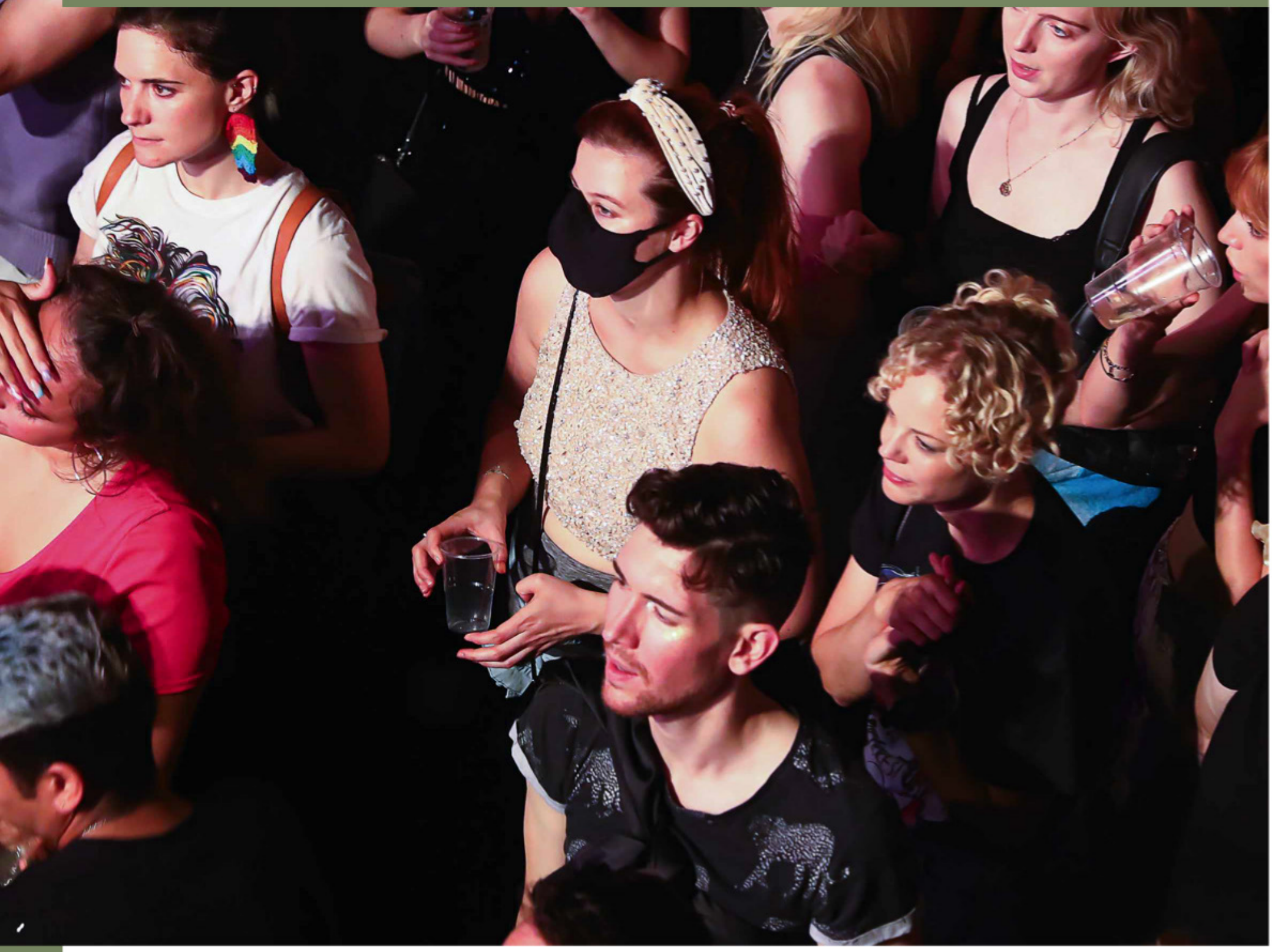
REALITY CHECK

SCIENCE BEHIND THE HEADLINES

COVID risk | Migraine cures | Happiness



REVIEW

COVID RISK: IS IT SAFE FOR ME TO RESUME ALL MY NORMAL ACTIVITIES?

In a restriction-free world, how risky is going to the pub vs going to the supermarket?

“A disease with a low mortality rate affecting several million people will kill more people than a disease with a higher mortality rate that only affects a few thousand”

BBC *Visit the BBC’s* Reality Check *website at* ***bit.ly/reality_check_*** *or follow them on Twitter* ***@BBCRealityCheck***

WILL VACCINES CONTINUE TO PROVIDE PROTECTION?

The latest strain (Omicron) is said to cause ‘mild’ COVID, but a big reason for this is that vaccines – in those who received a course and mounted a normal immune response – have blunted its deadly impact. Omicron is probably more deadly than the original wild-type variant, but the population is now better protected.

Importantly, being vaccinated doesn’t stop you catching and spreading COVID; it just reduces the severity of illness in most people. As we’ve let our guard down, case rates have skyrocketed. A disease with a low mortality rate affecting several million people will kill more people than a disease with a higher mortality rate that only affects a few thousand.

People with compromised immune systems (for example, anyone with a transplant, on chemotherapy, or taking steroids), and those who remain unvaccinated for any reason, are still at risk of severe disease and a possible fatal outcome. Hence, while vaccination is important, it’s only our first line of defence.

HOW DO DIFFERENT ENVIRONMENTS AFFECT THE SPREAD OF COVID?

Step two in living with COVID is to attend to air quality, since the virus spreads mostly in tiny invisible particles suspended in the air.

Airborne particles will spread throughout an enclosed space – a room, a car or a train carriage, for example – and can remain in the air for up to four hours after being exhaled.

This is why ventilation (by opening windows wide to get a through-draught, or using extractor fans) or filtration (using HEPA filters, for example) are excellent ways of reducing the risk of transmission of SARS-CoV-2.

Step three is to understand how airborne viral particles infect you and take steps to reduce this risk. Air is more likely to contain SARS-CoV-2 particles if the local prevalence of COVID is high. If 1 person in 30 in your town has the virus, for example, the chances are that someone in your gym, your supermarket, your open-plan office, your place of worship, or your child’s class is exhaling the virus into the air right now.

People infected with SARS-CoV-2 are at their most contagious before their lateral flow test turns positive and they become fully symptomatic, so it’s no good just avoiding people who have tested positive or reached the stage of feeling terrible. You must assume that someone, you, perhaps, may be unwittingly infecting the air.

SARS-CoV-2 infection doesn’t usually occur in a one-shot hit but by exposing the inside of the lungs to viral-laden air over minutes or hours. At any given prevalence of COVID-19, the chance of catching the virus is greater the smaller the space, the lower the ventilation, the more people are gathered together, the fewer of them are masking, the more noise they’re making and the longer they stay there.

Take, for example, an indoor space such as a church that measures 30 x 10 metres. Let’s say it is poorly ventilated, less than one air change per hour, and 50 people gather in it for one hour, not wearing face coverings and singing. If approximately 1 in 100 people in the population has COVID-19, the chance of someone catching the disease at this gathering is – depending on other factors such as humidity – 37 per cent. ➲

Cinemas can become crowded and there is little fresh air flow during the film

GETTY IMAGES, ALAMY

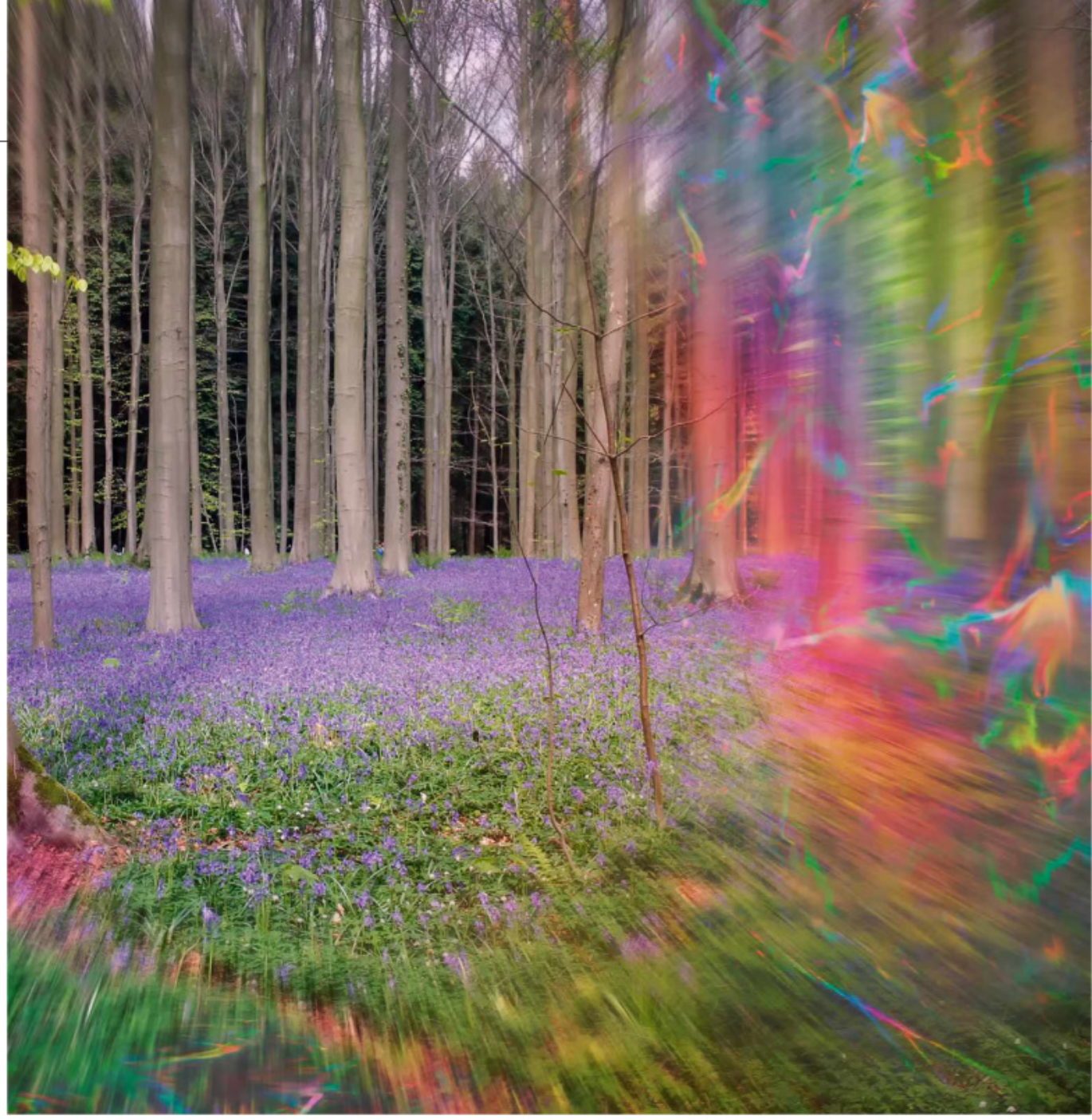
If, on the other hand, the room is well ventilated, having 10 air changes per hour, and everyone present wears a well-fitting mask, the chance of someone becoming infected drops to below 3 per cent. And if they stay silent, the risk falls to below 0.1 per cent.

To reduce the chance of getting infected, spend as little time as possible in small, enclosed and unventilated spaces, especially crowded ones. Walk rather than take the bus, for example. Shop in small stores early in the morning when they've been empty overnight. Hold work meetings by video call or while walking outdoors. If you're a teacher, send the kids out to play for 10 minutes every hour and throw the windows wide open until they return.

People emit more viral particles if they're puffing and panting while exercising, and also when speaking, shouting or singing. So while meeting outdoors is generally a safe way to socialise, mass events involving a lot of shouting – like music festivals – are the exception. In such cases, even outdoor events can be risky.

by **PROF TRISH GREENHALGH**
(@trishgreenhalgh)
Trish is a professor of primary care health sciences at the University of Oxford, and she trained as a GP.

TYPE AND LEVEL OF GROUP ACTIVITY	**LOW OCCUPANCY**			**HIGH OCCUPANCY**		
	OUTDOORS AND WELL-VENTILATED	INDOORS AND WELL-VENTILATED	POORLY VENTILATED	OUTDOORS AND WELL-VENTILATED	INDOORS AND WELL-VENTILATED	POORLY VENTILATED
WEAR FACE COVERINGS, CONTACT FOR A SHORT TIME						
SILENT	<0.001%	0.026%	0.16%	0.001%	0.091%	0.55%
SPEAKING	0.002%	0.13%	0.78%	0.005%	0.45%	2.7%
SHOUTING, SINGING	0.009%	0.78%	4.6%	0.033%	2.7%	15%
HEAVY EXERCISE	0.022%	1.8%	10%	0.077%	6.2%	32%
WEAR FACE COVERINGS, CONTACT FOR A PROLONGED TIME						
SILENT	0.003%	0.26%	1.6%	0.011%	0.91%	5.3%
SPEAKING	0.016%	1.3%	7.5%	0.055%	4.5%	24%
SHOUTING, SINGING	0.094%	7.5%	37%	0.33%	24%	81%
HEAVY EXERCISE	0.22%	17%	67%	0.76%	47%	98%
NO FACE COVERINGS, CONTACT FOR A SHORT TIME						
SILENT	0.001%	0.074%	0.45%	0.003%	0.26%	1.6%
SPEAKING	0.004%	0.37%	2.2%	0.016%	1.3%	7.5%
SHOUTING, SINGING	0.027%	2.2%	13%	0.094%	7.5%	37%
HEAVY EXERCISE	0.062%	5.1%	27%	0.22%	17%	67%
NO FACE COVERINGS, CONTACT FOR A PROLONGED TIME						
SILENT	0.009%	0.74%	4.4%	0.031%	2.6%	14%
SPEAKING	0.045%	3.7%	20%	0.16%	12%	54%
SHOUTING, SINGING	0.27%	20%	74%	0.93%	54%	>99%
HEAVY EXERCISE	0.62%	41%	96%	2.2%	84%	>99%



ANALYSIS

MIGRAINES: CAN NEW TREATMENTS HELP EASE THE SUFFERING OF MILLIONS OF PEOPLE?

Better understanding of the processes driving migraine pain is leading to promising new remedies

ABOVE Some migraine sufferers will experience a visual 'aura' of blind spots, shimmering lights or flashes before a migraine hits

GETTY IMAGES, SHUTTERSTOCK

For centuries, scientists have debated whether migraines are caused by blood vessels in the head expanding or by some malfunctioning of the nerves. Over the last few decades, however, a more nuanced picture has emerged. A migraine attack starts when the trigeminal nerve, a big pain-sensing nerve in the head, is stimulated.

The source of that stimulation is hard to pin down, but some people who get migraines find they are triggered by caffeine, stress or lack of sleep. The trigeminal nerve sends chemical signals to the protective layers that wrap around the brain. The signals cause blood vessels in some of these layers to expand. Together, the expanding blood vessels and the pathways of nerve fibres connected to the trigeminal nerve, which also reach deeper into the brain, are thought to cause the pain.

Thanks to King's College London neurologist Prof Peter Goadsby and colleagues, we now know more about the chemical messengers responsible for the signals: neuropeptide molecules called calcitonin gene-related peptides (CGRPs). These are now the focus for new treatments.

Since the 1990s, we've relied on drugs called triptans to treat migraines. These target serotonin receptors in the brain and are thought to work by constricting blood flow and preventing the release of the neuropeptides involved in migraines. We are now, though, starting to capitalise on some of the research into the mechanisms that trigger and drive migraines, with the last five years seeing new drugs reaching the market.

One way for preventing migraines is to stop the trigeminal nerve from firing in the first place. Drugs like erenumab or gepants effectively block chemical messengers (such as CGRPs) from interacting with the nerve – they essentially shut the biochemical door, stopping the chain reaction that leads to a migraine.

The gepants are the first drugs that seem to be beneficial both for an ongoing migraine attack and for preventing future attacks from happening – previously, drugs have only been prescribed for one or the other. Because there are no side effects from overuse, patients can take more or less depending on their needs.

"So the idea that you could tailor the therapy on a day-by-day, week-to-week basis with these new therapies is quite revolutionary," Goadsby says. He suggests that a patient could decide to take a tablet in the evening if they knew they needed to do something important the next day.

The difference that CGRP inhibitors have made is "very, very significant", according to migraine researcher Mikko Kallela from the University of Helsinki, who sees about half of his patients lose half of their migraine days. For the 1 to 2 in 100 people in the general population who experience at least 15 migraine days a month – chronic migraine sufferers – the benefits can be life-changing.

NO CURE

As it currently stands there is no known cure for migraines. Even if we are seeing a lot of progress in treatments, 'curing' migraines is a big ask, especially ➤

Fremanezumab is an injectable drug that inhibits chemical messengers called CGRPs, in order to prevent migraines

when we don't have all the answers as to what causes them in the first place. However, according to Goadsby, we could see more progress in prevention by focusing our efforts on the 'premonitory phase' – the prelude to the headache – which for many people brings mood changes, yawning, tiredness and other symptoms. This phase can last a couple of days. "If we could develop treatments in that phase, then it's perfectly plausible to think that we could start to eliminate the actual pain phase," Goadsby explains, adding that it could be a way to "head off attacks before they become troublesome."

Another approach that may start to make more of an impact in the near future is one of personalised medicine. A 2022 paper, published in the journal *Nature Genetics*, studied more than 100,000 patients and pinpointed 123 different genes associated with migraine, 86 of which were previously unknown.

"Not every migraine patient has every gene, so it's complex," explains Kallela, who worked on the study. "And that also fits very much to the way migraine patients respond to treatment."

We've known for ages that what works for one person doesn't necessarily work for the next person, but as our understanding of the genetic components and molecular mechanisms that contribute to migraines expands along with the suite of different drugs targeting them, we may be better able to use this to the patient's advantage, tailoring treatment regimens to the individual. Intriguingly, some of the known genes pulled out in Kallela's 2022 study were targets for existing treatments – the CGRPs, for example. This suggests we might be able to mine for new migraine targets among the 86 genes whose functions are unknown.

However, because of the way that people who get migraines are genetically predisposed to them, it's hard to imagine 'curing' them completely. People who get migraines may always go back to having them if they stop taking their medication, according to Kallela, but he remains "very optimistic" about the prospects for treatment.

"You cannot cure migraine," he says. "But in a way, you can take away the attacks."

by **HAYLEY BENNETT**

Hayley is a science writer based in Bristol, UK.

COMMENT

HAPPINESS: IS IT RIGHT TO PURSUE IT AT ALL COSTS?

Research suggests that focusing on your own happiness can end up making you miserable

All of us are striving to be happy. We put considerable time and effort into doing so, yet we often get caught up in bad habits and cycles of misery. We might even sometimes wonder whether happiness is a worthy pursuit at all.

In my book, *Happiness By Design*, I have made a case for the concept of happiness to include achieving feelings of purpose (or meaning and fulfilment) alongside feelings of pleasure (such as joy and excitement). For example, when I am teaching students, I am differently happy to when I am on a night out: the first is more fulfilling, the second is more fun.

There are two common roadblocks to consider when we talk about what makes us happy. The first is the notion that the pure pursuit of happiness causes people to care only about themselves, so that they become narcissistic and selfish. And the second notion is that, paradoxically, focusing on happiness can end up making us miserable.

HELPING OTHERS VS HELPING YOURSELF

When happiness is defined according to feelings of both pleasure and purpose, it becomes easy to see how helping others is good for happiness. We get a warm glow from helping other people, which comes in large part from the purpose we feel when we do so. Helping other people is, in fact, one of the main causes of happiness. Charitable giving and volunteering have both been shown to make people happier. Doing good is entirely consistent with feeling good.

This definition of happiness also explains why being productive at work, or learning a new skill, feels good: not only because it is fun, but because it feels fulfilling. Thus, we should each seek to find the right balance between pleasure and purpose in the activities we engage in, and from the people we spend time with.

You may then wonder if it is selfish to pursue altruistic acts simply because you believe they will make you happier. Well, research shows that those who share the belief that charity should be a purely selfless act, with no personal benefit,

SCIENCE PHOTO LIBRARY, GETTY IMAGES

“There is robust evidence that reminding people of the personal benefits of charitable acts will actually encourage people to adopt behaviours that help others”

actually discourage others from getting involved in altruistic acts. In fact, there is robust evidence that reminding people of the personal benefits of charitable acts – like it can be good for your own mental health – will actually encourage people to adopt behaviours that help others.

We also see higher rates of volunteering when potential volunteers are reminded that prosociality – behaviour intended to benefit others – increases happiness.

We should therefore do much more to celebrate the ‘selfishness’ of selflessness, and not make claims about the superiority of purely selfless acts that the evidence does not support.

ABOVE Listening to music is proven to make you feel happy

The second common mistake is about focus. As mentioned earlier, some researchers believe that the pursuit of happiness can actually make us less happy. What this means is that we should not be pursuing happiness directly. Rather, evidence suggests that it is the pursuit of the main causes of happiness that will result in us being happier. Listening to music, for example, has been shown to be one of the most important determinants of happiness. It’s such an obvious but overlooked way to feel good: do more of it, and you will be happier. But don’t think about how happy it’s making you while you listen, as that will make you feel less good.

In fact, if you’re constantly monitoring how you feel, in general, you’ll feel less good.

To take another example, getting totally lost in the zone with your work and achieving a state of flow is less likely to occur if you pay attention to how it is making you feel. Concentrating on the feelings merely takes you out of that immersion in the activity. You will be happier when you are not constantly being distracted by thoughts of whether you are, in fact, happy.

So, we do need to spend some time working out what brings us pleasure and purpose and the right balance between them. But once we have conducted that audit, we need to pay attention to the activities themselves rather than to how those activities make us feel.

We might also worry about becoming so obsessed with being happy in itself that we forget to enjoy how things feel along the way. But if you pay attention to the activities that make you feel good, you will be happier without even having to think about it. And who wouldn’t want that? **SF**

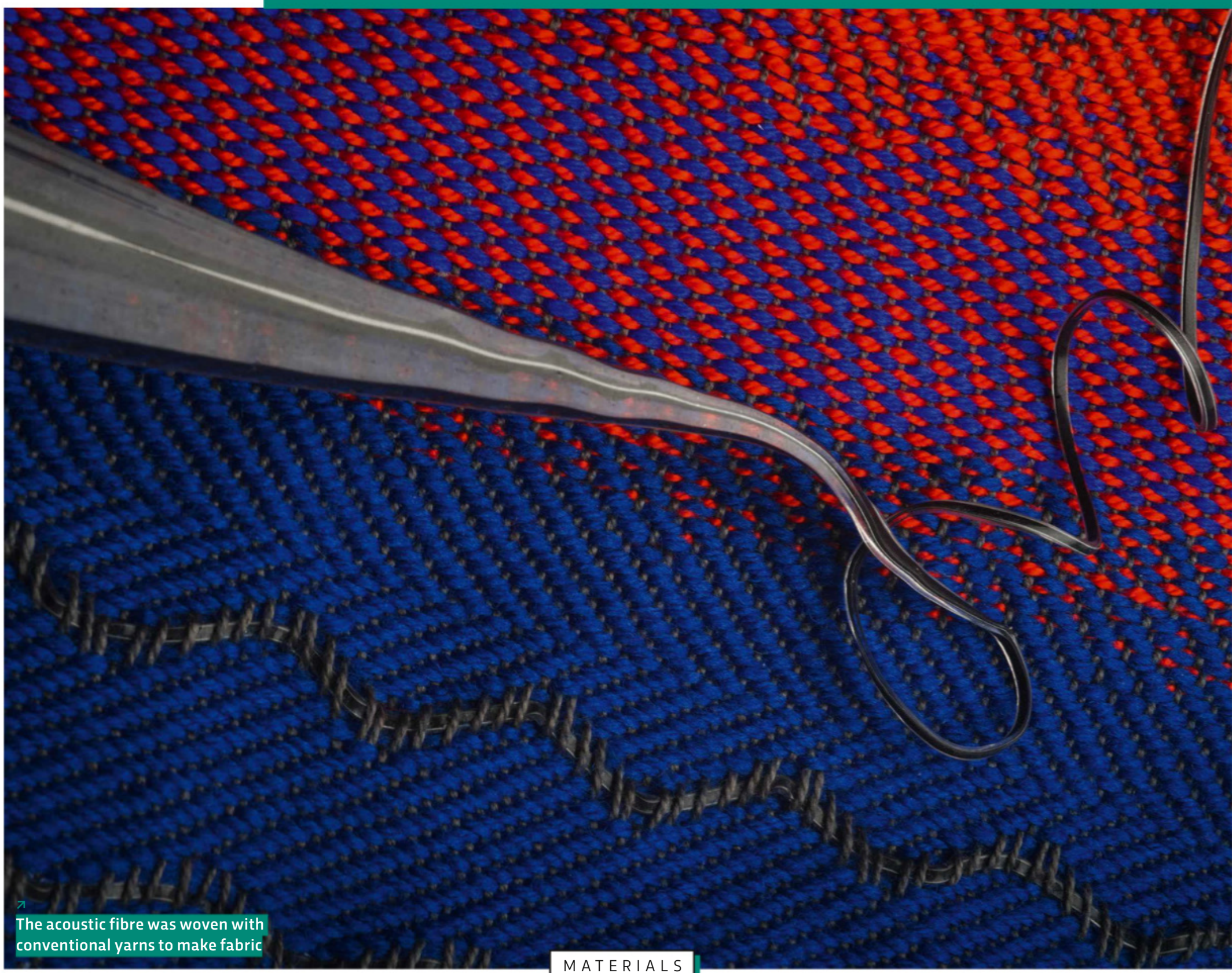
by **PROF PAUL DOLAN**

Paul is a professor in the department of psychological and behavioural science at the London School of Economics. He is a bestselling author, having written several books on happiness, and he is the creator and presenter of the Duck – Rabbit *psychology and neuroscience podcast.*

A space-age guitar that can do karaoke p40

INNOVATIONS

PREPARE YOURSELF FOR TOMORROW



The acoustic fibre was woven with conventional yarns to make fabric

MATERIALS

This fabric can hear your heart beat

I'm picking up good vibrations, she's giving me the excitations...

PROSTHETIC ARM

Atom Limbs is looking to create an artificial arm capable of a near-full human range of motion and mind control. It would involve complicated algorithms that analyse electrical signals coming from the muscles and a large number of electrodes. Not available until at least 2023.

ENERGY HARVESTER

Researchers from the University of Surrey have created a wearable made from recycled materials that is powered by human movement, so doesn't require any kind of electrical charging. The team hopes to create smartwatches and wearables that are kinder to the environment.

SMART INSOLE

Flextrapower has developed an insole that fits into your shoe and measures increases in temperatures and pressure in your feet, which can be an early warning sign of ulcers and potential diabetes. The insole is paired with an app that can alert you of health issues it detects.

"What's that? Sorry, I can't hear you, let me just turn up my shirt..." That's the idea behind a new kind of acoustic material that's been created to hear sounds, and even play them back.

This new kind of fabric is so sensitive that, if made into a T-shirt or a wristband, could be used to track your pulse or the rate of your breathing. The material can detect and orient louder sounds too, perhaps one day providing support for some of the 11 million people in the UK who have hearing difficulties.

This design – the product of a collaboration of researchers at the Massachusetts Institute of Technology and the Rhode Island School of Design – was inspired by the way the human ear turns sound into an electrical signal that the brain can understand.

Your clothes already pick up vibrations from the audible sounds around you, but this normally happens at an imperceptible scale. The team just needed to build a stiff but flexible fibre that, when woven into a larger piece of fabric, was light enough to move with these vibrations "like seaweed on the ocean's surface."

The material also needed to be piezoelectric, which means that when it was bent or deformed it would generate an electrical charge or signal, providing a means for the fabric to convert vibration into electrical signals.

"Wearing an acoustic garment, you might talk through it to answer phone calls and communicate with others," says lead author Wei Yan, who is now an assistant professor at the Nanyang Technological University in Singapore. "In addition, this fabric can imperceptibly interface with the human skin, enabling wearers to monitor their heart and respiratory condition in a comfortable, continuous, real-time, and long-term manner."

The team tested the fibre's performance by weaving it with conventional yarns to create panels of machine-washable fabric. "It feels almost like a lightweight jacket – lighter than denim, but heavier than a dress shirt," says Elizabeth Meiklejohn, a textile designer who wove the fabric using a standard loom.

A panel of the fabric was then sewn into the back of a shirt to find out what it could do in the real world. The researchers say it was able to accurately detect the direction of the sound to within one degree at a distance of three metres.

"WEARING AN ACOUSTIC GARMENT, YOU MIGHT TALK THROUGH IT TO ANSWER PHONE CALLS AND COMMUNICATE WITH OTHERS"

A single fibre was also stitched to the inside of a shirt, just over the chest area. They found that it could accurately track a heartbeat, and could even get a sense of its variability – a crucial measure in healthcare, particularly when it comes to tracking the health of infants. And finally, the researchers also found that they could reverse the process and input audio into the thread to generate vibrations in the clothing.

But it's not just in clothing that the team are now looking to expand the research. "It can be integrated with a spacecraft skin to listen to accumulating space dust, or embedded into buildings to detect cracks or strains," Yan proposes. "It can even be woven into a smart net to monitor fish in the ocean. The fibre is opening widespread opportunities."

Panels of the fabric were stitched onto a shirt and successfully detected sounds

GREG HREN, FINK LAB/MIT, ATOM TOUCH, UNIVERSITY OF SURREY, GETTY IMAGES

Can a smartphone be eco-friendly and desirable?

PROS:

- Replaceable parts and modular design
- Built with sustainable components
- Affordable price
- Solid and durable body

CONS:

- Camera quality can be dull and inconsistent
- Occasionally sluggish performance

Fairphone has a long history of producing some of the most eco-friendly smartphones around. In fact, it is currently ranked in the top 1 per cent of sustainable companies in the world according to EcoVadis, a sustainability ratings company.

But ethics don't come cheap. This has meant that, in the past, the Fairphone has fallen short of its competitors in terms of sheer performance, like battery life, camera quality, responsiveness and that sort of thing.

And yet with their latest model, the Fairphone 4, the right balance has finally been struck. This is a sustainable smartphone that stands up to its towering Android competitors.

ECO-CREDENTIALS

The Fairphone 4 is built to be repairable. A big problem with smartphones is that we have got into a habit of replacing them every couple of years. Once the battery gives in and the phone starts to slow, we switch to a new one.

While most brands these days completely seal off the back of their smartphones to prevent you from tinkering, Fairphone gives you complete access. With the included screwdriver, you can easily replace any part of the Fairphone.

You can change the battery when it stops holding charge, switch out the processor when things get slow, or swap any part that breaks. That includes the camera, screen, earpiece and speaker.

The Fairphone's case can be removed so that users can access and replace any slow or broken components

"THE BRAND IS WORKING TOWARDS THE GOAL OF A 100 PER CENT FULLY RECYCLED SMARTPHONE"

Fairphone is also the only phone company to be Fairtrade 'Gold Certified' for the parts that it uses, which are sourced at a fair price and with the environment in mind.

Fairphone uses parts gathered from small-scale mining, which is less harmful on the environment than larger mines. Components are also obtained from recycled Fairphone devices and the brand is working towards the goal of a 100 per cent fully recycled smartphone. It is currently the leading smartphone brand for recycled parts.

DESIGN

The back of the phone is made from 100 per cent recycled plastics. The phone feels sturdy, like it could take on a few bumps here and there. The materials used, along with the metal frame, make the Fairphone feel like a device that will last. It does have some weight to it – at 225 grams it is 51 grams heavier than the iPhone 13. While not uncomfortable, those with smaller hands might find the size of the device off-putting.

The Fairphone 4 features a fingerprint scanner, which is placed next to the volume switches on the right-hand side. It's a minor quibble, but it's an awkward place for a feature you'll be using a lot.

There is no 3.5mm headphone jack. Instead, the USB-C port can double up as a charging point and headphone point with an adapter.

DISPLAY

The screen on the Fairphone is sharp and as big as you'll find on most smartphones out there, coming in at 6.3 inches wide. That said, the display isn't technically as good as it could be. The display doesn't cover the whole phone, with bars at the top and bottom. The screen sometimes feels slow to respond to commands – it's capped at a 60Hz refresh rather than the usual 90Hz or 120Hz of newer phones.

The colours aren't as vibrant as you might expect. Unlike many handsets in this price range, the Fairphone 4 opts for an LCD screen (compared to the brighter, higher contrast OLED). Considering the £449 starting price, this is weaker than we would have expected.

↑ The display and cameras aren't quite as good as those of competitors phones

FEATURES

We were getting a full day of heavy usage, which is in line with what Fairphone expects. With a 3,905mAh battery, this isn't a huge surprise.

No USB-C charging cable or block is included. In order to reduce e-waste, Fairphone has skipped these features, expecting most customers to already have one.

While you can get the device with either 128GB or 256GB storage options, it's nice to see the inclusion of a MicroSD slot to increase the storage – a rare feature on phones these days.

POWER

The device uses a Snapdragon 750G chipset – a common option in smartphones around this price point. The Fairphone 4 was consistently good for performance. Load times were short for most everyday apps, with the occasional lag on more intensive apps.

In terms of gaming, while dominating the world on the more basic *8 Ball Pool*, there were absolutely no problems. When we stepped things up to high-speed and graphically intensive games like *Asphalt 9*, there was a noticeable lag.

CAMERAS

The biggest weaknesses are the cameras. On paper, the specs look solid. There's a 48MP main camera with an f/1.6 aperture, along with a second ultra-wide lens, also 48MP but with an f/2.2 aperture.

However, whether we took photos outdoors in various weathers, or indoors in a brightly lit room, our snaps ended up looking dull and lifeless. The images were crisp and fully in focus, but the lack of colour held them back, especially in low-light situations where images were blurry.

The other issue came from the 25MP f/2.2 selfie lens. Selfies would come out with a smudged background, especially around our hair. We even got a few friends to take some selfies with it too, making sure it wasn't just our poor genetics getting in the way.

VERDICT

The Fairphone 4 has its flaws, but it is the best eco-friendly handset around right now. It is a vast improvement on the last Fairphone device and will last you for years.

There are compromises to creating a phone that's affordable and kind on the planet, and for some the Fairphone's camera might be one compromise too far.

While it can still take great shots, most smartphones these days are more than capable of churning out excellent quality photos with ease. With Fairphone, you'll still get clear and detailed shots, they just might seem slightly dull and lacking in the pop of colour that its competitors achieve.

The Fairphone 4 is mostly a hard smartphone to criticise, especially considering its price point and small carbon footprint.

Ideas we like...

↑

...the ultimate barista setup

Forget the bar, cafe or smoothie shop, you could soon make hundreds of drinks from one machine! The Cana One is a 'molecular beverage printer' that can supposedly make hundreds of drinks with very little waste. Most drinks are made using water, different flavour compounds and a few key ingredients, so the folks at Cana have isolated the molecules that drive flavour, separating them into hundreds of ingredients – all fitted within one cartridge. Sugar and spirits cartridges complete the system. You can even customise each drink to suit your tastes, using the sleek touchscreen on the front.

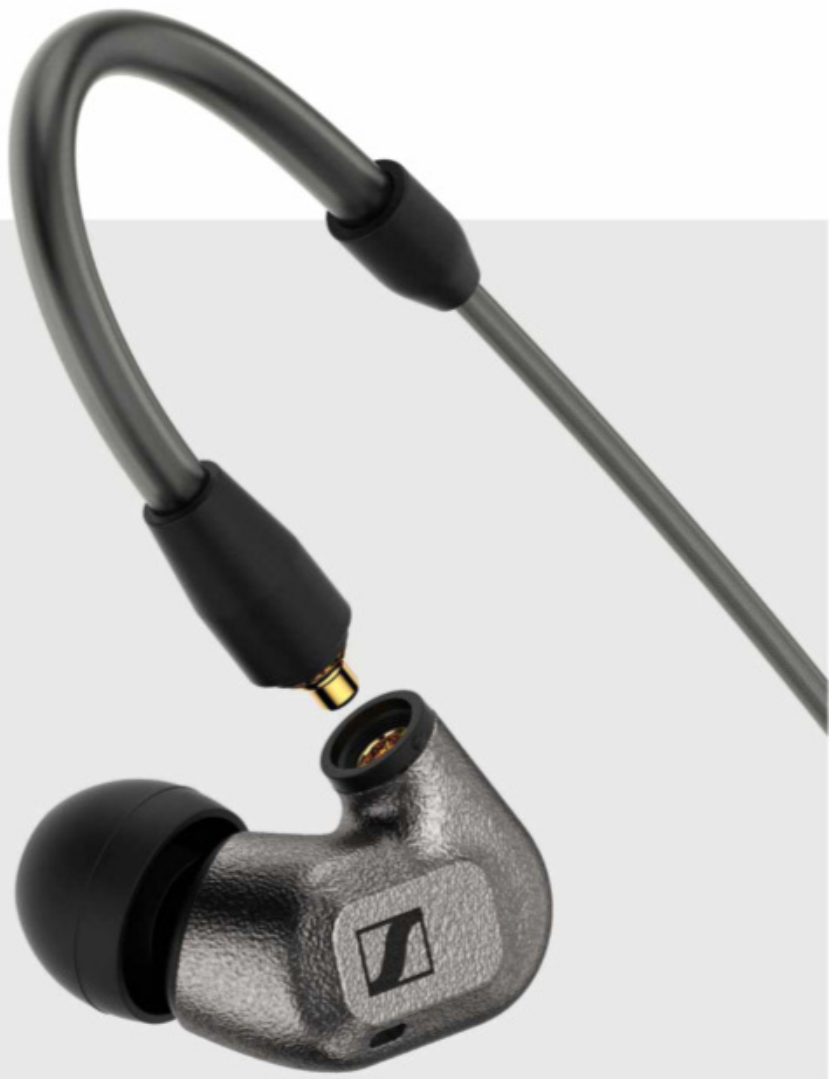
Cana One
$799 (£610 approx), cana.com

↑

...a guitar like no other

Enya's new NEXG guitar is packed full of wildcard features. Enya is calling it the first 'smart guitar' and we can see why. Want to play pre-recorded music? There's an onboard speaker for that, as well as a tuner, sound effects and a computer processor with a built-in sound card. Karaoke mode makes it a fun beginner's guitar, whereas the sound effects allow advanced guitarists to get experimental with their work. So who's up for the Skrillex remix of *Wonderwall*?

Enya NEXG
$899, enya-music.com



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...headphones made with space-grade metal

Remember wired headphones? Not only are they still a thing but audio giant Sennheiser seems determined to bring them back in the most over-the-top way... by making them from space-grade materials. By using 3D printing and the material 'amorphous zirconium' (we'd never heard of it either), Sennheiser has created an incredibly durable pair of headphones, complete with dual resonator chambers for 'unsaturated hi-fi audio', resulting in a supposedly 'intimate' sound.

Sennheiser IE 600
£599, sennheiser.com

PATRIK LINDGREN/TEKNIKENS VÄRLD

←

...a personal jet

Sure, a supercar is impressive, but if you really want to turn heads on your commute to work, then a personal 'aerial vehicle' is the way to do it. The company Jetson Aero has developed... well... the only way to really describe it is a flying car. It features four propellers that allow you to fly around in the sky at an altitude of up to 457 metres (1,500 feet), with a top speed of 101km/h (63mph). The one obstacle you might face (other than overcoming your fear of heights) is finances, as the Jetson ONE comes in at a whopping $70,000.

Jetson ONE
$70,000 (£53,500 approx), jetsonaero.com

↑

...a speaker oozing in style

Looking like something that's been dragged through the set of *Blade Runner*, the Astell&Kern ACRO BE100 is sure to turn heads. It features a 32-bit digital-to-analogue converter and Bluetooth 5 for the latest high-res quality wireless streaming codecs. Inside there's a 4-inch Kevlar woofer, along with two 1.5-inch silk dome tweeters, and an amplifier with 55W total power. That's a lot of impressive features, but at £449 we would expect nothing less from a speaker that looks like something Darth Vader would own.

Astell&Kern ACRO BE100
£449, astellkern.co.uk

↓

...Apple's latest desktop offering

Apple has done it once again: created a stylish, powerful product with a price tag that will leave your wallet shaking uncontrollably in the corner. The Mac Studio is its latest desktop, featuring either the new M1 Max or M1 Ultra processor. Both options are unbelievably powerful, with Apple claiming to outperform any other desktop on the market. The target audience is somewhat niche, mostly aimed at those trying to send their computer to hell and back with hundreds of tabs, 3D rendering, 8K video editing and niche creative tasks.

Mac Studio
From £1,999, apple.com

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FITO

INFLATION IS A USEFUL TOOL IN NATURE, ALLOWING ANIMALS TO PROJECT SOUNDS, SCARE OFF PREDATORS OR EVEN ATTRACT A MATE. LET'S BRING ON THE BLOAT! WORDS: JULES HOWARD

BUILT-IN BAGPIPES

CALAKMUL BIOSPHERE RESERVE, MEXICO

This painted tree frog produces a piercing screech that differs slightly in pitch to closely related species. To maintain the call for as long as possible, it squeezes the same breath of air back and forth across the larynx, creating a trilling sound. This is just one of thousands of different kinds of frog calls, each unique to its own given species. "Vocal sacs differ enormously across frogs," says herpetologist Dr Mark Scherz of the Natural History Museum of Denmark. "Some species have single sacs, some have paired sacs, some sacs even expand substantially down the body or expand hugely in front of the head."

Even female frogs have taken to inflation. Last year, scientists in Minnesota discovered that female green tree frogs inflate their lungs to cancel out the calls of rival species. The exact mechanism that causes this noise-cancelling effect is yet to be fully understood, but it is likely to help females locate males when multiple species congregate together at breeding ponds.

KEVIN SCHAFER/MINDEN/NATUREPL.CO

BURST

GERRIT VYN/NATUREPL.COM, GARY BELL/OCEANWIDE/MINDEN/NATUREPL.COM

←

HELLO, CHUBBY CHEEKS

SOUTH DAKOTA, USA

In birds, the voice box (called the syrinx) is double-barrelled. Some species, such as the greater sage grouse, also have a pair of vocal sacs, kept within a flexible throat pouch. As soundwaves escape from the syrinx they resonate against the elastic membrane of each sac which, as it inflates, is pulled taut like the skin of a drum. The throat pouch can also be brushed against the feathers on the wings to make a dramatic whooshing sound.

The resulting courtship noises are what evolutionary ecologist Prof Gail Patricelli calls a "swish, swish, coo, pop, whistle, pop," performed while the male struts in front of potential mates.

"The first notes sound like the swish of corduroys. That's followed by a gurgling or bubbling sound that comes out from the chest and through the vocal sacs," she explains.

The final flourish is, quite literally, a boom – a loud, deep, resonant sound that can be heard more than a mile away.

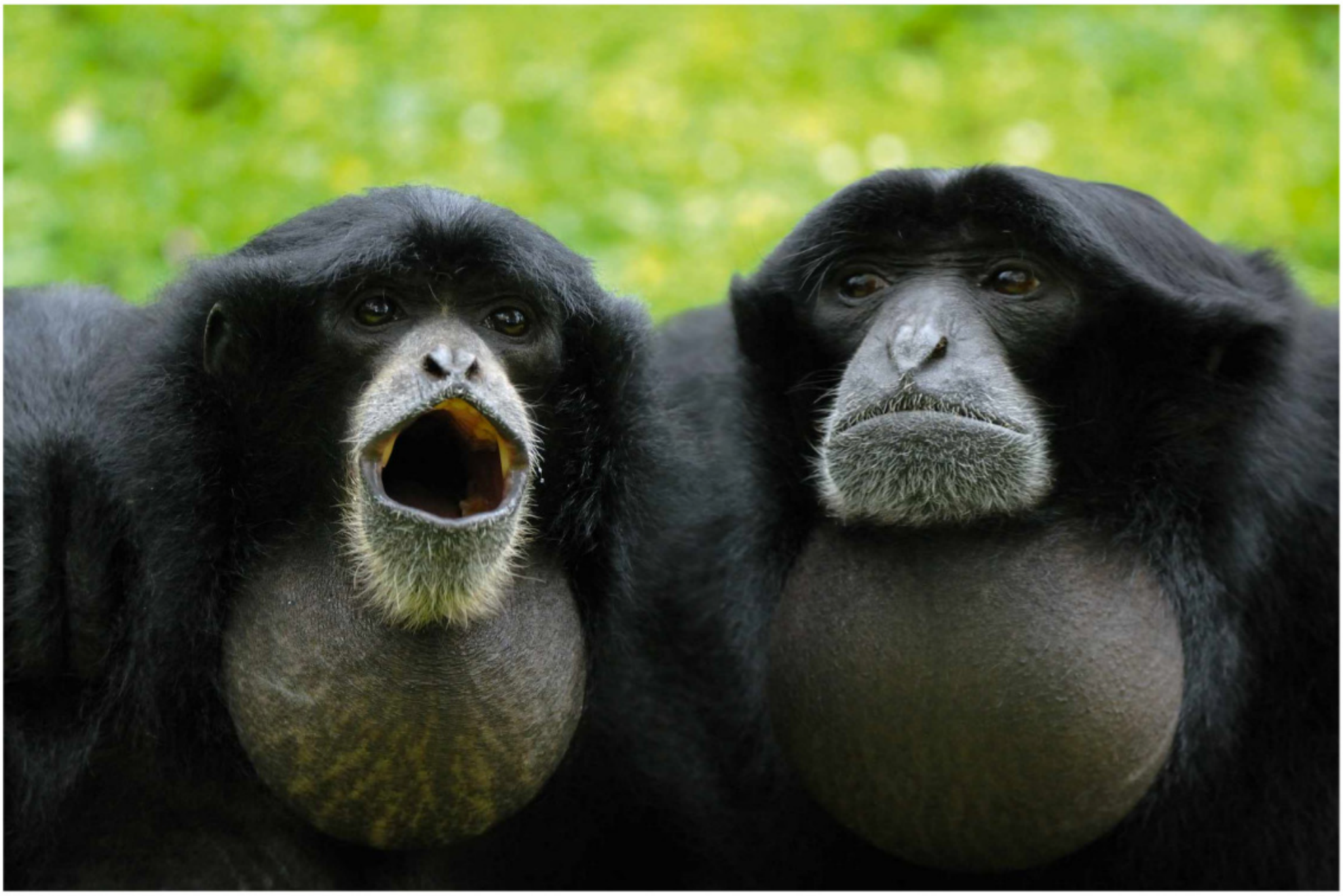
↑

DON'T HAVE A POP AT ME

VICTORIA, AUSTRALIA

The neurological pathways that control a pufferfish's puff have their roots in coughing. Closely related fish open their mouths and expand their throats in a similar manner, pulling water into the stomach which they then squirt out in a powerful 'cough' to dislodge items stuck in the mouth. This routine behaviour has been taken to extremes in pufferfish, like this slender-spined porcupinefish. To reach full size, an inflating pufferfish takes in gulps of seawater at a rate of two gulps a second, a process which causes its stomach to stretch to many times its natural size. To make space for the water flooding in, the pufferfish abdominal cavity is pleated like an accordion. Ribs, common to most fish, are reduced in pufferfish.

Though their puffing-up temporarily hinders movement, the rewards for pufferfish are worth it. Predatory fish may choose to hunt something smaller. And if its size won't convince them to back off, its spines might.



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MAKING MUSIC

SOUTHEAST ASIA

"In dense undergrowth, sound travels much better than visual cues," says Paolo Viscardi, curator of zoology at the National Museum of Ireland. Siamangs are territorial, and defend their patch by calling. They have evolved a flexible pouch under the chin, which can be inflated to a size comparable to their head. When air expelled from the lungs travels through the larynx, the sounds resonate within the pouch like a subwoofer in a speaker. This propels long-distance calls, that regularly top 100 decibels, more than three kilometres (two miles) across the forest canopy. By rapidly inflating their pouches and using their hands to manipulate the sounds coming from their mouth, siamangs are able to construct complex noises including barks, booms and 'ululating' bouts of screaming.

To help their calls travel further, siamangs call in the morning when the air is clearer. To stop their sounds from being muffled, they'll avoid calling from trees covered with hanging vines.

→

SEEING RED

TOWER ISLAND, GALÁPAGOS ISLANDS

In the great frigatebird, the pelican-like throat pouch has been co-opted for marketing purposes, serving as a precious advertising hoarding that can be inflated at potential mates flying overhead. The male briskly drums its beak against the inflated pouch, creating a rhythmic rattling that travels easily in the ocean breeze. Should a female notice, she will come down for a closer inspection. The redder the pouch, the better.

"Red colours are generally rare in nature," notes Prof Kevin McGraw, a behavioural ecologist who specialises in animal colours. "This is because they can be costly for some animals to produce, either in terms of the energy required to make them or because they risk being more easily spotted by predators."

For females, the efforts that a male goes to in maintaining his bulbous bib are clearly worth it. "In choosing to mate with a redder male, females get a mate who's showing they can incur those risks and still survive to show off," McGraw adds.

ERIC BACCEGA/NATUREPL.COM, TUI DE ROY/NATUREPL.COM

BLOW YOUR NOSE

MAGDALEN ISLANDS, CANADA

"On the pack ice, this inflated membrane is very visible," says Sylvain Cordier, the wildlife photographer who captured this image of a male hooded seal. "The bigger and redder it is, the more interested the females become."

To display this strange adaptation, the seal blocks off one of its nostrils and forces a jet of air into the other. This fast-flowing air catches a special membrane in the nostril that inflates like a balloon. Like a flag being raised and lowered, this signal communicates the size and strength of an individual male and helps keep rivals at bay.
Under the water, this inflatable sac has a different application. Connected to a large bladder that runs across the top of the head, it can be compressed in long or short bursts like a set of bagpipes, to create a range of musical notes. These underwater calls, recorded by scientists for the first time in 2021, include bursts of pulsating groans as well as 'pings' and 'ouwah' calls unique to hooded seals.

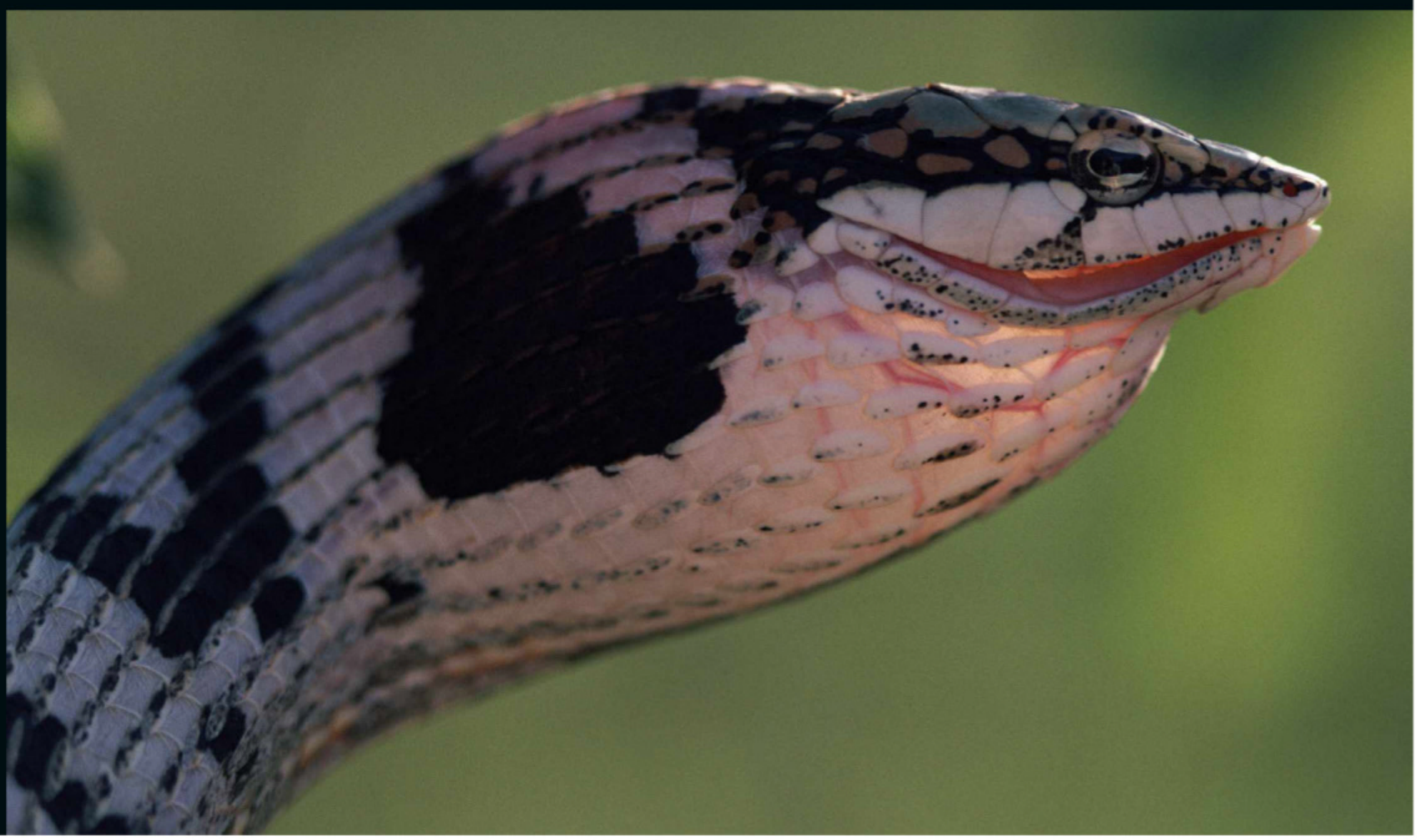
Though it may not have the beauty of birdsong, inflation of body parts can offer ways for animals to enhance their modes of communication.

PUMP UP THE FANG

SOUTH AFRICA

Rather than hiss or rattle their tails, African twig snakes opt for a more pneumatic approach. When threatened, these snakes pull air through the nostrils and inflate the throat to more than twice its normal size. As the twig snake expands, the scales upon its head stretch out to reveal conspicuous black markings on the scale edges. Known as aposematism, this form of animal communication warns animals that run-ins with twig snakes are worth avoiding. Its venom is, after all, a powerful blood-thinner capable of killing red blood cells within seconds of a bite.
Twig snakes tend to inflate most when face-to-face with predators, including cats and dogs. But twig snakes are also known to inflate when mobbed by flocks of birds who are eager to drive the snake away from their territories. In fact, so pervasive is this mobbing behaviour that zoologists once thought that inflated twig snakes were mimicking baby birds, in their puffed-up, fledgling plumage. The idea was that adult birds, consumed by parental urges, might investigate a puffed-up twig snake only to end up as dinner. SF

by JULES HOWARD (@juleslhoward)
Jules is a zoologist and science writer. His latest book, Wonderdog *(£17.99, Bloomsbury Sigma), is out in May.*



SYLVAIN CORDIER/NATUREPL.COM, MICHAEL & PATRICIA FOGDEN/MINDEN/NATUREPL.COM

THE RACE FOR THE MOON

WORDS: COLIN STUART

A new space race has begun. Over the coming years, an armada of rockets will head to the Moon to hunt down precious resources, satisfy the urges of billionaire tourists and maybe do some intriguing science along the way...

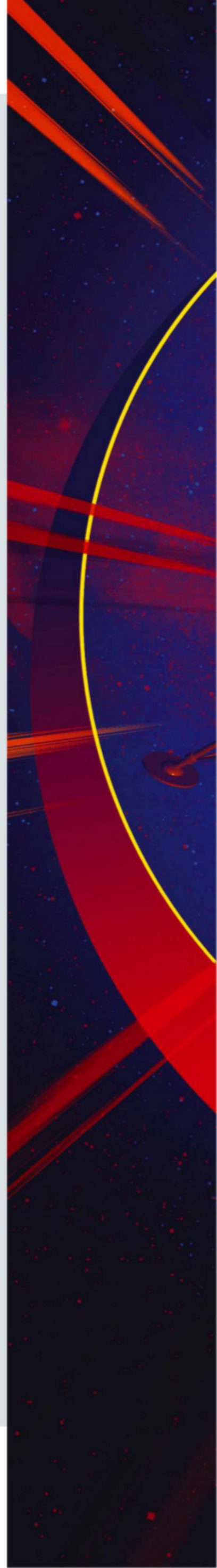


ILLUSTRATION: ANDY POTTS

WHY NOW?

In a prolific flurry of activity between 1969 and 1972, NASA landed 12 astronauts on the Moon. Starting with Neil Armstrong's famous first steps, they explored the lunar surface, left experiments there for us to improve our knowledge and returned Moon rocks so we could learn about our neighbour's history and origins.

Yet achieving those historic feats did not come cheap. The total cost of the Apollo programme in today's money was $280bn, according to a recent estimate by The Planetary Society. That's more than the GDP of 78 per cent of the world's nations. Adjusting the value to take into account changes to the USA's own GDP since the 1970s puts that figure at more like $641bn.

Ultimately, that money came from taxpayers, who were increasingly reluctant to sanction spending on something that had already been done six times. Schools and hospitals tend to be closer to people's hearts.

Fast-forward to today and we're in the midst of another space race, with a sizeable armada of spacecraft heading to the Moon in the years ahead. So what's changed?

First, taxpayers are no longer footing the entire bill. The last decade has seen an explosion in the number of private space companies, led by famous names like Elon Musk's SpaceX. By developing reusable rockets, they've driven down the cost of getting to space considerably. NASA already uses SpaceX technology to deliver astronauts and supplies to the International Space Station and they've inked deals to collaborate on sending landers to the Moon, too.

They've also hit upon a potential new revenue stream: space tourism. These reusable rockets could turn into celestial cruise ships, allowing the world's billionaires to enjoy a week-long voyage around the Moon and back. They could even spend some time on the Moon itself, seeing Earth rise above its craggy, cratered surface. The eye-watering sums they'd pay could then be used to fund further lunar exploration.

Second, recent missions to the Moon have confirmed that it is home to important resources that are both key to building a permanent human presence on the Moon and kick-starting a new industry in space mining. Corporations are starting to see dollar signs and are investing in exploratory missions to further scope out what's there and the feasibility of extracting it. Space tourism could help to pay for this otherwise loss-leading prospecting.

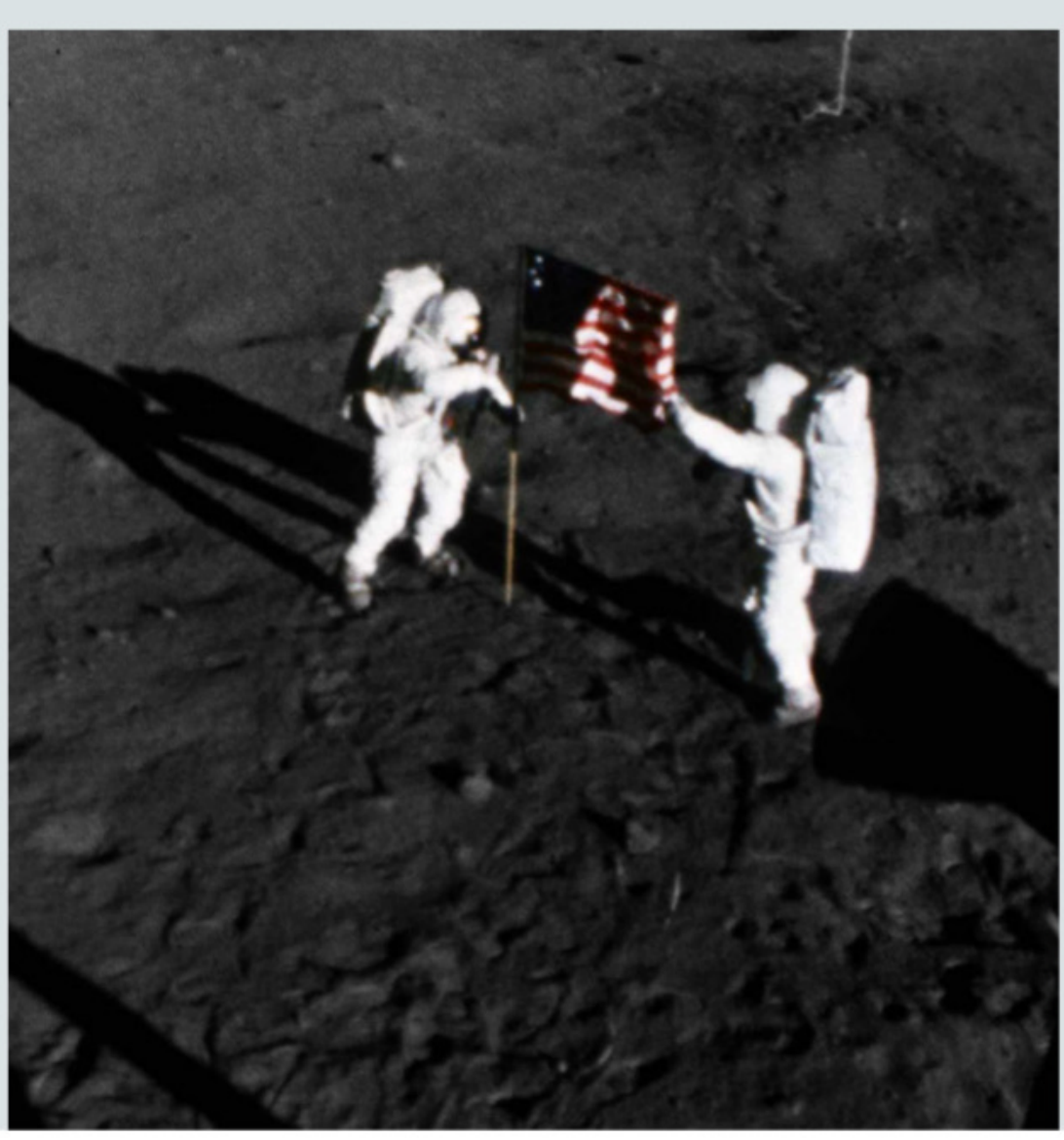
Then there's the original motivation of going to the Moon: geopolitical bragging

LEFT SpaceX's Crew-2 mission blasts off to the International Space Station in April 2021

RIGHT View from the SpaceX Crew Dragon, as it undocks from the International Space Station

"REUSABLE ROCKETS HAVE DRIVEN DOWN THE COST OF GETTING TO SPACE"

RIGHT The Apollo 11 astronauts were the first humans to set foot on the Moon back in 1969



rights. Emerging superpowers such as China have made no secret of their desire to land their taikonauts on the Moon. The numbers of landers and rovers they are sending to the lunar surface is starting to ramp up in preparation for a show of strength and power in the next decade. NASA too is planning to return astronauts to the Moon before the decade is out.

The Space Race, it seems, is well and truly back on.

SPACEX, ALAMY, NASA

WHAT WILL THE MISSIONS FIND?

The ultimate goal is to have a permanent human presence on the Moon – a base on which astronauts could routinely live and work. Many of the missions going to the Moon in the years ahead will help us learn how to pull this off.

One region that is going to see a lot of activity is the lunar south pole because there's water there, which is an invaluable resource for keeping astronauts alive. "The evidence that water ice is sequestered in permanently shadowed polar craters has been growing for quite some time," says Prof Ian Crawford, a space resources expert from Birkbeck, University of London.

Indian astronomers were the first to spot water from lunar orbit with their Chandrayaan-1 satellite in 2008. Then NASA detected water in plumes thrown up when it deliberately crashed the LCROSS spacecraft into a crater called Cabeus near the lunar south pole a year later. More recent missions have begun to map out where the water ice is hiding.

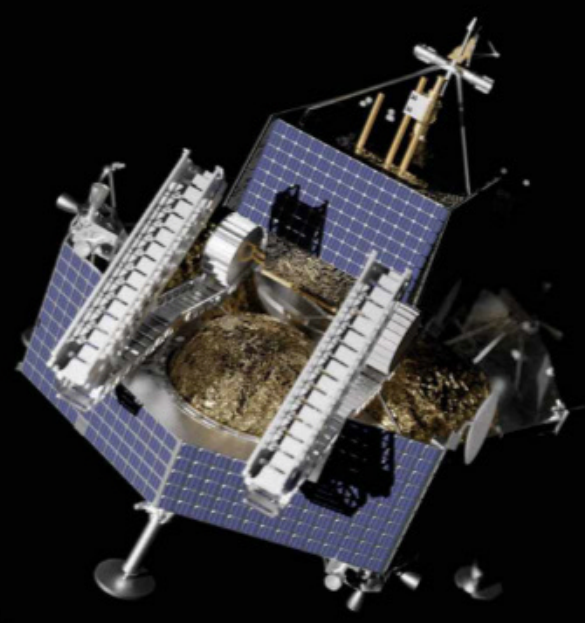
Upcoming missions will continue this quest, further surveying the region from orbit, while rovers will explore on the surface. The Chinese are even planning a miniature flying probe. NASA plans to send astronauts back to the Moon on Artemis III, probably sometime in 2026, and the south polar region is where they will head.

At the same time, NASA is part of an international collaboration that's planning to build an orbital outpost around the Moon, known as Gateway. If it is ready in time, it will act as a staging ground from which Artemis astronauts could head down to the lunar surface. However, it would also be a place to drive lunar rovers from in real time without the 1.3-second delay caused by the signal travel time from Earth.

One big obstacle to permanently living on or around the Moon is radiation. Without the protection of Earth's magnetic field and atmosphere, Moon-dwellers would be exposed to high-energy particles from the Sun and the Universe at large. Several upcoming missions are looking to measure these radiation levels in the hope that we can better understand how to protect astronauts from this considerable danger.

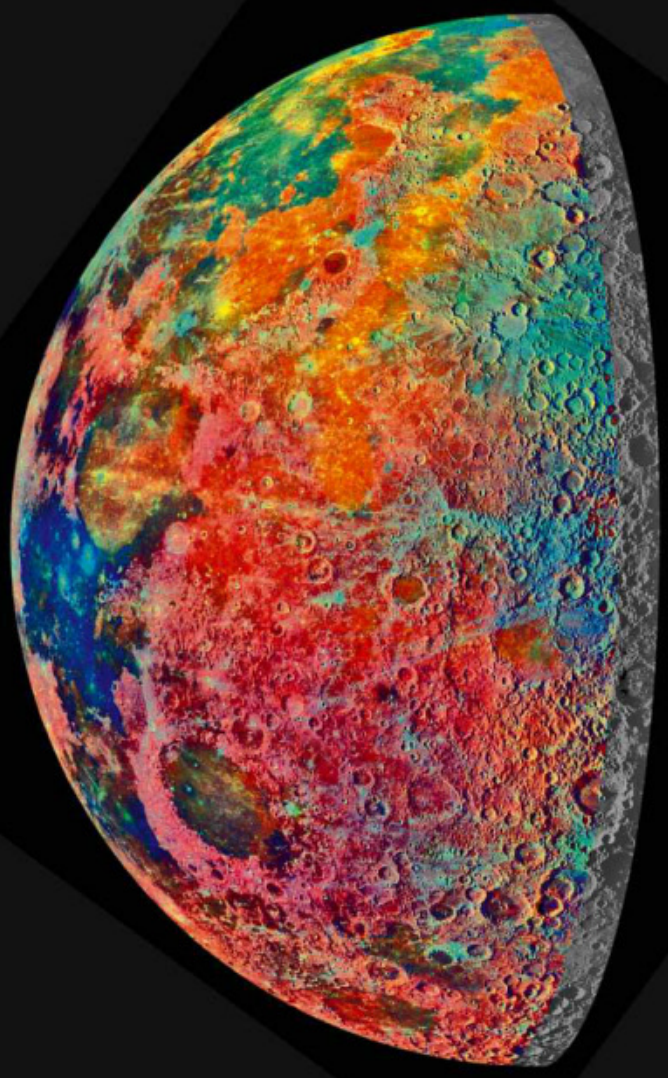
There are also scientific puzzles that we'd like to solve. The lunar rocks returned by the Apollo astronauts gave us valuable insights into the Moon's formation and history, but there's a lot of disagreement on how to interpret them. Robotic sample return missions will bring back more Moon rocks from a wider variety of locations on the lunar surface, helping to answer questions like how volcanically active the Moon still is.

On the industrial side, returning Moon material is a crucial step if we're to make lunar mining a reality. NASA is partnering with private space companies, such as Astrobotic and Intuitive Machines, to test out the feasibility of putting commercial landers on the surface. As we're about to see, that could be big business in the not-too-distant future.



ABOVE Astrobotic has teamed up with NASA to test the feasibility of commercial lunar landers

LEFT There are dangers to overcome before we can set up a colony on the Moon



This colourised image of the Moon maps out the presence of different materials

EYES ON THE PRIZE

The resources private companies want to get their hands on

METAL

Moving away from fossil fuels for good will require huge shifts in the way we build our infrastructure. Significantly growing the number of electric cars, solar panels and wind farms will require enormous quantities of metals known as 'rare earths', due to their scarcity.

The Moon rocks returned to the Earth by the Apollo astronauts showed that the Moon also contains some of these resources. According to Crawford, they might be hard to extract, in which case the financial cost of returning them from the Moon would make the endeavour unfeasible. Yet he can imagine a situation where we still might do it. "It might be economically worse, but environmentally beneficial," he says.

That's because extracting rare earth metals such as neodymium – used in magnets – leads to high levels of contamination of the surrounding environment. There may come a time when we deem the practice just too dirty and environmentally damaging to allow on the Earth. Yet we'll still need to get those metals from somewhere. The Moon could be a pricier but greener option, leading to a multitrillion dollar market.

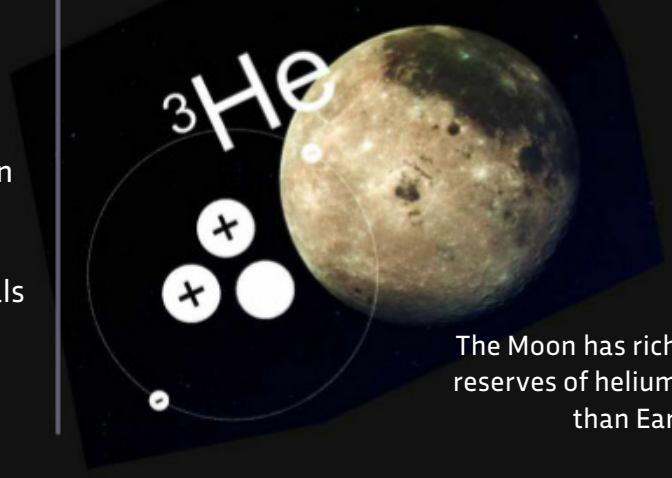
HELIUM-3

We're in the midst of an energy crisis. We want to wean ourselves off fossil fuels, but in the meantime we're starting to pay through the nose for oil and gas, thanks to COVID-induced supply chain disruptions and geopolitical tensions like those in Ukraine.

Fusion has long been lauded as a potential solution to our energy woes. The idea is to copy the way that the Sun creates its energy by turning hydrogen into helium. There are various ways to do this. One involves combining a rare type of hydrogen (called deuterium) with an even rarer type of helium (helium-3). The result is the more conventional form of helium (helium-4), protons and lots of energy.

We can extract deuterium from seawater, but helium-3 is so rare on Earth that it currently sells for $1.4m per kilogram. Some parts of the Moon, like the Sea of Tranquillity and the Ocean of Storms, have helium-3 concentrations of 20 parts per billion in the surface material. Without a magnetic field or atmosphere for protection, the lunar surface is bombarded by the solar wind, which deposits helium-3 there.

Although the economics of supply and demand means that bringing helium-3 back from the Moon would significantly drive down the price, at current levels there's around $1.5 quadrillion worth of helium-3 on the Moon.



The Moon has richer reserves of helium-3 than Earth

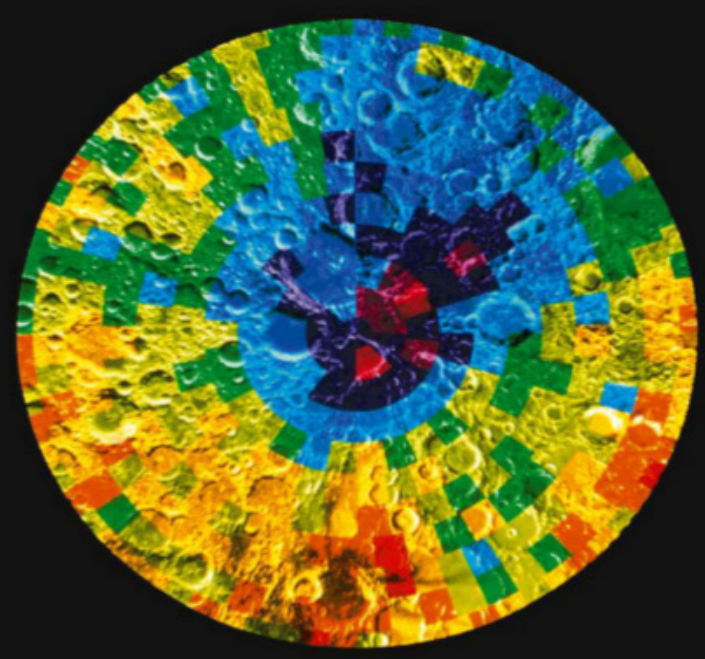
WATER

If there's one thing that Earth has in abundance, it's water. There's over a billion cubic kilometres of the stuff here. Yet water is also very heavy – a cubic metre of it weighs a tonne. It would cost more than $1m to get that into low Earth orbit, let alone to the Moon. Any water that's already in space is therefore worth its weight in gold. This is particularly true given how versatile water is. Not only do we need it for astronauts to drink and clean with, but what's inside water is particularly valuable.

A water molecule is famously H_2O – two atoms of hydrogen bonded to one atom of oxygen. Both liquid oxygen and liquid hydrogen are used as rocket fuel. These two elements can be isolated from water using electrolysis, a process that sees an electric current passed through the water. Astronauts aboard the International Space Station already rely on it for their oxygen supply.

NASA is intending to land its Volatiles Investigating Polar Exploration Rover, or VIPER, on the lunar south pole in late 2023 "to get a close-up view of the location and concentration of water ice that could eventually be harvested to sustain human exploration on the Moon, Mars – and beyond."

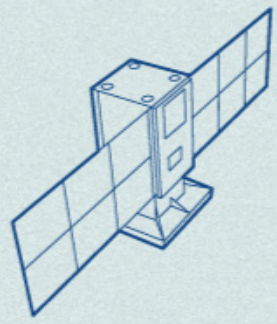
Water is so valuable that the Moon could become the refuelling station of the Solar System. Getting water off the lunar surface – where gravity is just one-sixth of the Earth's – is considerably more appealing. A 2019 study calculated that "water produced on the Moon has a current value of $10m per tonne, this value being based on the current costs to supply it from Earth." NASA estimates there could be 600 million tonnes of water ice on the Moon.

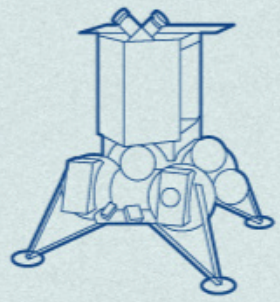


Water map of the Moon's northern hemisphere, showing more water around the pole

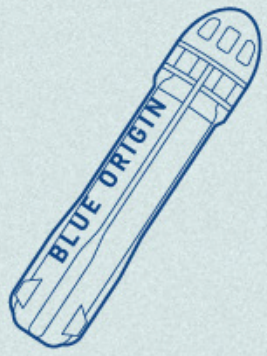
SHUTTERSTOCK, ASTROBIOTIC, NASA/JPL, ALAMY, SCIENCE PHOTO LIBRARY

The path to permanence





A rundown of future missions to the Moon, both real (near-term) and imagined (long-term)



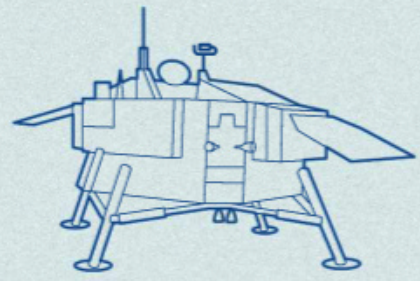
2024

ispace will send both a lander and a rover to the Moon.

Jeff Bezos's space company Blue Origin plans to land on the Moon and NASA will begin to send key elements for building Gateway to lunar orbit.

MAY 2022

NASA will launch the Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment (CAPSTONE). It's a technology demonstration mission to test and verify the stability of the intended orbit of Gateway.



2024

Chang'e 7 will see the Chinese land on the lunar south pole and send out both a rover and a flying probe to prospect for lunar resources. They'll be cooperating with the Russian Luna 26 orbiter that will be there at a similar time. Chang'e 6 could return samples from the lunar surface.

JULY 2022

Roscosmos, the Russian space agency, is set to send its Luna 25 lander to the Moon. It will touch down near the lunar south pole at the Boguslawsky crater.

LATE 2023

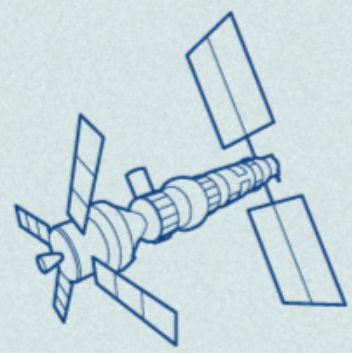
The Australia Lunar Exploration Mission will send nanosatellites in order to help NASA's Artemis programme. The Dutch will also send Laika to measure the radiation at the lunar south pole ahead of future human bases there.

2026

NASA will return humans to the Moon for the first time since 1972, including the first female astronaut and minority ethnic astronaut.

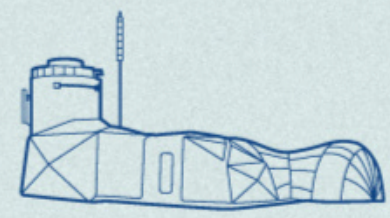
2027

China's Chang'e 8 could explore how to turn lunar resources at the Moon's south pole into usable materials through 3D printing.



2030

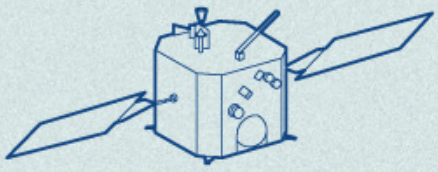
Gateway, which is like a version of the International Space Station in lunar orbit, will finally be finished. Astronauts will start to spend months living around the Moon.



2035?

Astronauts begin living on the lunar surface for extended periods near the Moon's south pole, just as we currently do with Antarctic research stations. It will largely be funded by paying Moon tourists.

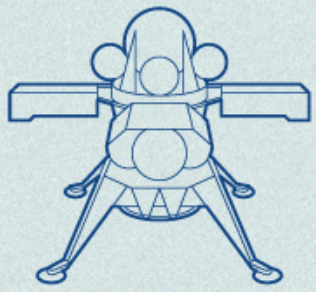
ILLUSTRATION: HANNA PIOTROWSKA



AUGUST 2022

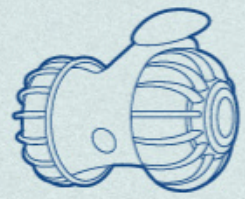
South Korea will use its Pathfinder Lunar Orbiter to survey and map lunar resources, including ice and helium-3.

After a failed attempt with Chandrayaan-2 in 2019, India will attempt a soft landing on the Moon with Chandrayaan-3.



OCTOBER 2022

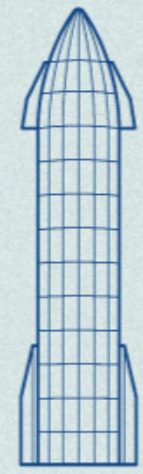
Private Japanese space company ispace will send a lunar lander called Hakuto-R Mission 1 to the Moon. It will also carry a lunar rover for the United Arab Emirates.



LATE 2022

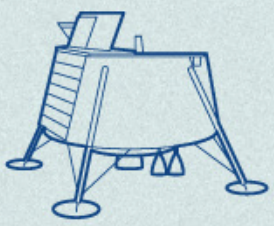
Efforts to commercialise the Moon will ramp up with the launch of Intuitive Machines 1 and 2 (IM-1 and IM-2). A collaboration with NASA, these landers are designed to deliver commercial payloads to the lunar surface.

In a new commercial space race, Astrobotic Technology's Mission One will carry seven rovers to the lunar surface.



2023

The first Moon tourists will fly around the Moon and return to the Earth aboard a SpaceX Starship, thanks to the deep pockets of Japanese billionaire Yusaku Maezawa.

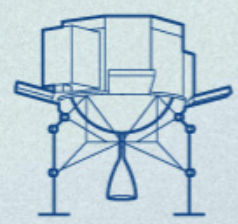


MID TO LATE 2023

In a demonstration of increasing public/private cooperation, Firefly Aerospace's Blue Ghost and Masten Space Systems' XL-1 landers will both carry NASA-sponsored experiments and commercial payloads to the Moon.

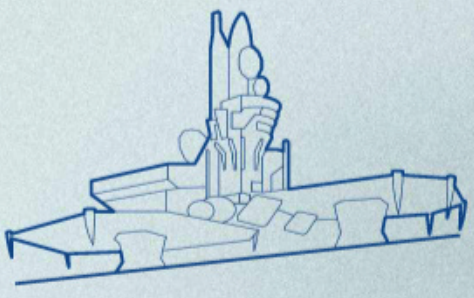
NOVEMBER 2023

NASA's Volatiles Investigating Polar Exploration Rover (VIPER) will begin prospecting for water ice around the lunar south pole.



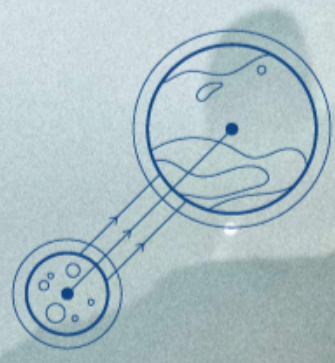
BEFORE MARCH 2023

The Japanese Space Agency (JAXA) will carry out its first ever lunar surface mission called Smart Lander for Investigating the Moon (SLIM).



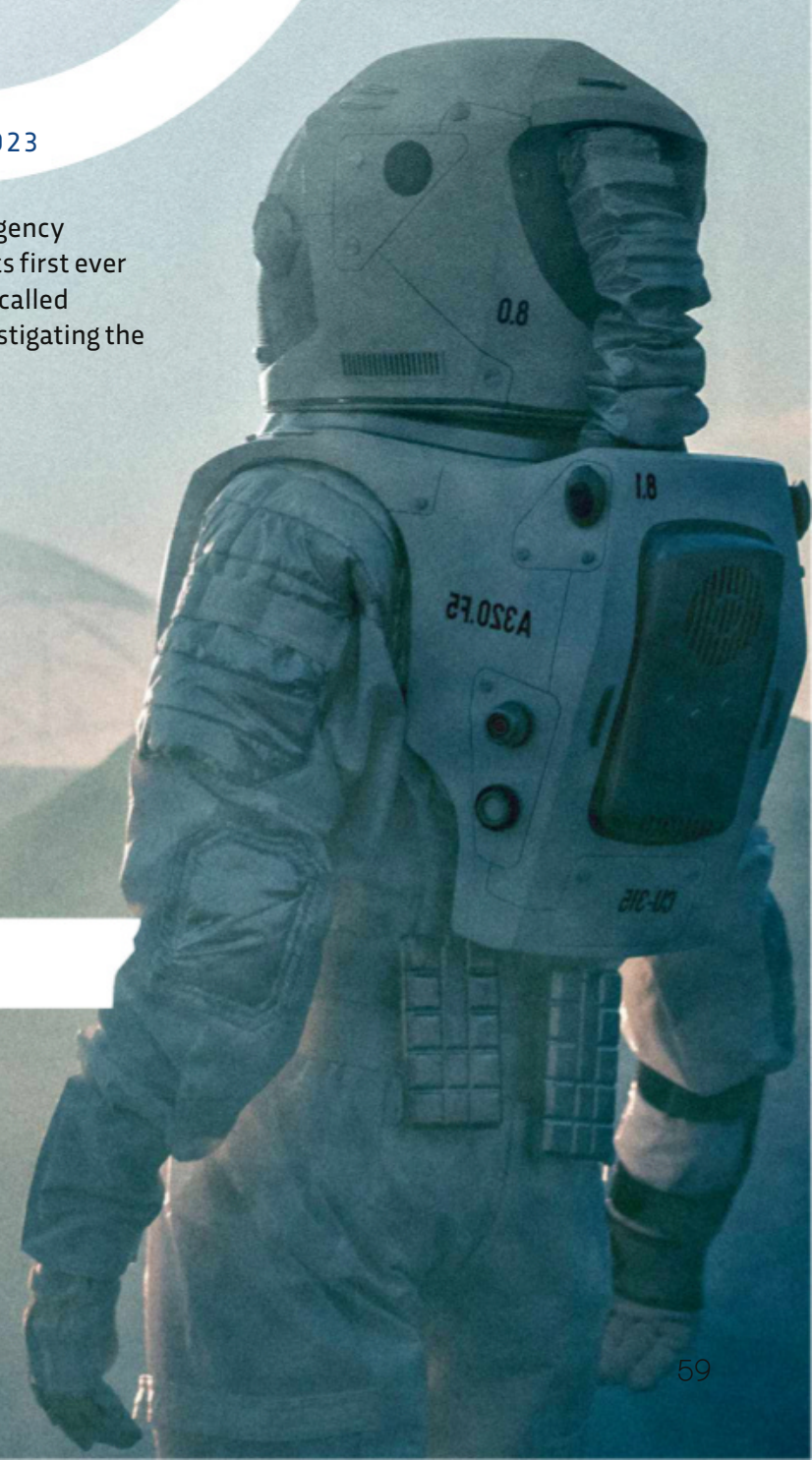
2040?

A flourishing lunar industry will see people relocate to the Moon to work in the mining sector. Helium-3 is returned to the Earth to sustain the latest fusion reactors powering the planet.



2050?

With climate change starting to really bite on Earth, more of our heavy industry will be moved to the lunar surface and the Moon will become a launch pad for regular crewed trips to Mars.



WHO WILL OWN THE MOON'S RESOURCES?

There are people who will try and sell you an acre of the Moon. It's supposedly yours for a bargain basement price of $25. One company has made millions off the back of it, but are you really getting your own little piece of lunar real estate?

The ownership of the Moon is a somewhat legal grey area. "The key legal framework here is the 1967 UN Outer Space Treaty," says Crawford. "It made clear that no nation state can claim the Moon." Over 100 countries are signatories to the treaty, including all the major spacefaring nations. It specifically states that:

→ **Outer space shall be free for exploration and use by all countries**
→ **Outer space is not subject to national appropriation or ownership**

Hands off! No piece of the Moon can explicitly belong to any one country

RIGHT The 1967 Outer Space Treaty being signed by Lyndon Johnson, who was the US President at the time

GETTY, SHUTTERSTOCK

The treaty was designed at the height of the Cold War in an attempt to prevent space becoming another theatre of warfare, including as a place from which to launch nuclear weapons. It has had some interesting consequences, however. For example, the US owns Apollo artefacts, such as landers, experiments and flags, that were left on the Moon. But it doesn't own the land where the historic first footprints still stand. There was talk of turning the area into a US National Park, but that would seem to violate the treaty. No piece of the Moon can be explicitly American. How we preserve our space history is an ongoing debate, though.

Given its aim to avert a space war, the treaty only mentions nation states. It fails to spell out the situation for private corporations. Some saw that as a green light to claim ownership of the Moon and start hawking acres. "The legal situation is a bit ambiguous," Crawford says.

The same goes for any business seeking to make a profit from the Moon's resources. In 2015, the US passed the Commercial Space Launch Competitiveness Act, which made space mining legal. Other countries have introduced similar laws. "There have been some vociferous objectors to this," Crawford says. "International law needs updating."

There have previously been attempts to clarify the situation. In 1979 the Moon Treaty was proposed. It would have established clearer rules regarding the Moon's resources, but no major spacefaring nation has signed it.

In recent years, those concerned about the Moon's future have drafted the Declaration of the Rights of the Moon. Clause 2a states that the Moon has "the right to exist, persist and continue its vital cycles unaltered, unharmed and unpolluted by human beings." Although, again, it remains unratified.

Ultimately, Crawford thinks that the situation is similar to fishing in international waters. Outside territorial waters nobody owns the sea, but if you invest in a boat and collect some fish, then international law entitles you to those fish. "Your rights of ownership are derived from the fact that you've put in your labour and your capital to extract from a common resource," Crawford says. Likewise, "if a commercial operator were to mine lunar materials... then they would be entitled to sell or trade in those materials."

"EMPLOYERS ON MINING COLONIES WILL LITERALLY CONTROL THE AIR THEIR WORKERS BREATHE"

Dr Evie Kendal, from Swinburne University of Technology in Australia, says it's an idea that stretches back thousands of years, pointing to the Roman concept of *res communis*, where there is no right to ownership of a communal good, but there is the right to use and freely access it.

Kendal also points to a potential legal minefield if humans are involved in the mining process. "Concerns about worker rights in a future lunar mining colony focus on the fact that living quarters and mining facilities are likely to be geographically and financially linked. In other words, employers will literally control the air their workers breathe," she says. "This opens up the potential for significant exploitation of workers, especially when considering that regulatory bodies might be very distant, limiting potential oversight."

A solution would be to strengthen employment laws to cover the situation. Kendal says that could include "a guaranteed passage back to Earth should an employee no longer wish to be employed in the facility." **SF**

by **COLIN STUART** *(@skyponderer)*
Colin is an astronomy author and tutor. Find out more about his Astrophysics for Beginners course at ***colinstuart.net/course***

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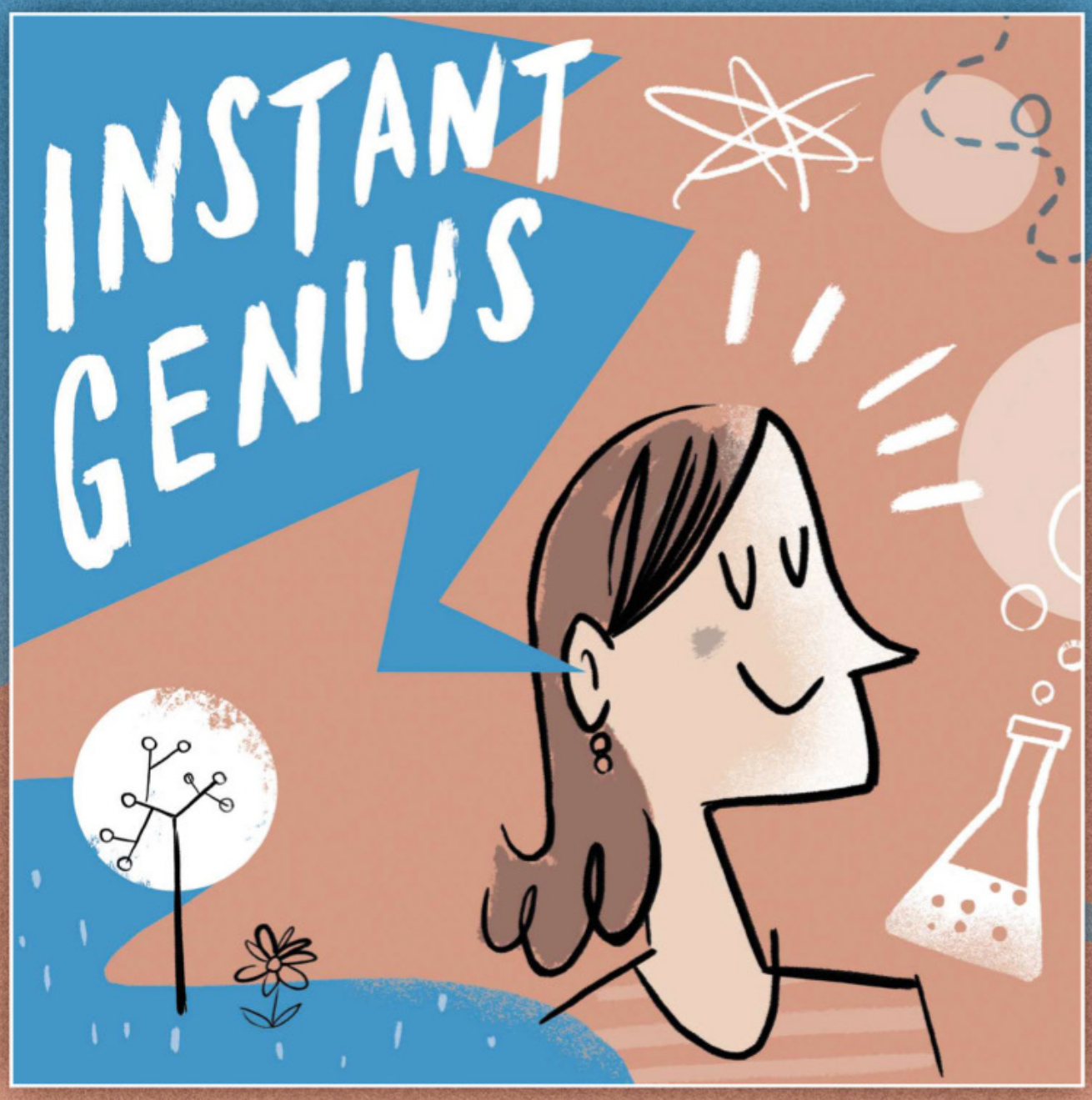


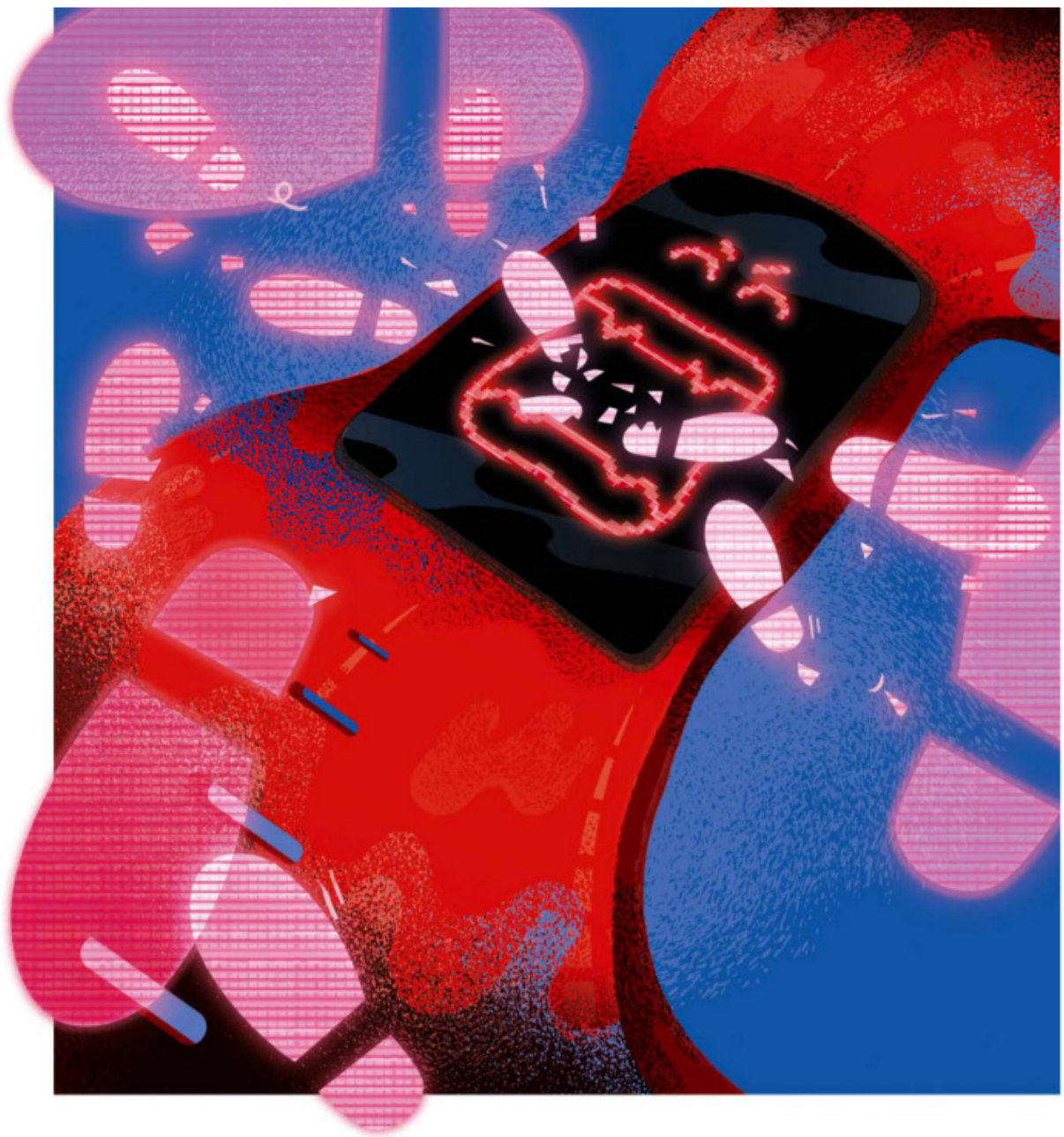
FEATURING

BRAIN MYTHS
with ***Dr Lisa Feldman-Barrett***

ALGAE
with ***Ruth Kassinger***

THE METAVERSE
with ***Prof David Reid***

ANCIENT MAMMALS
with ***Dr Elsa Panciroli***



COMMENT

WHY I DITCHED MY FITNESS TRACKER

Stop chasing a 10,000-step target – Active 10 is an easier, more effective way to get fit

Do you own an activity tracker? And do you find yourself, towards the end of the day, anxiously looking at your wrist, realising you haven't hit your 10,000 steps, and start pacing around the house, swinging your arms in a desperate attempt to hit that magical target? That was what I began doing when I first got an activity tracker, until my wife, Clare, told me that I was becoming really annoying.

The 10,000 steps figure was originally the product of a 1960s marketing campaign in Japan. A company, keen to flog its pedometers, came up with a device they called a Manpo-Kei, which translates into '10,000 steps meter'.

Since then, there have been many attempts to try and arrive at a scientifically based figure for the number of steps you need to take to achieve a long and healthy life. One of the most recent attempts was published in *The Lancet* in March 2022. It was a meta-analysis of 15 international cohort studies, involving more than 50,000 people from four continents.

What they found was the number of steps you needed to take depended on your age. For adults aged 60 or older (I am 65), the risk of premature death levelled off at 6,000 to 8,000 steps a day, and doing more steps provided no additional benefit for longevity. Adults under 60 needed to aim for 8,000-10,000 steps.

"The Active 10 group had done 30 per cent more 'moderate to vigorous physical activity' than the 10,000-steps group"

This is kind of interesting, but to be honest I have ditched my activity monitor in favour of ensuring I get a couple of brisk 20-minute walks a day. That's because of a podcast I did on the benefits of doing a brisk early morning walk, as part of my popular *Just One Thing* series, which you can find on BBC Sounds. It's also partly because of an experiment I did with Prof Rob Copeland from Sheffield Hallam University.

The goal was to compare the benefits and ease of doing 10,000 steps against something called 'Active 10'. With Active 10 you don't need to count steps, you aim to do three brisk 10-minute walks a day.

We got a small group of volunteers together, fitted them with activity monitors and then divided them into two groups. One group was asked to hit the 10,000-step target, the other to do three sessions of Active 10, which adds up to around 3,000 steps a day. We asked them to do this for a week. The group asked to do 10,000 steps struggled, while the Active 10 group said they found it relatively easy.

When Copeland analysed the data from the volunteers' monitors, he found that the Active 10 group had done 30 per cent more 'moderate to vigorous physical activity' than the 10,000-steps group, even though they moved for less time. This is important, because it's when you are moving briskly that you get the most health benefits.

To start getting Active 10s in your day, go to the NHS website where you can download a free app. It is a good way to see how much brisk walking you're doing, and how to do more. SF

MICHAEL MOSLEY

Michael is a health writer and broadcaster, who presents *Trust Me, I'm A Doctor*. His latest book is *The Fast 800 Keto* (£9.99, Short Books).

BBC TWO

PORTRAIT: KATE COPELAND ILLUSTRATION: CHRISTINA KALLI

COMMENT

ARGOS OR AMAZON: WHO DID IT FIRST?

You can thank an in-flight catalogue, not the internet, for the emergence of convenient same-day deliveries

We have been led to believe that the internet is a new idea. Yes, it is indeed something of a marvel, but the things we think it invented are mostly things we were already heading towards before it arrived on the scene.

Let's start with next-day delivery. Thirty-two years ago, back in 1990, a man named Bob Worsley had a dream of a new kind of shopping experience. It would be an updated version of the Argos catalogue, an on-the-go, one-stop hub of the things people needed but didn't know it until they'd been told they needed it by reading enthusiastic descriptions. A hot dog warmer! A self-winding wristwatch display case! A statue of a zombie boy crawling out of the earth! SkyMall had them all.

SkyMall was a genius proposition. People travelling through the US on aeroplanes before Wi-Fi and seat-back entertainment needed something to fill their time. Why not give them a magazine full of stuff that they could buy, and get before they realised what they'd done? Mail order had been a staple distribution channel for decades, but SkyMall tied it to a hyperspeed network and hit the right note with the right innovation at the right time.

Initially, SkyMall had warehouses at most airports across the country, which meant that travellers were often next to one every time they landed at their destination. So if the lady sitting in seat 32D decided she wanted zombie boy while she was en-route from New York to New Orleans, she could pick him up as soon as she landed in the Big Easy. The idea was to get customers their items within 20 minutes of arrival. And so same-day delivery of zombie boys, or any of the other things offered in SkyMall's catalogue, was born.

"The idea was to get customers their items within 20 minutes of arriving at their destination"

SkyMall struggled with the costs of keeping so many warehouses open, and then later with the advent of the internet and the dip in travel after 9/11. The company filed for bankruptcy in 2015. But it certainly demonstrated an appetite; at one point, it had a circulation of 20 million. But it didn't pivot quickly enough, and it missed the online train. And Amazon – who would eventually offer a marketplace to sell its own zombie boys – became the industry leader.

But there are shades of SkyMall in Amazon's business strategy. The online giant acquires companies not necessarily because they believe in the product they sell, or the technology they've developed, but because they have warehouses where they need them. Whole Foods is a great example. Upmarket groceries weren't Amazon's main focus in that sale; what it bought were warehouses and distribution centres in cities, which get the fancy foods to people pronto.

Now, we have Prime and Prime Day and all kinds of other ways to get our whatever-we-want right now. And we can only do that because an in-flight catalogue gave us a taste of it.

You'll be pleased to know that you can still buy a zombie boy from **skymall.com**. It just doesn't come the next day. **SF**

ALEKS KROTOSKI

Aleks is a social psychologist, broadcaster and journalist. She presents *The Digital Human*.

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BBC
TWO
Watch Prof Turi King in the new series of *DNA Family Secrets* on BBC Two in April. Check *Radio Times* for details.

THE DNA DETECTIVE

All sorts of mysteries lurk in our family trees, from long-lost relatives to adoptees' hidden heritages. In the new series of *DNA Family Secrets*, geneticist **Prof Turi King** sets out to solve them with the help of presenter **Stacey Dooley** and home genetic testing kits. She talks to **Sara Rigby**

TELL US ABOUT THE GENETIC TECHNOLOGIES YOU USE IN *DNA FAMILY SECRETS*.

DNA sequencing technologies have really moved on in the last 20 years. Now you can sequence entire genomes. For the medical side of things, we know a lot about genes that are involved in particular diseases, and we can tell people whether or not they have a gene that predisposes them toward something.

I got involved in the family history side of things by accident. My PhD was on the link between a surname and a Y chromosome. Surnames, like Y chromosomes, come down through the male line. So are all men with the same surname related to each other? Do they all have the same Y chromosome type? Back then the technology was based on DNA fingerprinting. We could do genetic genealogy where we could take two people with the same surname who couldn't find the genealogical links between them. We could take a look at their Y chromosomes and see if they're related.

Now it's moved on and there are direct-to-consumer testing companies. So, if somebody comes to us and says, "I don't know who my biological father is," we can get their DNA tested by one of these direct-to-consumer testing companies. They don't sequence your entire genome; they look at tiny differences, about 700,000 of them, which are places on the genome where we know people tend to differ.

We can then upload their DNA to various databases around the world and look for DNA sharing, which we measure with a unit known as a 'centimorgan'. You share half of your DNA with your parents and about half with your siblings and about a quarter with aunts and uncles. So, if somebody doesn't know who their father is, but knows who their mum is, you start to look for genetic matches that aren't from the mother's side. From that, you can start to build these family trees.

"I got involved in the family history side of things by accident. My PhD was on the link between a surname and a Y chromosome"

So this DNA sequencing technology – this ability to look at huge amounts of DNA all in one go, and look at these genetic measurements – has absolutely changed genealogical research over the last 20 years.

HOW ACCURATE AND RELIABLE ARE THESE CONSUMER DNA TESTING KITS?

In terms of health stuff, I always say you should go to your GP, ideally. It's not that the tests are unreliable, it's just that they might not be looking at all of the genetic mutations that are involved in something. They also don't give you the care and counselling that goes with that.

For ancestry, I always say take them with a pinch of salt. What the genetic companies do is test of all those little differences. They use a computer to cut your DNA into chunks and it goes, "Right, where's the closest match for this chunk?" Maybe for that chunk it's Japan. It'll do that for all the bits of your DNA that it's got and do it multiple times to give you a kind of average. It'll go, "This is where your matches are, in this part of the world." But it all depends on who's in the databases that the company has. You'll get differences if you go to another company because different companies have different databases. It shouldn't be too wildly out, but you'll get differences.

But in terms of building family trees, it's fantastic. It doesn't tell you precisely how somebody is related – it's too difficult to, based on just 200 centimorgans. But those companies are actually really good because they'll say, "You share 200 centimorgans, so there's X per cent chance that this person is a second cousin." And then you have to use the genealogy to work out how that person is related to you.

"There's a real excitement in being able to answer these questions for people. And that's part of the DNA technology nowadays"

It's only in the last decade or so that it's really taken off and it's extraordinary what you can do with it. In the first episode of this series of *DNA Family Secrets*, we follow Janet's story. Her parents have passed away now, but when Janet was young she overheard a rumour one night when they had friends around. A guest said, "So what's this about you having had a daughter in Austria during the war?" Apparently the guests were rapidly shooed out

ABOVE Stacey Dooley (left) and Prof Turi King use genetic testing to answer questions people have about the unknown parts of their family tree

BBC/ MINNOW FILMS, ALAMY

after this. But Janet's always wondered if she has a half-sister somewhere. So we had her DNA tested by the testing companies and I uploaded the data to various databases. I got a match on one of them. Within seconds, I was in contact with Janet's half-sister's daughter.

Then we have somebody like Jackie [in the second episode]. He's a Holocaust survivor and was brought to the UK as one of the Windermere children. Looking for relatives of people who were part of the Holocaust is difficult because so many people were killed. Ordinarily, when you upload somebody's DNA to one of these databases, you get matches – second, third, fourth cousins, even closer than that. With Jackie, we're weren't getting them because so many people were killed.

Then I had a breakthrough because these testing companies don't just look for the matches in terms of you sharing 200 centimorgans; they tell you how large a chunk of DNA you share with somebody. So you get half of your DNA from each of your parents and it comes in quite big chunks of chromosomes. When that DNA is passed down through the generations, those chunks break up into smaller chunks. So the more closely related you are, the bigger the chunks of DNA you share.

I found somebody who shared quite a large chunk of DNA with Jackie, which meant I could start to home in on that family and trace relatives. I can't tell you the excitement when you think you might have found a relative. You go, "Oh my goodness, is she still alive? Has she got kids?" There's a real excitement in being able to answer these questions for people. And that's part of the DNA technology nowadays.

ABOVE Genetic testing kits can provide you with information that sheds new light on your genealogy

PROF TURI KING
(@Turi__King)
Turi is a scientist, presenter, speaker and author who is passionate about communicating science to the public. She's been working in the field of genetic genealogy since 2000 and is perhaps best known for leading the genetic analysis for the identification of King Richard III.

YOU MENTIONED EARLIER THAT THE Y CHROMOSOME IS VERY POWERFUL IN TRACKING ANCESTRY, BUT WHY THE Y CHROMOSOME AND NOT THE X CHROMOSOME?

So we've got 23 pairs of chromosomes and pairs 1 to 22 are our autosomes. One half of each pair comes from mum and the other comes from dad and our 22 autosomes are the same between men and women. Pair 23 is the interesting one as it's sex-determining. Girls have two copies of the X chromosome, one from mum and one from dad. Boys have an X chromosome and a Y chromosome. We also have another piece of DNA known as mitochondrial DNA, and that's a small circular piece of DNA that's in the egg.

Autosomes get shuffled with every generation. So when you're looking at ancestry, it only takes you back a few generations because it's such a mixture of our ancestors. But mitochondrial DNA just comes down through the female line so you can trace it back from mother to grandmother to great grandmother all the way back through time. It's the same with Y chromosomes, you can do that on the male line all the way back and it's because they don't recombine, they just get passed down through the generations. They get little, tiny mutations, but we know how those work. So you can go, "Okay, well, this is a Y chromosome type that you tend to find in this part of the world."

WHERE DO YOU SEE THE FUTURE OF THIS SORT OF DNA TESTING GOING?

The databases are growing like mad. So from when we did the first series to the second series, something like over four million people had their genes tested. I think people are moving more and more towards having their entire genomes tested – people are interested in that kind of thing. And it's probably to do with issues relating to health. That's certainly the way things are moving.

So I think it's going to be the case that these databases are going to be absolutely huge and more and more people will get their entire genomes tested. **SF**

Listen to Dr Aleks Krotoski every week on *The Digital Human*. Available on BBC Sounds.

SHUTTERSTOCK

THE HITCH-HIKER'S GUIDE TO THE METAVERSE

Facebook recently changed its name to 'Meta' in order to position itself at the forefront of a new digital frontier called the metaverse. But what the heck is the metaverse, and what can it offer us mere mortals who do not inhabit the shiny Silicon Valley bubble?

WORDS: DR ALEKS KROTOSKI

WELCOME TO THE METAVERSE

In the beginning the metaverse was created. And to borrow from Douglas Adams "this has made a lot of people very angry and has been widely regarded as a bad move". In truth the metaverse was neither good nor bad and ever since its creation it's been imagined as place of extremes – either a utopian horn of plenty, brimming with creative expression and untold wealth, or a dystopian cyber surveillance state, leaning in to systemic abuses of power and inequality. When you start to dig in, it becomes clear that most of the people making these claims have never actually been in a metaverse. If you do go there yourself, you'll find the answer lies somewhere in between. Let's take a look inside…

WHAT EXACTLY IS THE METAVERSE?

Put simply, the metaverse is a whole lot of digital stuff that runs parallel to our physical life. That might sound like the internet, and that's because the metaverse is a bit like the internet, only with more dancing. Bear with us.

The metaverse is essentially a collection of virtual worlds, where users can meet, play games, chat and buy stuff. Mark Zuckerberg recently made the term famous when he changed his company's name from Facebook to Meta. At the same time, he showed off a new vision for the metaverse where you could be thrown into a virtual video call at any moment. Terrifying. This universe was accessed via virtual reality goggles, but today some 'metaverses' already exist in video games like *Roblox*, *Minecraft* or *Fortnite*. A metaverse can even take hold in augmented reality spaces, where objects from the virtual world are projected into the real world via our screens. In short, metaverses are virtual spaces that we coexist in, free from the constraints of our fleshy meatsuits.

"It is immersive experiences that let you do things with other people, like having fun adventures," explains Craig Donato, the chief business officer of modern metaverse poster child, *Roblox*. *Roblox* is one of the neighbourhoods in the wider metaverse-verse. When you venture into Donato's world, you can create games and share them with other people. But elsewhere in the metaverse's consensual hallucination, there are (or are going to be) companies providing social networking, education and commerce. And that won't be all you can do there.

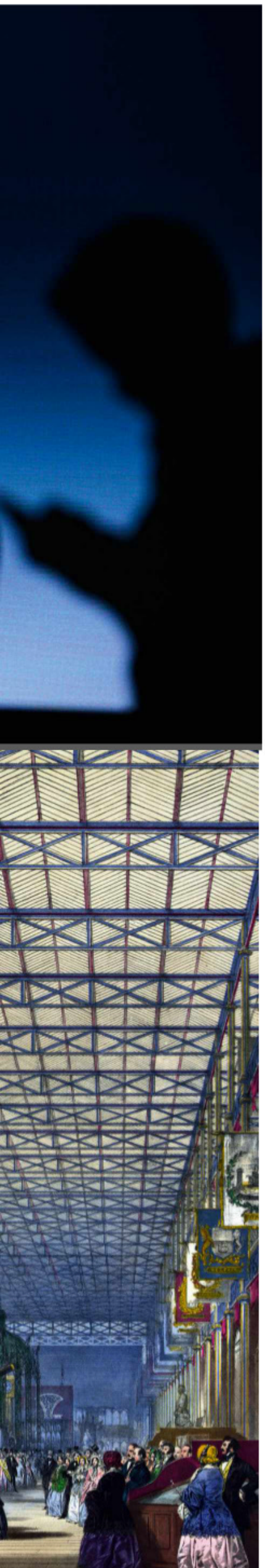
The real attraction is the other stuff – the things that aren't anticipated. "It's increasingly going to a concert or watching entertainment, or anything you can't do in the real world," explains Donato.

Eagle-eyed readers will recognise that all these things are possible in the so-called real world. "But the twist is that you get to do these things free of physical constraints, however you do it or how you enjoy it. It's transformed in a positive way," Donato says.

This guide recognises that this nuts-and-bolts description isn't as sexy as 'the future of the internet', or even 'a sandbox that lets us explore human imagination'. It doesn't come close to 'freeing people from geographical and economic limits'. But, at the moment, that is what it is. And indeed, what it has been. And until technology catches up with the hype, what it will be. Because when you venture into the metaverse, you'll discover that there's really no there, there.

RIGHT Towards the end of 2021, social media giant Facebook made the radical decision to change its name to Meta

BELOW Some people argue that the idea of a metaverse stretches right back to the Great Exhibition at Crystal Palace, which captured the imaginations of Victorians in the 1800s



ALAMY, AKG IMAGES

“THE TWIST IN THE METAVERSE IS THAT YOU GET TO DO THINGS FREE OF PHYSICAL CONSTRAINTS, HOWEVER YOU DO IT OR HOW YOU ENJOY IT. IT’S TRANSFORMED IN A POSITIVE WAY”

METAVERSE: NEED TO KNOW

CURRENCY
Some crypto, but mostly each specific neighbourhood has its own. There are some currency exchanges, if you want to turn your V-bucks into Robux into platinum pieces into Linden dollars.

LANGUAGE
A little bit of everything, though you’ll have to translate between them because the tech to do it for you hasn’t been invented yet.

TECH SPECS
A smartphone will give you access to basic metaversian experiences, and is necessary for some specific activities, like augmented reality.

TIME
All the time.

OPENING HOURS
All the time.

WHERE DID THE IDEA COME FROM?

Ground Zero for the metaverse is difficult to pin down. Some people suggest it reaches back to the Great Exhibition of 1851, when the future of the world was housed within Crystal Palace in the centre of London. Inside, Victorians could behold the wonders of the first fax machine, submarines and mechanical birds. In a sense, it was a metaverse filled with wonder and held together by the latest technology.

Others say the metaverse is based on the annual art festival in Black Rock, Nevada – better known as Burning Man. This is Silicon Valley’s metaverse mental model: building something out of nothing, bonding with strangers in the inhospitable desert, breaking it all down, and then never mentioning it again once the body paint has washed off.

Most say the metaverse premise fell out of the pages of the 1992 cyberpunk novel *Snow Crash*, written by world-builder Neal Stephenson. That metaverse isn’t an advertisement; it’s a warning. In the novel, the virtual world of hacker Hiro Protagonist is full of inequalities and end-capitalist horrors. Hiro wanted to escape the physical world, but he didn’t want to live in the virtual one.

Whatever the origin, all metaverses exist to eliminate friction, and that does sound like a nice bit of escapism after two years glued to Zoom and doomscrolling on our phones.

WHO CONTROLS THE METAVERSE’S LAWS?

The metaverse does have rules. Each jurisdiction has its own, and sometimes they correspond. Some of these are posted in the endless terms of service that you have to agree to before you can enter, but many are not. It is the responsibility of the metaverse dweller to learn each neighbourhood’s rules and adhere to them.

The majority of the metaverse operates on a general principle of civility. “The idea is just to spend a good life with a group of people, having as real an experience as you can have,” explains *Second Life*’s founder Philip Rosedale.

But sometimes, someone in the metaverse does something so bad that it calls for action by everyone else. And that’s when the collection of computer users decides someone *does* need to rule the world. Historically, that’s ended up being the person who owns the technology, and because he or she is a technologist and not a political or social scientist, they’re often the least qualified to take this role. They are, however, the people keeping the lights on. “There is a bargain that we do need to keep the servers running,” says Donato. So civility and governance end up being the domain of the technologist.

At best, the way the metaverse is run is at the whims of a mostly benevolent dictator.

LINDEN LABS, ROBLOX

PLACES TO STAY

ROBLOX

A game world where creators can make and share their projects. Although it's part of the new wave of metaverse tech, it's been around for almost two decades.

META

Née Facebook. Sprawling social media site with direct ties to (and impact in) the offline world, and increasing tendrils in fantasy. Meta owns a raft of metaverse technologies, and one of the most established virtual reality headsets that people use to access it.

MINECRAFT

Sprawling game and simulation world, mostly occupied by kids and teenagers, who create everything out of Lego-like building blocks. Also a long-term player in this space.

SECOND LIFE

3D virtual sandbox where you can build what you want, go to concerts, visit libraries and even attend a virtual Hajj. Poster child of the previous wave of metaverses, with more than 15 million accounts. "The original premise that I liked about *Second Life* was that it was this big, messy interaction between people," says Philip Rosedale, its founder.

WHAT TO PACK

The most important thing to pack when entering the metaverse is your identity. There are plans in place to make this one continuous self as you move from neighbourhood to neighbourhood, and so it requires some careful consideration. At the very least, your identity will be a profile picture. In many cases, it will be an avatar, the 3D representation of you when you're embodied online. Whatever the situation calls for, Donato says you should take the time to invest in it. "Have it express who you really are," he says.

Some denizens of the internet, however, believe being yourself in the metaverse is a waste of transistors. Why be Aleks Krotoski when you could be ZaphodBeeblebrox42?

In other words, tying who you really are to your metaverse persona might sell the experience short. And Donato agrees. "We've seen so many examples of how powerful this is for teenagers," he says. "They can be whoever they want to be and it's just so freeing. I don't think we want to roll backwards on that."

We have already learned with social media that past indiscretions can come back to haunt you. So if you're planning some out-there self-discovery, you might want to have another little identity in your pocket that you can wear for crazy times.

You can understand, though, why keeping the same self could be useful. You can carry gear and skills with you across virtual neighbourhoods and apps, like a kind of passport control. But bear in mind that one single identity makes it even easier for the companies building the metaverse to keep track of you. After all, these are the people upon whose lands you are treading.

THE TOP EXPERIENCES

The metaverse has no landscape. It has no ecology. And yet its panoramas are some of the most beautiful in the world. The way to enter it is from the outside, wherever you find a rabbit hole to fall through. You might receive a link to a teleconference. You might log in to a gaming platform. You might put on a VR headset and press 'On'. All you need is a screen. But when you get there, it seems like an awfully empty place.

The challenge is figuring out where to go. Do you want to work? To learn? To go to a gig? To immerse yourself in the synthesised experience of the hallucinations of someone with schizophrenia? Or just fly around? If you find yourself paralysed by the possibilities, you're not alone; there is no search engine in the metaverse to give you a destination. What you need is insatiable curiosity and the time to wander around the neighbourhoods to serendipitously find it.

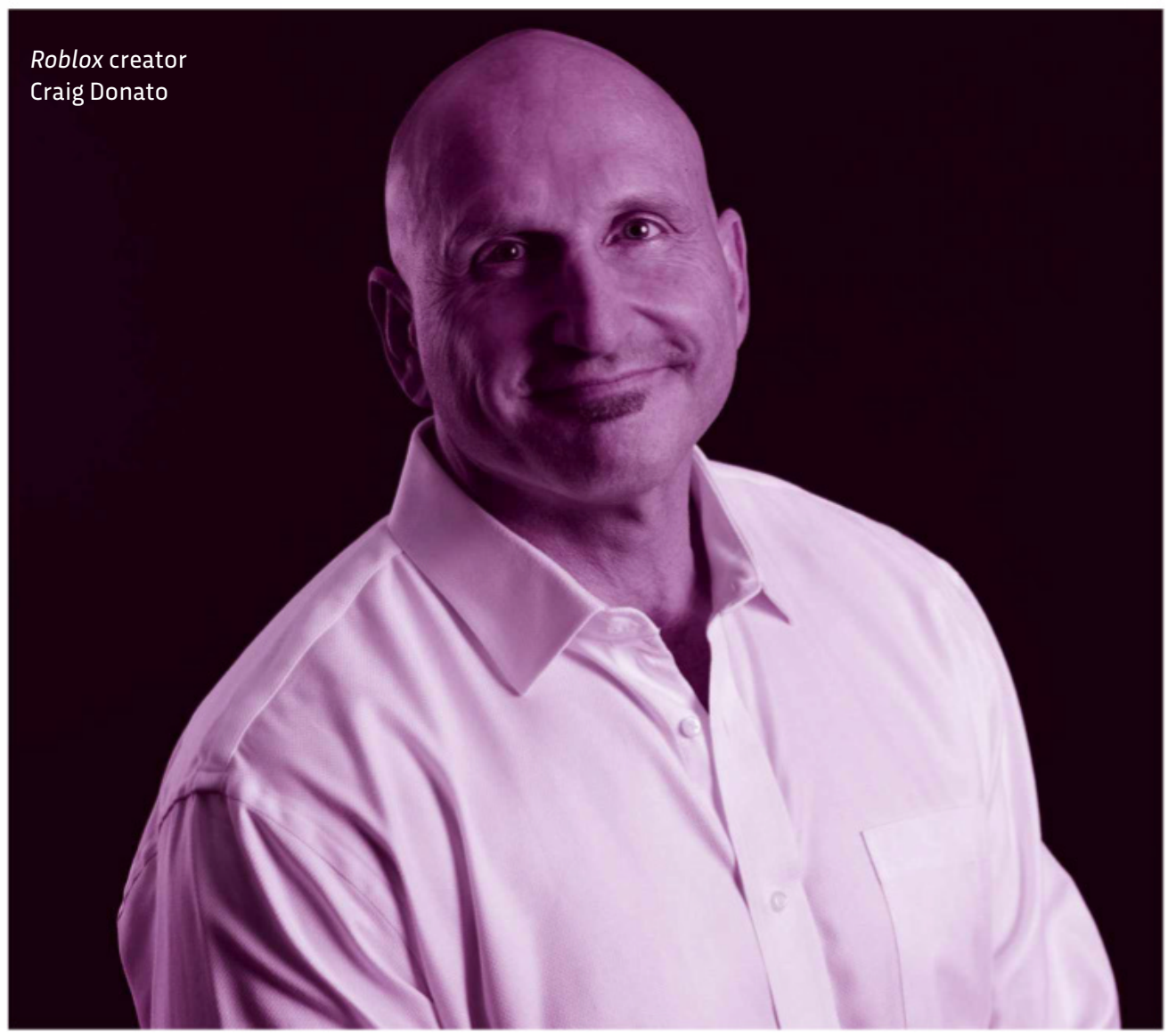
"I think we've already hit the tipping point for immersion," says Donato.

We have AR and VR and machine learning that map human facial expressions onto avatars. We have 3D surround sound. Some people are even working on smell-o-vision.

"I think the area where we need a lot more innovation is on the social side, how people come together in these spaces and act in ways that are productive," says Donato.

You might just be the person with the bright idea.

"I THINK THE AREA WHERE WE NEED A LOT MORE INNOVATION IS ON THE SOCIAL SIDE, HOW PEOPLE COME TOGETHER IN THESE SPACES"



Roblox creator Craig Donato

LANDSCAPE AND ECOLOGY

MEETING ROOMS

The earliest indication that something was going meta was when Facebook announced Horizon Workrooms just as everyone was getting a Zoom headache, circa 2021. Work is a likely way that people will fall into the metaverse – because they have to. All of the technologies we now use to get things done existed before, but there wasn't an ultimatum hanging over our heads that forced us to use them before the pandemic made them essential.

Workplace 'solutions' of this kind require the purchase of a VR headset, and an avatar. The thought process goes that seeing the cartoonish faces of your fellows will increase productivity. The idea is good. In the metaverse, people do need to feel like they are somewhere. When it comes to work, decades of research shows that in the absence of actual presence, telepresence is superior to voice-only.

And so there are walls and conference tables and fancy designer chairs. So far, these kinds of virtual embodied offices have yet to catch on, simply because they are more of a faff than clicking a Zoom link.

SEX, FASHION AND OTHER SUBCULTURES

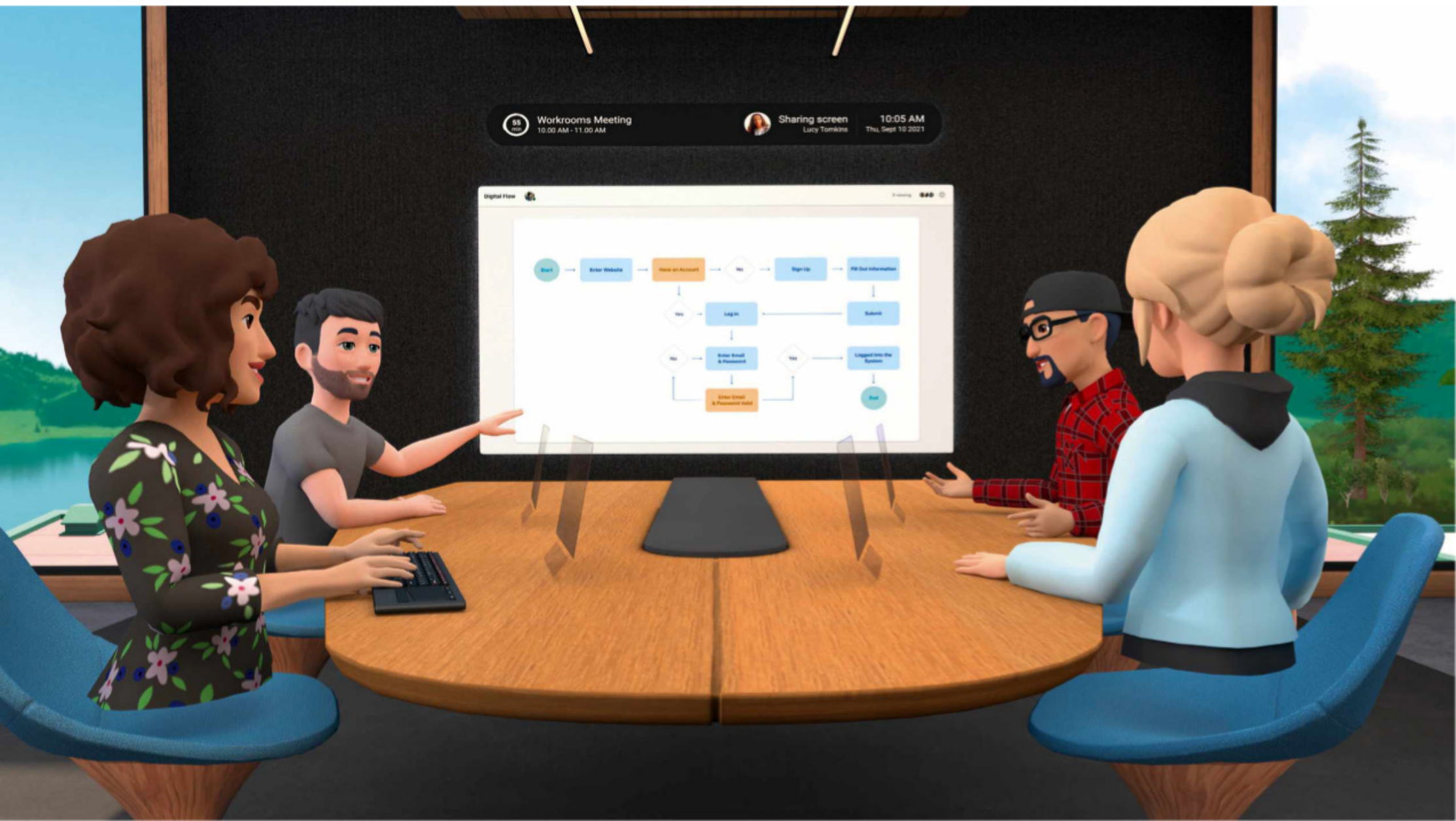
The first industry to colonise any new technology is pornography. The sex industry is forward-thinking, always coming up with out-of-the-box solutions. Usually, the industry is propelled towards new shiny tech because it has been regulated out of previous ones. So since the beginning, the metaverse has been a space of sexual self-expression. So much self-expression.

When it was a niche hobby, metaversians enjoyed all kinds of free (and hopefully consenting) fun. It was only when the masses arrived that it became inappropriate for people to build and deploy swarms of flying penises. The technologists creating the metaverse now have to consider what is and isn't appropriate for a much broader demographic. After all, the metaverse is supposed to be a place where everyone can go wherever they want. How will that work? Mostly, the solution will be to throw even more technology at the situation. Companies usually use machine algorithms to seek out inappropriate words or items of clothing, so if you're worried about getting caught with your virtual pants down, you might want to slap a password on your private space, or use a codeword.

There are other things to do in the metaverse. For example, educators love these spaces to show rather than tell. Fashion designers can prototype their latest looks and test drive them on not-people. Some governments are gung-ho; if their people are there, they may as well be too. You can expect an embassy or four to pop up in the next new worlds. Truly, if you can imagine it, you can make it. You'll have to dive in to see if you like it!

BELOW
Horizon Workrooms offers a VR space for teams to collaborate and connect

RIGHT
Players enjoy a gig in the 3D virtual world, Decentraland



META, DECENTRALAND

MAKING MONEY IN THE METAVERSE

Hanging out with avatars in work or play isn't the only reason people are interested in the metaverse. Word has it that there's money to be made in them thar digital hills.

We are currently in the midst of a virtual land grab. This is traditional with any new digital service. We saw this when people bought up website domains during the dotcom boom, and now people are buying up cycles of processing on computer servers stored in giant warehouses. One patch of not-there ground went for more than $2m in early 2022. It could pay off; one land speculator in *Second Life* became a multimillionaire by purchasing parcels and selling them to the highest bidder. And that's what these speculators are banking on.

Another popular speculative market is personalisation – stuff to pimp out the neighbourhoods or user avatars. These might be clothing, poses, park benches, animations and sometimes digital art, like a very popular sub-category called NFTs. Mostly, these tap into users' vanity; the amount of money you should be willing to spend on these items should correspond to how much you care about what everyone else thinks of you.

WHAT'S IN THE PIPELINE?

Most of what we imagine the current metaverse to be is based on what it was in the past, so if you've been online before, you'll know the general gist. But a few important things have changed that will have a big impact on what's to come. First, more people are online now. Metaverses used to be niche destinations, mostly determined by access and interest. Now, the portals are everywhere; we've lived with social media for more than a decade, and people are used to the idea of a virtual life. Second, technology has advanced, so that the things that undercut the old metaverse dreams are possible today. More people can get together in a single virtual space for a single virtual gig. Phones have enough power to do astonishing things. Third, cryptocurrencies – while still a specialist pastime – are changing expectations of how the metaverse can be built and owned.

Underlying all of this is the fact that the tech will purely be facilitating human interaction. While much has been written about how the metaverse will make the world a better place, it really won't. It'll be a sum of the people who go online. The metaverse is us. Mostly harmless. SF

by **DR ALEKS KROTOSKI** (@aleksk)
Aleks is a broadcaster, journalist and social psychologist who reports on technology and interactivity. She presents The Digital Human *on BBC Radio 4.*

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Q&A

YOUR QUESTIONS ANSWERED

... HOW CAN I GET BETTER AT *WORDLE*?
... DO WE FART MORE AS WE GET OLDER?
... WHAT'S THE ENVIRONMENTAL IMPACT OF CIGARETTE BUTTS?
... WHAT ARE THE DIFFERENT TYPES OF SPACE ROCK?
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... DOES SUNSHINE MAKE US HAPPIER AND HEALTHIER?
... WHY ARE EGGS SO USEFUL IN BAKING AND ARE THERE ANY GOOD SUBSTITUTES?
... WHY ARE MINOR CHORDS SAD AND MAJOR CHORDS HAPPY?

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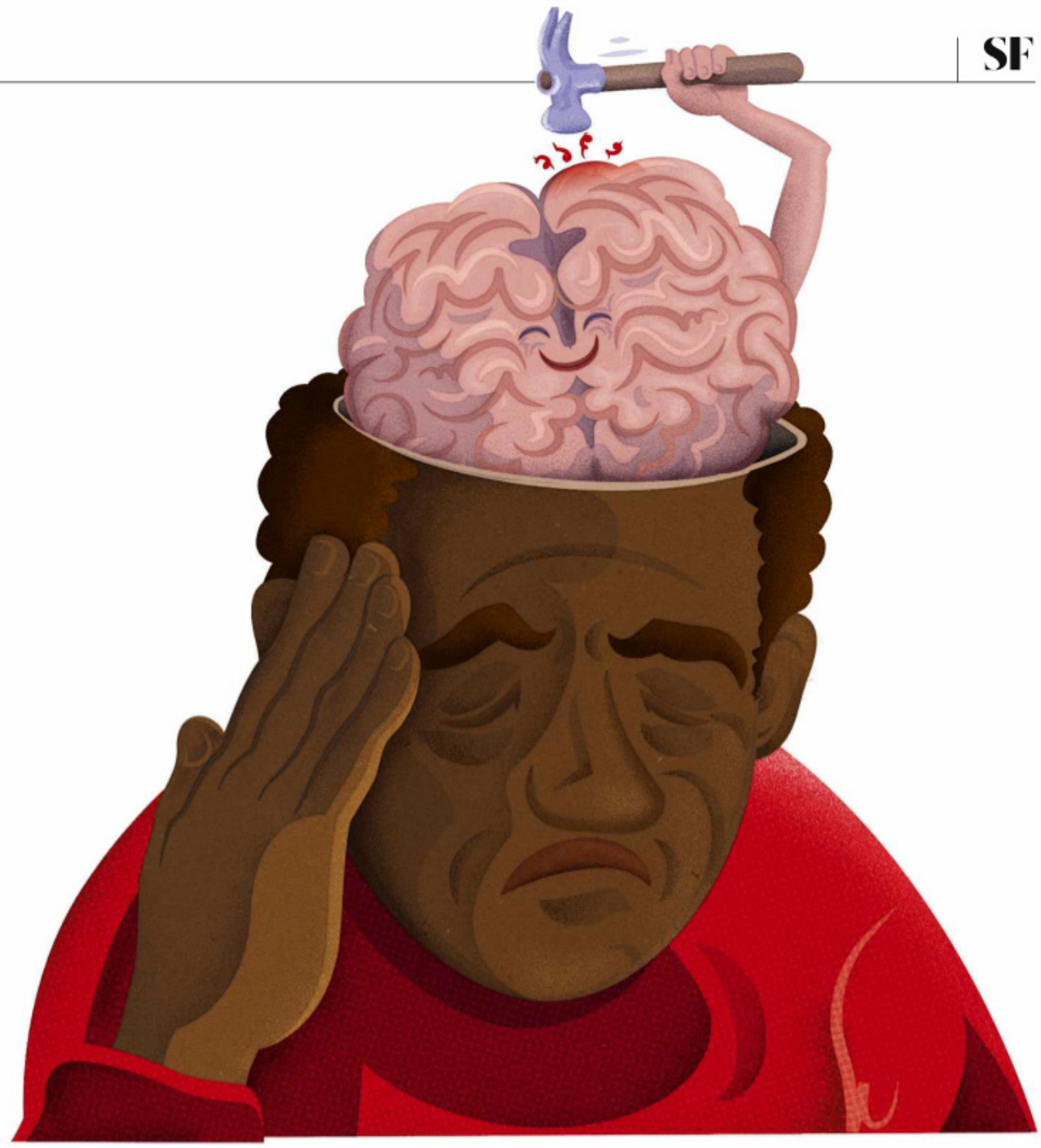


ILLUSTRATION: DANIEL BRIGHT

CHARLIE SIMPSON

IF MY BRAIN CAN'T FEEL PAIN, WHY DO WE GET HEADACHES?

We tend to experience pain when unpleasant stimuli activate sensory nerve fibres called nociceptors. Although it may feel like a deep pain in your brain, it might surprise you to know that headaches don't originate from the brain itself. We can find nociceptors in the skin, in the joints and in some internal organs, but curiously not in the brain. So the brain itself doesn't feel pain. This has been demonstrated in neurosurgical procedures, in which stimulation of the brain tissue itself in patients who are awake did not cause pain.

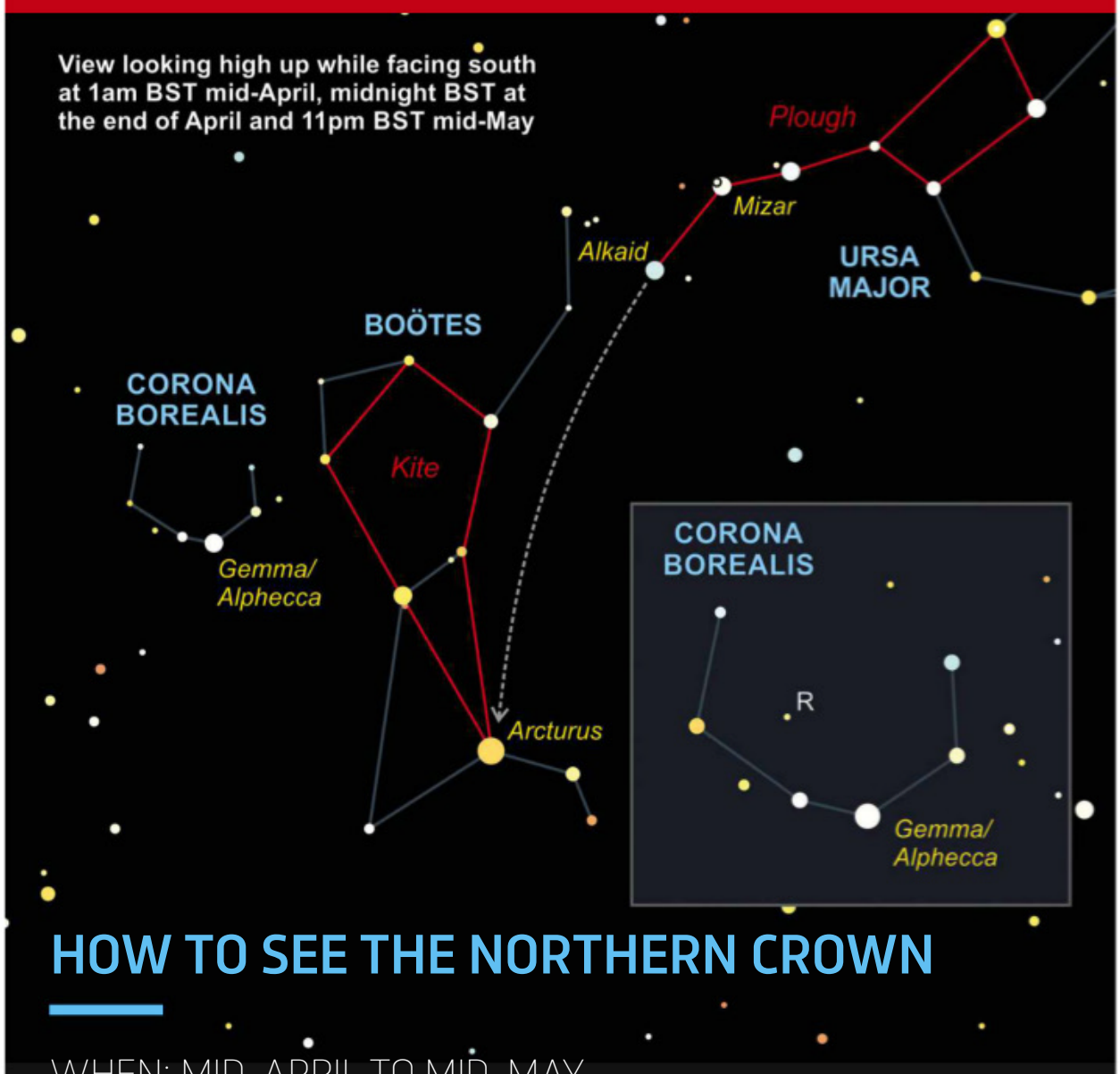
Even though the brain cannot perceive pain, its surroundings, such as the meninges (the covering of the brain), nerve tissues, blood vessels, and neck muscles, can. Once stimulated, a nociceptor sends a signal through nerve fibres to the nerve cells in the brain, indicating that part of the body hurts.

There are different types of headaches, thought to arise for different reasons.

For example, tension headaches may be caused by tightening of the muscles in the neck and scalp. There are also pain receptors in the face, mouth and throat, which is why problems in these areas might trigger a headache.

Migraines are different: we don't know the exact cause, but they're thought to be the result of abnormal brain activity temporarily affecting nerve signals, chemicals and blood vessels in the brain. Some people think that migraines are caused by the activation of sensory nerves which release peptides or serotonin, causing inflammation in arteries and the coverings of the brains, and also causing blood vessels to dilate. Oestrogen may also play a part, which is why some women get migraines during their menstrual cycle. Triptans, medications which treat migraines, work by blocking serotonin receptors and constrict blood vessels. ***NM***

ASTRONOMY FOR BEGINNERS



HOW TO SEE THE NORTHERN CROWN

WHEN: MID-APRIL TO MID-MAY

Corona Borealis is a small, attractive semi-circular constellation visible in the spring night sky. It represents the Northern Crown and as its name infers, has a southern counterpart called Corona Australis, the Southern Crown, which never rises above the UK's horizon.

To locate Corona Borealis start from the Plough, extending its handle away from the blade and following the natural arc to reach the bright orange star Arcturus in Boötes the Herdsman. The core of Boötes is kite-shaped, Arcturus marking the kite's pointed-end. If it helps to visualise it, the kite appears as high as the Plough is long.

Corona Borealis sits off the left shoulder of the kite, its distinctive semi-circle having a diameter a fraction larger than the distance between the last two stars furthest from the blade in the Plough's handle; Mizar and Alkaid.

The crown's brightest star has two common names, Gemma and Alphecca, and it represents the jewel in the crown. The inside of the pattern appears empty most of the time. However, a variable star known as R Coronae Borealis can sometimes be seen. This star periodically ejects clouds of carbon which eventually cool to form soot, therefore blocking the star's light and causing it to dim.

When the soot disperses, the star brightens. It can just be seen with the naked eye from a dark sky location when brightest, but when faintest you'll need a large telescope to spot it. This behaviour has led to R Coronae Borealis being nicknamed the 'dust puff star'.

Corona Borealis is associated with Theseus and the Minotaur in Greek mythology. In love with Theseus, Ariadne gave him a ball of thread which allowed him to enter the Minotaur's labyrinth, kill the beast and escape back to freedom. Theseus subsequently abandoned Ariadne, who went on to marry Dionysus. The pattern represents the crown given to Ariadne by Dionysus. ***PL***

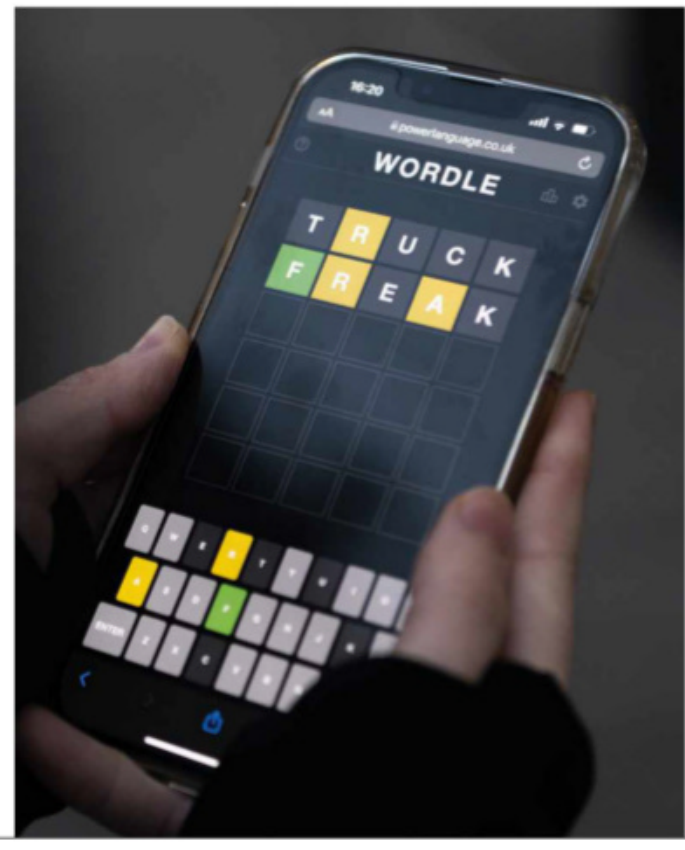
HARRIET MATTHEWS

HOW CAN I GET BETTER AT *WORDLE*?

It is of course, perfectly possible to cheat at *Wordle*. The JavaScript code for the game, with the complete word list, can be viewed in the Chrome browser by hitting F12. But if you don't want to stoop that low, you can use a branch of computer science called information theory to maximise your chance of a correct guess.

To explain how this works, let's look at a simpler game. In *20 Questions*, you can ask up to 20 yes/no questions to try and guess an object or person. Since you only have 20 guesses, you need to maximise the amount of information you get from each guess. If you are guessing a person, you could ask 'Are they a 19th Century Russian author?' and if the answer is 'yes' you will have gained a very useful clue. But if the answer is 'no' then it hasn't narrowed the field much. A much better question would be 'Are they female?', because whether the answer is yes or no, you have roughly halved the number of possibilities left. A question that divides the possibilities into equal-sized groups contains more information than one where the groups are very uneven.

In *Wordle*, words that contain lots of common letters contain more information. Even if the letter isn't in the word, it is more useful to know that the word does not contain E or S, than to be told that it doesn't have a Q. The YouTube channel 3blue1brown wrote some Python code to search through all the valid five-letter words and found that SALET contains the most information for the starting guess. Since this is not one of the possible answers though, you may prefer to lead with CRATE, which is nearly as good and offers the extra hope of a lucky win on the first try. ***LV***



MICHAEL MCNAMARA

DO WE FART MORE AS WE GET OLDER?

There is limited evidence that we fart more as we age.

Some people think that as people get older, they produce less digestive enzymes, like lactase which breaks down lactose in dairy products, and this causes more gas to be produced. Others have theorised that decreased muscle mass and tone as we age, as well as reduced physical activity, leads to slower digestion times and more gas build up. Sometimes older people might be on certain medications that increase flatulence, and others have speculated that swallowing more air due to loose fitting dentures or difficulty eating might contribute too. ***NM***

NATALIE RYAN

WHAT'S THE ENVIRONMENTAL IMPACT OF CIGARETTE BUTTS?

There are still over a billion smokers worldwide. More than 15 billion cigarettes are bought every day and this figure is actually expected to rise. Cigarette filters are made from cellulose acetate, a kind of plastic that takes several years to degrade in the environment. Cigarettes cause 90,000 fires each year in the US alone, and are a major cause of forest fires, but the impact of cigarettes on the ocean is even greater.

Discarded cigarette butts wash into storm drains and are carried into rivers and eventually the sea. Cigarette butts are the most common item of litter collected from beach cleanups. Worldwide, cigarette butts amount to 845,000 tons of litter per year. Cigarette butts are mistaken for food by fish, seabirds and turtles and are frequently found in the stomachs of dead animals washed up on the beach. Even when the butts are simply floating free in the water, the chemicals trapped in the filter during smoking – mainly nicotine and ethylphenol – are also toxic to marine life. At concentrations of one cigarette butt per litre of water, the toxins are lethal to small fish, and to planktonic organisms such as water fleas at one eighth of this concentration. The five trillion butts discarded each year are enough to render all the water in China's Three Gorges Dam completely lethal to aquatic life.

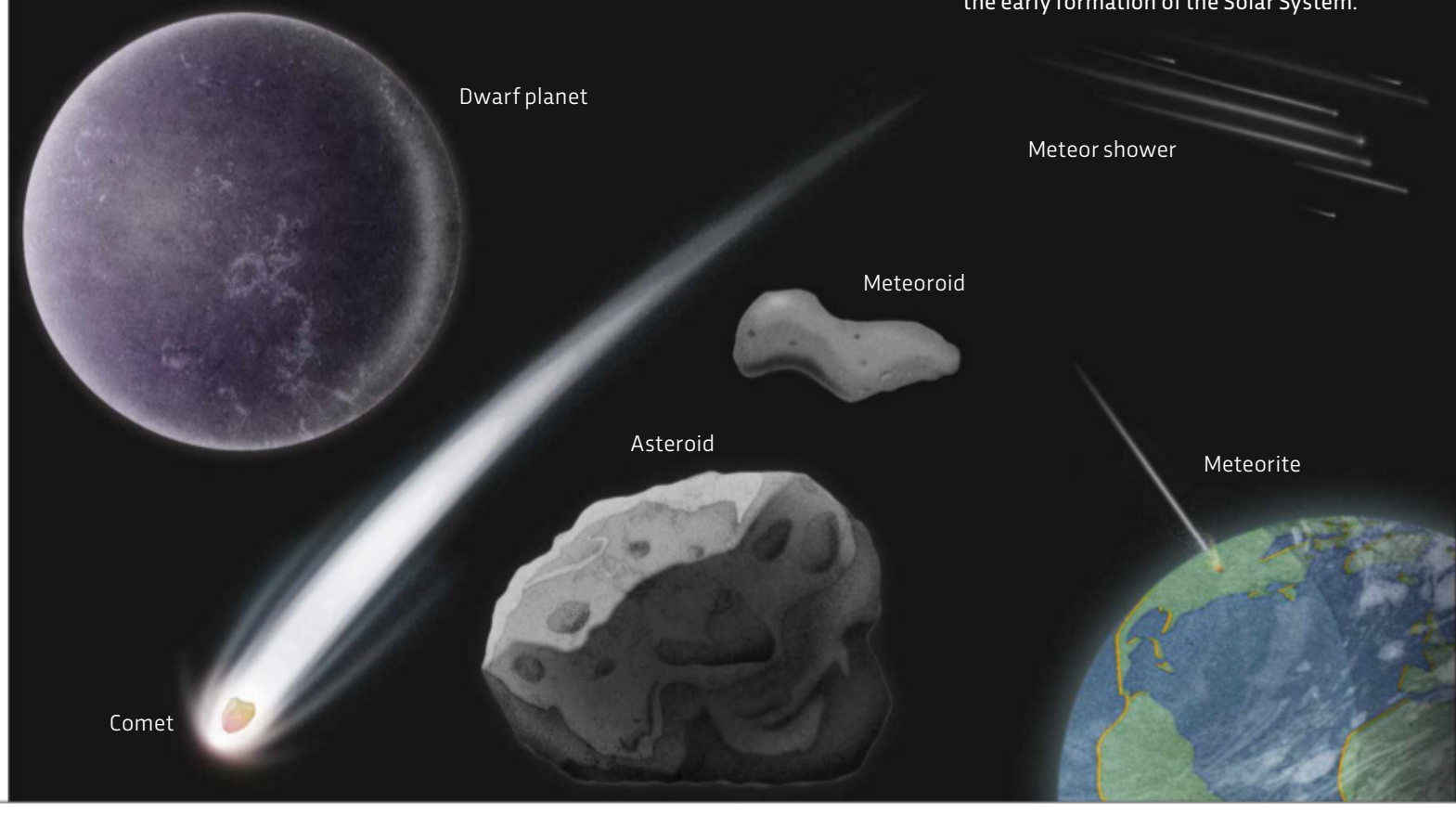
On top of this, cigarette filters may not even reduce the harm to humans from smoking. Some studies have shown that the perceived protective effect of cigarette filters encourages smokers to smoke more or be less inclined to quit. The 12,000 cellulose acetate fibres in the filter may also be inhaled directly into the lungs and trigger respiratory illnesses themselves. The tobacco manufacturers have looked at safer and less polluting filters, but none has found widespread market acceptance yet. ***LV***

WHAT ARE THE DIFFERENT TYPES OF SPACE ROCK?

DWARF PLANET
Dwarf planets are massive enough to be affected by gravitation and can pull themselves into a round, or nearly round shape. However, unlike planets, they are unable to clear their orbital path. Each of the known dwarf planets in the Solar System is smaller than our Moon.

COMET
Comets are the snowballs of the cosmos. These icy bodies of frozen gases, rocks and dust orbit the Sun on highly elliptical paths, often tumbling as they go. When their orbit brings them close to the Sun, they heat up. This causes the solid ice to turn into gas, which is swept into the distinctive comet tail.

ASTEROID
Asteroids are small, rocky objects that orbit the Sun. Most asteroids are irregularly shaped, although there are a few that are nearly spherical. There are over a million known asteroids, and most can be found in the asteroid belt between Mars and Jupiter. Asteroids are rocky remnants left over from the early formation of the Solar System.



METEOR SHOWER
As comets or asteroids travel around the Sun, they leave behind a trail of debris in their wake. When the Earth's orbit intersects with this debris, the result is hundreds (or thousands) of bright trails, appearing to radiate from one point in the night sky. This is why we often see meteor showers at the same time every year.

METEOROID
These are your classic space rocks. As fragments and debris from asteroids and comets, they are some of the smallest bodies in the Solar System. When a meteoroid enters the Earth's atmosphere and burns up, it leaves a glowing trail in the sky and is known as a meteor – or more popularly, a shooting star. Meteoroids can range in size from as small as a grain of dust to small asteroids.

METEORITE
These are the meteoroids that survive the journey to Earth's surface. So far, more than 69,000 meteorites have been found on Earth.

GETTY IMAGES X2, ALAMY ILLUSTRATIONS: PETE LAWRENCE, DANIEL BRIGHT

PETER ROBINSON

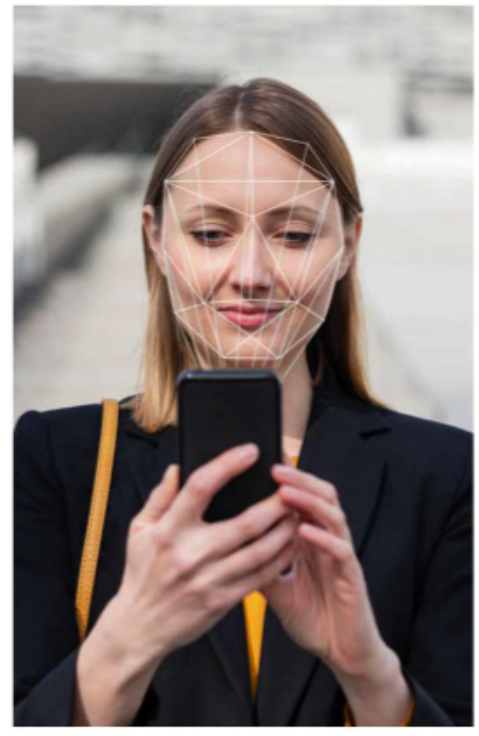
WHY DO SO MANY CATS HAVE WHITE PAWS?

The white socks of domestic cats have their origins deep in the past. During the process of domestication, which began around 10,000 years ago, the tamest moggies were bred together to produce calmer, friendlier animals, but there was an unanticipated consequence in the form of white flashes and paws. These features are caused by a developmental quirk, which occurs whilst the embryonic kitten slumbers in its mother's womb, and which stymies the ability of would-be pigment cells to mature properly. People liked these unusual markings, so they bred the animals together, and over time, white socks and splodges became more common. ***HP***

ARTHUR SIMMONS

COULD A DEEP FAKE UNLOCK AN IPHONE?

A deep fake can indeed duplicate a face, but modern iPhones cannot be unlocked by a picture because they use depth sensors as well as the camera to look at you. An infrared dot projector covers your face with invisible points of light that are then examined by an infrared camera to figure out the 3D shape. This debunks the movie *Red Notice* when it uses an iPad to mimic a face and unlock a door – unless the security of a billionaire's vault is worse than his iPhone! No, you need something like the sci-fi tech you see in *Mission Impossible*: 3D-printed masks that have the right shape and appearance. ***PB***



DOES SUNSHINE MAKE US HAPPIER AND HEALTHIER?

In many parts of the world, there's a deeply ingrained belief that sunny days make us feel more cheerful. It seems like common sense, but the scientific evidence is surprisingly equivocal. Yes, there are individual studies supporting the link – for instance, in 2013, researchers at the Freie Universität Berlin reported that people surveyed on exceptionally sunny days felt more satisfied with life than people surveyed on cloudier days. However, an earlier and larger influential paper led by Humboldt-University in Berlin involving over 1,000 volunteers found no evidence that people enjoyed more positive moods on sunnier days (although they did tend to feel less tired).

Flipping things around, even the idea that many of us are more prone to depression in the gloomier the winter months (known as 'seasonal affective disorder') is controversial. For instance, a US study involving over 38,000 participants failed to find any link between sunlight exposure and risk of depression. In short, the evidence for mood-enhancing effects of sunshine are not as robust as you might think.

When it comes to sunshine and health, however, the scientific evidence is more clear cut. While too much sunshine is undoubtedly bad for your unprotected skin, sunlight exposure is also beneficial in many ways because it allows the body to create more vitamin D, which can reduce the risk of cancer and lower blood pressure among other health benefits. Morning exposure to sufficient daylight is also important for entraining the circadian rhythm, which is important for healthy sleep. So, while excessive sunbathing is unwise, so too is closeting yourself indoors without any sunlight at all. *CJ*

GETTY IMAGES X3, ALAMY ILLUSTRATION: DANIEL BRIGHT

JACK HOWARD

WHAT IS A FOGBOW?

A fogbow is an arc that forms over the horizon in foggy conditions, kind of like a rainbow does. When light enters a raindrop, it bends. The angle that it bends depends on its wavelength, creating the vibrant colours of a rainbow. This is called refraction.

Fog droplets are much smaller than raindrops however, typically just 10 to 15 microns across. This is close enough to the wavelength of light that quantum mechanical effects start to have an effect. As well as refracting, the light diffracts into interference patterns, smearing out the rainbow colours and making the fogbow appear pale or white instead. ***DG***

HOW DOES PHOTOSYNTHESIS WORK?

Photosynthesis is the process used by plants, algae and certain bacteria, to turn sunlight, water and carbon dioxide into oxygen and energy, in the form of sugar. It's probably the most important biochemical process on the planet. It is essential for almost all life, as it's the primary source of oxygen in the atmosphere.

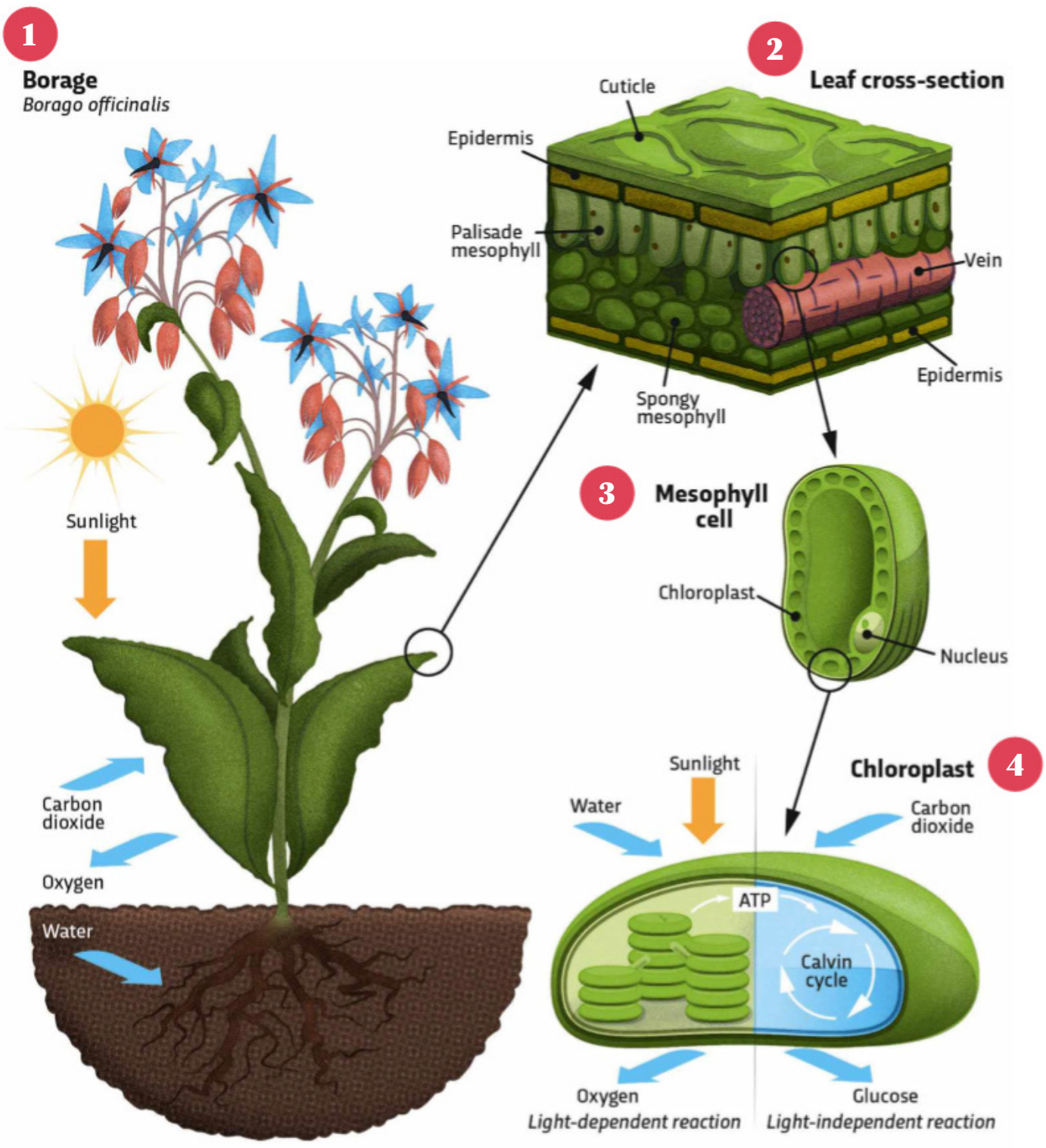
Carbon dioxide + water → glucose + oxygen

1. Plants absorb sunlight through the two top layers of their leaves, the cuticle and epidermis. These layers are thin, so light can travel through them easily.

2. Just beneath these layers are the palisade mesophyll cells, vertically elongated cells arranged closely together and packed with chloroplasts. Below these is the spongy mesophyll tissue, loosely packed for efficient gas exchange. As gases move in and out of these cells, they dissolve in a thin layer of water that covers the cells.

3. Inside the palisade mesophyll cells are the chloroplasts. They contain chlorophyll, molecules that don't absorb green wavelengths of white light. Instead, they reflect it back to us, giving plants their green colour.

4. Inside the chloroplast is where the magic happens. A light-dependent reaction takes place, where energy from the light waves is absorbed and stored in ATP molecules. Then, in a light-independent reaction (the Calvin Cycle), ATP is used to make glucose, a source of energy. Water is oxidised, carbon dioxide is reduced, and oxygen is released into the atmosphere.



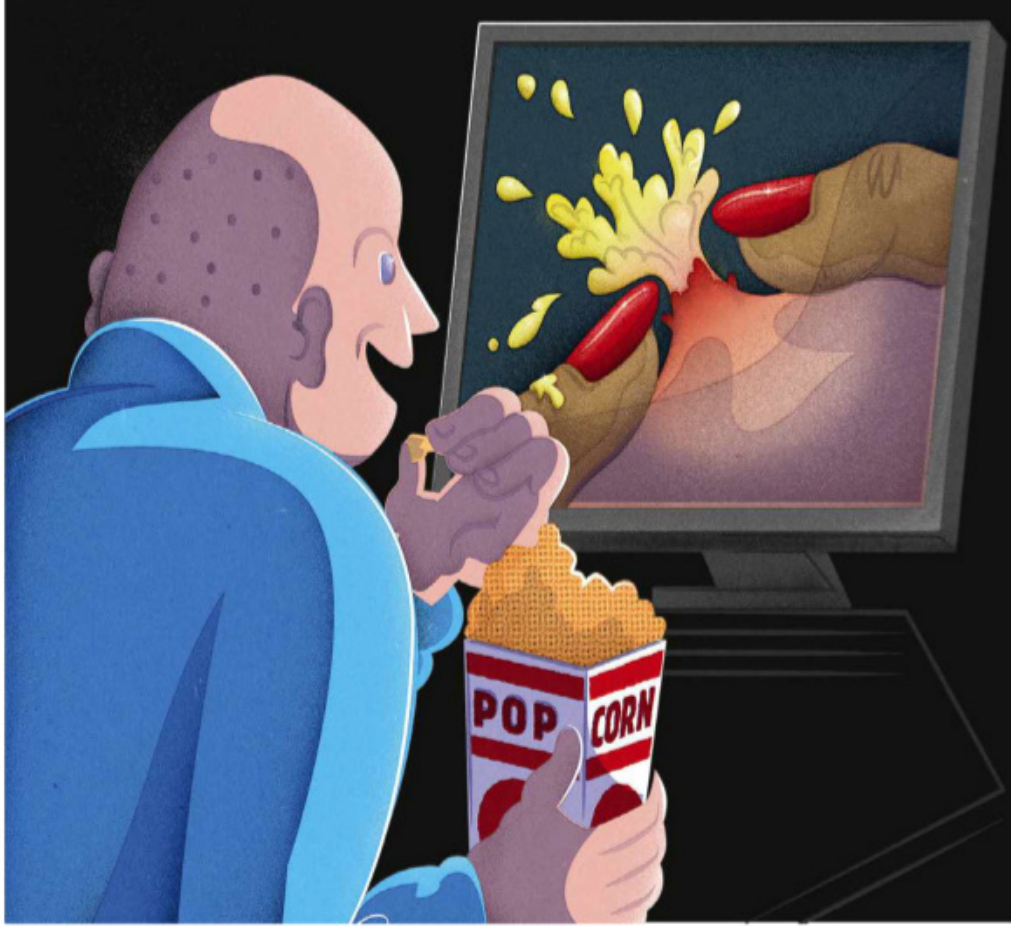
DEAR DOCTOR...

HEALTH QUESTIONS DEALT WITH BY *SCIENCE FOCUS* EXPERTS

I LOVE WATCHING *DR. PIMPLE POPPER* AND TEETH DESCALING VIDEOS. IS THERE SOMETHING WRONG WITH ME?

Graphic online videos of popped pimples and hardcore teeth cleaning are wildly popular, so you're far from alone. That should offer some comfort, but at the same time, it does seem odd that you and so many others should choose to watch, and even enjoy, videos that most of us would agree are disgusting. Humans evolved to avoid disgusting material; it's a natural defence mechanism to protect us from infection and contamination. So what's going on?

Psychologists suggest you may be displaying a form of morbid curiosity and taking an interest in disgusting material as a way to learn how to avoid it. More specifically, they posit that the appeal of pimple and teeth videos is similar to horror – essentially you get to practise experiencing an intense emotion (in this case disgust rather than fear) at a safe distance. Supporting this interpretation, researchers at the University of Graz recently scanned volunteers' brains while they watched pimple-popping videos. Fans of the videos showed greater activity in the front of their brains and less deactivation of pleasure-related brain areas, as compared with non-fans, and they experienced less disgust. What's more, the pimple-popping enthusiasts, while describing themselves as generally just as prone to disgust as the others, also reported being better able to control their disgust reactions. For you and others like you, then, these videos seem to offer a satisfying opportunity to practise your impressive disgust regulation skills. *CJ*



CLAIRE HILL

WHY ARE EGGS SO USEFUL IN BAKING, AND ARE THERE ANY SUBSTITUTES?

Eggs contain over 40 different proteins, which hold the key to their culinary success. The long protein molecules fold and coil so that water-hating (hydrophobic) sections are tucked safely away. Loose bonds hold each protein molecule in a tight unit, but heat or whisking causes the chains to unwind or denature. This allows different proteins to link their hydrophobic regions together and form a strengthening 3D network. The coagulation is irreversible and transforms eggs into a semi-solid or solid state.

Whisking egg whites unravels proteins and adds air bubbles. The proteins link together and collect at the surface of the bubbles to hide their newly exposed hydrophobic parts from water in the egg white. The proteins prevent the air bubbles from popping, even during cooking. In baking, egg proteins combine with wheat proteins in flour to form a strong network of trapped air bubbles that can expand in the oven.

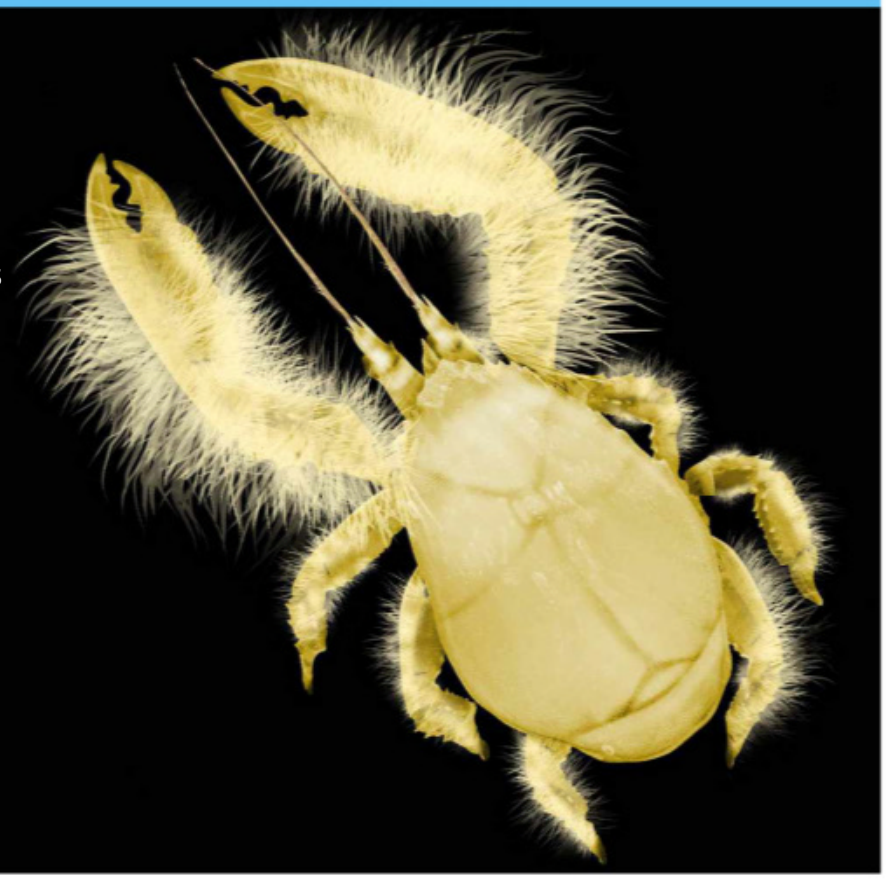
Meanwhile, egg yolk contains an excellent emulsifier called lecithin. Emulsifiers keep oil droplets dispersed in water, or water droplets in oil, preventing them from separating.

It's hard to find a total substitute for eggs. Egg emulsifiers are perhaps the easiest to replace. Plant-derived lecithins such as soya lecithin make good substitutes. Flax or chia seeds, bananas or mustard can also be used to stabilise emulsion droplets. Eggs are harder to replace as thickeners, although ground flax or chia seeds work quite well, especially in cookies or muffins.

Replacing eggs' foaming ability is tricky. This is where aquafaba comes in. Aquafaba is a temperature-resistant foamer made from the water in which legumes such as chickpeas have been cooked. The liquid contains enough protein, starch and fibre to work in tricky applications such as egg-free meringues. To obtain aquafaba, either use the liquid in canned chickpeas or boil your own and collect the cooking water. ***ED***

NATURE'S WEIRDEST ANIMALS...

THE YETI CRAB



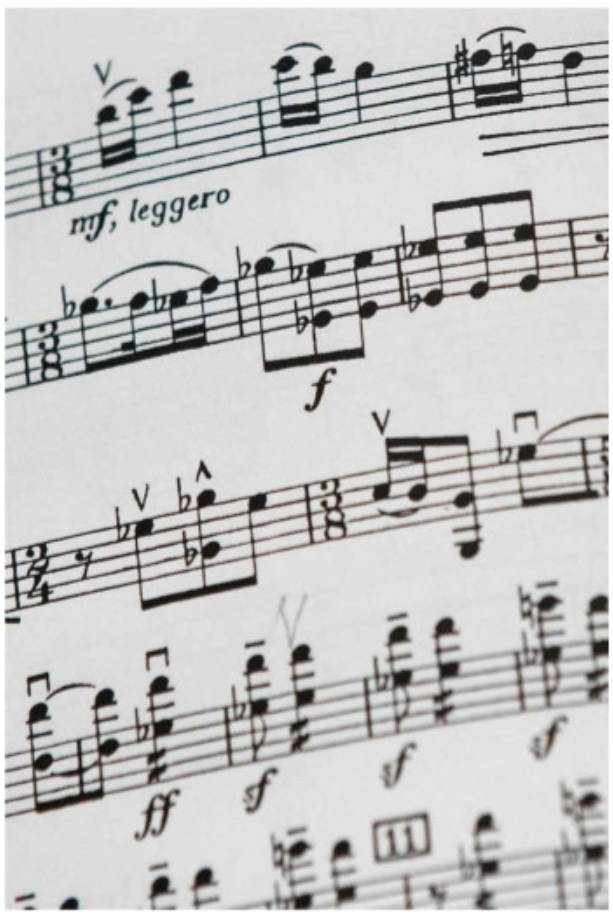
If a furry snow boot and a crab fell in love and had babies, this is what they would look like. Yeti crabs, which have ghostly carapaces and hair-like bristles on their legs and claws, hang out in the deep ocean next to hydrothermal vents and cold seeps. In 2005, when scientists discovered the yeti crab living on the Pacific-Antarctic Ridge, they realised they had stumbled not only on a new species, but also a whole new family, later dubbed Kiwaidae. A year later, a second species was discovered wafting its arms over a methane-belching cold seep. It's thought the bizarre dance helps to nourish colonies of bacteria, which it grows on its arms. The movement stirs up the water, bathing the bacteria in fresh supplies of oxygen and nutrients. They are then eaten by the crab, which uses comb-like mouthparts to harvest the bacteria from its bristly limbs.

There's another species of yeti crab, discovered in 2010, which lives on hydrothermal vents in Antarctica. Despite bearing literally no resemblance to cheesy crooner David Hasselhoff, it has tenuously been dubbed the 'Hoff crab' because scientists decided that the hairs on its exoskeleton resemble those on the Hoff's chest. They don't. ***HP***

QUESTION OF THE MONTH

PAUL FARNHAM-SMITH, FOLKESTONE

WHY ARE MINOR CHORDS SAD AND MAJOR CHORDS HAPPY?



GETTY IMAGES, ALAMY X2. ILLUSTRATIONS: DAN BRIGHT

Whenever a collection of notes is played or sung together, this is described as a 'chord' and even the simplest combination will convey some kind of recognisable emotion. Why and how this occurs has long been a matter of intrigue and debate for musicians, psychologists, physicists and even mathematicians.

A simple 'major' chord is made from the first, third and fifth notes of a major scale. This is reliably identified by Western adults and children as a happy chord. Then by simply lowering the middle note by a semitone – one white or black key to the left on a piano – this is turned into a 'minor' chord, which is typically heard as sad.

This phenomenon seems to be mirrored in natural language, with research showing that sad speech tends to use notes from minor chords, and happy speech major chords. Neuroscientists have also shown that major and minor chords provoke their own distinct pattern of activity in the brain's emotion centres.

Some have argued that there is a physical basis for this. Back in the 19th Century, German scientist Hermann von Helmholtz showed that minor chords create more complex sound waves, which are less harmonious and less comfortable to process. But if this is an inherently biological phenomenon then we would expect these perceptions to be universal across all cultures and while it is common, it is not always the case. For example, the Khowar and Kalash tribes native to northwestern Pakistan showed the exact opposite pattern to Western listeners, linking minor chords with positive emotions and major chords with negative emotions.

So while there may be some mathematical and physical reasons that humans started to use chords in this way, the research suggests that our tendency to hear emotions in chords is at least partly learned from very early and prolonged exposure to the associations that consistently occur in the music of our culture, and even in everyday speech. ***CL***

EMAIL YOUR QUESTIONS TO **QUESTIONS@SCIENCEFOCUS.COM**

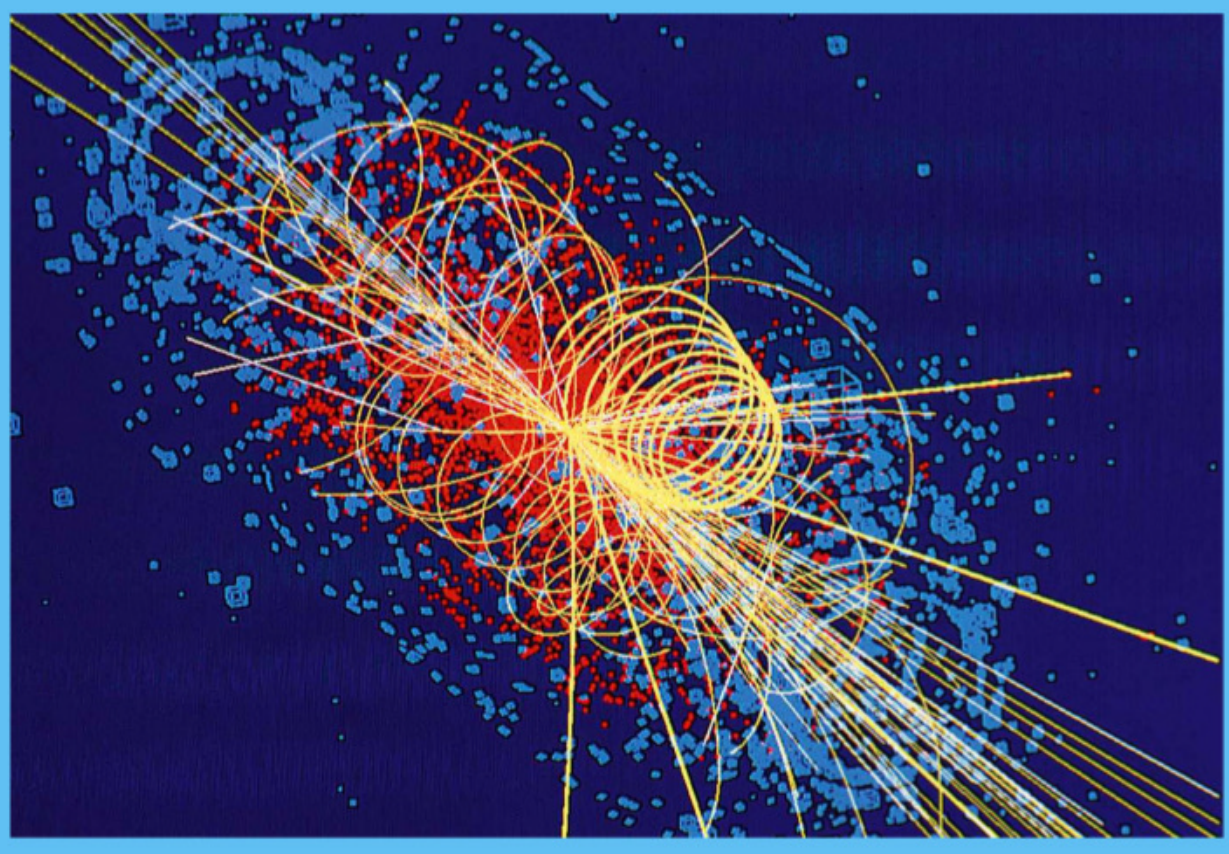
THE EXPLAINER

CERN

WHAT IS CERN AND WHAT DOES IT DO?

The European Organization for Nuclear Research – known by its French acronym, CERN – is the largest particle physics laboratory in the world. Located just outside of Geneva, Switzerland, it was established in 1954, as one of post-war Europe's first joint ventures, with the express aim of halting the 'brain drain' of talented scientists leaving the continent for America.

Today, more than 10,000 scientists hailing from more than 100 countries find themselves at CERN each year to use its facilities, which include some of the biggest and most complex scientific instruments ever created. Their goal: figure out what the Universe is made of and the laws of physics that dictate its behaviour.



WHAT DISCOVERIES HAVE BEEN MADE THERE?

Highlights include the 1983 discovery of a pair of elementary particles called the W and Z bosons, which was later awarded the Nobel Prize for Physics. British computer scientist Tim Berners-Lee helped invent the World Wide Web at CERN in 1989 by developing a way for computers to talk to each other, called hypertext transfer protocol (HTTP). In 1995, CERN scientists were the first to create atoms of hydrogen's antimatter counterpart, antihydrogen. In 2000, they discovered a new state of matter: a hot, dense, particle soup called quark-gluon plasma. And the Higgs boson was observed for the first time in 2012 at CERN's Large Hadron Collider (LHC), scooping its discoverers a Nobel Prize.

WHAT IS THE LARGE HADRON COLLIDER AND HOW DOES IT WORK?

The LHC is the world's most powerful particle accelerator: a giant machine that physicists use to smash tiny subatomic particles together at extremely high speeds to see what happens.

The particle collisions recreate, for a fraction of a second, the conditions that existed moments after the Big Bang, when the Universe was born. By studying the debris of these collisions, physicists try to settle mysteries such as what matter is made of and how particles get their mass.

The LHC, which was completed in 2008, was built primarily to put the Standard Model of particle physics to the test. This wildly successful theory from the 1970s describes the interactions between the 17 elementary particles and three of the four fundamental forces of the Universe: electromagnetism, the strong nuclear force and the weak nuclear force (gravity is the fourth).

The Standard Model long-predicted the existence of a never-before-seen elementary particle called the Higgs boson. After four decades of searching, in July 2012, physicists finally found it using the LHC. The discovery was a big win for fans of the Standard Model, but the theory is incomplete. It leaves many questions open, such as what is dark matter, and why does the Universe contain more matter than antimatter, which the LHC may help answer.

The machine is buried deep underneath the France-Switzerland border near Geneva, in a circular tunnel nearly 27 kilometres long. It uses more than 1,000 35-tonne superconducting dipole magnets (cooled to a temperature of -271.3°C – colder than outer space!), to guide two beams of particles (usually protons) in opposite directions around the ring. The protons race around the 27-kilometre ring at almost the speed of light, completing over 11,000 laps per second.

At four points around the ring, the two opposing beams are steered so that they cross paths. Where the beams intersect, the protons within them slam into one another and shatter into smaller particles. Most of the particles produced in the collisions are highly unstable and decay into more stable forms almost instantly. Seven enormous detectors – think of them as cathedral-sized digital cameras – are built around the four collision zones to capture data about these incredibly rare particles as they blaze briefly into existence.

GETTY IMAGES X2, CERN

WHY WAS THE LHC TURNED OFF AND WHEN WILL IT BE UP AND RUNNING AGAIN?

The LHC was switched on in September 2008, with a plan to run for at least two decades. The plan includes a handful of long shutdowns where the machine is turned off so that scientists can access the equipment, perform repairs and make upgrades that allow it to operate at higher energy levels, which means more potential discoveries, during the following run.

Right now, the LHC is nearing the end of its second long shutdown, which began at the start of 2019, according to Dr Monica Dunford, the physicist responsible for coordinating research on the Standard Model at the ATLAS Experiment (one of the two international collaborations credited with discovering the Higgs). By spring this year, protons should be colliding once again.

WHAT DOES THE FUTURE HOLD?

"With this next run, we're expecting to get roughly double the total luminosity that we had by the end of Run 2," says Dunford. Luminosity is how physicists describe the intensity of the particle beams. Doubling the luminosity doubles the likelihood of particles colliding. Last summer, ATLAS announced the first-ever observation of three W bosons being produced simultaneously, from a data set taken between 2015 and 2018. Compared to creating a Higgs boson, 'triple W' production is about 60 times less likely to happen during proton collisions.

"It's so rare a process that it makes us confident that maybe even in Run 3 we could possibly measure Higgs self-coupling," says Dunford. A Higgs coupled to two others – a 'trilinear Higgs' – is about 2,000 times less likely than a regular Higgs.

Things could really start to get exciting after the next long shutdown, currently slated for 2026-2028. During that time, the LHC will be upgraded so heavily that it warrants a new name: the High-Luminosity LHC (HL-LHC). Over 20-plus years of operating, the machine will work up to generating luminosities nearly 30 times greater than those produced to date, allowing physicists push the Standard Model to its limits.

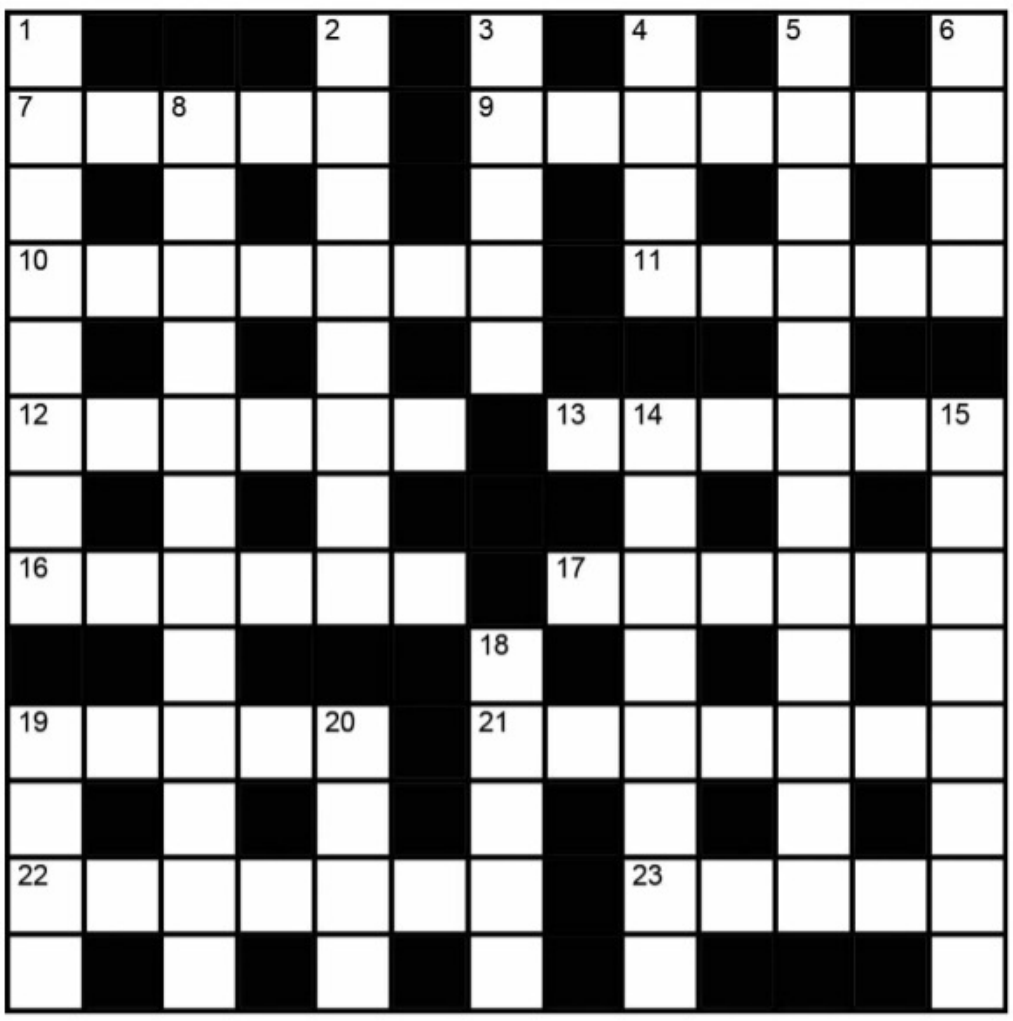
And the search for new physics doesn't end there. A proposed new collider – the Future Circular Collider (FCC) – would dwarf the LHC. "It's really just a concept right now, but ultimately this would be an even more powerful collider that would be 100 kilometres around," says Dunford. "The LHC ring would basically just be the booster ring for the FCC!"

by CERI PERKINS

Ceri is a science journalist and spent several years as the science writer/editor at CERN.

CROSSWORD

PENCILS AT THE READY!



ACROSS

7 Row between similar guests (5)
9 Pen has ran out in mass destruction (7)
10 Somewhere to put weapon? That woman has lost out (7)
11 Get volatile liquid from there, strangely (5)
12 Be dishonest, depressed, and keep out of sight (3,3)
13 Be at a race to conclusion (6)
16 Judge beginning to unwind with the Spanish to get more nourishment (6)
17 Friendly spin, say, with broken nail (6)
19 Beg for parking by the front (5)
21 Chap joining father, getting twitch of the liver (7)
22 Conscript sees object recur erratically at first (7)
23 Mackerel-catcher played parts (5)

DOWN

1 Composer has new role as single man (8)
2 Theorems about frail institution (4,4)
3 Twenty points (5)
4 Liberate at no cost (4)
5 Resist charge review for shop fitting (4,8)
6 Flyer right to have a drink (4)
8 Successful swindle to find sought-after item (6,6)
14 Invade ship after ruining repast (8)
15 Sensitive appointment about lice problem (8)
18 Colour with renewed energy (5)
19 Left some wine (4)
20 Daughter on strange instrument (4)

ANSWERS

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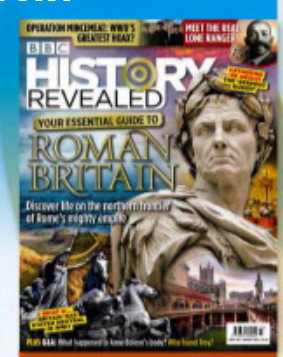

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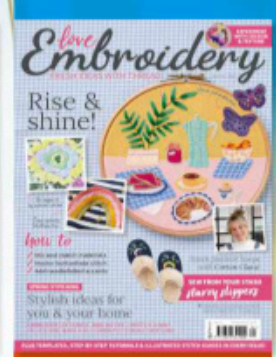

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POPCORN SCIENCE

Are we living in a multiverse?

Are there universes where the laws of physics do not apply, like in the newest Doctor Strange outing?

In a parallel universe, you are writing this article. You're probably doing a better job of it too. That's what the multiverse theory suggests anyway. You will no doubt have heard of it, if not from science then certainly from science fiction. *Star Trek*, *Stranger Things*, *Spider-Man: No Way Home* – TV and film is full of stories set around the idea that our world is but one of many alternative realities. However, with the release of the new Marvel film, *Doctor Strange In The Multiverse Of Madness*, the theory is set to achieve new heights of popularity. But what exactly is the multiverse? And is there any truth to the idea that in a different reality I'm actually a rich, handsome Premier League footballer?

The multiverse derives from the basic idea that beyond the grand sphere of our observable Universe are entirely different universes, distantly separated from ours. What characterises these universes is up for debate, but Richard Bower, professor of cosmology at Durham University, cites the work of fellow cosmologist Max Tegmark, who has theorised four levels of multiverse.

The first, explains Bower, posits an infinite universe in which "every possibility that could happen would happen", including another copy of Earth. Level two, meanwhile, gives us multiverses where the basic laws of physics are the same, but fundamental constants differ. "Newton's law of gravity would still weaken with distance," says Bower, "but maybe there are four spatial dimensions instead of three." Level four goes even further, presenting multiverses that have entirely different laws of physics. "So maybe there would be some sort of mathematics that we have no idea about," says Bower. "It could get weird." The trailers for the new Doctor Strange movie suggest an embrace of these weirder versions of the multiverse, with one shot showing him trapped in some sort of cuboid dimension.

But of course, the most popular iteration of the multiverse is level three, the 'many worlds' interpretation of quantum mechanics. It states that every choice causes a split in the Universe, leading to infinite parallel realities. In popular culture, it's the theory behind the multiple Spider-Men in *Spider-Man: No Way Home*. "There are many versions of you but you're only aware of one of those versions," explains Bower, who cites the famous Schrödinger's cat experiment. "You're seeing a cat that's either alive or dead, and you're incapable of realising that there's a version of you where the cat is alive. You're just conscious of the version where the cat is dead."

None of this has been proven, however. There are theories that if a neighbouring universe happened to collide with ours some time ago, it may have left behind proof in the form of cold or hot spots on the cosmic microwave background (electromagnetic radiation left over from the Big Bang). Bower himself is optimistic that advances in quantum computing – which utilises properties of quantum mechanics like entanglement and superposition – could demonstrate the strength of the many worlds interpretation. But at the moment, all of this is hypothetical. In fact, many scientists believe the mystery of whether the multiverse is real to be a philosophical question rather than a scientific one.

"I don't totally agree with my colleagues on that, because a lot of them seem to think, 'Oh, it's a philosophical question, and therefore we can't try to address it scientifically'," says Bower. "No, we just have to be more inventive about how we try to come up with ways to test it and new ways to interpret things."

Who knows, maybe in another universe someone has already figured it all out? **SF**

VERDICT

Okay, we can't prove whether or not the multiverse exists, but physicists think it could be likely, and that suits us.

by **STEPHEN KELLY** *(@StephenPKelly)*
Stephen is a culture and science writer, specialising in television and film.

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