BBC

AN IMMUNE SYSTEM FOR PLANET EARTH

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Science Focus

How magnets could
CONTROL YOUR MIND

What we really need
TO KEEP FUEL BILLS DOWN

The strange world of
ANIMAL FUNERALS

THE PRODUCTIVE BRAIN

A neuroscientist explains how to get your mind working at its best

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Michael Mosley
How your significant other changes your microbiome

Volcanoes
What a violent year of eruptions has taught us

NFTs
A legal expert explains why the tech isn't one big scam

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How do I know if my toe is broken or just bruised? →p84

FROM THE EDITOR

There's a certain genre of social media that sets my teeth on edge, and that's celebrity routines. If you haven't seen them, it's when the rich and famous share what they do in a day. It turns out the secret to their success is actually a meticulously devised routine: they wake up at 2:30am, play golf at 7:30am, and they're in the cryo-chamber by 9:30am while the rest of us are still scratching around for coffee. For them, breakfast might be a nourishing Buddhist chant or perhaps an algal powder cocktail because they haven't earned a meal yet. By the end of the day, the only way to really recharge is to sit in front of a Himalayan salt lamp for half an hour. If you can't find one of those, then some Tibetan throat singing should do the job. The whole charade is so absurd, only one of the above is made up.

Though the truth is, I'd love to know how to be more productive. I'd really like to get more done with my day, even if it's just so I can spend more of my free time in sloth mode. My brain, however, doesn't always play ball. Concentration, motivation or inspiration aren't always within my grasp. And my solutions are a little less extravagant than those favoured by the Hollywood set. Instead, coffee, biscuits and tea are my go-tos, when I find I need a little mental focus. Fortunately, it turns out that experts have some better solutions to this problem. That's why for this issue we've asked neuroscientist Dr Dean Burnett to bust some of the most common myths purported to boost your productivity, and share some tips, backed by scientific research, that might help you get your brain closer to peak performance. Head to p52 to find out more.

Daniel Bennett, Editor

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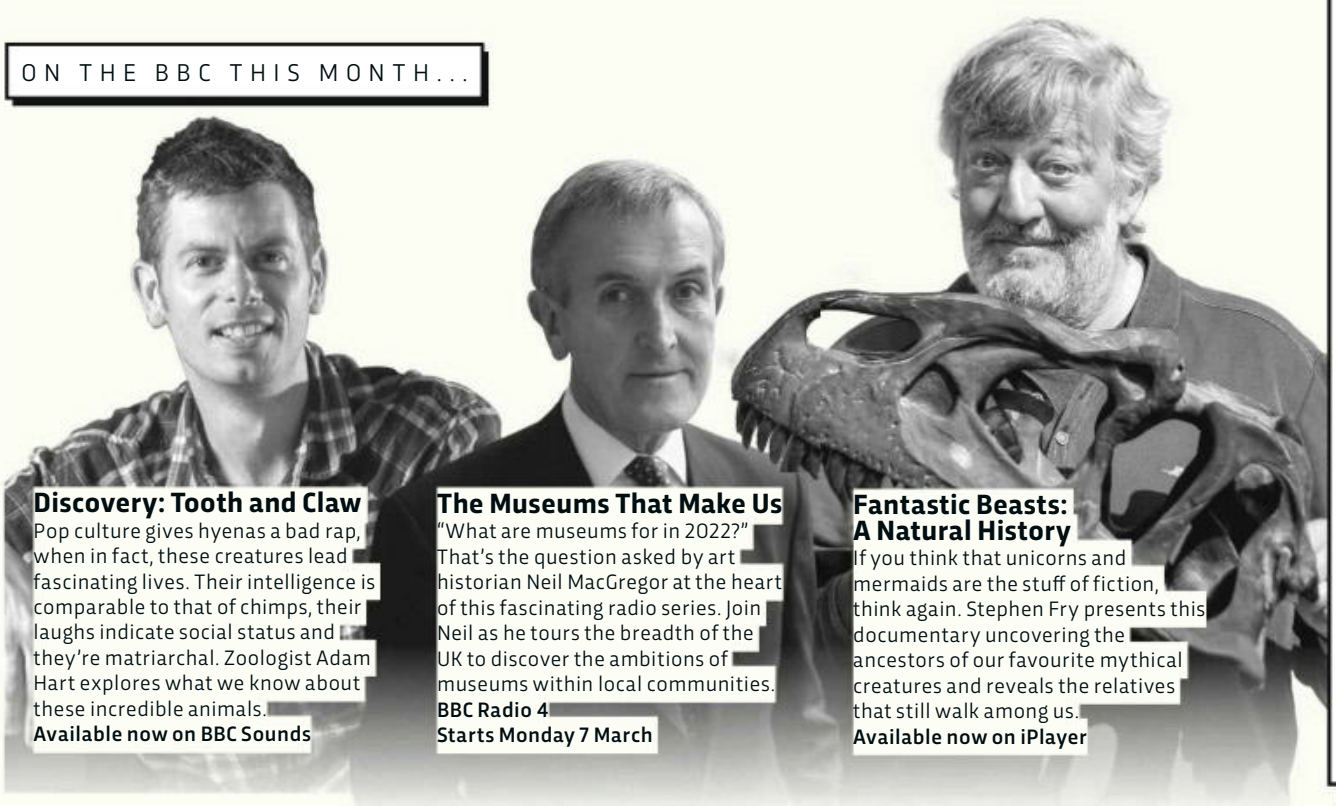
ON THE BBC THIS MONTH...



Discovery: Tooth and Claw
Pop culture gives hyenas a bad rap, when in fact, these creatures lead fascinating lives. Their intelligence is comparable to that of chimps, their laughs indicate social status and they're matriarchal. Zoologist Adam Hart explores what we know about these incredible animals.
Available now on BBC Sounds

The Museums That Make Us
"What are museums for in 2022?" That's the question asked by art historian Neil MacGregor at the heart of this fascinating radio series. Join Neil as he tours the breadth of the UK to discover the ambitions of museums within local communities.
BBC Radio 4
Starts Monday 7 March

Fantastic Beasts: A Natural History
If you think that unicorns and mermaids are the stuff of fiction, think again. Stephen Fry presents this documentary uncovering the ancestors of our favourite mythical creatures and reveals the relatives that still walk among us.
Available now on iPlayer

CONTRIBUTORS

PROF BILL MAGUIRE
A professor of geophysical and climate hazards at UCL, Bill looks back at a year of volcanic activity to explain what it's taught us about Earth's geology. →p44

DR KAELI SWIFT
Crows are incredibly smart: they can learn, imitate sounds, and even carry out rituals for their dead. Bird expert Kaeli tells us more. →p66

HAYLEY BENNETT
What if we could have spotted COVID-19 sooner? Science writer Hayley finds out whether it's possible to create a system that could stop a pandemic in its tracks. →p72

PROF DANN MITCHELL
Tornadoes, waterspouts, fire devils and snowspouts. Professor of climate science Dann gives us the lowdown on twisters and how they form. →p86

CONTACT US

Advertising
David.DSouza@ourmedia.co.uk
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Letters for publication
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We need to start worrying about tiny particles of space junk, rather than the big rocket fragments.

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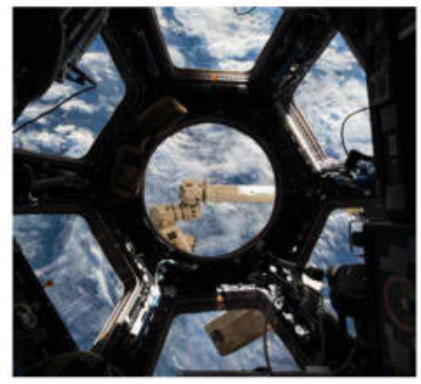

The ISS is being retired. What will happen to the iconic space station, and why can't we just leave it there?

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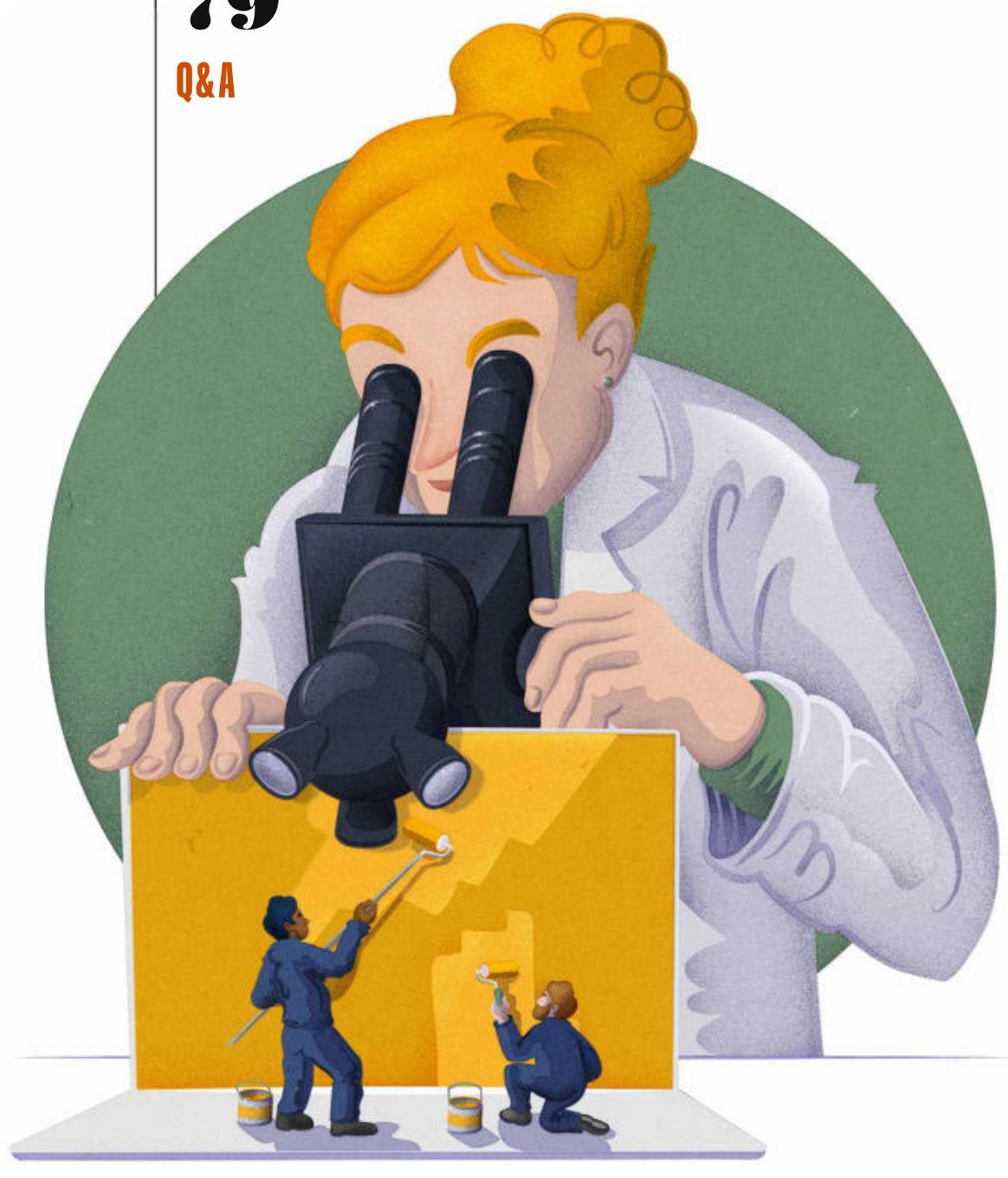
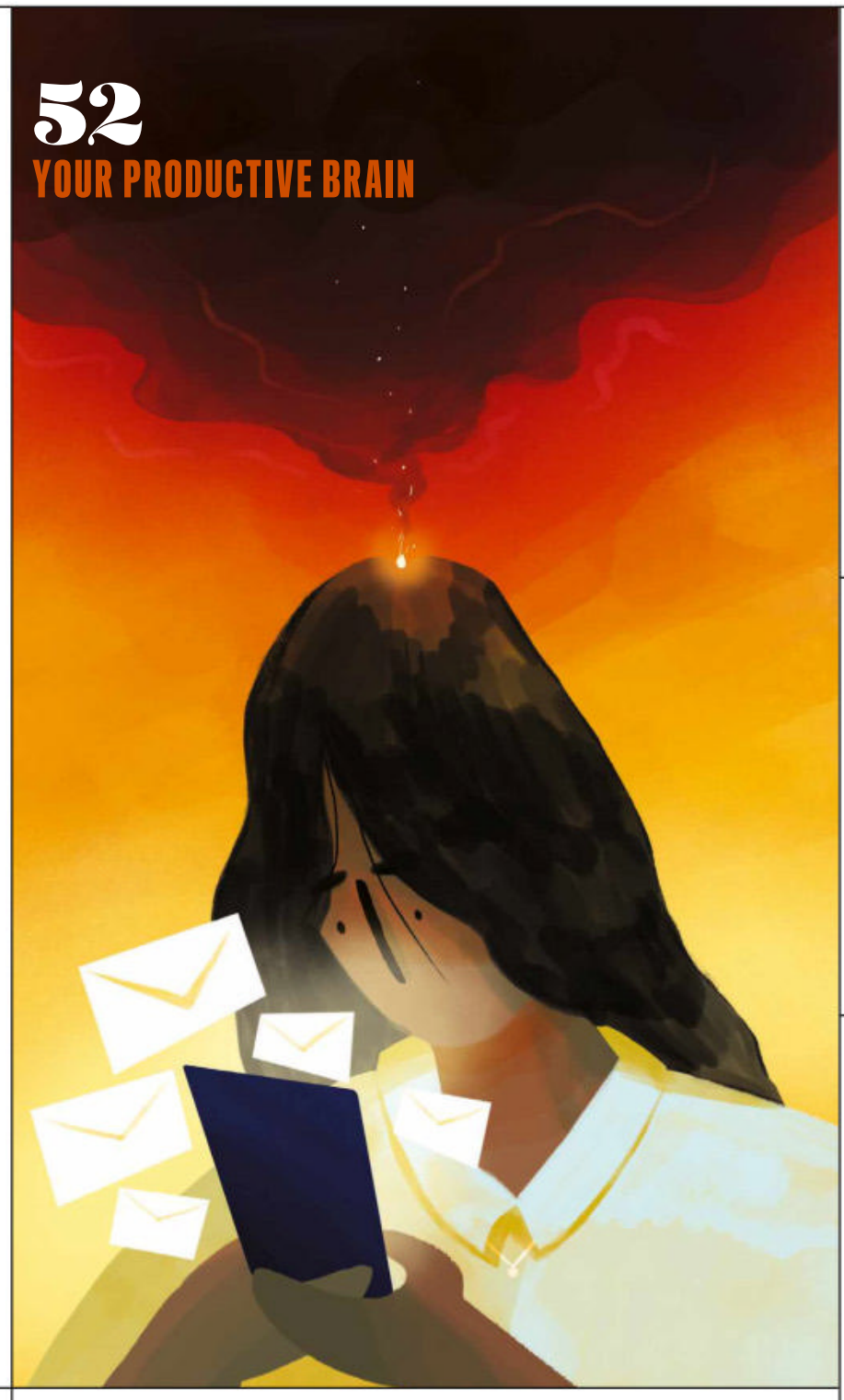


FEATURES



Worrying about the impending apocalypse? Grab snacks, a cricket bat and this jacket.

"THERE WERE TWO INSTANCES OF A MATED PAIR COMING DOWN AND SIMULTANEOUSLY MATING WITH THIS DEAD CROW AND EACH OTHER"

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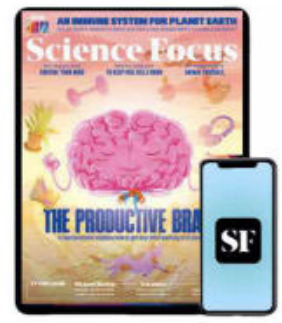

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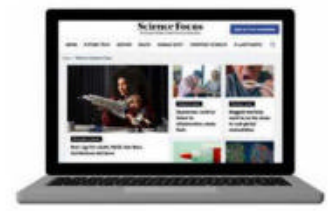
sciencefocus.com



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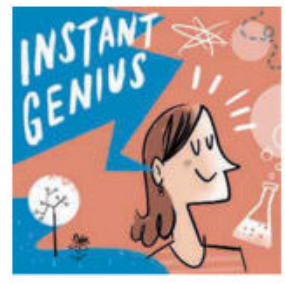

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EYE OPENER

Optimus wine

CHANGI AIRPORT,
SINGAPORE

If you find yourself in Changi Airport, Singapore, this pair of robotic arms will offer you a free drink.

Inside the airport's duty-free shop, Toni the robot bartender can provide you with a sample from the selection of 150 bottles hanging from the ceiling. To kick things off you have to install the Makr Shakr app on your smartphone, and from there you can concoct your very own cocktail. The robotic arms, built by KUKA, have been spared from a life working on a factory floor and have a suite of laser scanners to pull off the delicate, precise movements required to handle glass and make a vodka martini (shaken, not stirred).

In case you're wondering, should any tipsy customer decide to lurch behind the bar, Toni comes to a complete and sudden stop to make sure that no one gets hurt. You don't even need to leave a tip!

COVER IMAGES

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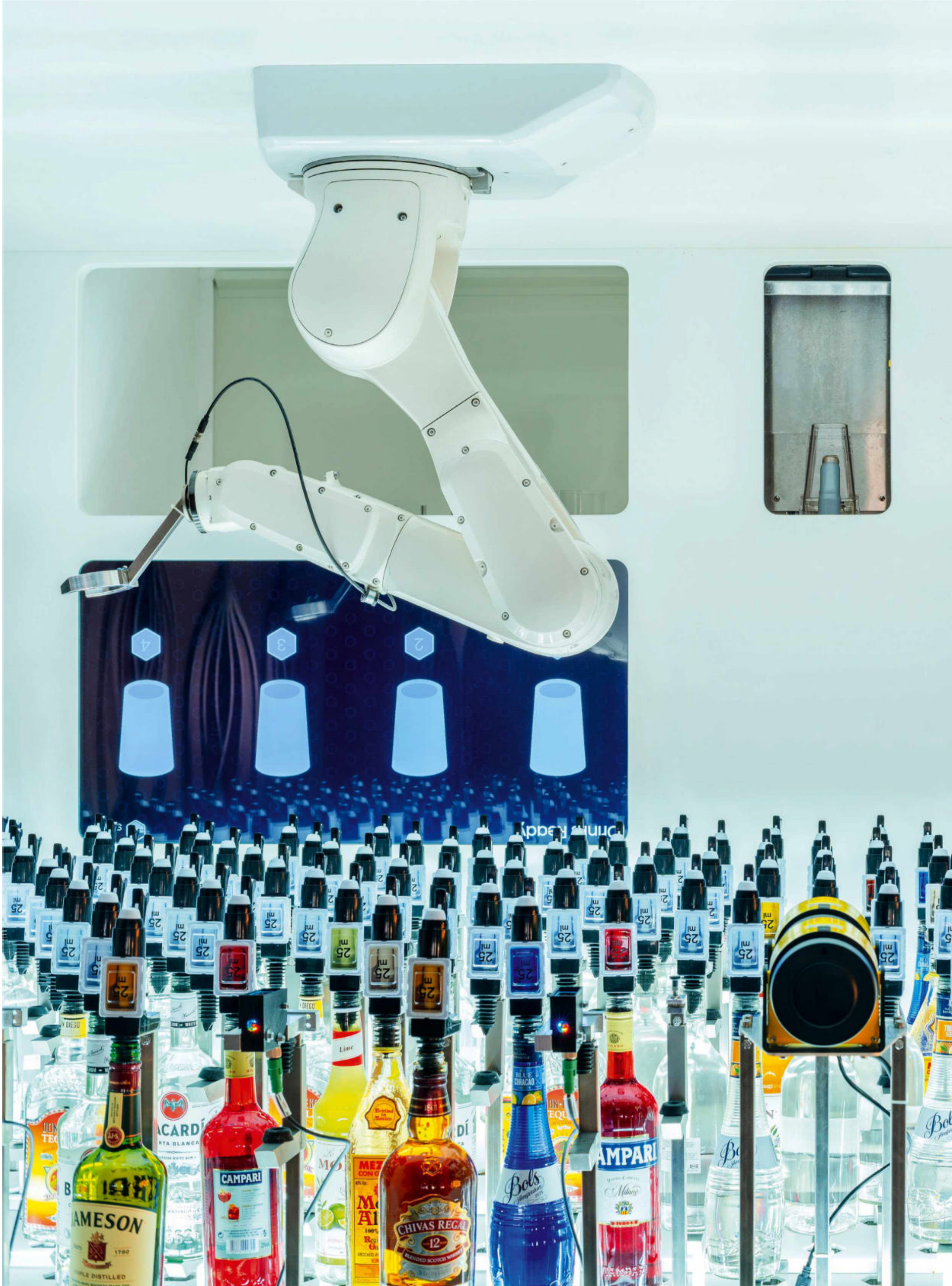
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CHIVAS REGAL
12
BLENDED SCOTCH WHISKY
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EYE OPENER

Quite a mouthful

LA AZOHIA, SPAIN

This Mediterranean painted comber (*Serranus scriba*) is almost as large as the prey it's devouring.

This carnivorous predator belongs to the family of fish that includes groupers and sea bass. The stripes on its body help conceal its outline so it can sneak up on its prey.

The comber uses its powerful swimming muscles to quickly open its mouth, and the rapid increase in volume creates a vacuum that sucks in its prey. In this case, an unlucky green wrasse (*Labrus viridis*), which can reach up to 47cm in length, is slurped up with overwhelming suction.

"The green wrasse swam slowly and roughly, it was probably sick, and a few metres away I could see the [comber] hiding among the *Posidonia* meadow to hunt it down," says photographer Javier Murcia.

Murcia has spent years studying animal behaviour, and this photo netted him runner-up in the behaviour category for Underwater Photographer of the Year.

JAVIER MURCIA/UPY 2022

EYE OPENER

Big oil to big algae

NOVARA, ITALY

Italian company Eni is one of the largest oil and gas companies in the world. The seven 'supermajor' companies, which also includes BP and Shell PLC, are dubbed Big Oil for their influence on economy and politics. But as science warns us of the link between fossil fuels and global warming, some of Big Oil's biggest polluters have pivoted to invest in greener energy.

One method to lower the carbon footprint of energy production is called carbon biofixation. Eni is using this process in reactors, pictured here, to feed algae with waste carbon dioxide. Algae, like plants, photosynthesise to grow. Photosynthesis uses sunlight to turn carbon dioxide into oxygen, but Eni researchers have taken Mother Nature's idea on step further. LEDs provide the algae with light at the exact wavelength needed to maximise their carbon consumption.

Research into biofixation solutions could make it commercially viable within the next decade.

SERGIO RAMAZZOTTI/PARALLELOZERO


GRUNDFOS
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CONVERSATION

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

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LETTER OF THE MONTH

Peek-a-poo!

I've been watching David Attenborough's new series *The Green Planet*. There was a plant that made its seeds the same size and appearance as antelope poo – it even smells like it! The plant has done this to fool dung beetles into taking the seeds and burying them, in order to give them the best chance of germinating, as the favourite food of dung beetles in the area is antelope poo. My first thought was: "That's amazing!" However, my second thought was: "But how does the plant know what antelope poo looks or smells like?" Then I must confess, my third thought was: "I bet someone at *BBC Science Focus* could tell me." So here I am. I'm hoping that you can tell me as I'm intrigued.
Kate Harris

Thanks to evolution, the plant has developed the perfect cocktail of volatile chemicals to attract dung beetles. It didn't 'know' what the poo looked or smelled like, it merely developed its shape and aroma thanks to random genetic mutations taking place over thousands of years. Those seeds that successfully germinated after being taken by dung beetles were more likely to survive, and therefore passed their pong-producing genes onto their offspring. You can read more about species that look like faeces here: bit.ly/poo_animals
Alice Lipscombe-Southwell, managing editor

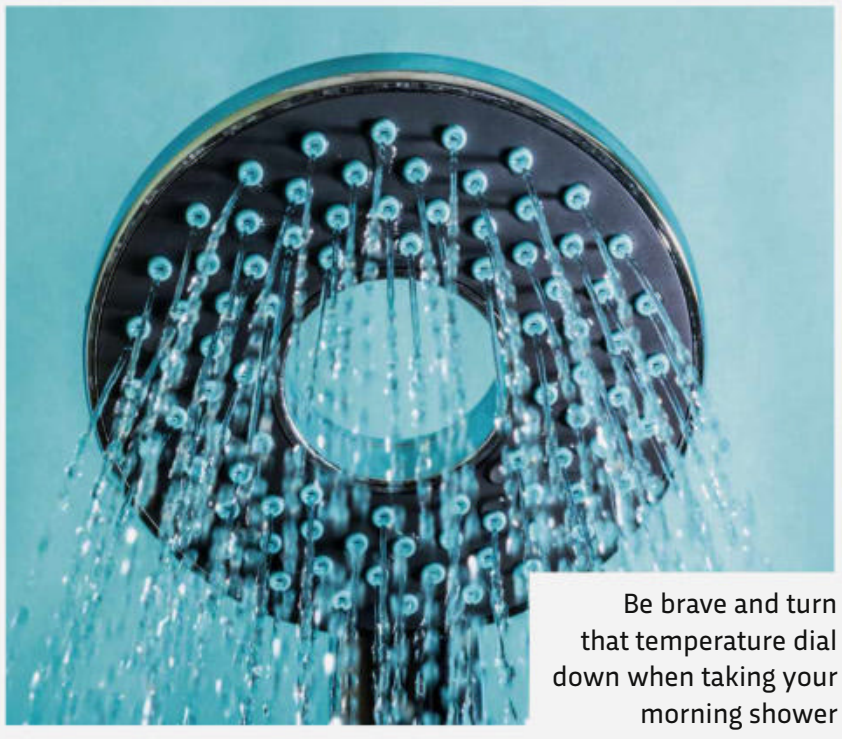
WRITE IN AND WIN!
The writer of next issue's *Letter Of The Month* wins an **STM Myth 18-litre rucksack.** This durable, water-resistant bag is perfect for lugging your laptop from work to home, as it comes with a cable-routing system to let you charge on-the-go with cords out of site, and is designed to keep your laptop safe from any bumps. **amazon.co.uk**

Pie in the sky?

There are several drawbacks to the idea that air taxis are about to take off in a big way (January, p44). First, these flying machines require batteries to power their electric motors, so can supply and demand constraints limit their growth? Second, as the skies fill up with these machines, won't this just lead to congestion? Third, what about the increased risks of collisions as the skies fill up? Fourth, these machines are likely to be expensive, so it is only the rich who are likely to benefit. No, I suspect this is just another pie-in-the-sky idea.
Steve Jones

Stay cool

We have heard so much from Dr Michael Mosley on his *Just One Thing* podcast and in *BBC Science Focus* about cold water being good for you (September, p61). But how cold should the water be in the shower? Should the dial be turned all the way down, or be from the cold tap (surely that can't be good for you in winter)? Or should it be, as some doctors on the internet have said, just cold enough to be uncomfortable? They say 20°C



Be brave and turn that temperature dial down when taking your morning shower

"THE INTERNET HAS TAKEN OVER THE ROLE OF THE VILLAGE ELDER, DISPENSING EASY-TO-SHARE, NOT-QUITE-RIGHT INFORMATION IN PINTEREST-FRIENDLY FONTS"

DR ALEKS KROTOSKI, P64

Will air taxis really be a feasible way for us to travel round our cities?

BBC, GETTY IMAGES, AIRBUS HELICOPTERS

or below constitutes a cold shower, and this is enough to feel the benefits.
Fred Isaac

An interesting question to which, as far as I know, there is no answer. Personally, I start off with warm water, then switch to fully cold and stay there until my breath settles, which is normally less than a minute. A cold shower is below 21°C, and the water that comes out of your tap is probably going to be below 10°C.
Dr Michael Mosley

Is anyone out there?

We have been coincidentally signalling our presence to the Galaxy for approximately, the last 100 years, since we started radio communications. In order that we could communicate with other civilisations, it would take 50 years for our signals to arrive and another 50 years for us to receive their response. How many stars are there within 50 light-years of Earth who may have planets with the capacity to contact us?
Ian Hutt

Quick, freeze!

Stephen Kelly explained that the vast majority of human cells can't be frozen without irretrievable damage (New Year, p92). So how can cryopreservation be used to preserve eggs and sperm?
Dr Richard Lindley

To preserve eggs and sperm, the cells are mixed with a cryoprotectant solution to protect them from damage during freezing. The samples are then cooled and stored in liquid nitrogen.
Alice Lipscombe-Southwell, managing editor

THE TEAM

EDITORIAL
Editor Daniel Bennett
Managing editor Alice Lipscombe-Southwell
Commissioning editor Jason Goodyer
Online staff writer Sara Rigby
Staff writers Alex Hughes, Holly Spanner
Editorial assistant Amy Barrett

ART
Art editor Joe Eden
Picture editor James Cutmore

CONTRIBUTORS
Claire Asher, Scott Balmer, Elana Bansh, Isaac Boakye, Hayley Bennett, Peter Bentley, Steve Boswell, Daniel Bright, Steve Brusatte, Dean Burnett, Emma Davies, Alastair Gunn, Phil Hart, Christian Jarrett, Christina Kalli, Stephen Kelly, Aleks Krotoski, Pete Lawrence, Nish Manek, Bill McGuire, Dann Mitchell, Michael Mosley, Ceri Perkins, Helen Pilcher, Colin Stuart, Luis Villazon, Joe Waldron.

ADVERTISING & MARKETING
Business development manager David D'Souza
Newstrade manager Rob Brock
Subscriptions director Jacky Perales-Morris
Direct marketing manager Kellie Lane

MOBILE
Head of apps and digital edition marketing Mark Summerton

INSERTS
Laurence Robertson 00353 876 902208

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Production director Sarah Powell
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PUBLISHING
Publisher Andrew Davies
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Chair, editorial review boards Nicholas Brett
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ADVERTISEMENT FEATURE

A lasting legacy

After losing nine family members to cancer, Jutlla has found hope by playing his part in beating cancer for future generations

Like many people, Jutlla's life has been touched by cancer. But having lost so many loved ones to the disease, he has found solace in helping Cancer Research UK to fund life-saving research and breakthroughs by leaving a gift in his Will. Together with their supporters, Cancer Research UK's vision is to bring forward the day when all cancers are cured, so Jutlla's pledge will have an incredible impact on future generations.

Cancer Research UK is the world's leading cancer charity dedicated to saving lives through research, influencing and information. Their pioneering work is changing treatment on a global scale.

Jutlla's family has a long connection with the charity. His father died of a form of blood cancer. He had been a charitable man and Jutlla, wanting to follow in his father's footsteps, began making regular donations to Cancer Research UK. Then, just over a decade later, Jutlla's wife tragically died from ovarian cancer. "I found it so difficult without her," admits Jutlla. "She was the ninth member of the family that we lost to cancer at that time."

By pledging to leave a gift in his Will, Jutlla is ensuring that Cancer Research UK can continue the fight to beat cancer when he is gone. "By supporting Cancer Research UK, I feel I am playing a part in the research – it's a very small part, but a very important part," he says.

Making breakthroughs

Every step that Cancer Research UK make towards beating cancer relies on vital support from the public. Today, 2 in 4 people survive their cancer for at least 10 years. Cancer Research UK's ambition is to accelerate progress so that by 2034, 3 in 4 people will survive their cancer.

Jutlla knows all about the historic milestones Cancer Research UK has reached. If you visit his home you'll see that he's even created his own archive brimming with clippings about Cancer Research UK's life-saving work. His pledge, to leave a gift in his Will, will help the charity to continue invest in research projects with huge potential, whose impact will be felt for generations to come.

He says: "When I see the information about progress that is made, I take a photo and put it in my file to show how much difference I have helped make – it keeps me going and I feel so strongly that we should support this work."

Gifts in Wills

Gifts in Wills are vital to Cancer Research UK because they fund more than a third of its research. They enable long-term research projects that lead to new treatments and cures, and ultimately, help save lives for generations to come. Thanks to research, cancer survival is improving and has doubled in the last 40 years in the UK. Without the support of the public none of this would be possible. When you pledge to leave a gift in your Will to Cancer Research UK, you're leaving a legacy that could help create a brighter future for millions of people.

CANCER RESEARCH UK

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To find out more, request a free Gifts in Wills guide.
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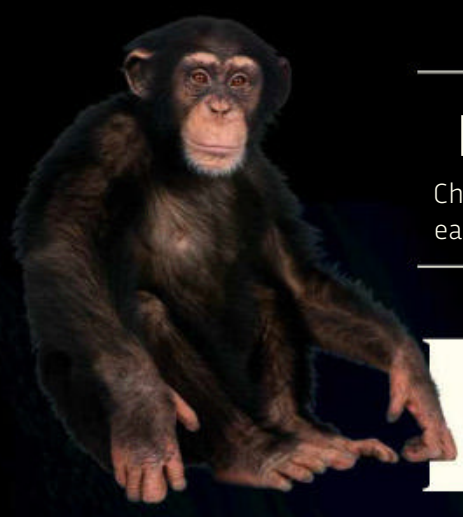

HEALING HANDS
Chimps use bugs to treat each other's wounds p19

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Fusion power may be a little closer p20

GREEN GENE
Your love of nature could be written in your DNA p21

HOLE LOT OF DUST
New perspective of black hole confirms 30-year theory p22

DISCOVERIES

SPACE

HOW CAN WE SOLVE THE SPACE JUNK PROBLEM?

Recent news of an out-of-control rocket crashing into the Moon sounds dramatic, but it's the millions of pieces of smaller debris that present the real danger, according to a UK expert

In January, Elon Musk's SpaceX once again made headline news: a large section of rocket booster belonging to the spaceflight company was found to be on course to smash into the Moon.

The errant chunk of space junk, which has been careering around the Earth for the last seven years, was spotted by American astronomer Bill Gray. He identified it as the upper section of a Falcon 9 rocket, launched from Florida in 2015, which had run out of fuel and become trapped in an 'chaotic orbit'. Many internet pundits and social media users were incensed.

Then shortly after Gray's announcement, a group of students ▸

ALAMY

Singing in the brain Specific neurons in the brain light up when you hear singing p23 **Broken hearted** The cutting-edge projects that could help people with heart failure p24 **Deflecting depression** How magnets could lead to mental health treatments p26

based at the University of Arizona's Space Domain Awareness lab eventually identified the offending piece of defunct space hardware as belonging to a Chang'e 5-T1 rocket launched in 2014 by the Chinese space agency.

However, a spokesperson from the Chinese foreign ministry has since told reporters that this cannot be the case as the Chang'e 5-T1 rocket in question safely entered the Earth's atmosphere and burned up.

At the time of writing, calculations showed that the rocket would crash onto the surface of the Moon on 4 March. But should we be worried about the potential damage it could cause? Not according to Prof Don Pollacco, director of the University of Warwick's newly formed Centre for Space Domain Awareness.

"It's no big deal," he said. "The Moon has actually been a handy dump for things like the Apollo spacecraft. Rather than let them float around, most of the first and second stages were crashed into the Moon."

ABOVE The rocket that will crash into the Moon could be from the Chinese space agency

"Once you start getting below spacecraft size, then we don't monitor things well enough to continually know what's there"

Not only is it no big deal, for those who study objects in Earth orbit it comes as little surprise.

"There are particular orbits that boosters were just dumped in," said Pollacco. "There are still about 50 objects, maybe more, that are from deep space adventures that are not tracked now. Space is big, but occasionally something like this happens."

TAKING OUT THE TRASH

The Centre for Space Domain Awareness launched in September 2021 to study the potential threats of space debris to technology, such as satellites, in orbit around Earth. They focus particularly on those in low Earth orbit, which is classed as anything below 2,000km. According to Pollacco, the greater threat is not posed by things like rockets colliding with the Moon, but by much smaller fragments of debris.

According to the most up-to-date statistical estimates carried out by the European Space Agency (ESA) there are currently around 8,000 satellites, functioning or otherwise, in orbit around Earth. Compare this to the 130 million pieces of space debris also occupying the same space and the magnitude of the problem begins to emerge.

What's more, all but around 36,000 of these fragments are thought to be less than 10cm in

SHUTTERSTOCK, UNIVERSITY OF WARWICK

LEFT Prof Don Pollacco from the Centre for Space Domain Awareness

diameter. This makes them particularly difficult to track – the errors in measurements of their position are currently in the range of kilometres.

"Most stuff that's tracked at low Earth orbit is done with radar. And that stems from history, really. It stems from the fact that we have these really big military radar – Fylingdales – that are designed to see missiles," said Pollacco. They can be used, not in the most efficient way, to look at things a few hundred kilometres up."

"Once you start getting below spacecraft size, then we don't monitor things well enough to continually know what's there. The numbers of small things, even 10 centimetres in size, are just not known, except through models. They're not observationally verified, so it's a pretty serious situation," he said. "There are already some orbits where there is a significant chance of collision. Put it like this – it's not going to get better."

As these small pieces of debris are travelling at more than 28,000km/h (17,400mph) – 10 times faster than a rifle bullet – any impact they make with a spacecraft could potentially cause significant damage.

Moreover, unless action is taken to remedy the situation, the risk of triggering a Kessler event becomes more and more of a possibility. This is a catastrophic scenario named after NASA scientist Donald Kessler, who first proposed the theory in the 1970s. It involves a runaway effect in which a satellite that is hit by a lump of space junk breaks into hundreds of tiny pieces, which then hit other satellites and create a domino effect. This could make it extremely dangerous, or even impossible, for rockets to leave the Earth.

"We're at a situation where it's not too late. But my worry has always been it's only when, say, a spaceship carrying people on it is clobbered that we actually take it more seriously. But now we could deal with it before anything really bad happens," he said. "But we have to be careful because if we don't do something, then you can be sure that some kind of Kessler event is going to come our way."

SPACE JUNK IN NUMBERS

9,800 tonnes
Total mass of all space objects in Earth orbit

30,040
Number of debris objects regularly tracked by Space Surveillance Networks

Debris objects estimated by statistical models to be in orbit

36,500
Number of objects greater than 10cm

1 million
Number of objects from 1cm to 10cm

130 million
Number of objects from 1mm to 1cm

Source: **sdup.esoc.esa.int/discosweb/statistics/**

So what options do we have?

"I think it's a mixture of being responsible and abiding by the Outer Space Treaty, which means deorbiting things, paying some sort of levy when you launch so that there is a government or a company that goes to remove the old spacecraft that are there," said Pollacco.

"And then for the rest of the stuff that doesn't deorbit, we need to know where it is. So instead of having error boxes for each bit of debris that are kilometres in size, you need to have a much more reliable measurement."

Cyanide was present in the atmosphere of a young Earth

Cyanide may have played a key role in the origin of life on Earth, and could help us find alien life

The chemical may drive reactions that produce organic molecules

Though perhaps better known as the lethal substance taken in pill form by captured spies in cheesy thrillers, cyanide may have helped life to evolve on Earth. And looking for signs of it on alien planets could help us to locate life elsewhere in the Universe, chemists at Scripps Research have discovered.

The scientists found that the chemical compound, which contains a carbon atom bonded to a nitrogen atom, could have enabled some of the first metabolic reactions on Earth that created carbon-based compounds from carbon dioxide. Metabolic reactions are reactions that generate energy out of food and are essential for sustaining life.

"When we look for signs of life – either on the early Earth or on other planets – we base the search on the biochemistry we know exists in life today. The fact that these same metabolic reactions can be driven by cyanide shows that life can be very different," said the study's lead author Ramanarayanan Krishnamurthy, an associate professor of chemistry at the institute.

To make the discovery, the team focused on a set of chemical reactions that combine carbon dioxide and water to create the more complex compounds that are necessary for life, known as the reverse tricarboxylic acid cycle.

The cycle is used by some bacteria, but it relies on the use of complex proteins that weren't present on the planet four billion years ago.

As previous studies have shown that certain metals can trigger the same reactions under extremely hot and highly acidic conditions, the Scripps team had a hunch that another chemical may also be able to do so, only under the less violent conditions seen on the early Earth.

"We mixed together these molecules, waited and the reaction happened"

They already knew that cyanide was present in the atmosphere back then, so they mapped out a set of reactions that could potentially use cyanide to produce complex organic molecules from carbon dioxide and then tested them in the lab.

"It was scary how simple it was," said Krishnamurthy. "We really didn't have to do anything special, we mixed together these molecules, waited and the reaction happened spontaneously."

Although the experiment doesn't provide proof that cyanide was involved in this process on the early Earth, it does offer a fresh way of thinking about the origin of life, and perhaps a new means of searching for life on other planets.

SCIENCE PHOTO LIBRARY, TOBIAS DESCHNER

ZOOLOGY

Chimps seen treating each other's wounds using 'medicinal' insects

The behaviour suggests that the apes are capable of a feeling similar to empathy

Back in November 2019, Alessandra Mascaro, a volunteer working at the Ozouga Chimpanzee Project in Loango National Park, Gabon, West Africa, saw something she couldn't quite believe – one of the apes named Suzee noticed her son Sia had hurt his foot. After seemingly thinking about the best course of action, she then plucked an insect out of the air, licked it and applied it to the wound.

Mascaro captured the whole touching moment on film and showed her supervisors, Dr Tobias Deschner, a primatologist working for Ozouga, and Prof Simone Pika, a cognitive biologist based at Osnabrück University.

The Ozouga team then set about monitoring the chimpanzees in the park and looking for other examples of the behaviour. Over the following 15 months they captured 76 incidences of the apes applying insects to wounds on themselves or other group members.

The researchers are uncertain why the chimps use the insects, or even which insects they are, but suspect they might have soothing properties that could provide pain relief.

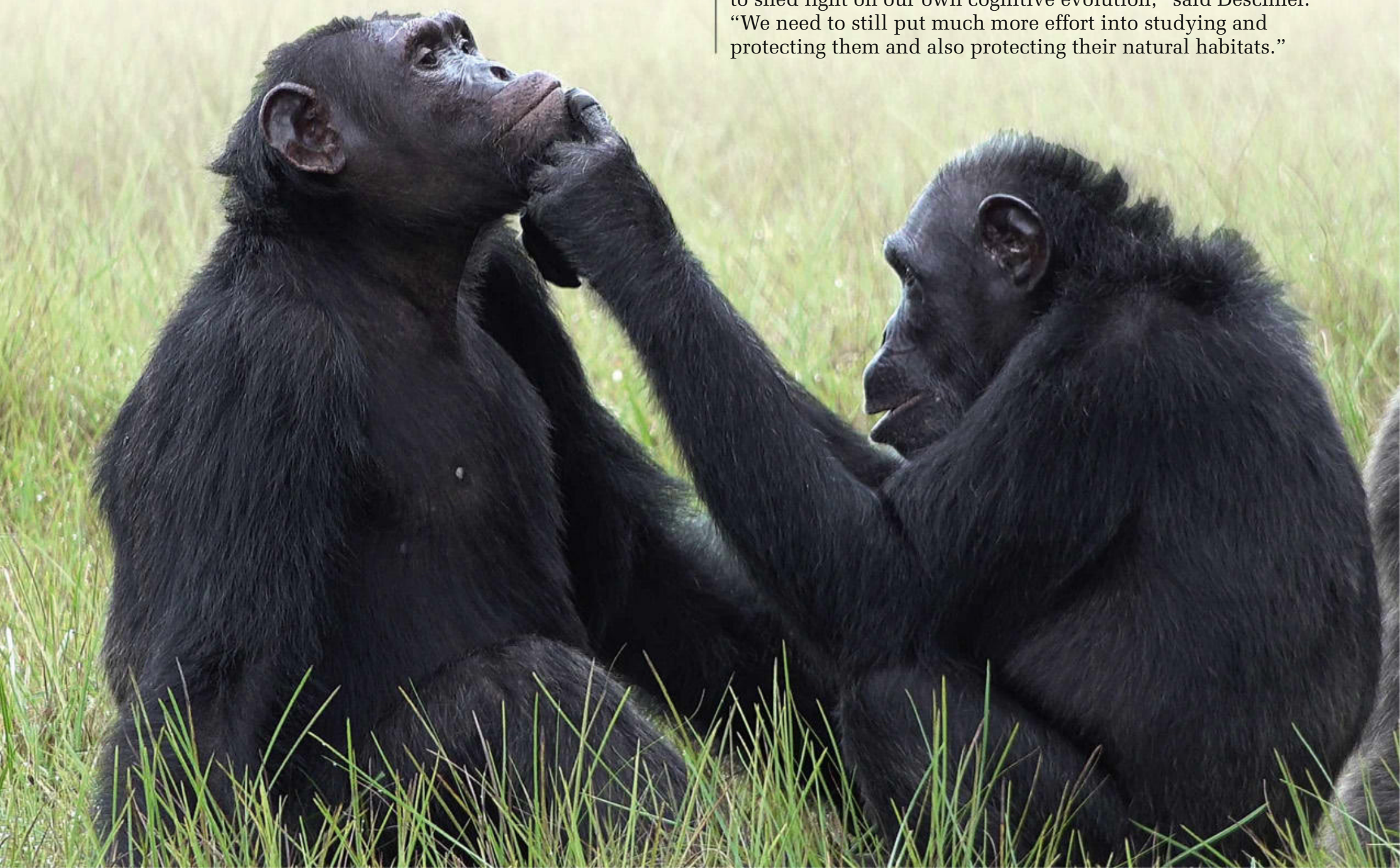
While animals such as bears, elephants and bees have previously been observed applying 'medicines' to themselves, this study marks the first time that animals have been seen treating the wounds of others.

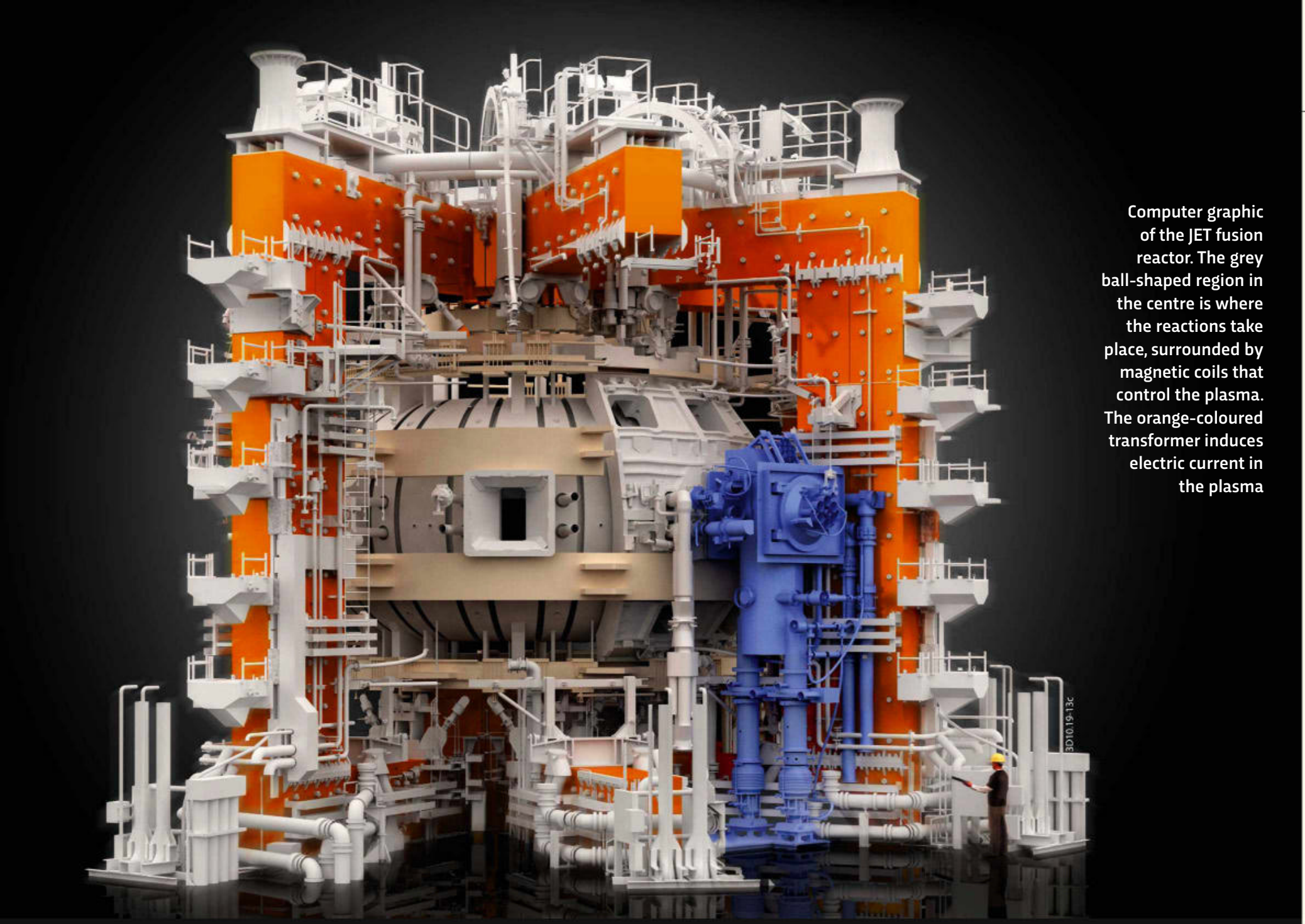
Pika argues that the act of applying an insect to treat another's wounds is a clear example of prosocial behaviour that echoes the acts of empathy displayed by human beings.

"This is, for me, especially breathtaking because so many people doubt prosocial abilities in other animals. Suddenly we have a species where we really see individuals caring for others," Pika said. "Humans use many species of insect as remedies against sickness – there have been studies showing that insects can have antibiotic, antiviral and anthelmintic [antiparasitic] functions."

The team now aims to identify the insects being used by the chimpanzees and investigate who is applying insects to whom to establish whether the behaviour is based on a hierarchy.

"Studying great apes in their natural environments is crucial to shed light on our own cognitive evolution," said Deschner. "We need to still put much more effort into studying and protecting them and also protecting their natural habitats."





Computer graphic of the JET fusion reactor. The grey ball-shaped region in the centre is where the reactions take place, surrounded by magnetic coils that control the plasma. The orange-coloured transformer induces electric current in the plasma

ENERGY

Fusion energy one step closer after Oxford reactor breaks record

UK-based JET facility has more than doubled the world record for nuclear fusion energy generation set in 1997

The long-standing dream of using nuclear fusion to create a safe, efficient supply of energy has come closer to reality. Scientists at the Joint European Torus (JET) near Oxford have used their reactor to generate the largest-ever amount of energy in a sustained fusion reaction.

In an experiment carried out in December 2021, the team used JET to produce 59 megajoules of heat energy over a five-second period. The previous record of 22 megajoules was set by JET in 1997.

"The record, and more importantly the things we've learned about fusion under these conditions and how it fully confirms our predictions, show that we are on the right path to a future world of fusion energy," said Prof Tony Donné, EUROfusion programme manager. "If we can maintain fusion for five seconds, we can do it for five minutes and then five hours as we scale up our operations in future machines."

Fusion is the process that takes place inside stars. It smashes together lighter atoms such as hydrogen at incredibly high temperatures to form heavier elements and release huge amounts of energy as heat.

The researchers say that the experiment's success sets the scene for the International Thermonuclear Experimental Reactor (ITER), which is a larger, more advanced version of JET. ITER is a global fusion project based in Saint-Paul-lès-Durance, southern France. It involves scientists from China, the European Union, India, Japan, South Korea, Russia and the US. Although it is much larger than JET, ITER plans to use the same deuterium-tritium fuel source and operate under similar conditions when it goes online in 2025.

"This is a big moment for every one of us and the entire fusion community. Crucially, the operational experience we've gained under realistic conditions gives us great confidence for the next stage of experiments at ITER," said Donné.

It is hoped that nuclear fusion will play an important role in addressing the effects of climate change, thanks to the low amounts of carbon it generates.

"It's clear we must make significant changes to address the effects of climate change, and fusion offers so much potential," said Prof Ian Chapman, the UK Atomic Energy Authority's CEO.

"We're building the knowledge and developing the new technology required to deliver a low-carbon, sustainable source of baseload energy that helps protect the planet for future generations. Our world needs fusion energy."

EUROFUSION, GETTY IMAGES

HEALTH

Nature lover? It may be written in your genes

A study of more than 1,000 sets of twins suggests that affinity for natural spaces is partially inherited from parents

Our love of the natural world is partially baked into our genes, a study carried out by researchers from the University of Queensland and the National University of Singapore suggests.

Using data collected by TwinsUK, the most detailed and extensive twin study ever carried out, the team compared the genetic heritability of two types of trait – how strongly a person feels connected to nature, and the amount of time they spend in nature – in more than 1,000 sets of twins.

They found that identical twins, who share almost all of their genes, were more similar to each other than fraternal twins, who share around half of their genes, in their appreciation of nature.

BELOW Genetics appear to play a part in how much we seek out outdoor experiences

This genetic influence was present in between 34 per cent for frequency of garden visits and 48 per cent for public nature space visits, they say.

"We were truly surprised by what we found," said study co-author Prof Richard Fuller, of the University of Queensland. "This means there may be innate genetic differences among people's psychological connection with natural environments and how they experience them. Our results help to explain why some people have a stronger desire than others to be in nature."

Previous studies have shown that the environment in which people are raised and live in, be it urban or rural, influences how strongly they desire to be among nature or seek out outdoor experiences, with those in more rural areas having a closer affinity with nature. However, this is the first study to suggest that genetics plays a role in how strongly we feel a connection to nature.

"Increasing accessibility to nature for urban residents through projects such as communal gardens will be beneficial"

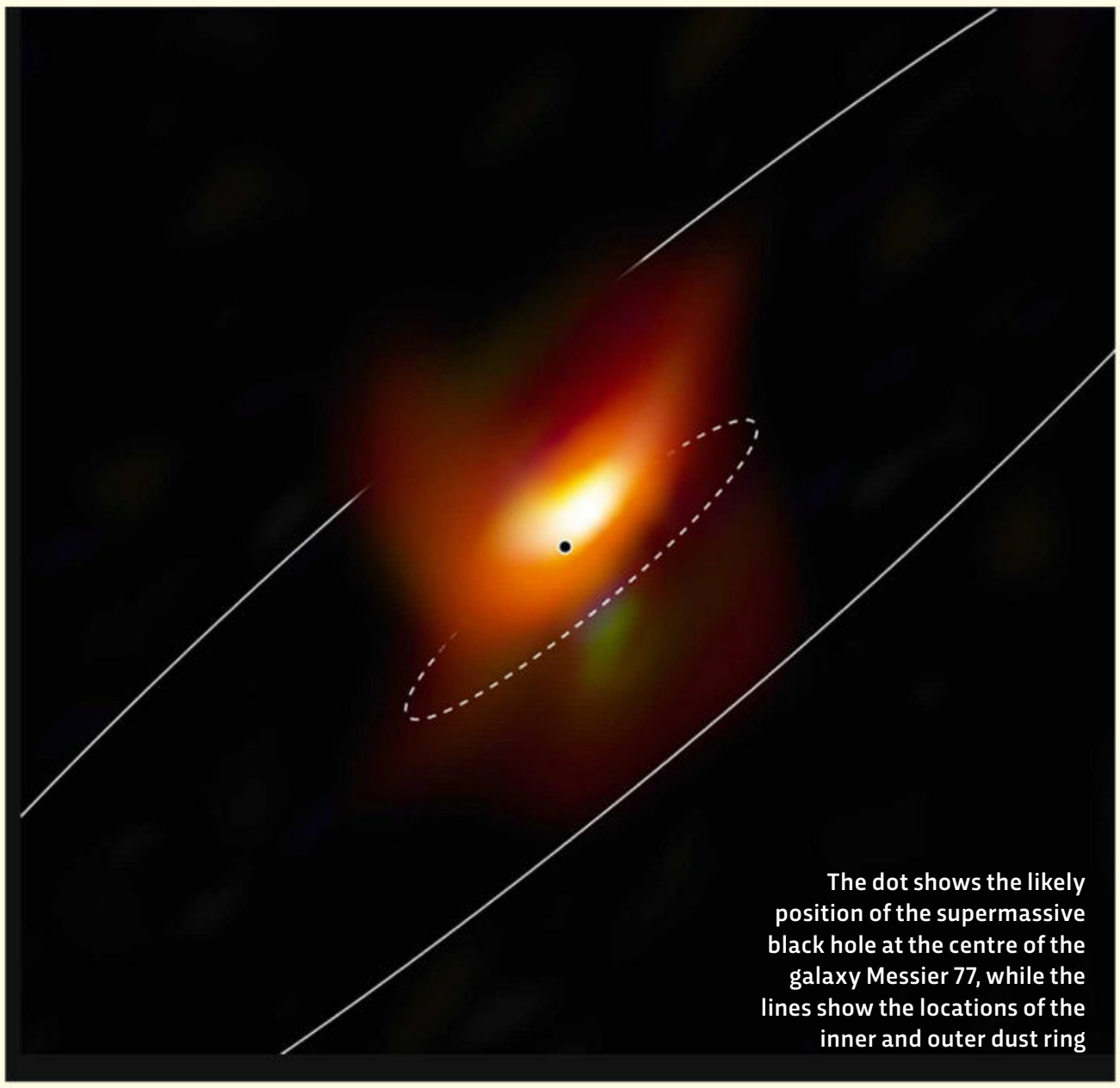
As more and more people living in urban areas are reporting lower levels of wellbeing, and are at a higher risk of mental health disorders such as depression and anxiety, the study highlights the importance of bringing people closer to nature, the researchers say.

"Spending a little time at home in the garden can be a great way to experience some nature, but this can't always be achieved, especially for those in urban areas," said lead author of the study Dr Chia-Chen Chang, of the National University of Singapore.

"Increasing accessibility to nature for urban residents through projects such as communal gardens will be hugely beneficial and will play an important part in improving people's wellbeing overall."

SPACE

New perspective of black hole confirms 30-year-old prediction



The dot shows the likely position of the supermassive black hole at the centre of the galaxy Messier 77, while the lines show the locations of the inner and outer dust ring

ESO/JAFFE/GAMEZ-ROSAS ET AL, GETTY IM AGES

Observations by Europe's Very Large Telescope could help us to shed light on the history of the Milky Way

Since they were first spotted in the 1950s, active galactic nuclei, or AGNs, have puzzled astronomers. In the night sky, an AGN is a bright, compact region at the centre of a galaxy that gives off much more light than would be expected to be produced by stars.

The source of this luminosity is thought to be supermassive black holes, or more precisely the matter that swirls around their edges at close to the speed of light before getting sucked into the black hole's event horizon.

Although it's thought that supermassive black holes are the source of all AGNs, it's not clear why some are less energetic (bright) than others. But now astronomers have their answer, thanks to some observations of a supermassive black hole in a galaxy not so far away.

The Unified Model of AGNs, which was first theorised 30 years ago, states that although some AGNs appear to emit radio bursts, others visible light, and others still X-rays, they all consist of supermassive black holes surrounded by a ring of cosmic dust that emit electromagnetic radiation not originating from stars. The difference in appearance between the AGNs is simply caused by the orientation at which we can see the black hole through the ring from Earth – some are more obscured by the dust than others.

Close-up observations taken by the European Southern Observatory's Very Large Telescope Interferometer (ESO's VLTI), located in Chile's Atacama Desert, have now provided evidence to support this model.

The team made the discovery by studying Messier 77, a spiral galaxy situated 47 million light-years away from Earth in the constellation Cetus, using the VLTI's Multi AperTure mid-Infrared SpectroScopic Experiment (MATISSE).

By mapping out the changes in dust temperature – which vary from room temperature to a blistering 1,200°C – caused by the radiation emitted by the black hole, they were able to piece together a picture showing where the black hole must lie. What they found was as predicted by the Unified Model: a supermassive black hole surrounded by a thick disc of cosmic dust.

"The real nature of the dust clouds and their role in both feeding the black hole and determining how it looks when viewed from Earth have been central questions in AGN studies over the last three decades," said lead researcher Violeta Gámez Rosas from Leiden University in the Netherlands. "Whilst no single result will settle all the questions we have, we have taken a major step in understanding how AGNs work."

The researchers are now looking to use ESO's VLTI to further confirm the Unified Model of AGNs by observing a larger number of galaxies.

"Our results should lead to a better understanding of the inner workings of AGNs," said Gámez Rosas.

"They could also help us better understand the history of the Milky Way, which harbours a supermassive black hole at its centre that may have been active in the past."

NEUROSCIENCE

Specific neurons in your brain only light up when you hear singing

Neuroscientists hope to learn more about what aspects of singing cause these neurons to respond in this way, building on earlier work investigating the relationship between music and the human brain

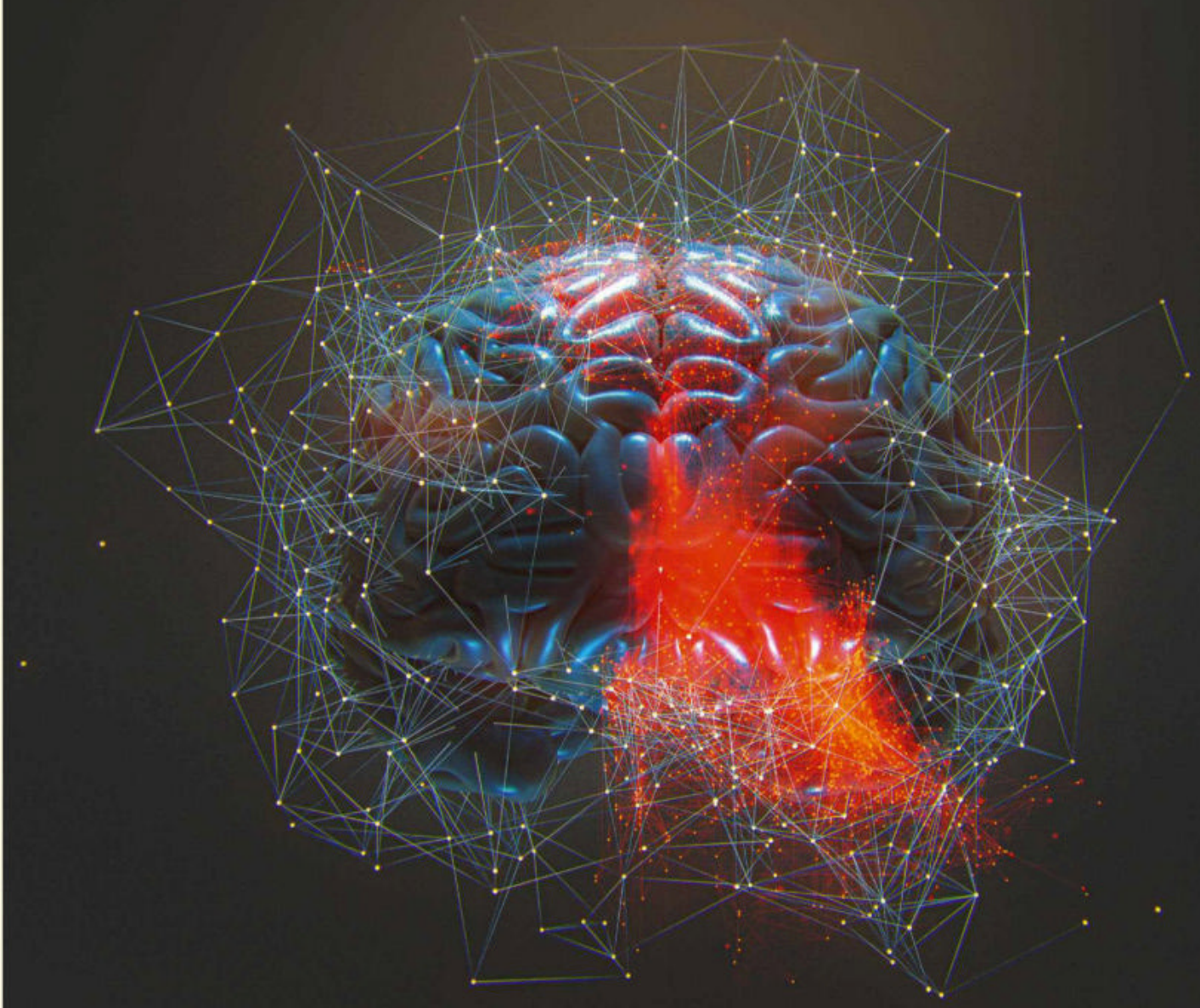
There are neurons in the human brain that light up when we hear singing, neuroscientists at Massachusetts Institute of Technology (MIT) have discovered, publishing their results in *Current Biology*.

Found in the auditory cortex, the part of the brain's temporal lobe that processes sound, these neurons appear to respond to the specific combination of voice and music, rather than just ordinary speech, or instrumentals with no vocals.

"The work provides evidence for relatively fine-grained segregation of function within the auditory cortex, in a way that aligns with an intuitive distinction within music," said lead author Dr Samuel Norman-Haignere.

These findings build on a 2015 study from the same team, where they investigated the relationship between music and the brain using functional magnetic resonance imaging (fMRI).

In this earlier research, the brain networks of professional composers were explored during music creation. The researchers found that when creating music, composers subconsciously rewire their brain. The parts they don't need – the neurons that integrate the visual and motor areas – are put to use on another job. It seems these neurons actually get to work enhancing the connectivity to between the two other areas typically responsible for emotion and imagination, the anterior cingulate cortex (ACC) and the default mode network (DMN) respectively. This suggests that when creating music, a specific brain state is formed that enables composers to integrate musical notes with emotion.



And now this new study takes the research one step further. Using a method called electrocorticography (ECoG), where electrodes are placed inside a person's skull, the researchers have been able to precisely record the electrical activity that occurs in the brain when listening to music.

"There's one population of neurons that responds to singing, and then very nearby is another population of neurons that responds broadly to lots of music. At the scale of fMRI, they're so close that you can't disentangle them, but with intracranial recordings, we get additional resolution, and that's what we believe allowed us to pick them apart," said Norman-Haignere.

In combining this data with that from the previous fMRI study, researchers were able to more accurately pinpoint the locations of these neurons that respond to singing.

The difficulty, however, comes with obtaining data using ECoG. Although accurate, it is an invasive procedure that involves placing electrodes directly onto the exposed surface of the brain via a craniotomy (a surgical incision into the skull), and as such, it's not one that's typically employed for brain research.

However, ECoG is used to monitor people with epilepsy prior to surgery, to determine where their seizures are originating. During this window a patient can opt-in to other studies that measure brain activity, such as this one.

Neuroscientists hope to learn more about what aspects of singing cause these neurons to light up. It is also hoped they can investigate how (and when) these brain regions develop, by looking at responses in infants.

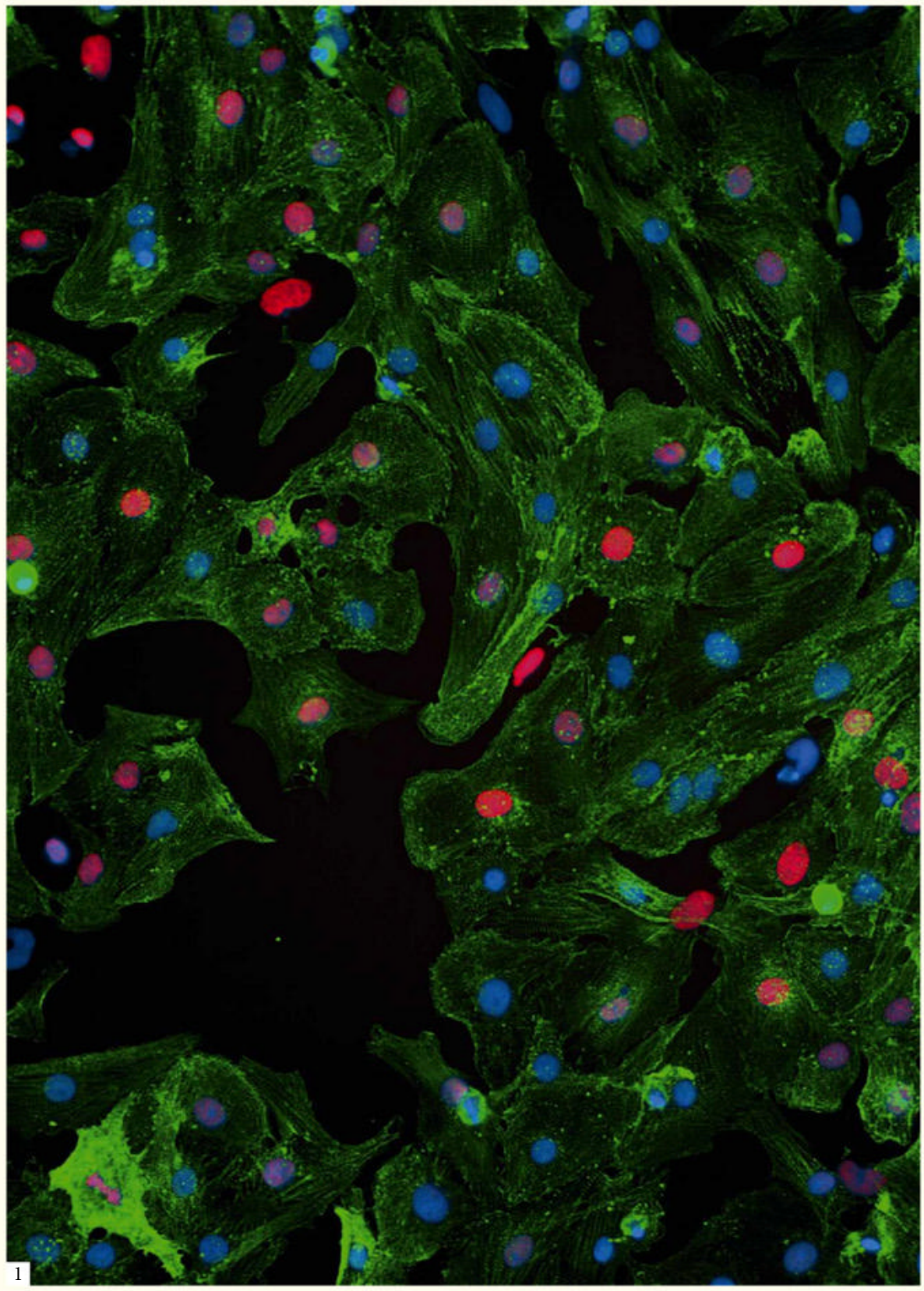
MEDICINE

Fixing a broken heart

These stunning images are some of the highlights from eight cutting-edge projects that will receive millions of pounds of funding from the British Heart Foundation (BHF) in 2022. The funding is going to be raised by the 2022 TCS London Marathon.

"BHF-funded research has spearheaded treatments to give people with heart failure longer, healthier lives, but there is no cure. Regenerative medicine offers that hope," said Prof Metin Avkiran, associate medical director at the British Heart Foundation.

"The money raised by the 2022 TCS London Marathon will enable these researchers to push the boundaries of medicine by finding ways to teach the heart to repair itself. Unlocking these secrets could help heal hearts and transform the outcomes for people living with devastating heart failure."



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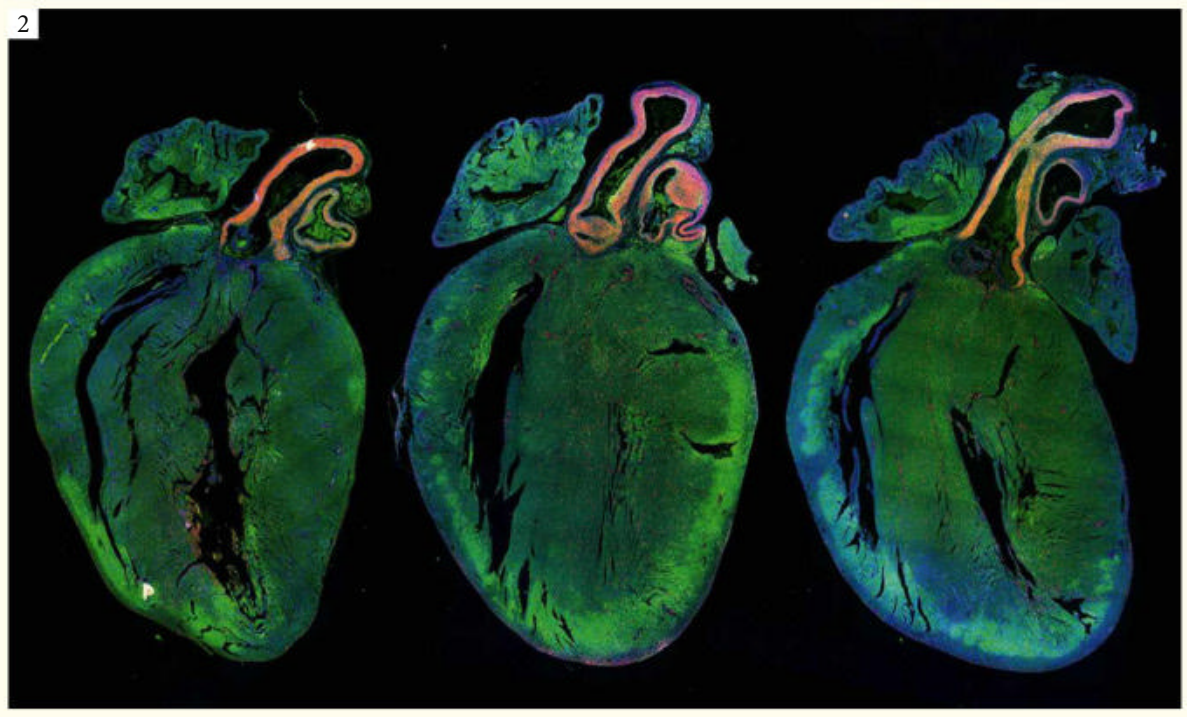


2

MARIO GIACCA X2, DR SARAH DE VAL, PROFESSOR SANJAY SINHA

1 & 2. Researchers at King's College London created these luminescent mouse hearts to demonstrate the effect of the microRNA technique they are developing to strengthen heart muscle tissue.

MicroRNAs are small molecules that regulate the expression of certain genes. The two hearts on the right of the second image have been injected with microRNAs chosen to stimulate the growth of heart cells, resulting in the development of much stronger muscle tissue – notice their thicker muscles and differing colours.

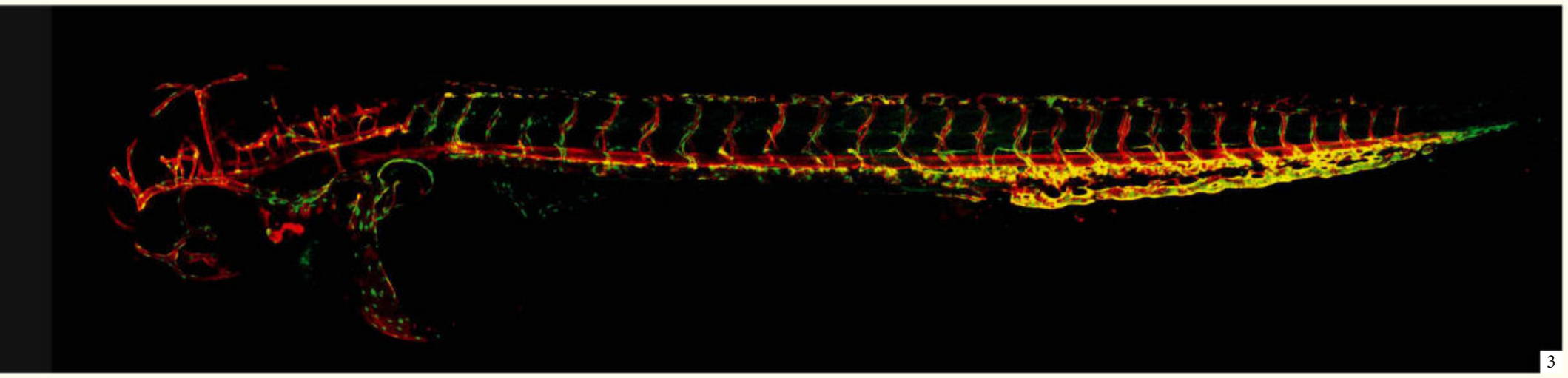
The red dots in the first image show which cells are multiplying to make the heart muscle stronger.

3. This image, taken by researchers at the University of Edinburgh, shows a two-day-old zebrafish that has been injected with different coloured proteins to highlight its complex array of veins, arteries and lymph vessels. The veins can be seen glowing green and yellow, while the lymph vessels and arteries can be seen in red.

The ultimate goal of the project is to develop methods of controlling blood vessel growth in human hearts.

4. This close-up image shows what could be one of the most technically advanced sticking plasters ever created. It was grown from stem cells by a team at the University of Cambridge and shows a patch of red heart cells peppered with white nuclei.

The patches could one day be applied to a damaged heart, much like a sticking plaster, to help it to repair itself.



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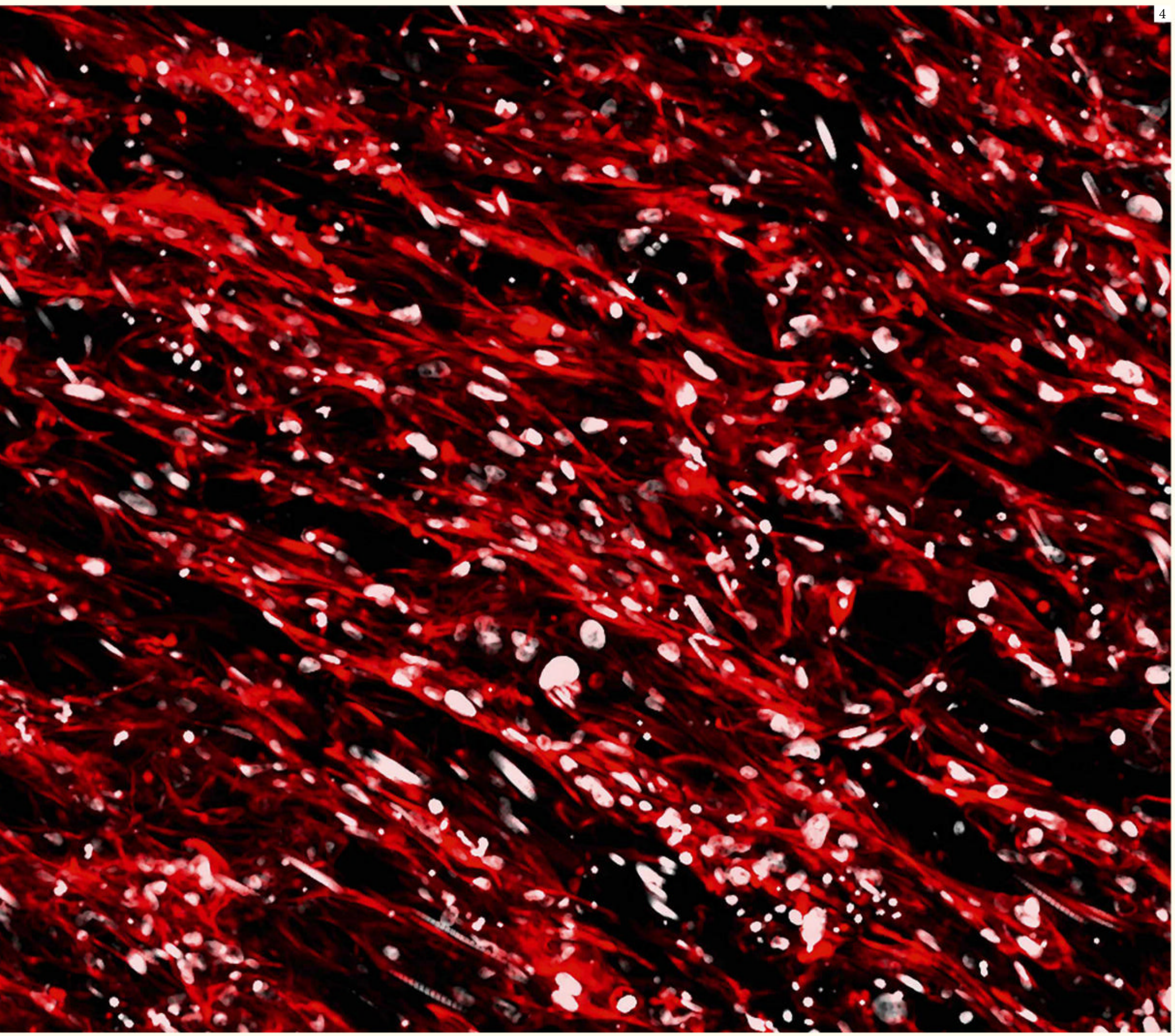

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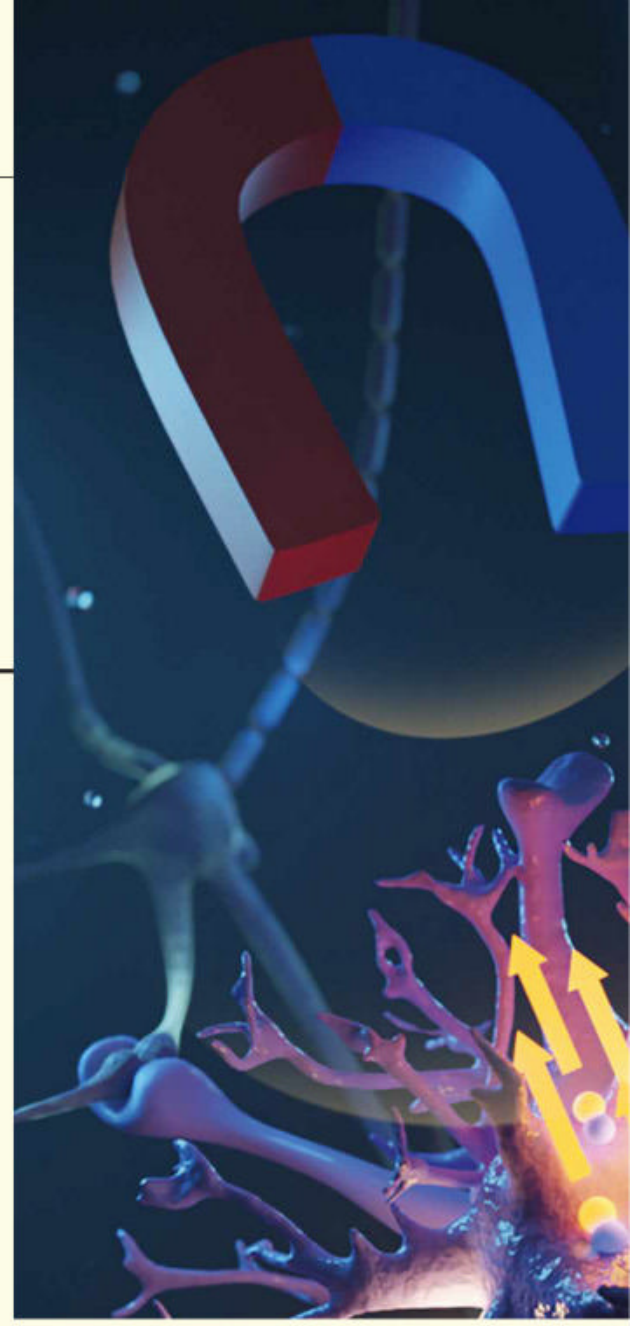
DR YICHAO YU AND PROF MARK LYTHGOE
Neuroscientists



Horizons

Using magnets to influence the brain could lead to revolutionary new depression treatment

The method, tested in rats, targets star-shaped brain cells called astrocytes. Neuroscientists Dr Yichao Yu and Prof Mark Lythgoe at University College London tell us more...

YOUR TECHNIQUE FOCUSED ON ASTROCYTES. WHAT EXACTLY ARE THEY?

Yichao Yu: They're a type of glial cell [non-neuronal cells that are found in the brain and spinal cord]. They're very abundant, they outnumber neurons [nerve cells] many times over. Traditionally they're viewed as support cells, they recycle the neurotransmitters that neurons release. They do many logistical maintenance jobs in the brain. But in recent years, as we've learnt more about these cells, we've found that they have many other functions, such as regulating cognitive behaviour.

Mark Lythgoe: For the last hundred years they've been the second-class citizen in the brain in terms of cells. Neurons have taken the limelight because they're electrically active [send electrical signals] and supposedly control all our functions. But astrocytes, although not electrically active in the same way, can communicate and sense and process and control bodily functions.

About 30 years ago, they were called the genius cell. This is because when Einstein died in 1955, his brain was taken out by the pathologist Thomas Harvey and it remained hidden for nearly 30 years. Harvey then started to release a couple of the sections to Marian Diamond, an amazing neuroscientist. She found that Einstein did not have more neurons in certain areas of his brain. He actually had more glial cells, and because of that they were known as the genius cell.

WHAT ARE THE MICROMAGNETS THAT YOU USE MADE FROM?

YY: They're very simple magnetic particles. They have a core that is made of iron oxide and a polymer shell, which enables us to attach various things to their surface. For example, we attach the antibody to the surface of these magnetic particles so that they will be targeted to astrocytes specifically.

THE MICROMAGNETS ARE INJECTED INTO THE BRAIN THROUGH A HOLE IN THE SKULL. BUT WHAT HAPPENS ONCE THEY'RE IN THE BRAIN?

ML: Astrocytes have all these finger-like projections that come off them, a bit like a Christmas tree. You decorate a Christmas tree with baubles, but in our case we use magnetic particles. They're bound to the Christmas tree by little hooks – antibodies that are specific to the branches of the astrocytes. When you put force on the baubles and move them [by applying an external magnetic field], they can sense this touch. The astrocytes are constantly feeling and sensing their environment.

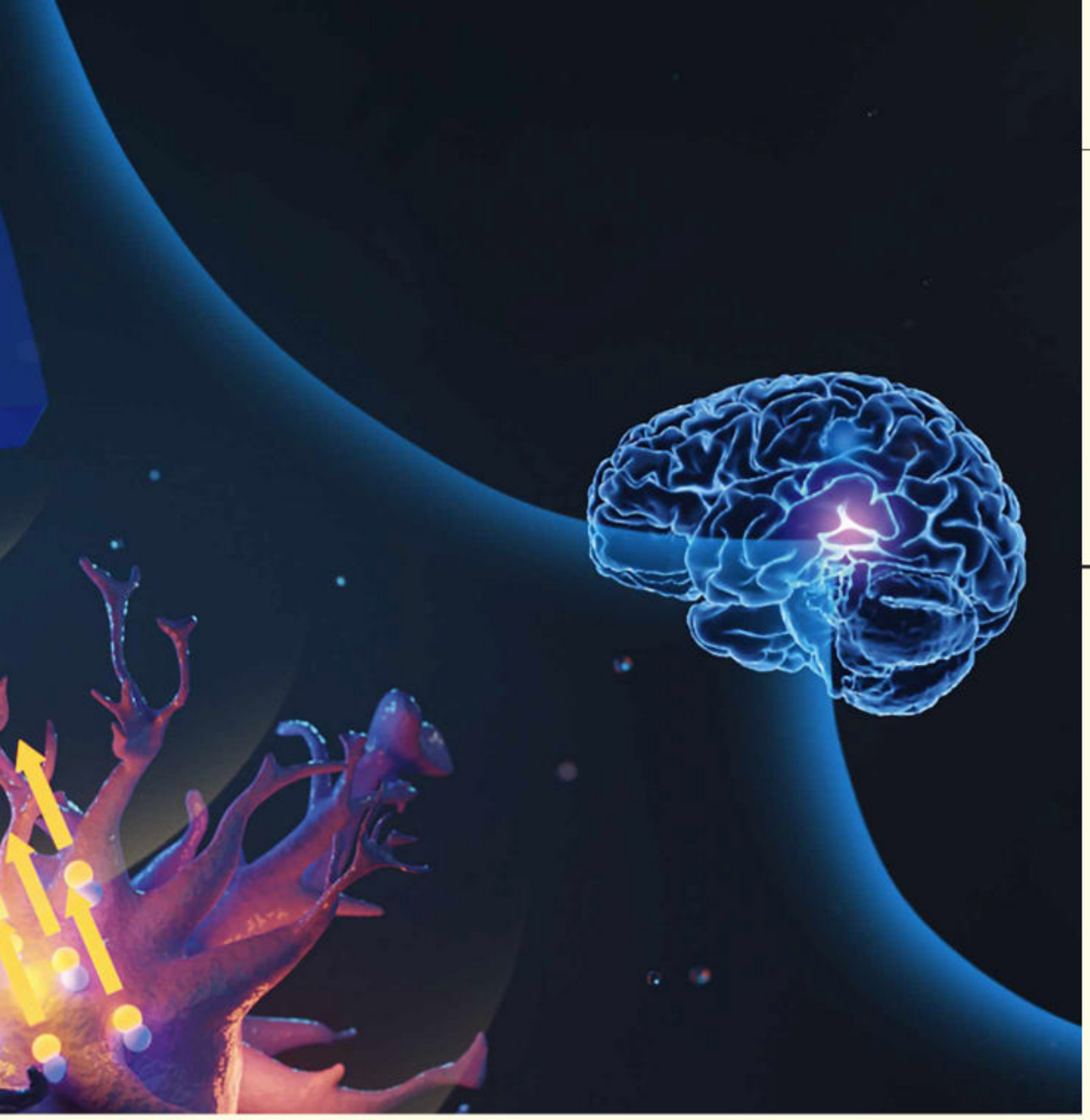
WHAT EFFECT DOES THIS HAVE ON THE BRAIN?

YY: We are trying to activate very specific signalling pathways. One is the release of a single molecule called ATP, adenosine triphosphate. Our collaborator Prof Alex Gourine previously discovered a small region within the brainstem that acts like a master regulator of sympathetic neural activity, which is the part of the autonomous nervous system that controls your fight and flight responses. He found that if you stimulate astrocytes in this region of the brainstem, you release ATP. The ATP then acts on the neurons in that area, which then directly stimulate the sympathetic nervous system and cause heart rate and breathing rate to increase, and blood pressure to rise.

So what we found in this study is that if we target those specific astrocytes with micromagnets, we saw the same response he saw.

WHAT ARE THE ADVANTAGES OF THIS TECHNIQUE?

ML: Deep brain stimulation is used



Magnetic particles bind to star-shaped astrocyte cells within the brain and can then be stimulated by an external electric field

YICHAO YU/MARK LYTHGOE/UCL

“We want to be able to stimulate cells without inserting anything into the brain”

remarkably widely and with great success for treating Parkinson’s, epilepsy and depression. But this involves inserting two long electrodes deeply into specific regions of the brain and requires a complex and lengthy neurosurgical procedure. And then you’re left with a second procedure where you have to implant the electrodes that come out of the back of the head under the skin into a powered box that lives underneath the collarbone. The simple notion of just being able to have an external magnet that you can bring in contact with the particles to get the same effect as the electrical stimulation is really appealing because it doesn’t have the invasive complexities of this full-on neurosurgical procedure.

The other thing with deep brain stimulation is that it will activate anything with which it comes into contact, whereas we’re trying to be very specific and selective, just targeting the astrocytes.

YY: The other advantage is that to implement our technique the target cells don’t have to be genetically modified. Currently, some of the most widely used cell-control technologies, such as optogenetics and chemogenetics, require a protein to be inserted into the cell membrane of the target cells, usually with the help of virus. This has been a slight obstacle to clinical translation and led us to develop our technology.

WHAT CONDITIONS COULD THIS TECHNIQUE BE USED TO TREAT?

YY: One is depression. We are interested in that because there has been some very robust evidence in animal models to show that ATP from astrocytes has strong antidepressant effects. As we have shown that we can cause the astrocytes to release ATP in whichever brain region we target, our technique will be a very good candidate for the development of therapies for major depression – the kind that’s resistant to common antidepressants. That’s one of the most promising applications in terms of the clinical development in the near future. But there are other things as well, because astrocytes do all sorts of things in every area of the brain.

ML: It could be used post-stroke. The release of the ATP would hopefully mop up some of the toxic molecules that lead to inflammation and therefore reduce the overall size of the stroke damage. This could be the same for epilepsy as well. Epilepsy is also [currently] treated by deep brain stimulation, and we could see this as a replacement.

WHAT’S COMING UP NEXT?

YY: In its current form we still need to drill a hole in the skull and insert a needle to inject the particles into the target brain region. Our next step would be to employ a more advanced particle delivery approach so that we don’t have to do brain surgery at all. This will further reduce the invasiveness of the technique.

ML: What we’re looking for is a trapdoor into the brain. We can do that with ultrasound. We can decide exactly what parts of the brain we want to target, and then fire focused ultrasound at them. This creates a slight weakness in the brain lining that opens for a short period of time, then the particles can rush in and because they’ve got the antibodies on them can bind to the astrocytes. Then the trapdoor closes and we can do the magnetic activation, all with a single intravenous injection.

DR YICHAO YU
Yichao is a research associate at the UCL Centre for Advanced Biomedical Imaging.

PROF MARK LYTHGOE
Mark is the founder and director of the UCL Centre for Advanced Biomedical Imaging.

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REALITY CHECK

SCIENCE BEHIND THE HEADLINES

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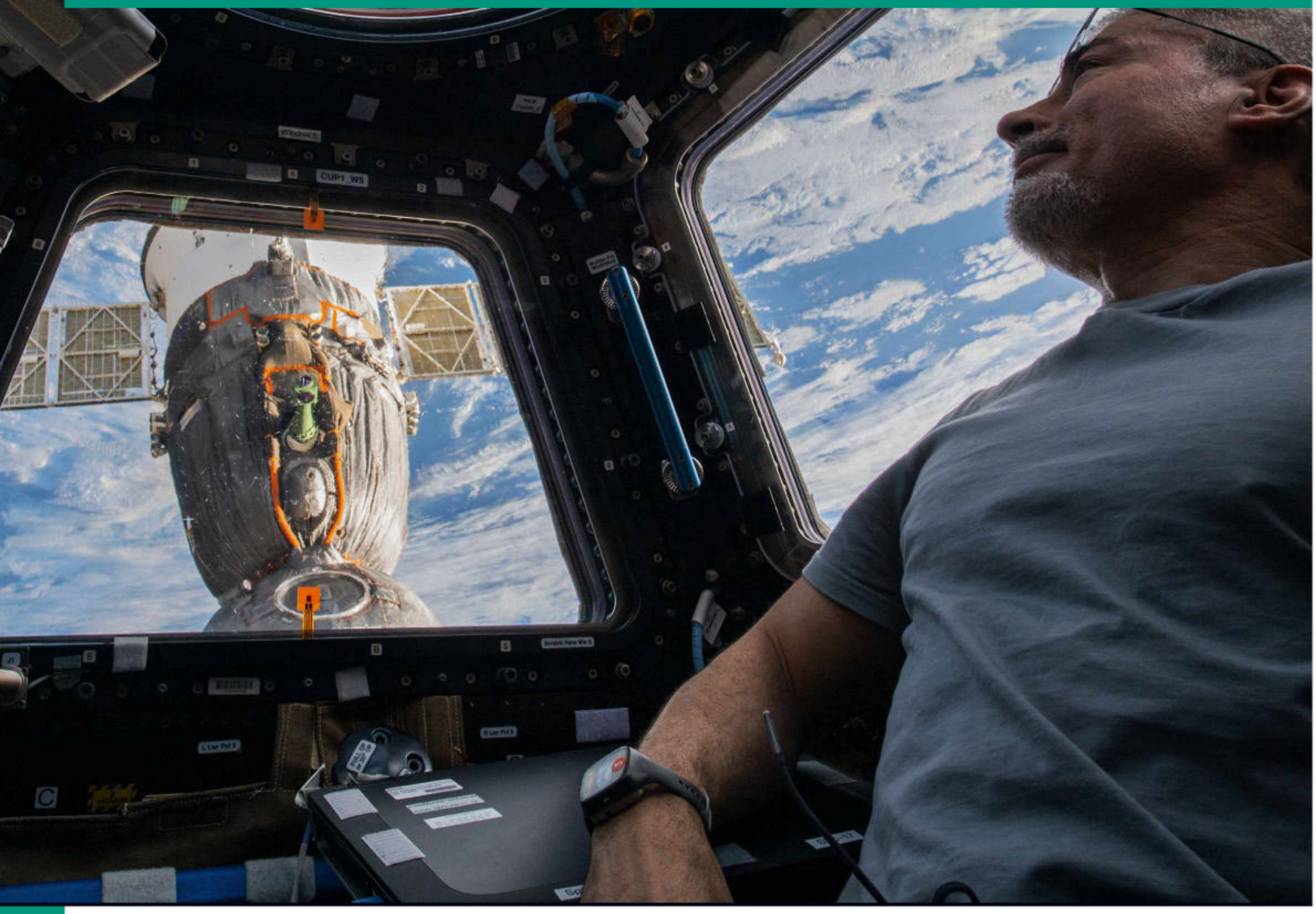


REVIEW

THE INTERNATIONAL SPACE STATION: WHY IS IT BEING RETIRED AND WHAT WILL HAPPEN TO IT?

The last decade of the ageing space station's life will feature private occupants, movies and an eventual watery grave

"There are some adults who can now say that there has been someone in space for every single day of their lives"

BBC

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

It is one of the most iconic pieces of space hardware in history, but the days of the International Space Station are now officially numbered. NASA has announced that the curtain will finally fall on the ISS in 2031. The football-pitch-sized orbit outpost will be decommissioned and brought crashing back to Earth before splashing down in the Pacific Ocean.

HOW LONG HAS THE ISS BEEN UP THERE?

The ISS has a rich history. The first segment was launched in 1998 and it has been continuously inhabited since November 2000, with crews of astronauts swapping in and out for typical six-month stays. There are some adults who can now say that there has been someone in space for every single day of their lives.

It was designed as a home from home. A tentative first toe into the celestial waters. A place to test out how to live in space for months at a time, while relatively close to the safety of the Earth. The lessons we've learned about living in microgravity have set us up with the confidence to return to the Moon later this decade and then to venture out to Mars after that.

WHY IS IT BEING DECOMMISSIONED?

As with everything in life, nothing can last forever. In September last year, Russia warned that at least 80 per cent of its section has in-flight systems that are past their expiry date. Cracks have started to appear in the Zarya cargo module. There have also been air leaks in the crew's living quarters.

This structural fatigue is part of the reason the ISS will be vacated in 2030 and de-orbited the following year. NASA made this plan official in January when it released an updated International Space Station Transition Report.

WHAT'S NEXT FOR THE ISS?

With eight years left before the last crew leaves, there will now be a shift in emphasis. The last few years have seen a growing collaboration between publicly funded space agencies like NASA and privately owned businesses like Elon Musk's SpaceX.

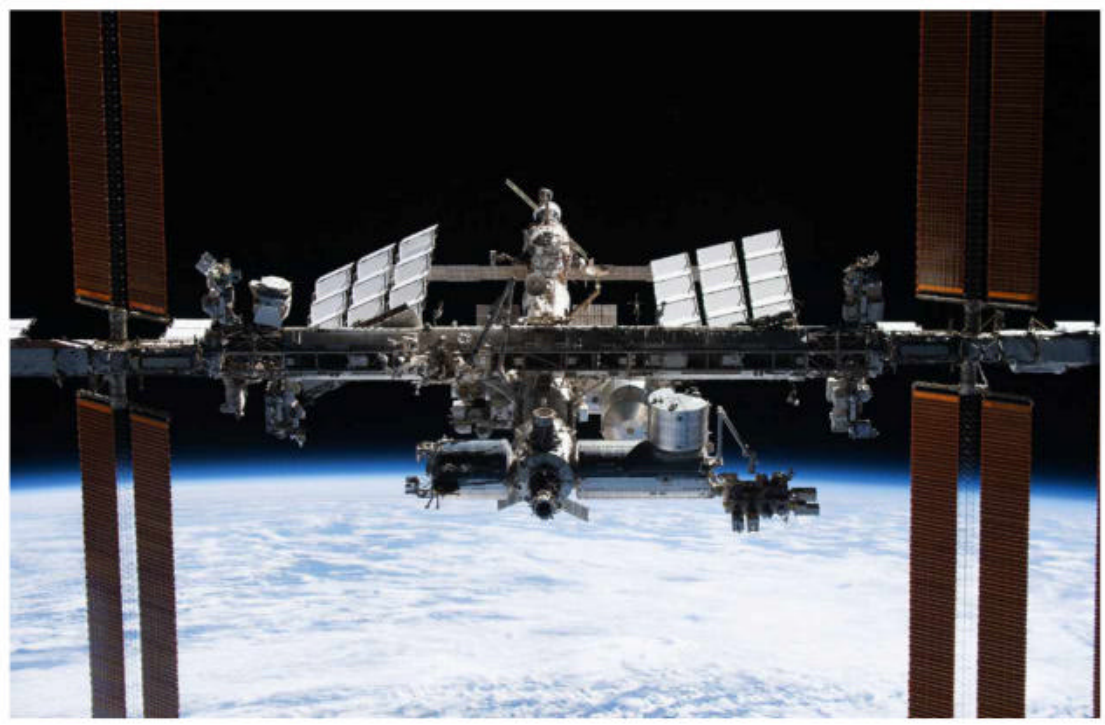
The rest of the 2020s will see the increasing commercialisation of the ISS, with habitable modules available for private space travellers to stay in. December 2024 should see the launch of a six-metre-wide film studio called Space Entertainment Enterprise-1 (SEE-1). It will be a place to make Hollywood blockbusters in a weightless environment, with Tom Cruise widely reported to be shooting a film there.

Then comes the tricky part: what to do with it. Leaving it in space would pose a significant danger. The ISS is the biggest thing orbiting the Earth after the Moon. If it was hit by a piece of space junk it would create a shower of debris that would threaten all of our satellite infrastructure in low-Earth orbit.

So the ISS will join a host of other retired space hardware in a watery grave in the Pacific Ocean. It will be brought down in place known as Point Nemo, or the Oceanic Pole of Inaccessibility. Situated between New Zealand and South America, it is 2,688 kilometres (1,670 miles) from the nearest land, so the falling debris poses little danger to humans.

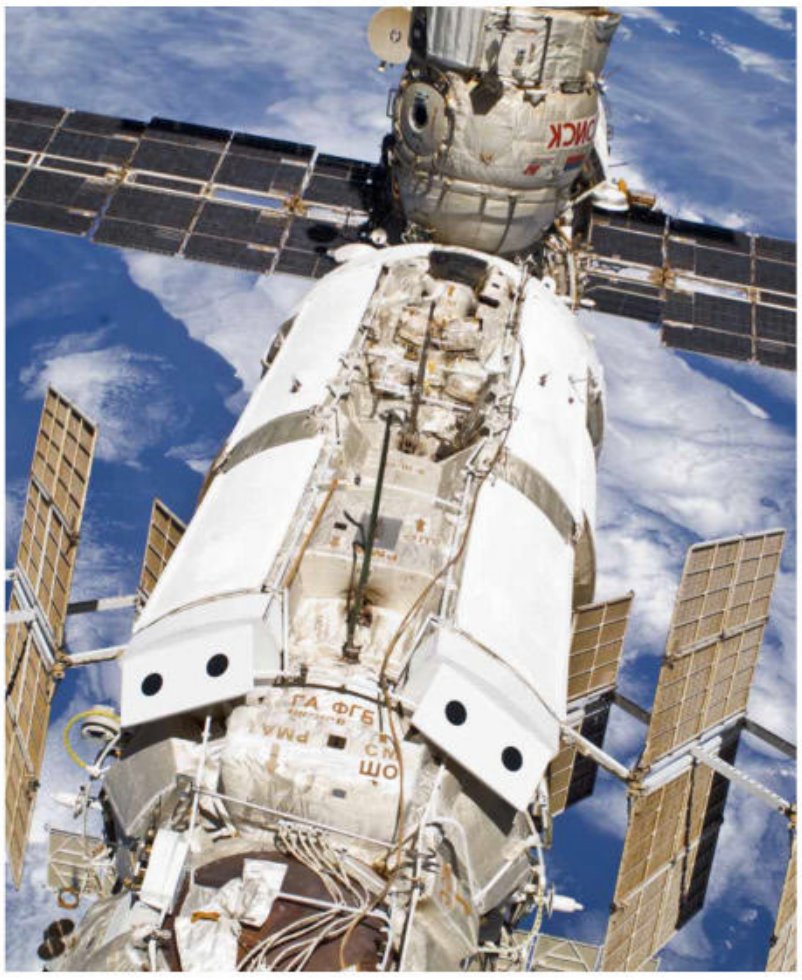
WHAT WILL THE ENVIRONMENTAL IMPACT BE?

"There are potential impacts to the marine environment," says Dr Vito de Lucia, from the ➤



NASA/ESA X2

The ISS has allowed us to carry out important research, but has also helped us prepare for exploration of the Moon and beyond



The main portion of the ISS's Zarya cargo module, which is now starting to show cracks

Norwegian Centre for the Law of the Sea, and co-author of a report into protecting the marine environment in the so-called spacecraft cemetery. "But those seem to have been generally neglected by space agencies."

One key issue is that toxic or radioactive materials may survive atmospheric re-entry.

"Once the debris enters the ocean, it would be expected to settle to the ocean floor and some would become encrusted and incorporated into the sediments," a NASA spokesperson says. "Although unlikely, some leakage could occur from previously sealed containers that remained intact through re-entry and impact. However, no substantial long-term impacts would be expected."

That may not be the end of the matter, however. de Lucia says that a new international treaty is currently being negotiated to tackle the issue of marine biodiversity conservation in areas which are in international waters, like Point Nemo.

"This new treaty may be adopted and perhaps even enter into force within a time frame relevant to the re-entry of the ISS," he says.

Whatever its ultimate fate, the ISS has paved the way for the future of human space exploration. NASA is planning to build a similar station – called Gateway – in orbit around the Moon. Astronauts will live and work there, using it as a staging post for trips to the lunar surface. That wouldn't be possible without the valuable lessons we've learned from the ISS.

—

by **COLIN STUART** *(@skyponderer)*

Colin is an astronomy writer and speaker.

ANALYSIS

LONDON TUBE: DOES ITS AIR HARM YOUR HEALTH?

The Mayor of London hopes that 80 per cent of trips in the city will be made on foot, bike or public transport by 2041. But how polluted is the Underground's air?

On any given weekday, the London Underground can see up to five million passengers hopping on and off. Its 11 lines serve 272 stations, and at peak times there can be more than 500 trains hurtling around beneath the streets of London. As it's been in constant use since the 19th Century, the London Underground has remained largely the same, and hasn't been updated or researched as much as other forms of transport.

The pandemic did provide Transport for London (TfL), which manages the London Underground, the opportunity to make some improvements. Ventilation

NASA/ESA, SHUTTERSTOCK

ABOVE The London Underground's air quality is affected by emissions in the city, as well as particles that come from the trains and passengers themselves

systems were assessed and, according to the Mayor's Transport Strategy Update in 2021, "the London Underground ventilation infrastructure is typically designed in excess of statutory minimum requirements with an adequate provision of fresh air."

But how fresh is the air you're breathing on the Tube?

"The air, even before it gets to the Underground, isn't perfectly clean," explains Dr David Green, who leads the aerosol science team at Imperial College London and is a member of the UK's Committee on the Medical Effects of Air Pollution (COMEAP). Green is also part of a group commissioned by TfL to regularly assess the COVID-19 risk on the Underground.

"The urban background air already has a low level of particulate matter, but on top of that you have all these extra emissions [coming from the Tube]," he adds.

These include particles that come from the carriage moving along the rails, the brake blocks rubbing on the wheels, and the electrical connection between the collector plate and the live rail. There are also particles that come from Tube passengers, human and otherwise. Hair and skin cells, plastic fibres from clothing, and debris from the creatures that call the Underground their home all contribute to the air quality.

"It is much better that people get on the Underground than to get in their car to move around London"

Some particles are large enough to be caught by the hairs in our nose and throat, stopping them from getting into our lungs and causing damage. This particulate matter is less than 10 micrometres in diameter, or roughly 0.01mm, and is known as PM10. The smaller particles that are under 2.5 micrometres in diameter are referred to as PM2.5, and these are the ones that can penetrate deep into the lungs and may also enter the bloodstream to be transported around the body, affecting the brain, heart and other organs.

UK exposure values for PM2.5 are still higher than the guidelines set by the World Health Organization (WHO), which recently changed its target to an average yearly exposure not exceeding 5 micrograms per metre cubed (µg/m^3). Previously, this was 10µg/m^3. The European Union limit is 25µg/m^3, which is also the limit put in place by UK law.

"The new WHO guideline is very challenging and currently I don't think any location in the UK will meet this," says Green. According to the latest COMEAP study, concentrations of PM2.5 on the London Underground were many times greater than in other London transport environments, and greater than on other subway systems around the world.

CHOOSE YOUR TRANSPORT

However, when thinking about the air quality in the Underground, Green said it's important to consider the context within the range of transport modes. A report in 2021 compared the PM2.5 averages across the Tube, bus, car, three types of trains, cycling and walking. Interestingly, the lowest exposures were found on electric and hybrid-style trains, even compared to cycling and walking, though this was not the case when these trains were in stations alongside diesel-powered trains.

"[Travelling on the Tube] for one hour every weekday for 48 weeks a year on the Victoria line would increase your annual exposure to PM2.5 by 6.8µg/m^3. This increase is on top of individuals' usual exposure to pollutants in the air, which varies by location," says Green. "This compares to 1.2µg/m^3 in a car. But remember the car pollutes everyone else as well."

For Green, this is key. "It is much better that people get on the London Underground than it is for them to get in their car to move around London. That's because if you're sitting in your car, you're exposed to very high concentrations of vehicle pollutants.

You're sitting directly behind the exhaust of the car [in front], so you have a higher exposure than cyclists riding along the road or the pedestrians walking past. And the other thing is you're also polluting the world for everybody else. So, while the car isn't worse than the Tube in the case of PM2.5, it is much worse for other pollutants like nitrous oxides."

For those who do have to travel on the Tube, it becomes a matter of choosing the best route. Green's research found that lines that run deeper, like the Northern line, are generally worse than higher level lines like the Circle, District, Hammersmith & City, and Metropolitan lines. Older lines and the type of trains used all play a part, so Green suggests opting for newer lines and stations that have platform doors installed to reduce exposure. However, he does admit that sometimes there isn't a lot of choice.

Green is also concerned with the health of the staff on the London Underground. Unfortunately, there isn't enough data to say yet what the long-term health impacts of working on the Tube will be.

"We're working closely with Transport for London to compare sickness absence from people working in London Underground with other TfL workers," he says. "We also want to look at pension data, to see if people who work on the Tube may die a little earlier than people who don't. But [these studies] are in the early stages at the moment."

Tube passengers can be reassured that the risk of catching COVID-19, however, is minimal.

"Tube trains and stations are cleaned with hospital-grade cleaning substances that kill viruses and bacteria on contact and provide ongoing protection," a TfL spokesperson told *BBC Science Focus*. "Independent testing by Imperial College London has been carried out monthly since September 2020, taking swabs of touch points in stations, on buses and of air samples in ticket halls and up to the last verified testing round in December 2021 has found no traces of coronavirus on the public transport network."

—

by **AMY BARRETT**

Amy is the editorial assistant for BBC Science Focus.

COMMENT

RENEWABLE ENERGY: WHY CAN'T IT KEEP UK ENERGY PRICES DOWN?

Huge increases in gas prices have sent UK bills skyrocketing. Can green energy offer a solution?

From April 2022, average household energy bills will jump by more than 50 per cent as a result of energy providers having to swallow massive increases in the cost of gas. Gas supplies come from global supply chains that are subject to changing market demands and regional geopolitics. And the pandemic, of course, has created all kinds of anomalies.

But why, in an age of renewable energy, is the UK still at the mercy of gas prices? The contribution to UK power generation from renewable sources has more than doubled since 2014. Yet we're in a situation of dependence on fossil fuels that is going to put a serious strain on people's finances for the foreseeable future.

The most obvious explanation is that the capacity of our renewable sources isn't yet big enough. The contribution to the National Grid averages around 40 per cent, mostly from wind power and solar, biomass and hydroelectricity.

Renewables don't contribute more for very good reasons. By using fossil fuels we have been able to meet variations in demand for power by turning more power stations on or off, or running them harder or slower.

With renewables we are always dependent on weather conditions. For example, the third quarter of 2021 saw energy prices rise because of a lack of autumn winds. Renewable electricity production dipped by 17 per cent on the previous year and gas had to come to the rescue.

Interseasonal storage remains a core challenge for the renewable energy industry. At any one time huge amounts of energy need to be shunting around the UK's National Grid – an average of more than 30 Gigawatts, rising to more than 40 Gigawatts at peak times.

For the nation to be able to rely on renewable power, there would need to be massive banks of batteries to cope with the overcast, still days. Even then, this system would only work for a few days. The technology isn't yet available to allow for a week or a month of unreliable conditions. At present, we still need fossil fuels to meet the expectations of power being available whenever we demand it.

GETTY IMAGES X2

"With renewables we are always dependent on weather conditions. For example, the third quarter of 2021 saw energy prices rise because of a lack of autumn winds"

ABOVE We cannot depend on solar or wind power without more battery storage on the energy network

One solution to price hikes would be to have more control over our 'locally-grown' gas. After all, around half of our gas supply comes from the North Sea – 30 per cent is imported from Norway, the rest from around Europe.

But the UK has to buy its gas as an international commodity on the global market. We pay a global price that's subject to the behaviour of other buyers and sellers, and are open to the global context of threats and risks.

Some practical supply chain issues have been a problem as COVID-19 affected the ebb and flow of gas supplies. When industrial production shut down globally, gas and oil tankers were left sitting around. Now tankers have been rushing to service Asia where the greatest surge in demand occurred. The US ramped up its exports of liquefied natural gas to Europe, to prevent Europe from being held to ransom.

Global production could be increased to make gas supplies settle and prices come down, but where are the incentives for an energy industry that is enjoying the profits from sky-high prices?

The UK could think long-term about localism to minimise its exposure to global markets. That means renewing our belief in the value of distributed contributions to the National Grid, supporting household, local community and residential-scale developments. In this way, individual households would take back control and choice over what they paid for their energy by producing some for themselves. If more people put solar panels on their roofs and had a smallish battery for storage, they could reduce their grid-supplied energy needs, lowering demand for gas and cutting emissions. We could start to change the structure of energy demand and move wholesale to a model of distributed generation.

Reduced dependence would also come from improving the UK's old and leaky housing stock, with more incentives and private and public money going into insulation of roofs, walls and windows, rather than emergency payments to offset big energy bills.

The easiest win of all would be to introduce more progressive planning rules, by insisting all new houses are built with energy efficiency in mind: brilliant insulation, solar panels, car-charging facilities, energy storage and heat pumps. Every new home becomes its own little castle of energy generation and efficiency.

The sight of bills in the coming months, and maybe years, should be quite enough motivation to encourage investment into a personal and national energy independence. **SF**

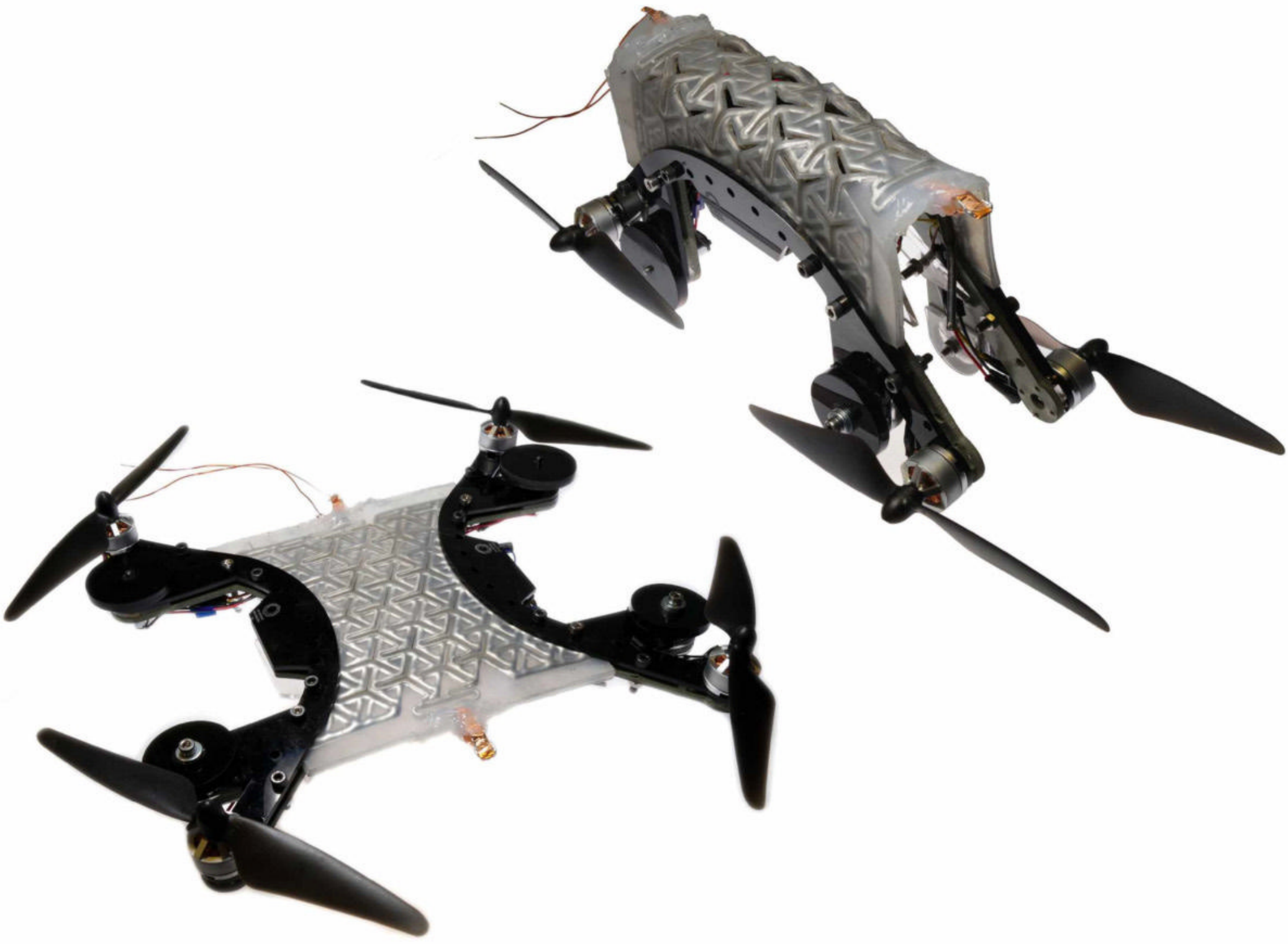
by **PROF PHIL HART**

Phil is the director of energy and power at Cranfield University. He has held a number of senior roles within the energy and power sector in the UK, Asia and North America.

Finally, a handheld console for PC gamers p40

INNOVATIONS

PREPARE YOURSELF FOR TOMORROW



ROBOTICS

Transformers... activate!

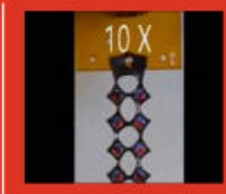
Shape-shifting tech inspired by kirigami allows robot to change shape and function

WOUND HEALER

Using shape memory polymers (SMPs), a scientist at Virginia Tech has developed a material that can be formed into a temporary shape when exposed to heat. This could be applied to an injury where it would expand out to fill the wound when it reached body temperature.

INSPIRED BY NATURE

In a study published by the American Chemical Society, researchers printed liquid metal circuits onto a piece of polymer that curls under pressure. It could be used in soft robots to mimic behaviours seen in nature. This is normally hard to do, due to the clunky machinery that is needed.



ENERGY COLLECTOR

Researchers from the University of Massachusetts Amherst have created a rubber-like solid, capable of absorbing and releasing large amounts of energy. This could be used to enable robots to have more power, or even on helmets and armour to dissipate energy.

This new soft robot (pictured left) can morph from a four-wheeled car into a drone and back again, with the application of a little heat.

To create this bot, a team at Virginia Tech needed to develop an entirely new type of flexible material.

"When we started the project, we wanted a material that could do three things: change shape, hold that shape, and then return to the original configuration, and to do this over many cycles," says Michael Bartlett, an assistant professor who led the team.

"One of the challenges was to create a material that was soft enough to dramatically change shape, yet rigid enough to create adaptable machines that can perform different functions."

To achieve this, the team took inspiration from kirigami – the Japanese art of making shapes out of paper by cutting and folding. Kirigami differs from origami, which only uses folding. It is popular among engineers since it gives paper the ability to support many times its own weight with the help of some smart geometry.

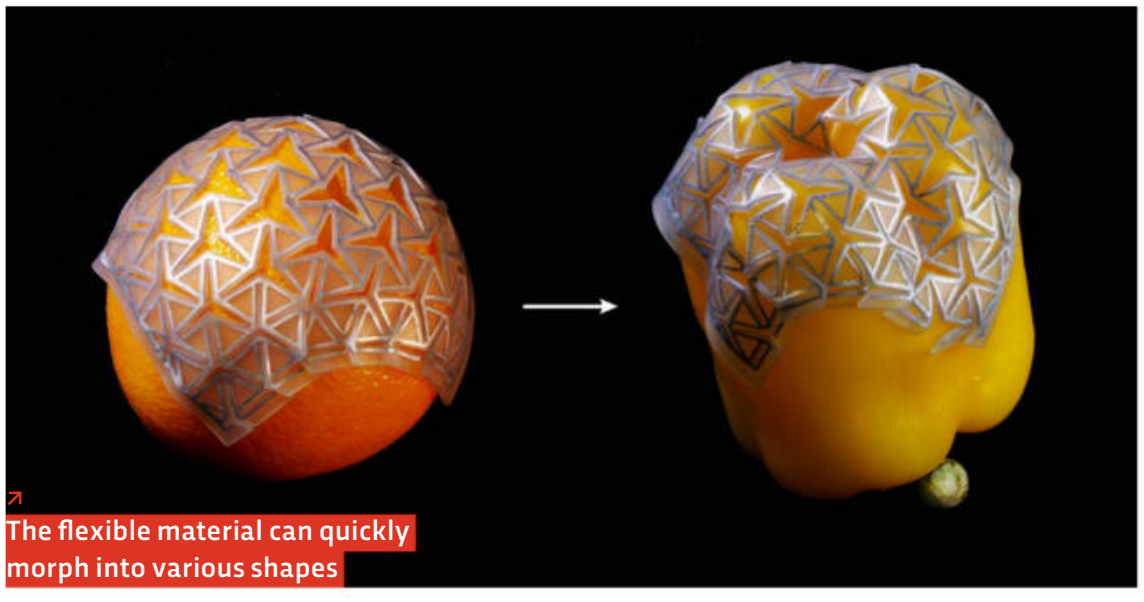
The final design was a kirigami-inspired grid of repeating geometric patterns, made of metal alloy. The alloy used was chosen for its low melting point of 60°C. Tendril-like heaters were woven around this frame so that an operator could apply heat to melt the metal and turn the material back to its original shape. The metal grid was then embedded into a rubber skin. The device could change and fix into place in less than one-tenth of a second, and the alloy was strong enough to repeatedly retain its desired shape, despite being stretched every time it transformed.

"These kirigami-inspired cuts, combined with the unique properties of the materials, were really important to morph, fix into shape rapidly, then return to the original shape," said Dohgyu Hwang, a graduate student who co-authored the paper.

The material was used to create various complex shapes, including a car (pictured left) that could rapidly transform into a drone.

Looking to the future, this technology has clear potential. As well as a car-to-drone transformer, the team produced a prototype submarine that could retrieve objects from an aquarium by morphing its belly around a target item.

Edward Barron, Michael Bartlett and Dohgyu Hwang with their material



The flexible material can quickly morph into various shapes

It is comprised of a metal alloy grid embedded in rubber, with tendril-like heaters woven within it

ALEX PARRISH/VIRGINIA TECH X4, DARYL LOVELL/SYRACUSE UNIVERSITY, GETTY IMAGES, UNIVERSITY OF MASSACHUSETTS AMHERST

INTERVIEW

Are NFTs really the future of society?

Alex Hughes spoke to blockchain expert Merav Ozair to find out whether NFTs are just a gimmick, or essential future tech

NFTs have captured the world's attention, with pictures of monkeys selling for millions, celebrities and influencers launching their own projects, and a lot of people losing or making huge amounts of cash. But are they a scam, or are they the future of authentication?

WHAT IS AN NFT?

NFT stands for non-fungible token. Fungible means something that is interchangeable. A dollar is fungible because it doesn't matter which dollar you use. Non-fungible is everything that is unique, so that could be a one-off painting like the *Mona Lisa*. Everything physical or digital that is unique is non-fungible.

The token part is simply its existence in the digital world and the fact it is traceable online through blockchains – more on that later. A Bitcoin is fungible because it is traceable on the blockchain, it is a token.

If you think about the concept of non-fungible, then all of the NFTs we've seen online fit into this because they are all unique. The focus so far has been on collectables but the true value of the NFT is authentication, because you can authenticate any asset – digital or physical – via this process.

HOW DOES AN NFT ACTUALLY WORK?

An NFT is basically a one-of-a-kind token. It creates a digital smart contract that has all of the information you'd need about a particular asset, whether it's memorabilia, a photo, a painting or a housing contract.

An NFT is housed on what's known as a blockchain – a digital ledger that can't be edited or deleted and can be seen by anyone. Most NFTs are housed on a blockchain known as Ethereum.

When you buy an NFT, it creates a digital contract on a blockchain. Here, every purchase and sale is listed for the particular asset as well as other bits of information like the copyright owner, who created it and how much it has sold for each time.

MOST NFTS HAVE BEEN FOR ART, WHAT ELSE COULD IT BE USED FOR?

Art is the obvious first step because it's where our minds go in the physical world for something that

A gallery assistant looks at a digital reproduction of *Madonna del Cardellino* by Raphael, which is on display as part of the Eternalising Art History exhibition in London, and is certified as an NFT

GETTY IMAGES, ALAMY, CFA SOCIETY NEW YORK

"THE ORIGINAL JOURNALIST, ARTIST OR CREATOR WILL ALWAYS BE THE ONE WHO MADE IT, BUT THEY NO LONGER OWN IT"

is non-fungible. It made sense that the applications initially were in the art world, sports or memorabilia and collectables. However, the power of NFTs is authentication.

Everything in our economy is transaction-based. Even when you transfer any information like an email or an online payment, that's a transaction. For that to work in our physical world, every asset or piece of information needs to be authenticated. In the traditional world, we use all kinds of intermediaries to do this, such as lawyers or banks.

In the digital world, you need this kind of authentication. So the power of an NFT is authentication because it doesn't require this third party. Whether it's a digital or physical asset, an NFT can carry all of the information that states something is original, who created it and authenticate the timestamp of when it happened, and so on.

Thanks to the features of the blockchain, you can't change the information set up in an NFT. No one can alter or erase information in an NFT for a housing contract, large payment, or marriage licence.

DO YOU OWN THE COPYRIGHT IF YOU BUY AN NFT?

The legal side of this is still uncertain but it depends on the smart contract itself and what is stated in there. There are some intellectual property issues that are very questionable. It is the same idea as buying a painting.

Do you own the rights? You can't claim that you made it, but you do own it. Obviously the original journalist, artist or creator will always be the one who made it, but they no longer own it. As long as you own it and you paid for it, no one is going to stop you from selling it.

IS THERE ANY REGULATION FOR NFTS?

It is developing as it happens. I know that the UK has proposed all kinds of obligations and the EU and US are also working on some but it's not definite yet. There are a lot of things that are not quite certain.

I'm working with the International Association for Trusted Blockchain Applications on proposals to submit to the EU Commission to outline what the policy has to be around decentralised finances, NFTs, cryptocurrencies etc. When there is a better understanding of how it works, the right policies and regulations can be made.

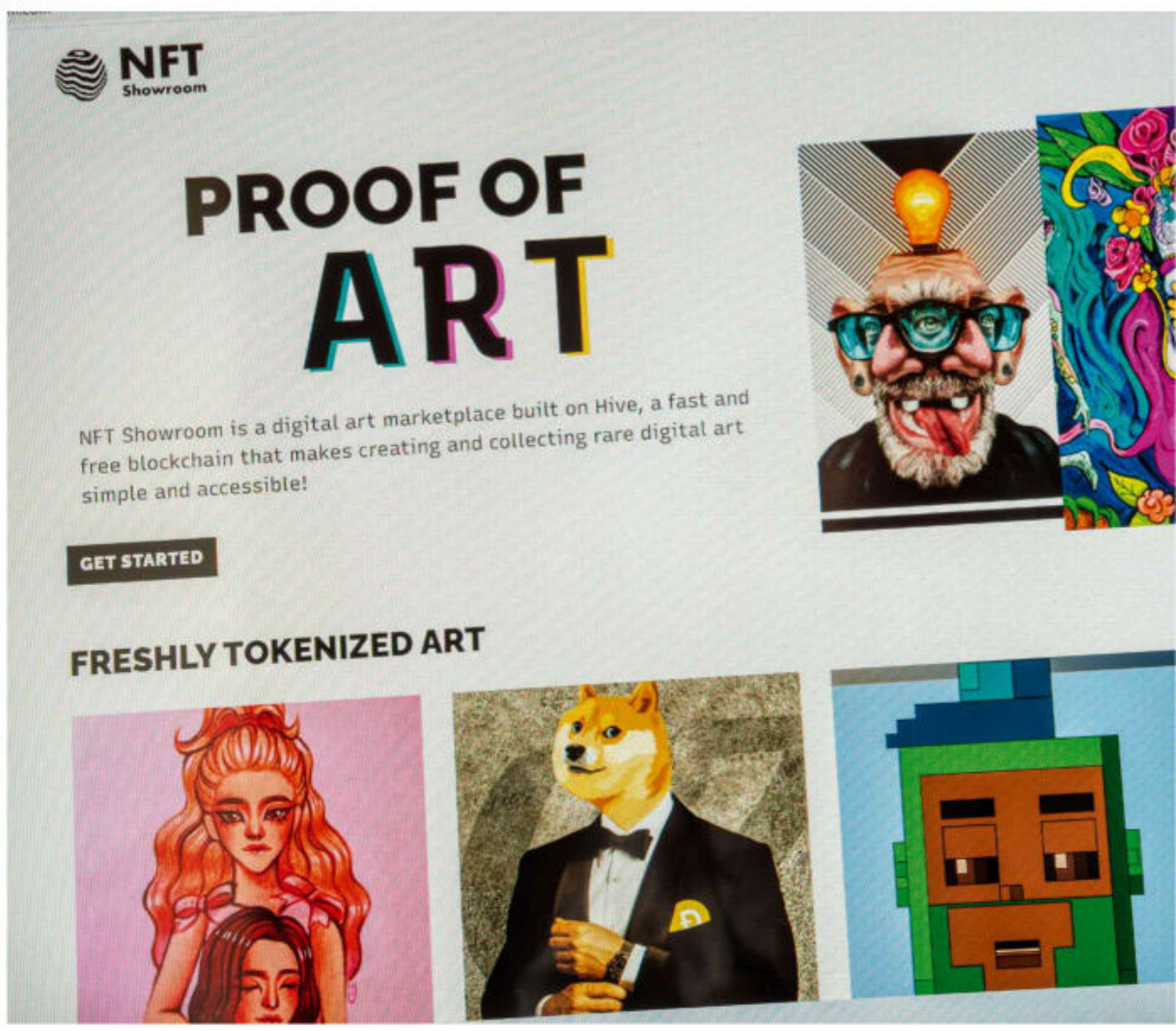
We hope that if that happens there with the EU, then other countries will adopt something similar.

THERE ARE A LOT OF INFLUENCERS CREATING NFTS, IS THIS GIVING THE WRONG IMPRESSION ON WHAT AN NFT CAN BE?

I have my reservations with that because it gives a misconception of what NFTs are. These influencers and all the hype and the gimmicks give people the wrong impression. If they don't understand the technology behind it and what it can offer, they get the wrong impression. And then if there are scams it's called fraud.

People were saying the same about the internet back in its early days. People say it's a fad, it's a gimmick. And lots of it was a scam. I would not be surprised if many of these NFTs are fads or scams. But I don't want people to get the wrong impression. If influencers want to be involved with NFTs, they also have to educate.

The value of the technology is there, people just need to understand it and see beyond the gimmick to focus on the technology, not the hype and misconception that they can make a million by launching an NFT.



↑ NFT Showroom, where you can collect digital art

DR MERAV OZAIR

Merav is a blockchain expert and fintech professor at Rutgers Business School, New Jersey. Along with lecturing on digital currencies and blockchain solutions, she is also actively involved with the advancement and regulation of NFTs and cryptocurrencies.

Ideas we like...

↑

...a lighting setup for your webcam

For those of us in office jobs, video meetings are going nowhere, so why not look your absolute best while you do them? Logitech's new webcam light, built for budding streamers, beams out a soft glow that should conceal just how recently you've got out of bed. Sensors on the Litra Glow will adjust the brightness to adapt to different skin tones and diffuse the light so that you don't look like a deer caught in the headlights. Litra Glow has also undergone testing, clearing guidelines to ensure it's safe to use over long periods of time.

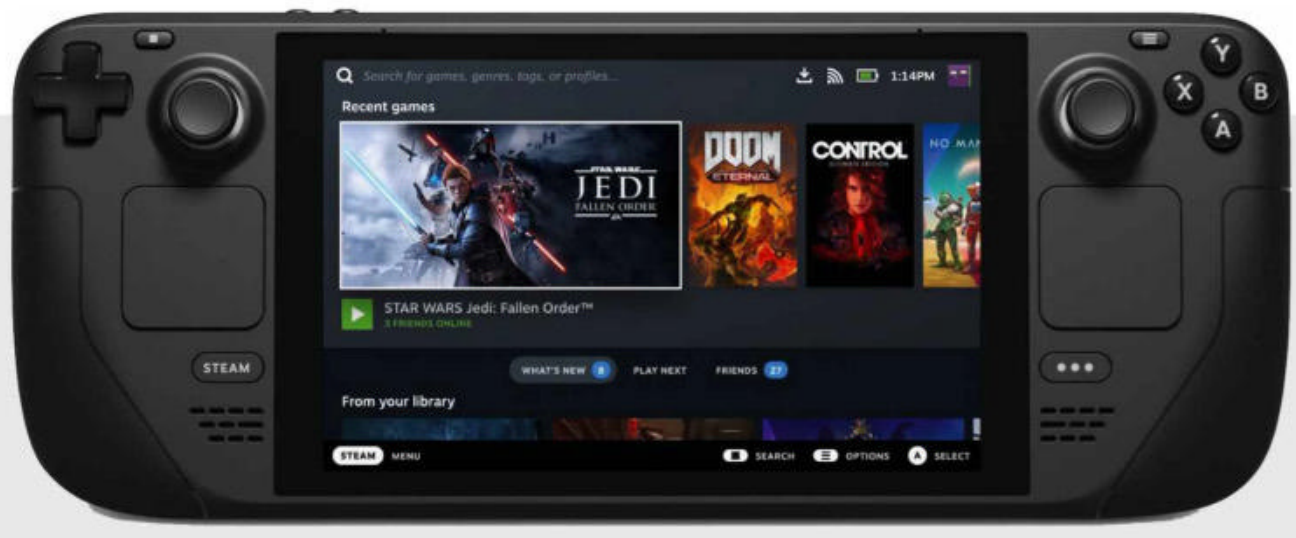
Litra Glow
£59, logitech.com

↑

...an electric surfboard

Awake is a company that specialises in electric surfboards and with the RÄVIK S22, they're happily claiming it's the "most extreme electric surfboard in the world". Rad, dude. With a top speed of around 56km/h (35mph) and a 0-50km/h (0-31mph) acceleration in four seconds, it certainly sounds extreme, tubular even. But with only 15-20 minutes of riding time between charges, you'll need to cram your bodacious board time into small bursts.

Awake RÄVIK S22
€12,900 (£10,760 approx), awakeboards.com



↑

...a handheld gaming device with the power of a PC

From Steam, the big name of PC gaming, the Steam Deck has been hinted at for a while. Now available to buy, the Steam Deck allows you to log in to your entire Steam library on the go and play your games from where you left off on your computer. Where it differs from handheld devices before is in its high-powered processor, which allows for much more demanding games than its competitors. It is expected to have a battery life of between two and eight hours (depending on usage), can be connected to a TV, and at £349, will be cheaper than most consoles and gaming PCs.

Steam Deck
From £349, store.steampowered.com

...an apocalypse-ready jacket

As we lurch out of the pandemic, and with the new series of *The Walking Dead* fresh in our minds, we wonder whether it might be time to reassess our wardrobe. Sci-fi British clothing brand Vollebak agrees, and has created a coat tailor-made for Armageddon. World-ending super volcano? This coat has got your back. Flash fires? You'll be hot, but safe. Zombie invasion? Sure, you're covered. Vollebak claims its Apocalypse Jacket is made with material that can withstand black lava, flash fires and chemical erosion – but strangely, we couldn't find a volunteer to test out their claims. It even features 23 pockets to store your snacks when the world ends.

Vollebak Apocalypse Jacket
£995, vollebak.com

...a discreet yet powerful wearable

Now in its 3rd generation, the Oura Ring is more advanced than ever. It can tell you how well you slept, how warm you are, how relaxed you are – we wouldn't be surprised if it knew your darkest secrets too. Among the features Oura crams into this latest ring is 24/7 heart tracking, detailed sleep monitoring, mindfulness sessions and graphs detailing your exact mental state to a decimal point. It's not the cheapest wearable on the market, but it's certainly one of the most discreet.

Oura Ring Generation 3
$299 (£225 approx), ouraring.com

...headphones that don't cut you off from the world

Sony has always been at the forefront of headphone technology and with its latest pair, it's doing something rather unique. These earbuds feature a hole in them (by design – don't worry, no parts are missing). This means you can be more aware of your surroundings and people desperately trying to get your attention while you're enjoying your music. It includes other clever features like Wide Area Tap, which allows you to control your music by tapping the skin in front of your ear.

Sony LinkBuds WF-L900
£149, sony.co.uk

SFP375

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A MOST VI

WORDS: PROF BILL MCGUIRE

With Italy's iconic Etna volcano erupting at the beginning of the year, followed by the lava flows of La Palma making headlines for weeks in autumn, then activity starting at Hunga Tonga-Hunga Ha'apai in late December, it felt like 2021 was a particularly big year for the planet's volcanoes.

When we look at the statistics, however, we see that this level of volcanic activity is nothing special. In 2021, 80 eruptions occurred at 75 volcanoes, with 32 new eruptions recorded. This is pretty much par for the course, and looking at the year-on-year figures for the past few decades, there is no indication that volcanic activity is increasing.

Still, the volcanoes of 2021 seemed to capture the attention of the world's media, and blew our minds at a time when much of the world was still reeling in the aftermath of the COVID pandemic, reminding us once again of the awesome power of nature.

MOUNT ETNA, ITALY

Something is always happening at Sicily's Mount Etna, and 2021 was no different. Etna demonstrates two different types of activity: ash explosions and overspilling lava flows from one or more of the four summit craters, and larger volume lava flows lower down on the flanks. During 2021, the action was all at the summit, where spectacular lava fountains up to a kilometre high often lit up the sky over eastern Sicily. Periodically, more violent blasts launched huge columns of gas and debris high into the stratosphere, deluging surrounding communities in ash, and closing Catania airport at the foot of the volcano on a number of occasions. Etna's eruptions have certainly become more violent in recent years, and there may be further activity in 2022.

GETTY IMAGES

OLENT YEAR

JAKE SCHOEN/TOLEDO ZOO

↑

FAGRADALSFJALL, ICELAND

An eruption in Iceland is hardly news, but this one was different. For the first time in more than 800 years, lava was flowing once again on the Reykjanes Peninsula. Following a period of unrest, lava reached the surface in mid-March 2021, via a system of new fissures. Activity soon became focused at one point, rapidly building a cone that reached a height of more than 330 metres in just nine months. The eruption site became a magnet for tourists, but Reykjavik residents did not need to travel, as jets of magma more than 300 metres high could be seen from the capital 60 kilometres away.

The eruption eventually ended in September after 181 days, but the return of activity to this part of the island suggests that more eruptions could be on the way in due course.

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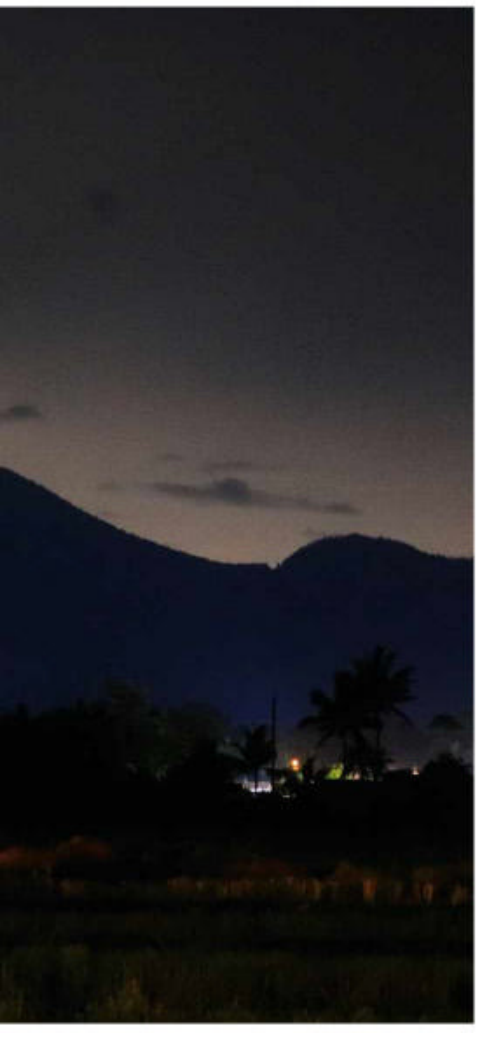


← SEMERU, INDONESIA

Located in southern Java, Semeru is an archetypal, steep-sided, volcanic cone, beloved of tourists and hikers alike. It is also very dangerous. Semeru's eruptions tend to be moderately explosive rather than huge, but often lead to loss of life. The volcano has been almost continuously active since 1967, the latest outburst beginning in early December 2021, when heavy rains contributed to the collapse of the summit lava dome. This triggered an explosive eruption that sent a column of ash and debris to a height of more than 12 kilometres, and fed pyroclastic flows and mudflows. Travelling at speed down the flanks, these soon reached the villages at the foot of the volcano. Similar activity continued over the following month or so, leading to the destruction of 5,200 buildings, causing more than 70 deaths, and displacing in excess of 10,000 people. Semeru continues to be active as of February 2022.

↑ KILAUEA, HAWAII

If you are determined to see flowing lava, Kilauea in Hawaii is your best bet. Between 1983 and 2018 the volcano was in almost continuous eruption, spewing out lava that covered more than 100 square kilometres, buried nearly 800 homes, and remodelled the coastline. After a short pause, a new eruption began in December 2020 at the summit's Halema'uma'u crater. Active vents in the crater floor began to fill it with lava, so that by the end of February 2021, the crater was occupied by a huge lake of churning lava more than 200 metres deep. Things quietened down after May, but a new eruption began in September 2021, when new fissures opened within the crater, feeding fountains of lava that reached heights of more than 60 metres. As the level of lava in the crater rose, all but one of the vents became submerged, leaving a single vent to continue to ooze lava.

SOUFRIÈRE, ST VINCENT

Eruptions of St Vincent's Soufrière volcano can be deadly. In 1902, a major blast killed close to 1,700 people, but when a smaller eruption began in 1979, the authorities were better prepared, and timely evacuation meant that there were no deaths. Following more than four decades of quiet, a new eruption began just after Christmas 2020. In early April 2021, a violent explosion obliterated a colossal lava dome that had grown over the previous three months, launching an eight-kilometre-high eruption column that dumped ash across the island and closed the airport on neighbouring Barbados. Big explosions continued over the next few weeks, feeding pyroclastic flows and mudflows, before activity died down at the end of the month. The eruption was as big as that of 1902, and could have been similarly lethal, if not for the fact that more than 16,000 people were evacuated from the highest risk areas.

→

HUNGA TONGA-HUNGA HA'APAI, TONGA

Prior to December 2021, the only visible bits of this submarine volcano were the tiny islands of Hunga Tonga and Hunga Ha'apai. Soon, even these were gone. Towards the end of the month, violent explosions tore the islands apart and dumped ash across the Tonga archipelago. The eruption climaxed on 15 January 2022, when a colossal detonation, likely caused by the mixing of magma and seawater, spawned shock waves that circled the planet four times, and was heard as far afield as Alaska, 6,000 kilometres away. A series of tsunamis followed, which reached heights of 15 metres on some islands, and crossed the Pacific to take two lives in Peru. Because of eruption damage to an undersea cable, communication with Tonga remains poor, and it may be some time before the true extent of the damage is known.

ALAMY, SHUTTERSTOCK, REUTERS

←

NYIRAGONGO, DRC

Nyiragongo is an impressive volcano, having a kilometre-wide summit crater filled by a lava lake that periodically drains, feeding lava flows that often threat the neighbouring city of Goma. In 2002, such an eruption destroyed several thousand homes and led to the evacuation of a quarter of a million residents. The 2021 eruption began in May and followed a similar path. Drainage of the lava lake coincided with the opening of fissures low down on the volcano's south flank, from which rapidly flowing lava issued. Within hours, the flows had reached the northern outskirts of Goma, leading – ultimately – to the destruction of more than 3,500 homes and the displacement of 20,000 people. Lava production stopped after a couple of days, but strong earthquakes followed, accompanied by the opening up of ground cracks in the city itself. With a new lava lake growing, the stage is already being set for the next eruption.

↑

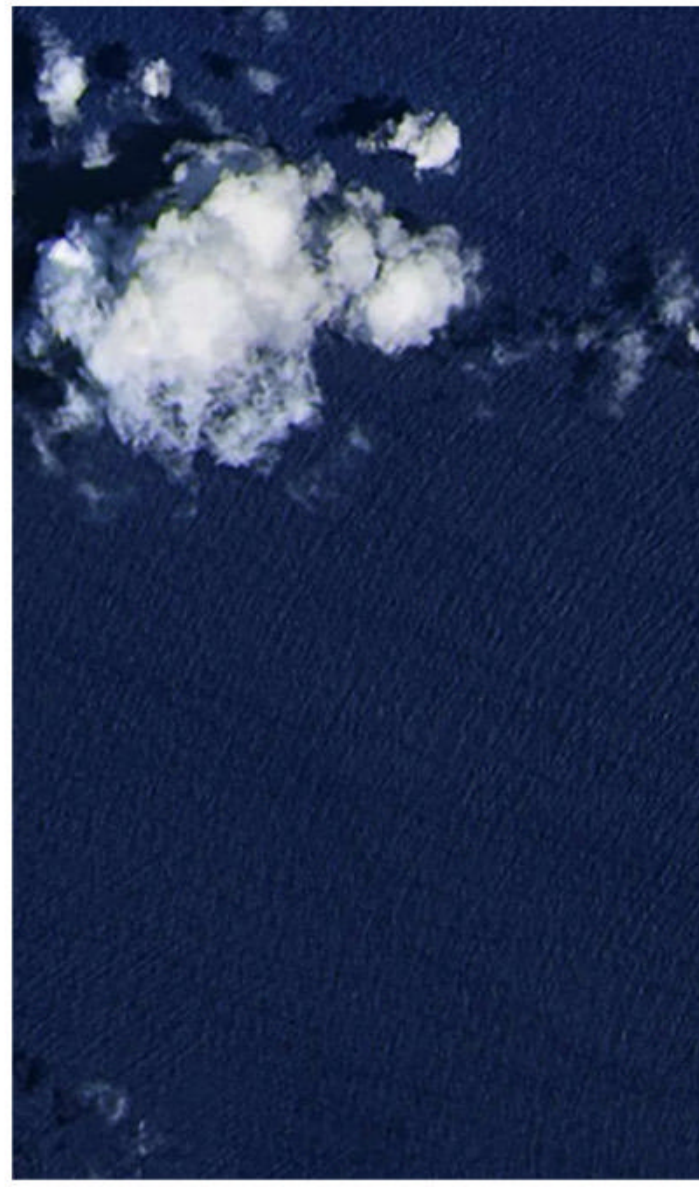
TAAL, PHILIPPINES

The active cone of Taal volcano is pretty much unique in that it forms a low-lying island – known as Volcano Island – at the centre of a huge lake-filled crater formed by a mega-blast during prehistoric times. As such, it presents a unique set of hazards, most notably surges of boiling water, gas and ash that scoot across the lake surface before crashing into the shore. More than 1,000 lives were lost to such surges in 1911, and a further 100 or so in the 1965 eruption, which obliterated villages around the lake edge. The latest eruption began in January 2020, when a violent blast dumped ash across Manila, the capital of the Philippines, and then erupted again in July 2021. Since then, it has continued to periodically blast out clouds of ash and steam, and to generate a sulphurous volcanic fog (known as vog), causing health problems for the local inhabitants.

→

FUKUTOKU-OKA-NO-BA, JAPAN

Hidden away in the Bonin Islands, 1,500 kilometres south of Tokyo, the existence of this submarine volcano has barely impinged upon most people's radars – even those of most volcanologists. Fukutoku is something of a now-you-see-it, now-you-don't volcano, at times taking the form of a small island, at others marked only by a patch of discoloured water. Half a dozen small eruptions were recorded in the first decade of the century, but the volcano had been quiet before waking with a bang in August 2021. The colossal 16-kilometre-high column of ash blasted into the atmosphere was impossible to ignore, as were the immense rafts of pumice that covered the surface of the sea near the eruption site. Seemingly nothing more than a curiosity at first, the pumice rafts reached the Japanese mainland a couple of months later, clogging harbours, contaminating fisheries and damaging hundreds of vessels.



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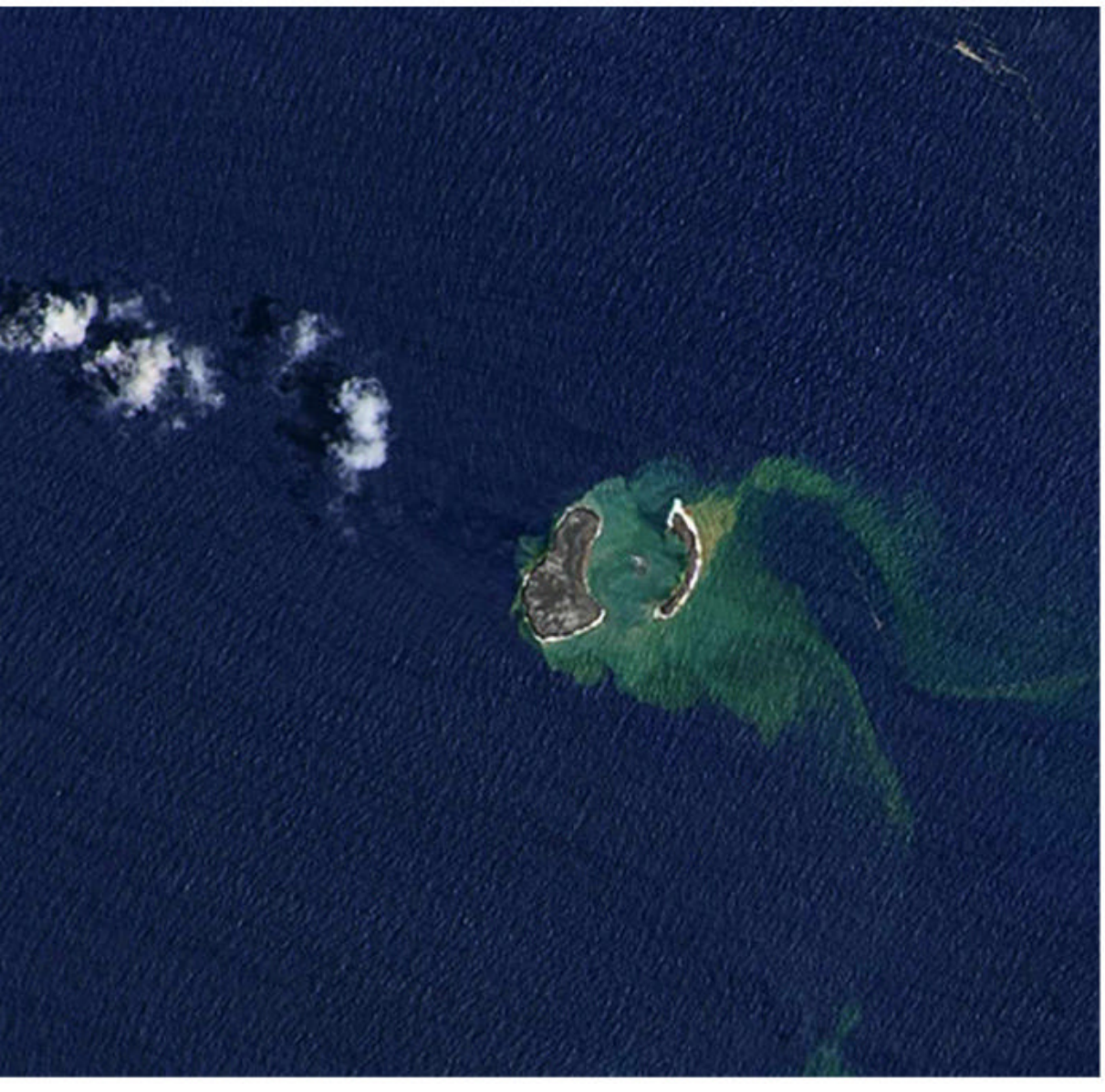

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LA PALMA, CANARY ISLANDS

Eruptions at La Palma's Cumbre Vieja volcano – the most active in the archipelago – tend to occur in clusters separated by a few hundred years, the last one ending in the early 18th Century. Following a couple of hundred years of quiet, the volcano erupted again in 1949 and 1971. Since 2017 it had been restless again, so when magma broke the surface in September 2021, it was not unexpected. Eruptive activity was a mix of ash explosions, lava fountaining, and the voluminous production of flowing lava. Over the course of three months or so, successive flows destroyed more than 5,000 buildings, including all those making up the town of Todoque, and built a new delta on the island's western coast. The total cost of the 85-day eruption is estimated at close to €1bn, and its official ending on 25 December came as a much-needed Christmas present for the island's long-suffering inhabitants. **SF**

by **PROF BILL MCGUIRE**

Bill is a volcanologist, climate scientist, writer and broadcaster. His latest book is Sky Seed *(£8.99, Book Guild Publishing).*

YOUR PRODUCTIVE BRAIN

Increasing your productivity is easy. It's just a matter of making a few simple changes to your routine, or behaviour, or thinking, and your productivity will soar. At least, that's what countless online articles claim. The actual science tells a different story. Even a modest amount of research reveals that some of the most commonly touted claims about how to boost productivity fall apart in the face of the evidence. So, here are some of the most common myths around boosting productivity, along with a number of approaches that have a more robust scientific basis.

WORDS: DR DEAN BURNETT ILLUSTRATIONS: RACHEL TUNSTALL

"WAKING UP AT 4AM WILL MAKE YOU MORE PRODUCTIVE!" (FALSE)

It's regularly claimed that you'll be more productive if you get up early. Very early. According to a 2016 *Wall Street Journal* article, the most successful (and therefore productive) people typically rise at 4am.

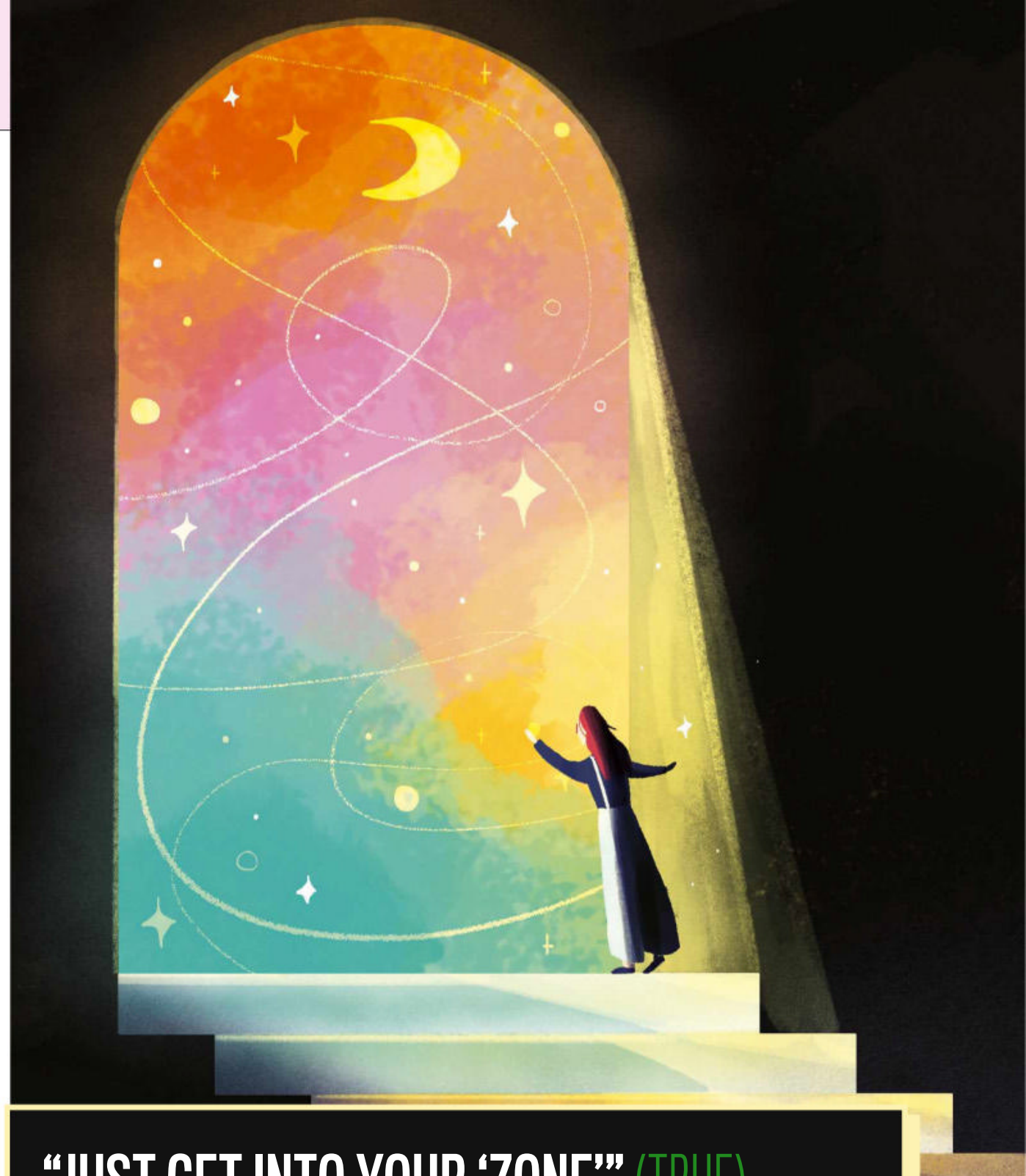
There's some logic to it. For instance, if you're awake while everyone else is still asleep, they won't distract you, so you'll be more productive.

However, there are many reasons why waking up at 4am could be actively unproductive. An important one stems from our own biology; sleep is crucial for our ability to function, and depriving yourself of it does more harm than good.

A typically healthy amount of sleep for adults is around seven to nine hours. Less than that quickly has negative health effects, compromising focus, mood, memory, stress tolerance, and more. Forcing yourself to wake at 4am means you're losing sleep, and will be less productive as a result.

Some people seem able to get away with it, being natural 'early risers'. But the veneration of such people may be misplaced. A study by the National Sleep Foundation stated that "Individuals who habitually sleep outside the normal range may be exhibiting signs or symptoms of serious health problems or, if done volitionally, may be compromising their health and wellbeing". Another study claims sleeping far fewer hours than average is more likely to be self-imposed than anything natural, and will incur a significant sleep debt, harming health.

Overall, while there may be some productive advantages to waking up in the early hours, these can easily be cancelled out by the consequences of lost sleep.



"JUST GET INTO YOUR 'ZONE'" (TRUE)

With everything discussed so far, it's important to consider one important caveat; everyone is different, and what works for one person may not work for another. Individual differences play a considerable role in how we end up being productive. But if you can eventually figure out what factors work best for you, it would be wise to exploit this awareness, because it increases your chance of reaching a state of cognitive 'flow', known to most people as being 'in the zone'.

Flow is arguably the most productive state of mind it's possible to be in. It's when you're the most focused on a task, whatever it is, and thus demonstrating the maximum level of skill in performing it that you're capable of.

Despite how much time and effort people dedicate to achieving a state of flow, it's actually tricky to do. This is likely due to the fact that our brains are actually doing dozens of things at once, and often, like with our attention systems, many of those things will get in the way of other things.

Sometimes, though, all of the scattered bits of our consciousness join forces and focus on one specific task, and so we enter a flow state. The issue is, what effectively occupies the myriad parts of your brain will vary from person to person. So the particular setup that allows you to be most productive will likely be unique to you.

The point is, reading articles and advice columns on how to be more productive is all well and good, but nobody is going to know the best way to boost your own productivity better than you.

"BACKGROUND MUSIC IS BENEFICIAL" (TRUE)

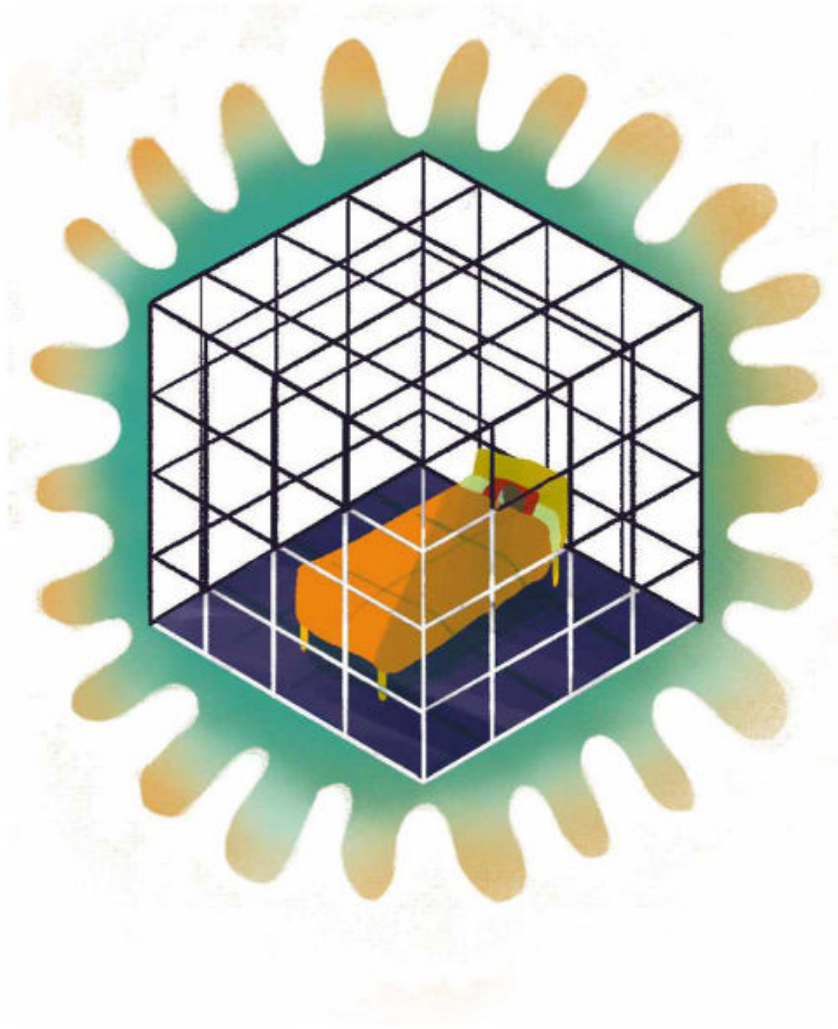
There's a lot of debate at present regarding what's more productive. Is it working from home, or working in the office? And both sides regularly argue that the other offers more distractions from work.

However, one thing that rarely gets mentioned is the fact that certain distractions can be helpful for productivity. Some people prefer to work in relative silence, but a great many find they're more productive with some sort of background noise. Generally, this takes the form of background music. This helps, rather than distracts, because of how our attention works. Basically, we have two attention systems: the conscious one, which we direct and control, and the unconscious one, which alerts us to anything significant that our senses pick up and diverts our focus towards it.

When we're trying to focus on a task, our conscious attention is occupied, but can still be diverted by the unconscious system. And if we're in complete silence, any creaks or sighs or murmurs or other random sounds stand out more, meaning our unconscious attention is more likely to be distracted, which hinders our productivity. But if we play music in the background, it masks obtrusive noises and occupies our unconscious attention, like giving a bored child a toy to play with while you're trying to work. Obviously, the type of music will make a difference. Things with lyrics aren't as good because our brains are more stimulated by linguistic information, and music that has a negative impact on mood can sap motivation. Weirdly, one type of music that seems to readily boost productivity and focus is video game soundtracks. It makes logical sense, really; it's music designed to be stimulating while you're focusing on something else.

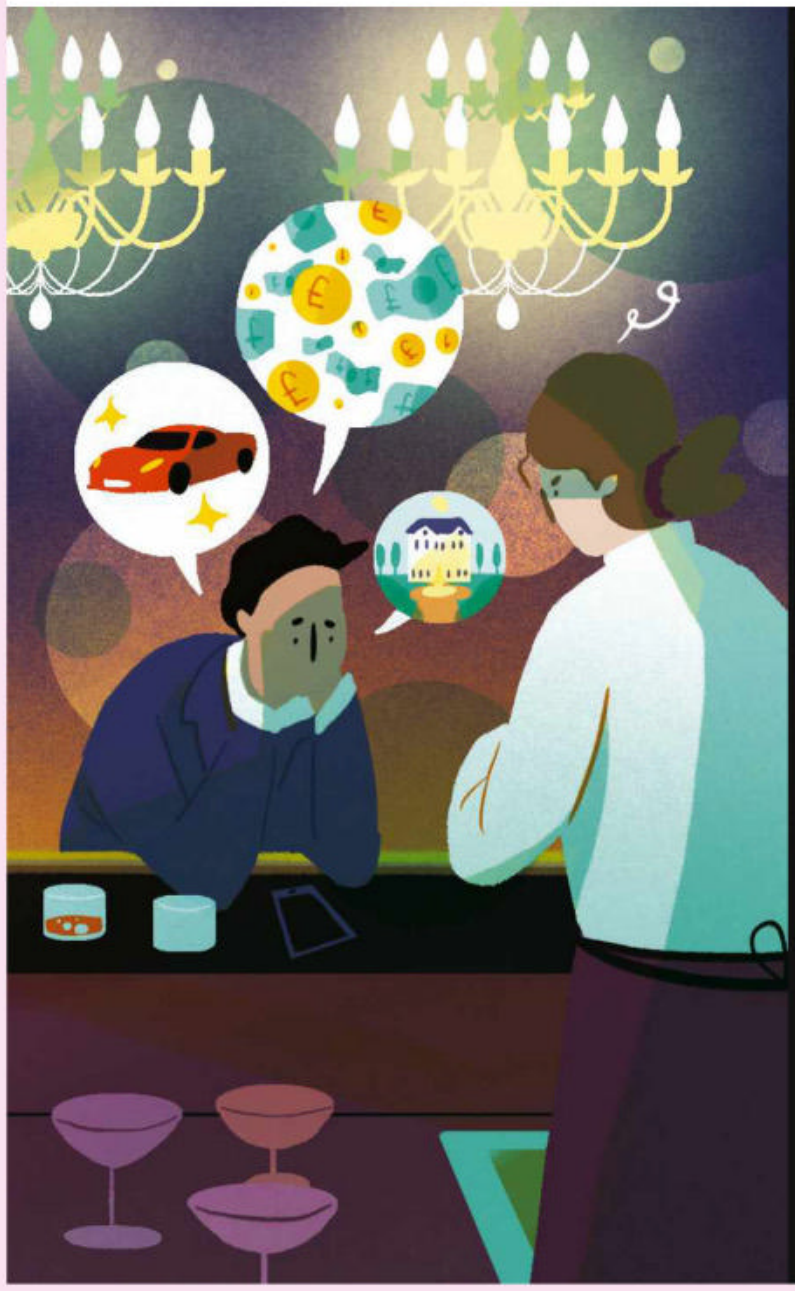
In any case, there are many situations where background noise and music can actually enhance productivity and not disrupt it.

"WAKING UP WHEN YOU'VE HAD ENOUGH SLEEP IS BETTER THAN WAKING AT 4AM" (TRUE)



We previously saw that forcing yourself to wake before dawn in order to be more productive can become self-defeating. However, this need not be the case. In truth, any wake-up time can be productive, if you've had enough sleep. So if you wake at 4am after going to bed at 8pm, you've almost certainly had enough slumbering time. There are many health benefits of sufficient sleep. It boosts memory retention, aids focus, improves general health, elevates mood and reduces irritability, all of which increase your capacity to be productive.

Sleep can aid productivity in other ways. Sleep is when our brains process all the memories and thoughts we've accrued during the day, and integrates them into our existing neural networks. This is why 'sleeping on it' is a legitimate approach to problem-solving. If we can't get our head around an issue, sleeping on it means more of our brain is connected to our experience of it, opening up new approaches, while staying up all night trying to figure it out is less effective. So yes, sleep is important for productivity – more so than waking up at certain times.



"WE ALL HAVE THE SAME 24 HOURS!" (FALSE)

The most successful people experience 24-hour days just like anyone else. Much 'advice' on increasing productivity includes this observation. The implication is that you, the less successful person, could do the same as them if only you used your time better. This is, presumably, meant to motivate you to be more productive.

Many have pushed back against this claim. Yes, we all experience 24 hours in a day. But the ability to use those hours productively differs tremendously from person to person.

Context is everything. Someone who is working nights to pay for their studies during the day will not have the same ability to use their time 'productively' as, say, someone who was born a millionaire thanks to their father's lucrative diamond mine. Hypothetically.

Similarly, there's the impact of societal gender roles and other unhelpful factors. Ultimately, it's far easier to use time productively when you have the money and resources, or faithful individuals taking care of the 'unproductive' demands of everyday life. And the vast majority of people lack these things.

Also, the idea that you should use 24 whole hours productively is objectively nonsensical. Psychology has repeatedly emphasised the importance to wellbeing (and thus maintaining productivity) of a healthy work-life balance. Dedicating every possible hour to 'being productive' actively goes against this.

The 'we all have the same 24 hours' claim actively downplays the fact that few people have the option to use that time 100 per cent productively.

“KEEPING BUSY MEANS YOU’RE BEING MORE PRODUCTIVE” (FALSE)

When a boss appears in the workplace, you need to ‘look busy’, because if you aren’t visibly in the middle of several tasks, you aren’t being productive.

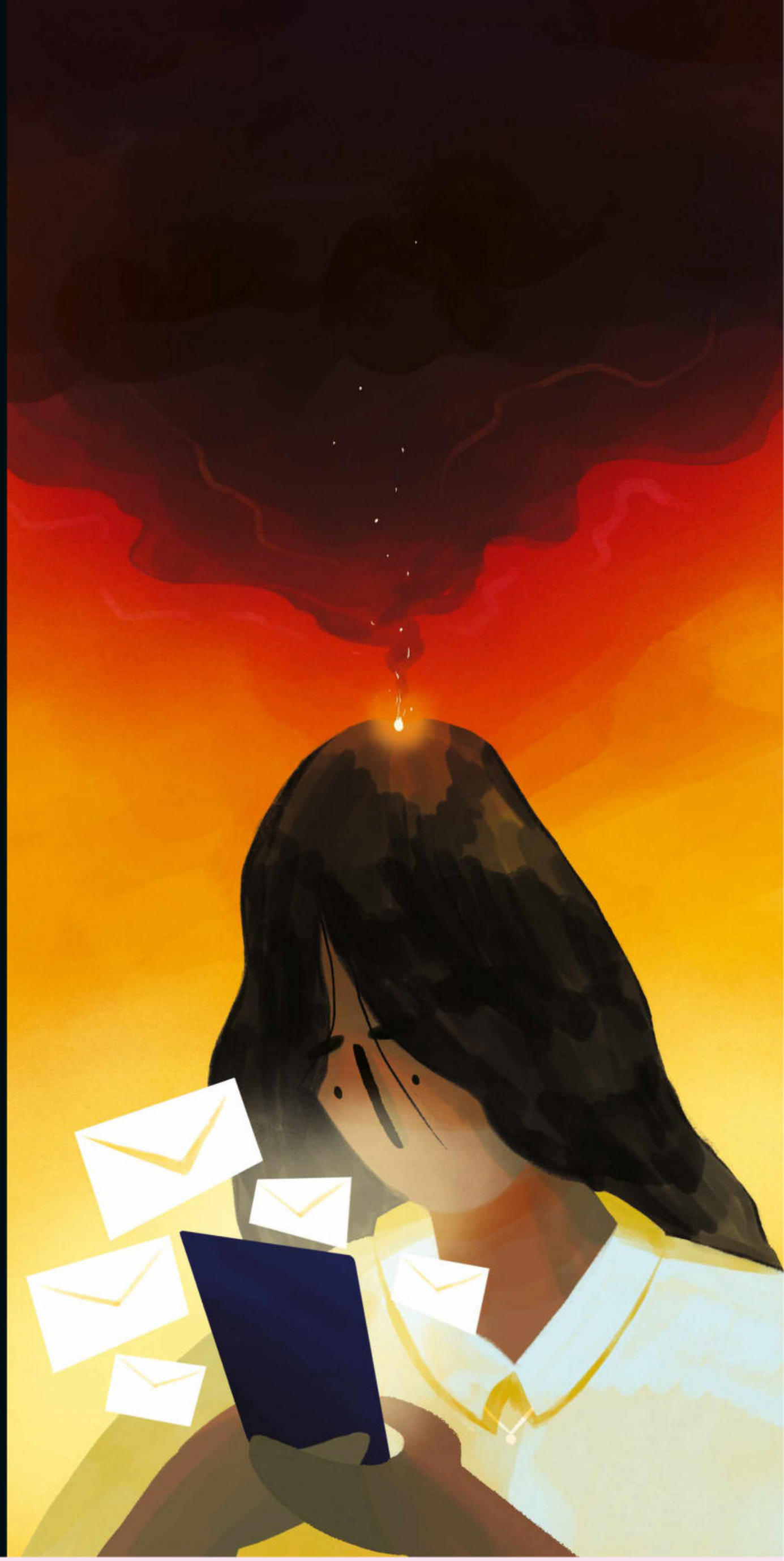
The idea that constantly being busy is the only way to be truly productive is the default assumption for many people. It echoes the ‘we all have the same 24 hours’ claim from earlier, with the implication that any time not spent productively is time wasted. Those who take on many tasks and roles at once are often looked up to and feted as the productive ideal. But the science tells a very different story.

In truth, it has long been known that multitasking or ‘task switching’ actually erodes your productivity. Impressive as it is, the human brain has limited resources when it comes to attention and working memory – our abilities to focus on and think about things. These are both essential qualities for performing tasks successfully and productively, and if you overwhelm your attention and working memory with too many demands at once, then you will compromise your ability to do even the most straightforward tasks effectively.

This can then have knock-on effects on the productivity of other people too. Everybody will have experienced an increased workload because a colleague didn’t do their job right, meaning others have to fix their mess (and if you haven’t experienced this, then I’ve got bad news for you...).

But even if you are somehow able to handle an excessive workload successfully and effectively, this becomes detrimental, as ever-increasing cases of burnout in the workplace clearly reveal.

Thanks to how we and our brains work, productivity is often more about quality rather than quantity. Anyone insisting on trying to do as much as possible at once is just shooting themselves in the foot.



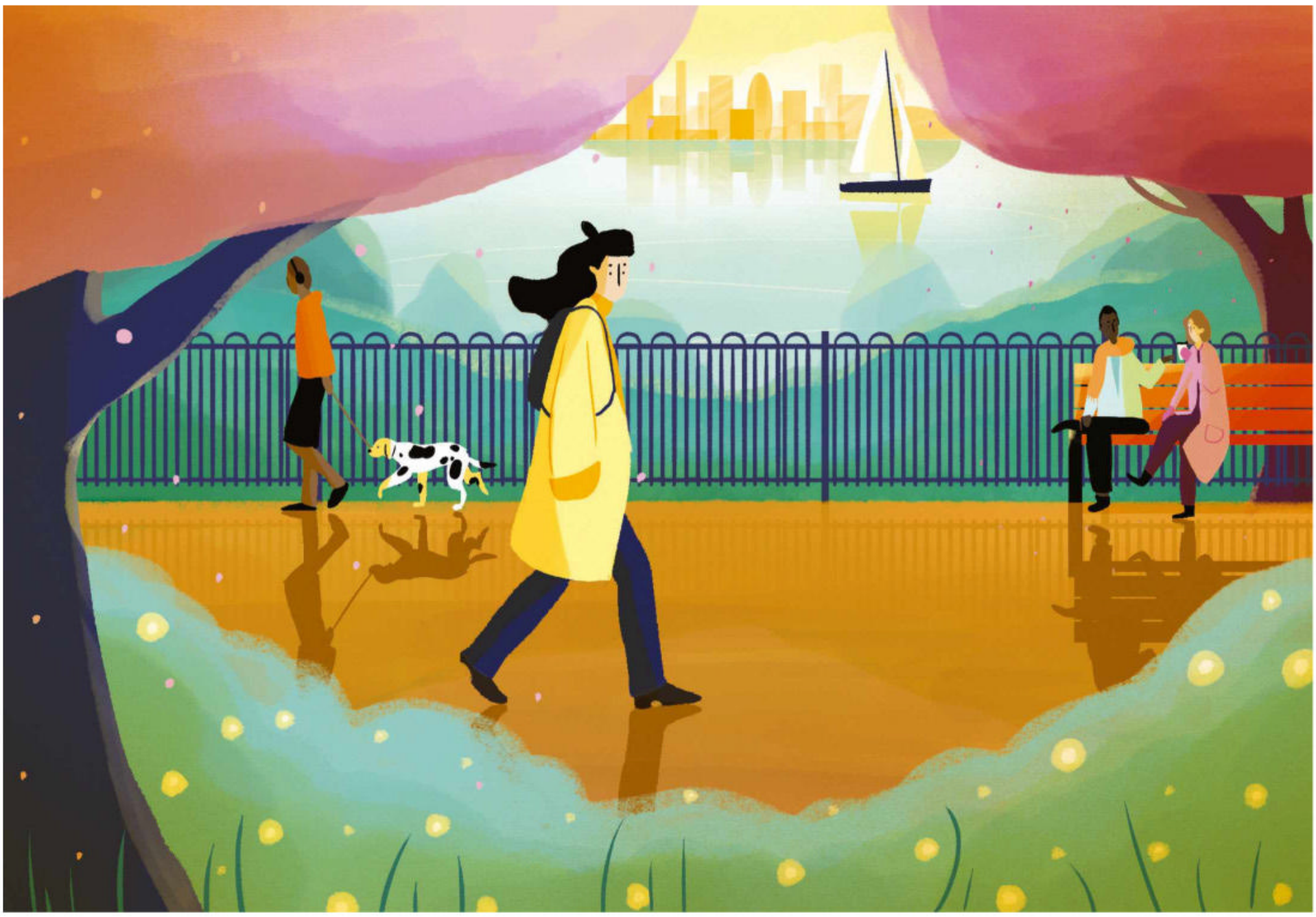
"GO FOR WALKS AND DECORATE YOUR WORKPLACE WITH PLANTS" (TRUE)

It's rather common for people to liven up their workplace by incorporating houseplants into it. Or to covet the desk or office with the window that looks out onto the nearby park or wooded area. Some organisations frown on such things, opting instead for greater uniformity, but by and large, plants (and green views) in the workplace are sought after and appreciated by employees.

Why, though? Why would we, as a society, put so much time and effort into constructing buildings that keep nature out, only to constantly keep bringing bits of it inside them?

It's not just for aesthetic reasons; it turns out that plants, foliage, and other types of greenery are actually good for productivity. This has been borne out by many studies which report increases in productivity when plants are introduced into the workplace. This happens, at least in part, thanks to the process of attention restoration, which is sometimes called 'fascination'. The problem is, in most modern human environments, there are things that 'actively' attract our attention. Screens, billboards, writing, numerous colours and shapes, an ever-changing variety of people, and more. Our brains like all these things, sure, but they invariably have to work hard to pay attention to them all, to decipher the sensory information they're providing, and so on. But, as we saw earlier, our brains only have finite resources to do all this, so eventually they'll just become depleted. However, this doesn't seem to happen when we look at plants and similar stimuli. When we look at natural greenery, it seems our brains are occupied without being taxed. It's the cognitive equivalent of putting your feet up with a good book; it's doing something, but something restorative, rather than demanding.

This is why greenery is helpful for productivity. It replenishes your brain's resources. So if you feel that you need to go for a walk to 'clear your head', you're probably being more literal than you realise.



"YOU SHOULD BE HAPPY IN YOUR WORK" (FALSE)

According to many people, productivity is linked to happiness. As in, the happier you are, the more productive you'll be.

Again, there's logic to this. We're often instinctively motivated to do things we find rewarding and make us happy, and avoid those we find unpleasant. Also, scientific studies reveal that happy workers are around 12 per cent more productive. So, if you've got a workforce of 100 employees, and they're all happy, you'll get the productivity of 112 employees, at no extra cost! It's therefore unsurprising that so many organisations are fixated on employee happiness.

However, the simple yet persistent idea that 'happiness = productivity' overlooks considerable evidence to the contrary. For instance, other studies reveal that persistently happy employees can have negative effects on productivity in the workplace. They go to pieces quicker during difficult periods, are more easily exhausted (constant happiness is draining), and can even be more selfish.

Also, there are productive benefits of more negative emotions. Fear, anger, stress and envy have been shown to make people more productive in various situations.

As well as this, compelling people to be happy, whether via advice on how to be productive or employers insisting on 'service with a smile', often backfires. Studies reveal that if people believe they must be happy, it's harder for them to achieve that. It's like your hobby becoming your job; you stop enjoying it.

This feeds into the whole 'Toxic Positivity' issue of insisting that people must be happy at all times, and it's entirely their responsibility to be so (because we can all choose our emotional state, apparently). This can quickly lead to the exact opposite outcome.

Even if being happy does make you more productive, efforts to force this outcome can easily backfire.

"DIET AND EXERCISE IMPROVE PRODUCTIVITY, AS LONG AS YOU IGNORE THE FADS" (TRUE)

Of the countless articles about how to be productive by following the advice of 'highly successful people', many focus on the individual's diet and exercise regimen.

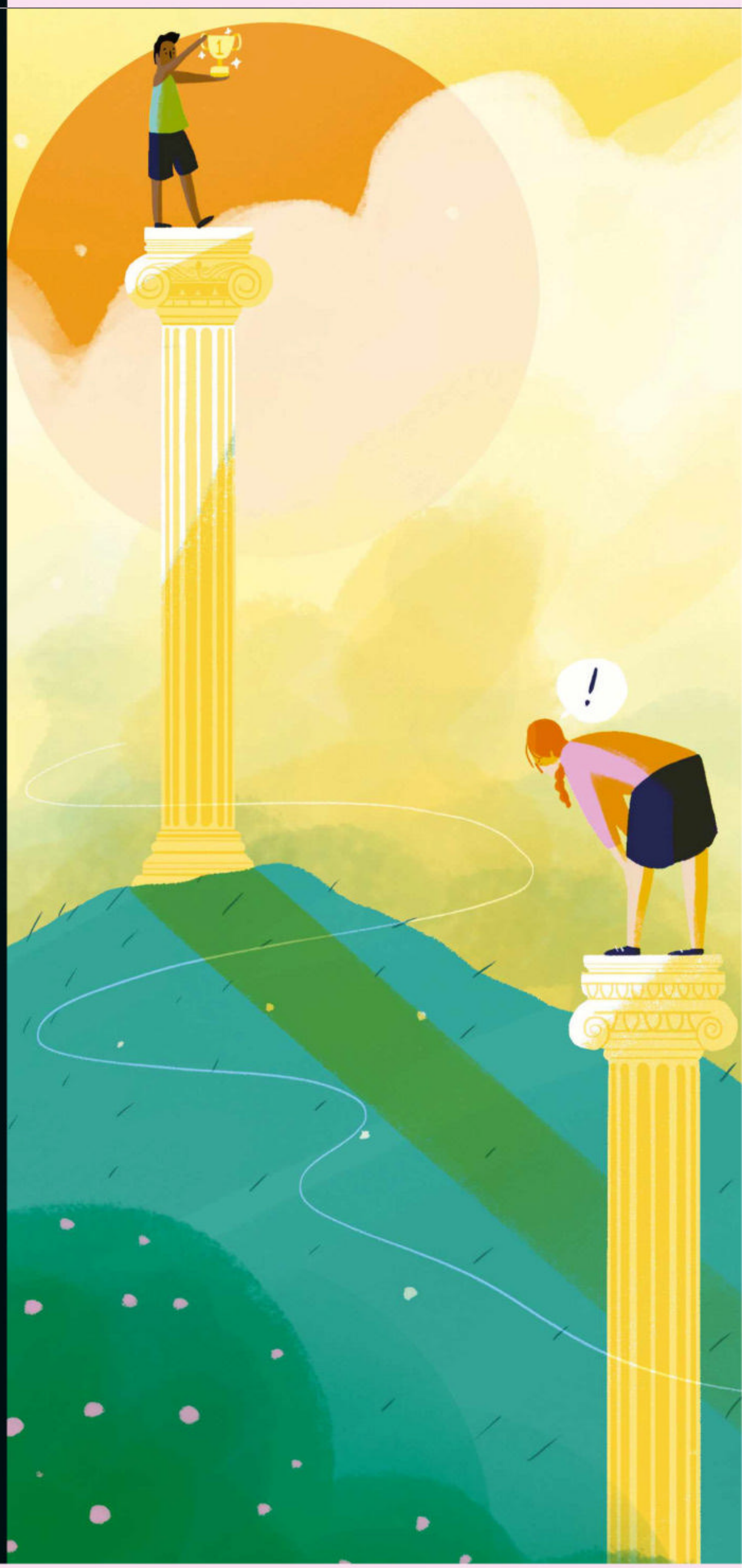
While their exercise routines are typically unobtainable purely due to practical concerns (most people lack a home gym, dedicated personal trainer, and four spare hours a day to use them), their diets can often be classed as ludicrous. You've probably read an article about some go-getter pulling in seven figures who seemingly breakfasts daily on a bowl of unfamiliar berries and leaves deemed to be 'superfoods', washed down with several glasses of ionised water, or the secretions of a beluga whale, or something equally bizarre.

If their claims come across as sanctimonious and superior, that's because they are. It's a way of displaying status and achievement to the unwashed masses. But if we ignore the ridiculous aspects, it's fair to say that diet and exercise can be a big help with productivity.

Regular exercise has been shown, countless times, to have many benefits for your body and brain. Your brain is ultimately another organ after all, and the better shape your body is in, the more resources it can dedicate to the brain, improving functionality and productivity.

Diet can have a direct impact on our brains too. While the indirect health consequences of 'junk' foods are worth keeping in mind, recent studies show that such foods can have rapid negative effects on the brain's workings, affecting our ability to focus and stay motivated on the tasks at hand.

So while you needn't fill your fridge with the latest superfoods, improving your diet and exercise can boost productivity.



"HARD WORK ALWAYS PAYS OFF" (FALSE)

If you want to be productive, to achieve something, you just need to work hard, and you'll get it. Because hard work always pays off.

That's the mantra adopted by many. Unfortunately, reality is rarely as formulaic. As much as we might want to believe otherwise, when countless people are working equally hard for the same goals the most important factor is actually going to be... plain old luck. Unfortunately, you can't tell people to 'be lucky' in the same way you can cajole them to work hard.

In fact, telling people that hard work inevitably leads to productivity and the outcomes they want is unhelpful. Our brains are sensitive to the balance between effort and reward. Our subconscious systems are constantly assessing how much work a task will involve and the likely outcome from putting that effort in, and asking 'is it worth it?' And when the effort we put in is not rewarded as expected, it causes stress and negative emotions. This is believed to be a key factor in workplace stress, because modern jobs often mean the person putting the effort in to something is far removed from the eventual outcome.

Given all this, why do people still believe that hard work always pays off? Possibly because of the 'just-world hypothesis', the cognitive bias where we assume that the world is a fair place, that good work is rewarded, and bad deeds are punished. It would also explain why successful people insist they're solely responsible for their success, which is a common aspect of advice about productivity. SF

by **DR DEAN BURNETT** *(@garwboy)*
Dean is a neuroscience writer. His latest book is Psycho-Logical *(£9.99, Guardian Faber).*

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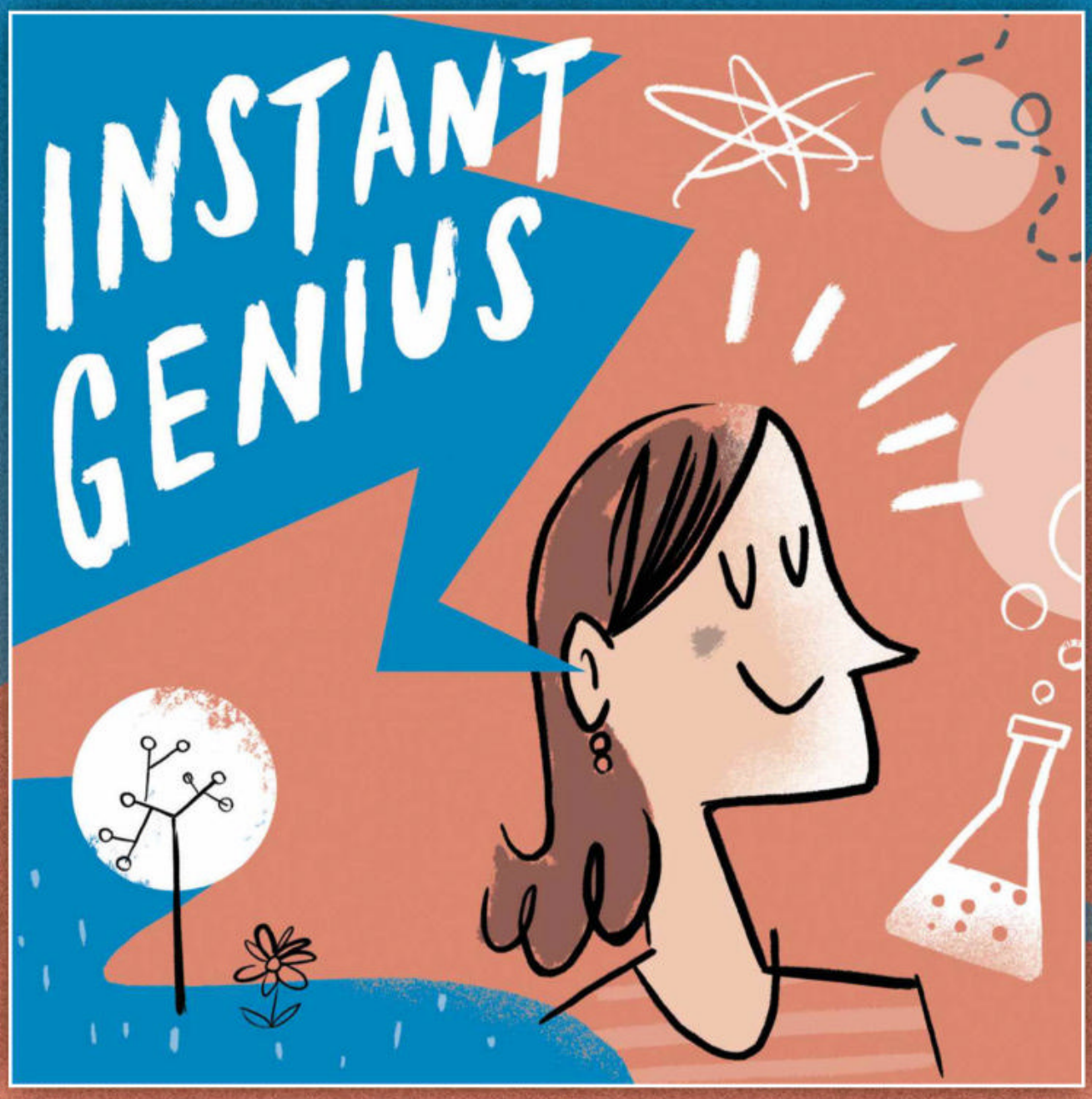

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COMMENT

YOU, ME AND OUR MICROBES

Why you are more like your partner than you might think

I have known my wife, Clare, since our first year at medical school, which was more than 40 years ago. Since then we have we have grown an almost telepathic understanding of each other's moods and thoughts. That might sound rather dull but it is actually a very bonding experience.

This got me wondering about the extent to which we were also growing more alike in other ways. Take looks. There is a wealth of research which shows that long-term couples tend to look alike. But is this because they start off looking like each other, or is it that couples become more similar-looking over time? Perhaps because of shared diets, or lifestyles, or mannerisms, or some other factor?

To find out, a team of researchers from Stanford University in the US put together a database of pictures of 517 couples, taken soon after getting married and then decades later. Using advanced facial recognition software and human judges, they showed that although long-term couples do tend to look alike, they don't become more alike over time. In other words, this study supports the claim that we tend to choose partners who look like us.

"This brings facial appearance in line with other traits – such as interests, personality, intelligence, attitudes, values and wellbeing – which show initial similarity but do not converge over time," they wrote.

"Computer algorithms could identify cohabiting couples with 86 per cent accuracy based on their skin microbiomes"

But though we may not grow more alike in appearance, over the years our skin microbiome certainly does. In a study carried out a few years ago, which was published in the journal *mSystems*, scientists decided to analyse the skin microbiomes of cohabiting couples and they found that living together significantly influences the microbial communities on each other's skin.

To carry out the study, the researchers collected samples from numerous sites on the volunteers' bodies, including their upper eyelids, outer nostrils, inner nostrils, armpits, torso, back, navel, and palms of hands.

The impact of living together on their microbial community was so strong that computer algorithms could identify cohabiting couples with 86 per cent accuracy based on their skin microbiomes alone. The area of the body where cohabiting couples were the most alike, microbe-wise, was the feet. This is not altogether surprising as many of us will pad around our homes barefooted.

Although the couples did show striking skin microbiome similarities, there were some areas of the body where the gender of the volunteer mattered more than whether they were cohabiting. For example, they discovered that the microbial communities growing on the inner thigh were more similar among people of the same biological sex than between cohabiting partners.

And again, it turned out that their computer algorithms could differentiate between men and women with 100 per cent accuracy by analysing inner thigh samples alone. Who knew? 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

THE PERILS OF FOLKLORE

Seemingly innocuous folk cures and old wives' tales can have a darker side

Ever since I was a kid, I've cracked my knuckles. I don't want to do it, but it's compulsive – the release of the pressure pent up in my fingers. And so, despite years of resolutions, promises to myself and systems of reward and punishment, I continue. I know that eventually I will end up with terrible arthritis.

But wait – it turns out I won't. Just the other day I discovered that a doctor in 2009 won the IgNobel Prize for Medicine for doing the research that broke the long-held link between knuckle-cracking and arthritis. He cracked the knuckles on one hand for 60 years, to find out if he would develop arthritis (he didn't).

The IgNobel Prizes are awarded annually for extraordinary research achievements in science that make us laugh, and then think. It worked for me, because this finding about knuckle-cracking has sent me down a rabbit hole of medical folk wisdom. And that hole is dark.

A paper published in *Nature* in 2019 investigated folk medicine in the US, and the researchers included the link between knuckle-cracking and arthritis as 1 of 11 theories. It was nestled among other things I thought until that moment were true: fizzy drinks can help stomach aches; taking vitamin C can prevent illness; cold weather causes colds.

ALEKS KROTOSKI

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

BBC RADIO 4 92–95FM & 198LW

"I, like others who believe that chicken soup can cure a cold, are victims of a cognitive bias"

The good news is I am not any more or less ignorant than their average respondent. But this is still a kind of misinformation. It is inconsistent with medical evidence. It's enough to make your knuckles crack.

Like other misinformation, this apparently innocuous medical folk wisdom taps into what the researchers describe as an "expert discounting hypothesis" – the belief that I know better than medical science. I, like other people who believe that chicken soup can cure a cold, are victims of a cognitive bias called the Dunning-Kruger effect.

It doesn't take an IgNobel Prize to see that discounting medical science in favour of an unconfirmed 'truism' can shape health behaviours and attitudes to policy. And this is what the researchers found: people who believe in medical folk wisdom, even the innocuous kind, value medical expertise less. Take this to the next level, and medical folk wisdom has created a marketplace in anti-science ideas. Other research has found correlations between Dunning-Kruger overconfidence and anti-vaccine attitudes, mask-wearing advice and climate change conspiracies.

When this kind of knowledge was passed around by a matriarch, it didn't pose nearly as much threat to society as the professionally organised mass media folk wisdom machine. The internet has taken over the role of the village elder, dispensing easy-to-share, not-quite-right information written in Pinterest-friendly fonts to ever-insular echo chambers. Dunning-Kruger-infected collective action is causing harm to public health.

I told you that rabbit hole was dark. But that's why folklorists and anthropologists look at what wisdom we're sharing. Because while it might not be true, it does tell us a lot about what we think is. SF

PORTRAIT: KATE COPELAND ILLUSTRATION: SCOTT BALMER

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MAMMUT

AS THE CROW DIES

Corvids, such as crows, rooks and ravens, are some of the smartest animals out there. They can learn to make new sounds, they can cooperate and even use tools. But as **Dr Kaeli Swift** tells **Alice Lipscombe-Southwell**, they also have some intriguing rituals when it comes to their dead... and could even be capable of feeling empathy

WHAT EXACTLY IS A CORVID?

Corvids are a kind of songbird. Corvids, so the Corvidae family, includes crows, ravens, magpies, jays, rooks, jackdaws and choughs. Ravens are the biggest songbird in the world.

THEY'RE SONGBIRDS? BUT A CROW MAKES A 'CAW CAW CAW' NOISE, WHICH SOUNDS PRETTY DIFFERENT FROM OTHER BIRDS.

'Songbird' is a little bit of a tricky name because the designation of songbird is based on both the positioning of the feet and, most importantly, the anatomy of the vocal area. And that's the feature that these birds share with birds like robins and sparrows and all that kind of thing.

Humans produce the sounds that we do using a larynx, and most birds, including songbirds, have what's called a syrinx. The anatomy does differ a little bit across groups, but the corvid syrinx is going to look pretty similar to other kinds of songbirds. The main difference, though, between crows and ravens and other types of songbirds has less to do with their anatomy and more to do with their brain.

MIKE KANE PHOTOGRAPHY

Most songbirds have a short window of time when they're young where they learn every sound that they're going to make, then that window closes, and that's it. They don't make any changes moving forward.

But one of the really interesting aspects about crows and ravens is that they can learn new sounds throughout their lives. They have really, really impressive vocal repertoires. Part of the reason that they can make such a wide variety of sounds, including human speech, is because they have independent muscle control on either side of their syrinx, so they can produce two different sounds at the same time.

IN THE UK, SOME OF OUR MOST COMMON CORVIDS ARE CROWS, ROOKS AND RAVENS, BUT PEOPLE QUITE OFTEN GET THESE CONFUSED. IS THERE A WAY YOU CAN EASILY TELL THEM APART?

It takes practice, but there are definite tools that you can accumulate and you can get really good at it. The first thing is ravens are quite a bit bigger than crows. The second feature is if you look at the throat, ravens have these really kind of rough, heavily textured throat feathers, whereas the throat of a crow is smoother. And then the last feature is the shape of the tail. When ravens fly they have this kind of wedge-shaped tail, whereas crows have a more c-shaped, rounded tail. Rooks are really easy to distinguish once they've had their first adult moult, as they lose all of the feathers at the base of their beak. We don't quite know why this happens, but it could be because rooks are incredibly insectivorous, and so they probe in the grass a lot for bugs. The lack of feathers might be a hygiene thing.

"Corvids are incredibly smart. One might make the argument that primates are really about as smart as a crow"

HOW INTELLIGENT ARE CORVIDS?

Corvids are incredibly smart. One might make the argument that primates are really about as smart as a crow!

One of the challenges to studying intelligence is making sure that your tests make sense and are executable by the animal in question. There are tests that we give to chimpanzees to evaluate their intelligence that we simply can't give to a raven because

ABOVE New Caledonian crows can peel and whittle leaves and twigs into hooks so they can extract grubs from logs

ALAMY, NATUREPL.COM, KAELI SWIFT

ABOVE An American crow tries to mate with another dead crow

LEFT After their first adult moult, rooks are easy to distinguish from crows, as they have a bare area at the base of their beaks

they can't participate in it as they don't have hands. There are a variety of categories – like analytical skills, ability to understand quantities, problem-solving skills, ability to understand cause and effect, ability to cooperate or pick up on social cues – that reflect intelligence on a pretty high cognitive level. We've been able to demonstrate that in humans and primates, but more and more we've been able to design those kinds of tests that are appropriate for crows and ravens. And we see that the performance is often quite similar to what we see in primates.

WHAT ABOUT TOOL USE?

New Caledonian crows make a variety of tools, most impressively hooks. There's a plant that's native to the area where the crows live, called the pandanus, which is really rigid with a serrated edge. The birds will peel off sections of the edge of this plant and then whittle it down to the appropriate size and stick it into the crevices of logs and rotting wood to pull out grubs, in a similar way to how chimpanzees will take twigs and then modify them so that they can extract ants.

Beyond that, they'll also snap off branches and modify them in ways that the resulting tool meets the minimum definition of a hook, which is incredibly impressive. Tool use is rare in the animal kingdom, only about 1 per cent of the animals use them. But making tools, actually taking objects and modifying them, is much more rare. Other than crows, we recently found this in a parrot and then a couple of primates.

SPEAKING OF BEHAVIOUR, YOU STUDIED DEATH RITUALS IN CORVIDS. TELL US MORE.

For a long time, humans have recognised that these birds respond strongly when one of them dies. And you can see that evidenced in religious text and mythologies. For example, there's a story in the Qur'an about ravens teaching Cain to bury his brother Abel, because they understood that that's what you did when somebody died.

The way that this strong response manifests in crows, is that when a crow dies and is discovered by another, that crow will make an alarm call and it will draw in other crows in the area. They all get together in this big, raucous mob and take notice of this event. And then after about 15 or 20 minutes or so, the group disperses.

If these animals are engaging in this behaviour, it's something that they have done for tens of thousands of years. There's a reason. And so what is it? Do they engage in these 'funerals' as a way to learn about danger? Some reasons may be just as valid, like are they grieving, but they're not testable.

DOES ANY OLD DEAD CROW CAUSE THIS EFFECT? OR DOES IT HAVE TO BE A CROW THAT THEY ARE FAMILIAR WITH?

We exclusively tested unfamiliar birds, so it's still an open question of how their behaviour might be different if it's a bird they know. Certainly, it would make sense given how closely these birds pair bond, how long that ➲

relationship can be, that the behaviour might actually look a little bit different if it's their mate of over a decade that had passed rather than some random crow. But that's not something that I looked at.

YOU SAID THEY SEE THE DEAD CROW AS MAYBE A LEARNING OPPORTUNITY. BUT DID THEY EVER DO ANYTHING ELSE? DID THEY SEE THE DEAD CROW AS A FOOD SOURCE AND TRY AND PECK AT IT?

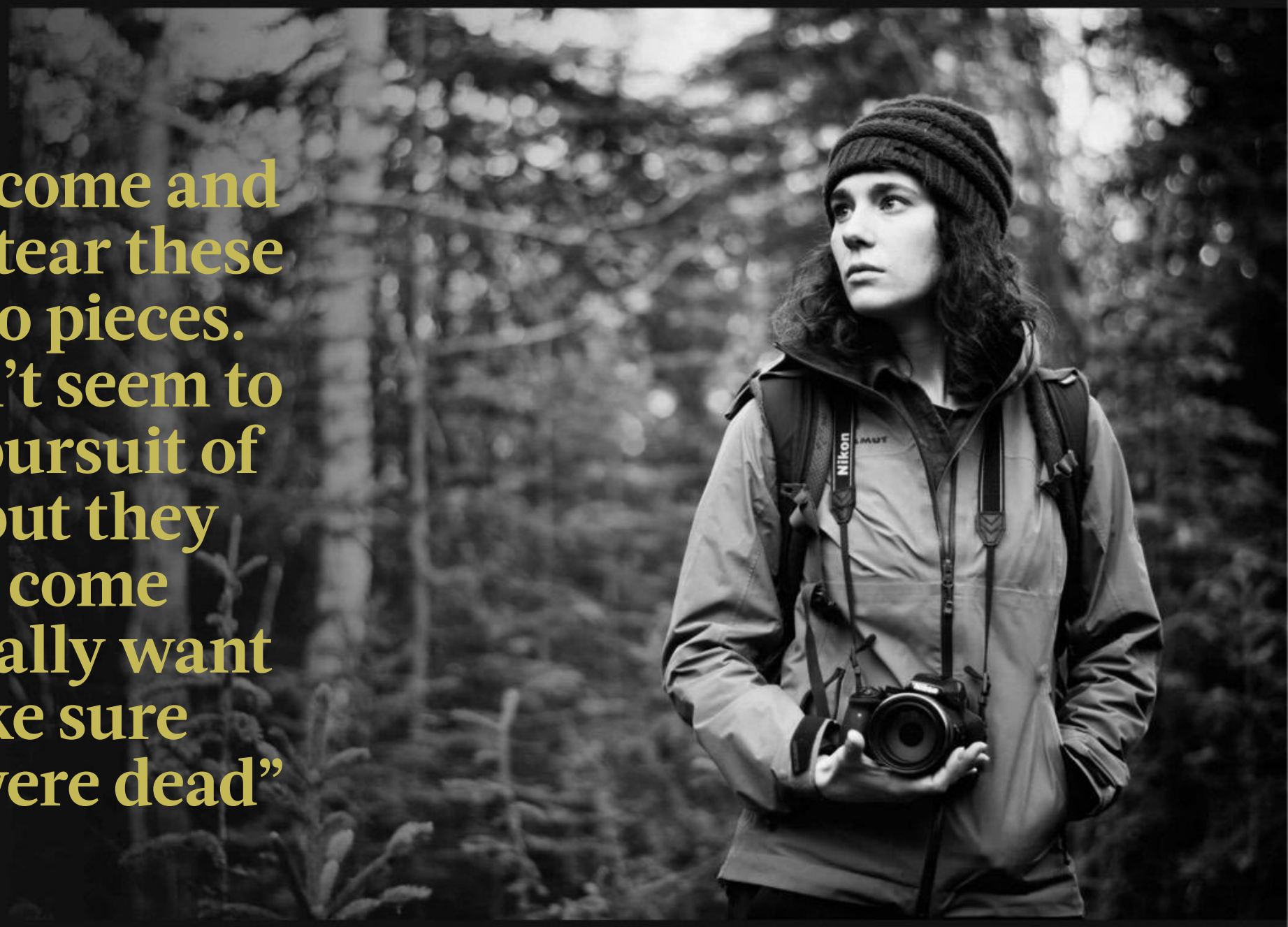
That was one of the questions that I tested later on as a graduate student. We had started feeding the crows over the course of several days, and then we exposed them to a person paired with a dead crow. We found that in the following three days they were more wary to come to that pile of food, and they learnt people were associated with dead crows. So if they saw somebody they'd never seen before holding a dead crow, and then they saw that person again in the future without the dead crow, they would treat them like a predator. So clearly they're making some kind of connection between danger and dead crows.

If it's about danger, then we would expect them to respond more strongly to dead adults because adult survivorship is much higher than it is for juveniles. Juvenile survivorship for that first year is only about 50 per cent, but for a prime-of-life adult it can be as high as 80 per cent. It's not unusual for crows to live for 14 to 17 years.

To study this, we didn't put out dead crows paired with predators, we just put dead crows out on the sidewalk. And so I'm doing one of those experiments, kind of not thinking much of it. And suddenly the crows are doing something I hadn't ever seen them do in that first round, which is coming down and actually interacting with the body. And so that spun off into an entirely different study.

We found that any kind of contact between crows and dead crows happens somewhere between 30 and 40 per cent of the time. And that contact can be very variable. Sometimes it was a curious 'sneak and peck', where they just kind of prod it like a kid might if they saw a dead bear in the woods.

BELOW Bird expert Dr Kaeli Swift studied death rituals in crows for her PhD, and is currently researching Tinian monarchs



"They come and really tear these birds to pieces. It didn't seem to be in pursuit of food, but they would come and really want to make sure they were dead"

It could also be incredibly aggressive. They come and really tear these birds to pieces. It didn't seem to be in pursuit of food, but they would just come and really want to make sure that they were dead. And then in a minority of cases, about 4 per cent of the time, we found that the behaviours could actually be sexual. So we saw copulatory attempts between living crows and dead crows, and even two instances of a mated pair coming down and simultaneously mating with this dead crow and each other. So it got it got surprising, to say the least!

SURELY HASN'T BEEN RECORDED IN MANY OTHER SPECIES, HAS IT? THAT'S JUST NUTS!

So here's the rub. Actually, it has been recorded in most animals that have really robust responses to their dead, like elephants, primates, whales, dolphins. We see all three of those behaviours manifest. So the kind of curiosity-based behaviours, aggressive behaviours and sexual behaviours. And in fact, dolphins are way more prone to that than crows are. I had the exact same reaction the first time I saw it. I thought, "Oh my gosh, what is happening here?" And then I looked in the literature and I was like, "Oh, this really is a thing among these social, intelligent animals." There seems to be this very variable way that they respond to their dead. It is being represented over and over again.

DO THESE RITUALS SUGGEST THE BIRDS ARE FEELING ANY SORT OF EMPATHY FOR EACH OTHER?

That's a tricky question. One of the things we did was a neural-imaging study where we took wild crows and brought them temporarily into captivity. And we have this really cool non-lethal imaging technique where we could take an awake crow and show it a dead crow and then anaesthetise it. We put it in a scanner and use a chemical to track their brain activity from earlier when they were awake and looking at a dead crow. And then the crows come out of the scanner, they wake up and then we let them go.

We wanted to get at the question of how they were feeling about the dead crow. We thought that by looking at the brain, it might give us a bit more insight. The avian brain and the mammalian brain are quite different in a lot of ways, but in other ways, they are similar. They have parts that do basically the same thing, including the amygdala, which is the emotional centre of the brain.

We wanted to see if the amygdala lit up when they saw dead crows. And we found that it did not. The area that lights up is analogous to our prefrontal cortex, which is the decision-making, thinking part of our brains. This aligns quite well with what we saw in our other field studies where crows are using these experiences as indications of danger and making all kinds of decisions based on that information. Now again, like I mentioned before, we were showing them unfamiliar crows, so would their amygdala light up if they saw their dead mate? I can't answer that.

However, if we put all of that aside and say that those particular studies may not be able to get at that question, we have done other studies that were specifically designed to evaluate empathy. These have shown some really promising indications that yes, in fact, these birds may well possess empathy.

The way we've done those studies is to look at what's called 'emotion contagion'. Contagion is basically the idea that if your friend is sad and you're like, "Hey, what's up?" And they're like, "I'm really sad." And then you say, "Oh no, now I'm sad, too!" That is empathy, right? It's taking on the emotions of another.

We've been able to show that ravens are capable of something that looks exactly like that. There was this cool little study where they have two chambers where you had a demonstrator raven and an observer raven. They couldn't interact with one another, but they could see each other. The demonstrator raven is given a box and it can look inside that box. The observing raven can't see what's in there. It can only see how the demonstrator reacts to it. And in half the cases, the demonstrator was given something really cool, something delicious. They got very excited about it. And in the other half of the trials, they were given something boring. They look in the box and they're like, "I don't care about this." And the observer watches that. Then the researchers would give the observer raven a box, and they found that observers that had seen a demonstrator get really excited about what was in their box were like, "Oh, let me at this! I'm going to look in this box. I'm so excited!" And in the other group, they're like, "I don't want to go near that box. I don't know what's in there. I don't care, get it away from me."

And that is emotion contagion. That is looking at someone's reaction and feeling the same way as them too. So I wouldn't use my studies as a way to get at whether or not these birds possess empathy, but there are folks who are pursuing that, and there does seem to be evidence that they very well could. **SF**

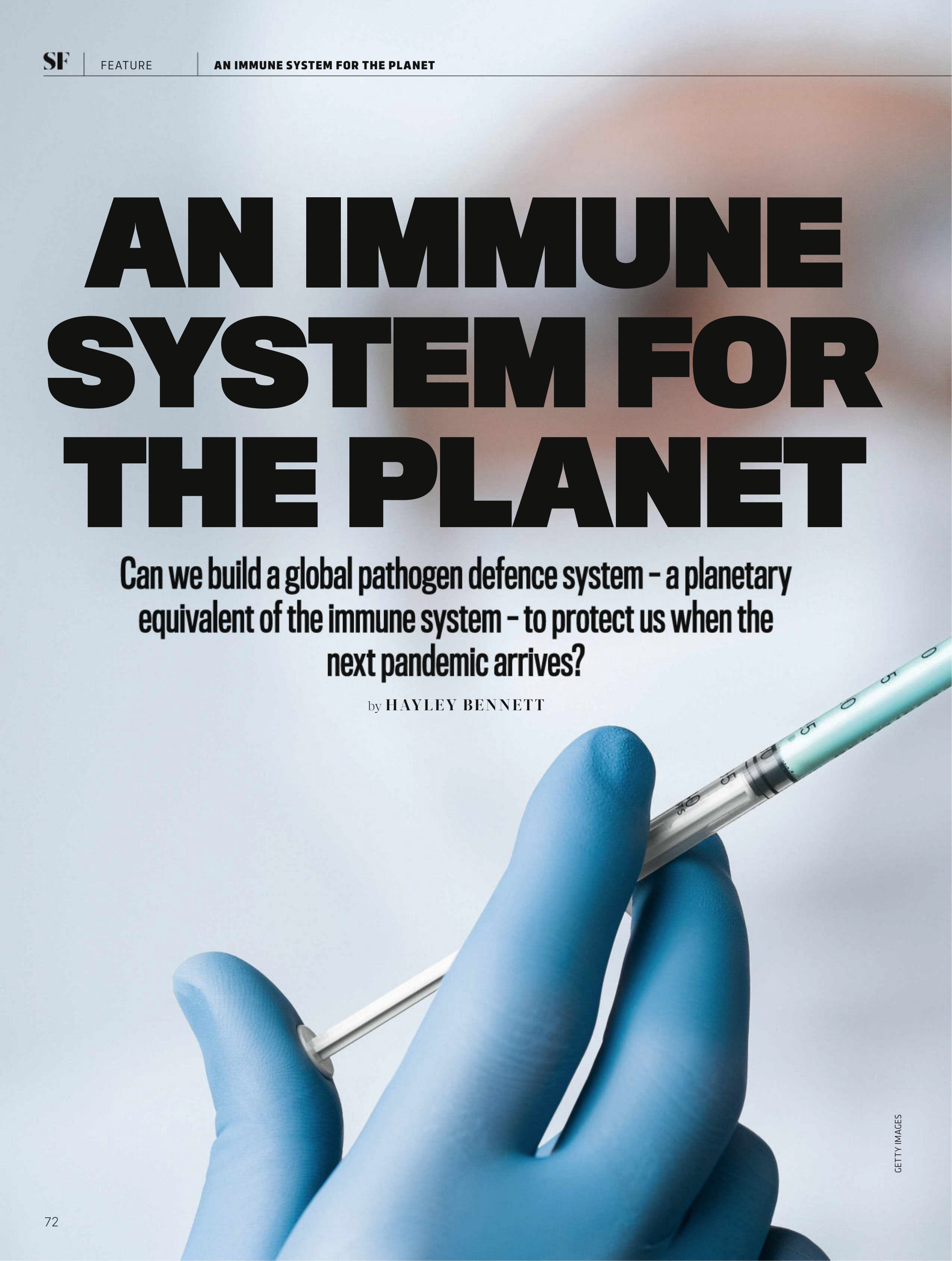
JACOB GAPOSCHKIN

DR KAELI SWIFT
(@corvidresearch)
Kaeli is a bird researcher at the University of Washington. She did her PhD on crow death behaviours. She runs the weekly #CrowOrNo challenge on Instagram, Facebook and Twitter.

AN IMMUNE SYSTEM FOR THE PLANET

Can we build a global pathogen defence system – a planetary equivalent of the immune system – to protect us when the next pandemic arrives?

by HAYLEY BENNETT



GETTY IMAGES

Most of the time we all walk around in a little bubble, a defence system that can spot a threat and neutralise it before it has a chance to harm us. That's the wonder of the human immune system, and it's only when we get ill do we become aware that it's there at all.

What if we could give the planet an immune system just like ours? A silent network of satellites and supercomputers quietly keeping track of anything that could cause the next pandemic; primed to sequence the culprit and capable of rolling out vaccines and treatments the second someone presses the right button. That's the vision of global technology expert Dr David Bray, who believes that we need to build "an immune system for the planet".

"I'm talking about a dynamic system that learns to respond to what's present in our world," Bray says. "If you think of our world as an organism and we are parts of that organism, then what do we need to do, much like the immune system of our bodies, to detect that there's something going on that's not healthy?"

Bray is a Distinguished Fellow at the Stimson Center, a not-for-profit based in Washington, DC, that carries out research to solve big, real-world problems using technology. He talks at the speed of his brain – fast – probably because he has a lot to cover. Starting at age 15 working for the Department of Energy, he's used satellites to spot forest fires, built computer models of HIV/AIDS, got a PhD in "organisational responses to disruption", briefed the CIA on bioterrorism and carried out independent analysis on the Afghanistan situation for the Obama administration.

It's not just big problems that Bray is interested in solving; it's the near-impossible ones. "You tell me it's never been done before, you tell me it's impossible and I'm like, 'okay, that's what I want!'" he laughs. Like preventing pandemics? Yes, he says, though he explains that the goal is not necessarily preventing them, but detecting and reacting to them as early as we can. What happened with COVID, he says, is that we burned up too much time before it was taken seriously.

"WE ALL GO TO THE TOILET, SO WHEN YOU THINK ABOUT IT, THAT'S UNBIASED SAMPLING"

ABOVE LEFT
A network of satellites could help track patterns and detect anything unusual to help alert scientists ahead of potential pandemics

ABOVE RIGHT
Dr David Bray thinks we need to build an immune system for the planet by looking for quirks in data

But can we really prevent the next pandemic by throwing technology at the problem? University of Glasgow epidemiologist Prof Sarah Cleaveland is sceptical. "I just think we have to temper our expectations about some magic technological solution," she says. Though we are getting closer to being able to look at a virus, or its genome, and predict whether it's going to be a problem for humans, that's "not possible" right now, Cleaveland adds. Not possible: all the encouragement Bray needs.

DETECT AND DEFEND

The planetary immune system is an idea Bray proposed to the US Defense Advanced Research Projects Agency (DARPA) in 2013. DARPA was busy with Iraq and Afghanistan, so he was told to come back in "about seven or eight years, which, of course…" Bray nods to the COVID situation again. "Well, here we are now."

In 2021, he outlined a new scheme for the concept, which is perhaps easiest to understand in the context of how our own immune systems work. Human immune systems detect disease carriers through a diverse array of receptors on living cells, spread throughout every organ and tissue. Likewise, Bray imagines a system that picks up on potential threats via a global detection network, one that would include sensors spread through the air, soil and water, as well as artificial intelligence (AI) programs trained to spot weird blips in patterns of human behaviour and economic markets that might point towards infectious interference.

With a potential threat identified, the system's vast processing power would be thrown at sequencing it, characterising its interactions with human cells and using that information to figure out how to stop it. In an ideal world, this would all happen in machines, with as little input from us as possible, reducing the response time from years to three or four weeks.

Perhaps it sounds a little out there. But taking it piece by piece, we're already doing a lot of it, and it just needs tying together. Take weird blips, for instance – something Bray specialises in. Between 2000 and 2005, Bray was the IT chief for the Bioterrorism Preparedness and Response Program at the US Centers for Disease Control and Prevention, where part of his job was looking for quirks in data that might act as early indicators of a bioterrorism attack. If the President was speaking at the Super Bowl, his team would start three days ahead, establishing baseline levels of over-the-counter drug sales, emergency calls and school absences. "If all of sudden I [saw] a spike when the President [was] speaking, that could be a bioterrorism event," he says.

Another example is garlic in China, where it's considered a remedy for all ills. The price shot up when SARS struck the Guangdong province in 2002, and again in early 2020, as COVID was taking off. In 2002, the garlic price hike, combined with the increasing number of cars showing up in hospital car parks, gave Bray and his colleagues a hint that something was going on. "We knew about it five and a half months before it hit the world stage," he says. Artificial intelligence could detect these sorts of oddities, according to Bray's concept, forming a key component of an early alert system.

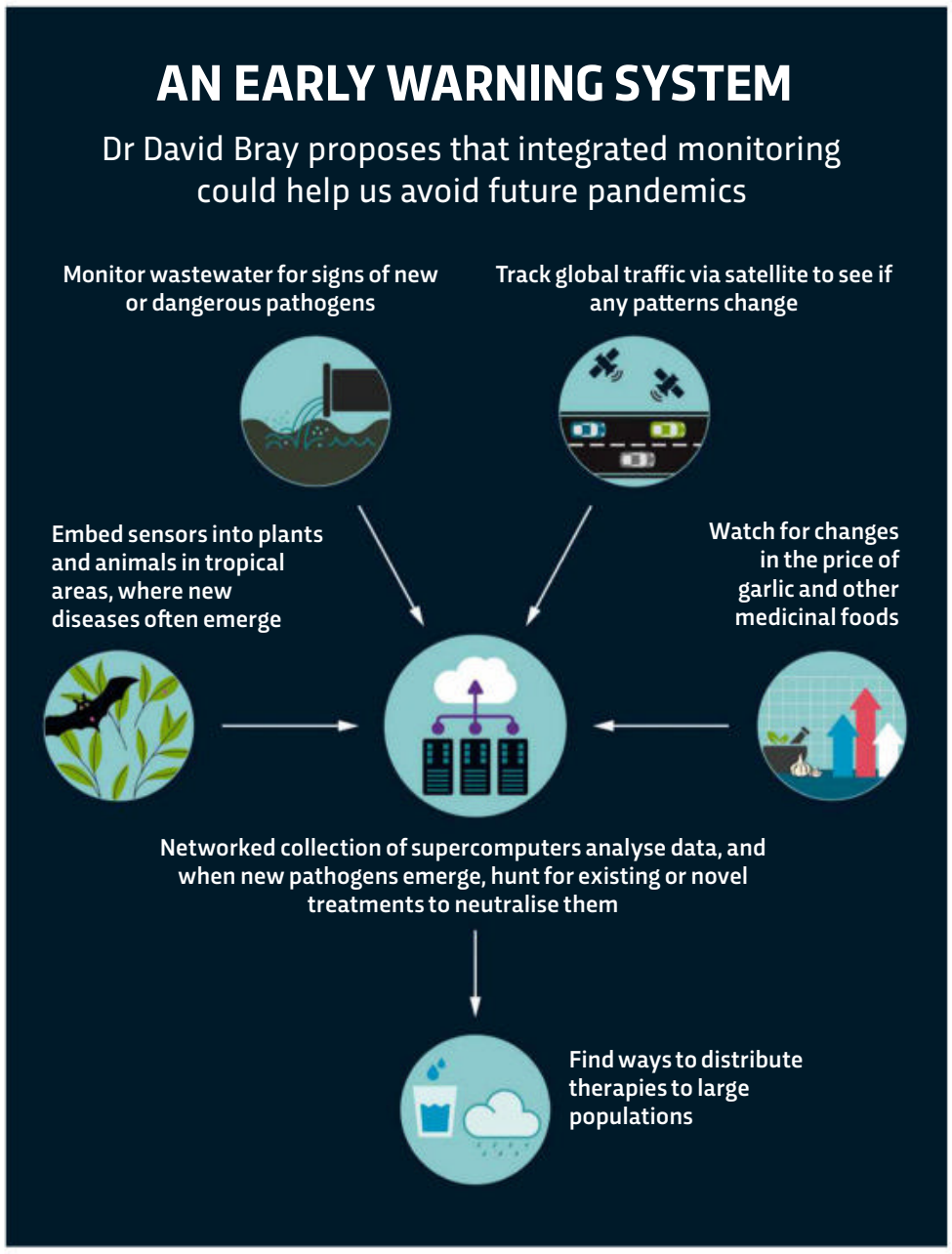
GETTY IMAGES, TELEPORTEC, KNOWABLE MAGAZINE, ALAMY

This surveillance for strangeness is just one small part of the scheme. The planetary immune system would double-down on disease by combining different detection methods.

SEWER SURVEILLANCE

Next up: the sewers, one of the places Bray suggests we should be looking for pathogens. Here again, there's a precedent. In 2013, sewer sampling caught a silent epidemic of a poliovirus in Israel, triggering a vaccination campaign that helped to avert a more serious outbreak of polio. Now, across Europe and the US, wastewater testing for COVID-19 is helping scientists to get an unbiased picture of how the virus spreads. Italian researchers, for example, retrospectively analysed samples of raw sewage collected before the first wave officially began, detecting traces of the virus in samples from three Italian cities in December and January, weeks before the first non-imported case was reported in late February. And according to Prof Dragan Savic, CEO at KWR Water Research Institute in Nieuwegein, the Netherlands, we're already looking at levels of new variants.

Sewage, Savic explains, provides a window on literally everyone's business. So you don't have to wait for mass testing to get up and running, or worry about whether people are testing when they should be. "There are people who don't have symptoms, there are people who are recovering – who will not go for testing – and there are limited tests," he says. "But we all go to the toilet, so when you think about it, that's unbiased sampling."



So our wastewater can give us a heads-up when an emerging disease first infects a new area. With AI, the same information could also be combined with other data sources, like weather patterns or gatherings of people, to help reveal how an infectious agent is spreading and plan allocation of resources.

Another key component of Bray's system is a biosensing network that he envisions being embedded into plants and animals. In his 2021 scheme, he describes transmissions from these biosensors feeding into a supercomputing network. Such biosensors aren't fantastical; they are promising and, in some cases, already commercially developed devices (think glucose sensors for diabetes) based on biological components. They're set to make a big impact as "low-cost sensing systems that can be deployed in the field", according to synthetic biologist Prof Paul Freemont, who is developing biosensors at Imperial College London.

Freemont's biosensors are fluorescent beads that lose their fluorescence when they contact proteases, which are enzymes used by a wide variety of organisms. Many viruses, from HIV to herpes, use proteases to replicate. Freemont has tailored them to detect different targets, including proteases from a plant virus, as well as from *Schistosoma mansoni*, a parasitic worm. The technology uses components that the researchers suggest could be modified to

ABOVE In China, garlic is seen as a remedy for various illnesses. Ahead of the SARS outbreak, garlic prices in China started to skyrocket. This happened again before the COVID pandemic

detect different pathogens, perhaps in portable devices in regions where the risk of animal diseases crossing over into humans is high.

INTO THE UNKNOWN

However, embedding biosensors into plants and animals may be taking the idea too far for Freemont. He isn't convinced that biosensors would help us get ahead of a new disease. "My question is: how can we embed sensors to detect things that we know nothing about?" he says. "It could be useful for existing targets, for sure, and for emerging targets that we know of, but the problem is something completely new. Would you have enough time to redesign that system and get it back into the wild?"

It's a good question. Our immune systems don't just respond to bacteria and viruses that they've met before. They detect and protect us against any foreign invader, using receptors that distinguish between 'self' (us) and 'non-self' (invaders). It's hard to envisage how we might replicate this system on a planetary scale. But we need to be able to work out what, from the multitude of unknowns, might pose the biggest threats. This, Bray says, will be "the most novel part" of the system.

Dr Kevin Esvelt, a biochemist at the Massachusetts Institute of Technology, has his own ideas about how we should detect new and dangerous pathogens. His theories are aimed primarily at dealing with what he calls "the deliberate variety" of pandemic – to his mind a more difficult problem than a naturally occurring one. Why? Because, he says, bioterrorists have to be expected to design weapons to evade any defences that we might set up. We therefore need a more open approach in order to detect this stuff; one that would catch not just new variants of old diseases, but something the like of which we've never seen.

In a pre-print paper published on arXiv in August 2021, Esvelt proposes a global Nucleic Acid Observatory that would sequence the genomes of everything we encounter in the sewer space and beyond. But how would this approach help us to pinpoint those organisms we need to be particularly wary of? As the paper outlines, the real hallmark of any organism with pandemic potential is unbridled growth, which would be seen as an explosion in levels of its genome sequences.

"Any serious threat must by definition grow exponentially," Esvelt explains. "This should allow us to detect anything potentially problematic, be it an invasive pest, a crop blight, a novel pandemic virus unrelated to anything we've seen before, or even something totally new that [an] adversary has devised."

Perhaps something like this observatory could form a key part of the immune system for the planet? Freemont, for his part, says it's a "compelling" proposition for solving the problem of detecting entirely new pathogens. Yet to do all of this, we'd need armies of sample collectors to mail samples back to the lab every few days. Compared to the seamless detection system that Bray imagines, this does seem rather laborious. But Esvelt argues it would be worth it. "Doing this for next-day sequencing is a tiny cost relative to that of the sequencing itself, and losing a day in exchange for reliability is an excellent trade-off," he says.

"DEEP VZN WILL CHARACTERISE THOUSANDS OF VIRUSES FROM WILD ANIMALS ACROSS 12 COUNTRIES"

ABOVE Workers check the sewage system for traces of COVID-19 in Hong Kong in January 2021. Sewage surveillance is an excellent way to detect the prevalence of pathogens, especially if many people are asymptomatic or mass testing isn't possible

RIGHT Dr Kevin Esvelt's work outlines how early warning systems can detect invasive species, as well organisms that could cause pandemics

Sequencing won't tell us everything though. Any candidates with pandemic potential would have to be probed in exquisite, molecular-level detail, not just to work out whether they're real threats, but also how we might tackle them. "That's going to involve some research," Bray admits.

At Washington State University, a project called Deep VZN is already aiming to do something similar. Deep VZN will characterise thousands of viruses from wild animals across 12 countries, focusing on the families of viruses that spawned COVID-19, Ebola and measles. Project leader Dr Felix Lankester says his team plans to probe the molecular structure of those whose genomes are "unknown", looking for a lock-and-key type fit between molecules on the surface of viruses and receptors on human cells. They will also use an algorithm to assess the likelihood of the viruses spilling over into humans and look at whether these viruses could evade or inhibit our immune defences. "This information will be made available for the design and development of countermeasures, such as new vaccines and diagnostics," says Lankester.

In the future, Bray anticipates a lot more of the work being done by machines. With AI programs like DeepMind's AlphaFold already making huge strides in predicting the 3D structures of proteins, such thinking might not be such a stretch. So, if you leave aside the difficulty of predicting how symptoms might play out in real humans (before any have actually been infected), all of this might sound quite feasible, eventually.

It's when we get to Bray's ideas about how we should respond to such threats that things get a bit wild. He would have us rolling out machine-designed vaccines at the touch of a button and even suggests distributing antibodies in drinking water, a step that would seem less drastic if we were talking about something more dangerous than COVID. Which he is. "We're not talking about a slow-spreading pandemic like we have now. It's one where you would have an hour or less to survive," he says, suggesting that the first place to trial this would be in countering the use of bioweapons on military battlefields.

BELOW *Schistosoma mansoni* parasitic worms. The female (pink) lives within a groove on the male (blue). Prof Paul Freemont has developed biosensors that lose their fluorescence when they come into contact with enzymes produced by the worms

GETTY IMAGES X2, SCIENCE PHOTO LIBRARY

The question is: will policymakers be persuaded to think ahead on pandemics? Even post-COVID, warnings of epidemiologists are still ignored, Cleaveland points out. Hendra virus, a bat disease that can be fatal to horses and humans if it spills over, is a case in point. In 2020, Australian and US researchers warned of a high risk of spillover during the coming winter, but to no avail. "For me that was a really fascinating insight," she says. "We have a vaccine. This is a fatal disease. We had a good indication that there was a risk coming and still, people didn't respond." Luckily, things turned out okay, but only because the bats were kept at bay by an unexpected crop of fruit.

So if policymakers aren't willing to act, who is going to invest in the immune system for the planet? "Can we find a coalition of the willing?" asks Bray. It's always going to be a hard sell because if it works, nothing will happen – preventing a pandemic just looks like a colossal waste of cash. Unless, maybe, you're still reeling from the financial fallout from the last one. **SF**

by **HAYLEY BENNETT**
(@gingerbreadlady)
Hayley is a science writer based in Bristol, UK.

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Q&A

YOUR QUESTIONS ANSWERED

... HOW IS COAL FORMED?
... WHAT IS PAROSMIA?
... DO DOGS GET TIRED WAGGING THEIR TAIL?
... HOW DOES NUCLEAR FUSION WORK?
... WHY DOES LEFTOVER PIZZA TASTE SO GOOD?
... HOW DO MILANKOVITCH CYCLES AFFECT CLIMATE?
... WHY DO WE GET BORED?
... WHAT IS WATERMELON SNOW?
... HOW DID DINOSAURS SLEEP?
... HOW DO YOU READ BINARY NUMBERS?
... HOW DO I KNOW IF MY TOE IS BROKEN OR JUST BRUISED?

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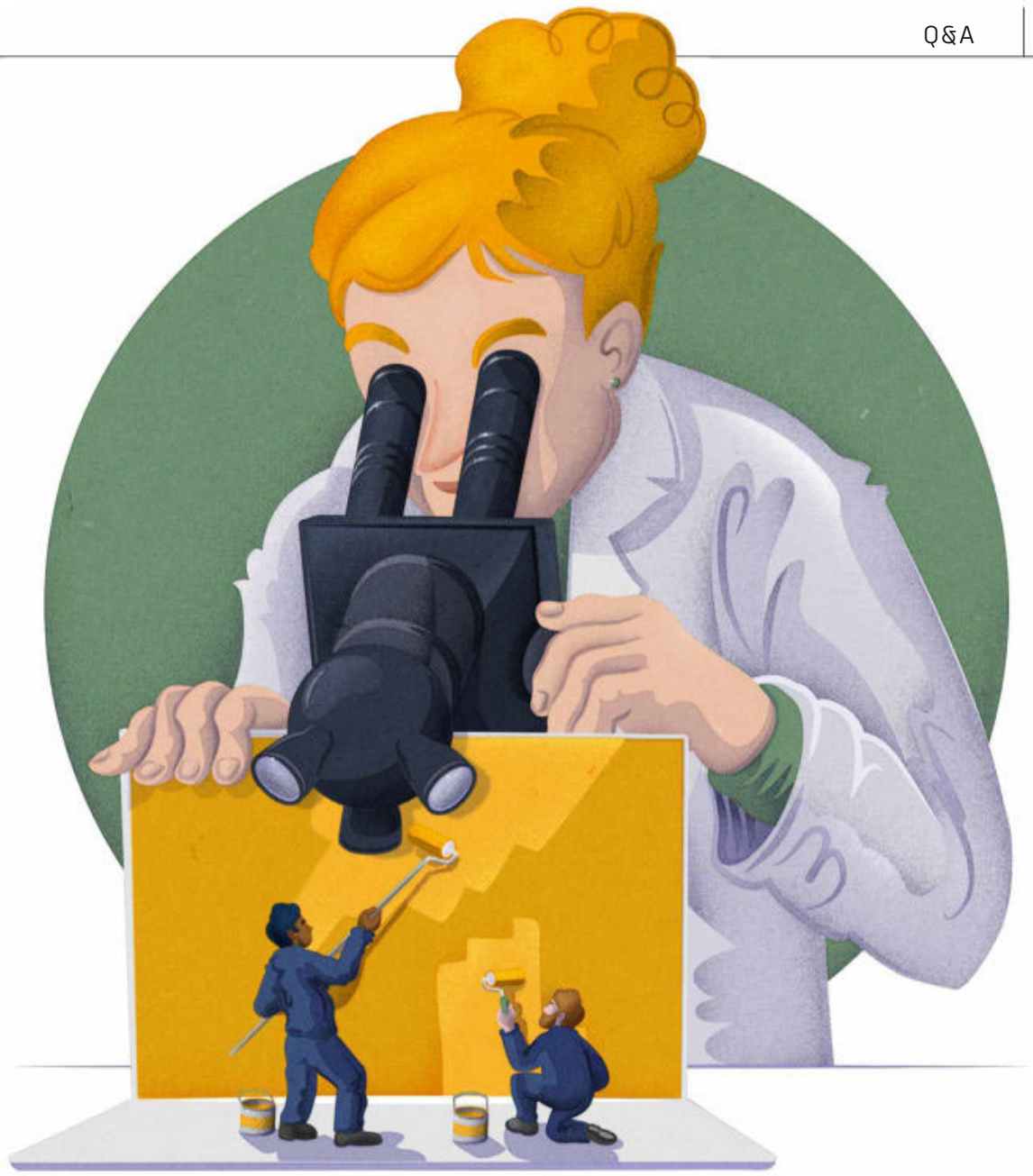


ILLUSTRATION: DANIEL BRIGHT

JOSIE MCGREGOR, CREWE

WHAT IS THE BEST WAY TO DECORATE MY HOUSE, ACCORDING TO SCIENCE?

Who needs glossy property magazines or home-improvement TV programmes when you can revel in a more nerdy approach, and make your decisions based on findings in the psychology literature?

Take the colour of your walls. You might want to consider painting your bedroom blue because people associate that colour with calmness and relaxation, and there's tentative evidence that it can even have a stress-relieving effect. If you have a home study, though, you might consider opting for a more reddish hue since that colour has been associated with heightened focus. Perhaps you should have at least one wall blue in that room too, since the same study found that blue boosted creativity.

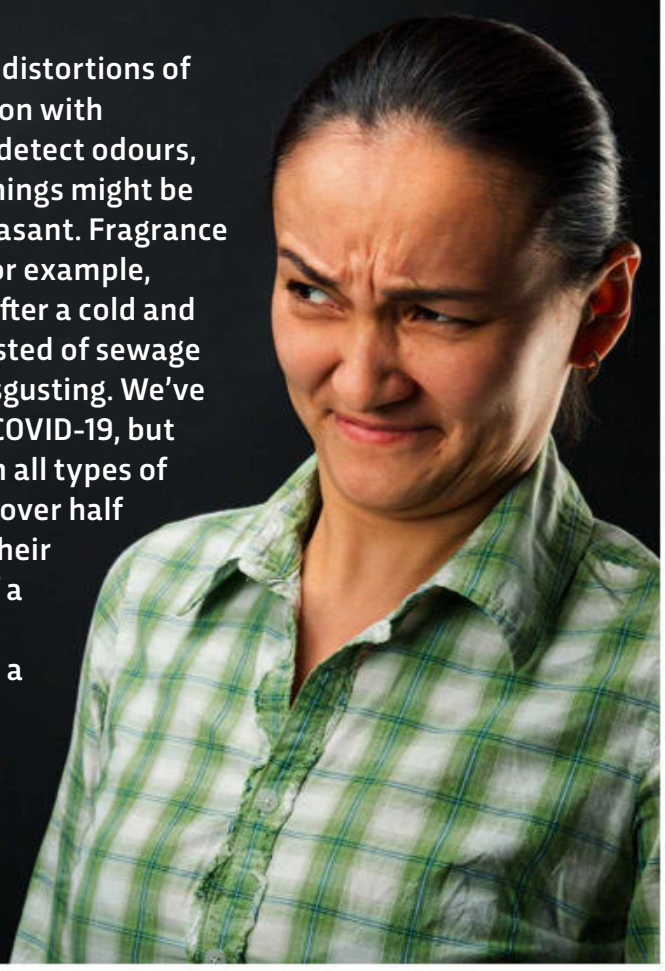
In terms of your furniture choices, the psychology literature is clear – you should definitely opt for a curvy aesthetic and avoid straight lines and hard edges. People tend to find curvy shapes more beautiful and relaxing. This actually extends to the shape of rooms and buildings, with curvy structures triggering more activity in pleasure-related parts of the brain, so if you have any ability to lend some bendiness to your home's layout, that's another option to consider.

Of course, many of us wish our homes were bigger and more spacious. There's some empirical evidence to draw upon here too: larger windows help create a sense of space, as does making a room more rectangular rather than square-shaped (you could use furniture to provoke this effect). Speaking of windows, if possible, you should consider laying out your room in such a way to optimise views over any green space – doing so will be good for your health.

Finally, if you're not lucky enough to have sight of greenery outside, then be sure to bring it into your home. While the air-purifying properties of house plants are probably modest at best, there is considerable evidence for their psychological benefits, including for reducing all the stress involved in redecorating! ***CJ***

VINCENT HAWES, LONDON

WHAT IS PAROSMIA?



Parosmia is experiencing distortions of the sense of smell. A person with parosmia may be able to detect odours, but the smell of certain things might be different and often unpleasant. Fragrance writer Louise Woollam, for example, suffered from parosmia after a cold and found that most foods tasted of sewage and most things smelt disgusting. We've heard a lot about it with COVID-19, but parosmia is common with all types of post-viral smell loss, and over half of people who have lost their sense of smell because of a virus will experience it. Unfortunately, there isn't a quick cure, but charities such as Fifth Sense and AbScent suggest it often gets better with time. ***NM***

SHAUN GARDNER

DO DOGS GET TIRED WAGGING THEIR TAIL?

Like all essential doggy business, such as breathing, barking and begging for treats, tail wagging uses energy. When a dog is happy, knows it, and really wants to show it, muscle cells in the tail produce the energy that is needed via a process called aerobic respiration. This uses oxygen, but if the tail wags too much, and the muscles work really hard, the cells start to respire anaerobically, without oxygen. This generates less energy, and a by-product called lactic acid which causes temporary muscle fatigue and soreness. It's enough to make even the most exuberant pooch take five and wait for their cellular batteries to recharge. ***HP***

WHY DO WE GET BORED?

Boredom is like an annoying itch that flares up when you know you want to do something other than what you're currently doing. Sometimes it's the situation that's to blame, such as when you're stuck on a repetitive work shift or listening politely to a loquacious neighbour. Other times, you might be free to act as you wish, and you know you want to do something, but you just don't know what to do. Notice how these scenarios are different from the apathetic state of simply not wanting to do anything.

Boredom is uncomfortable and, evolutionarily speaking, its adaptive function would seem to be that it motivates us to make a change to our circumstances, to do something more personally meaningful. Related to this, there's research showing that boredom can boost creativity, presumably because of the way it galvanises us to reflect and search for meaning.

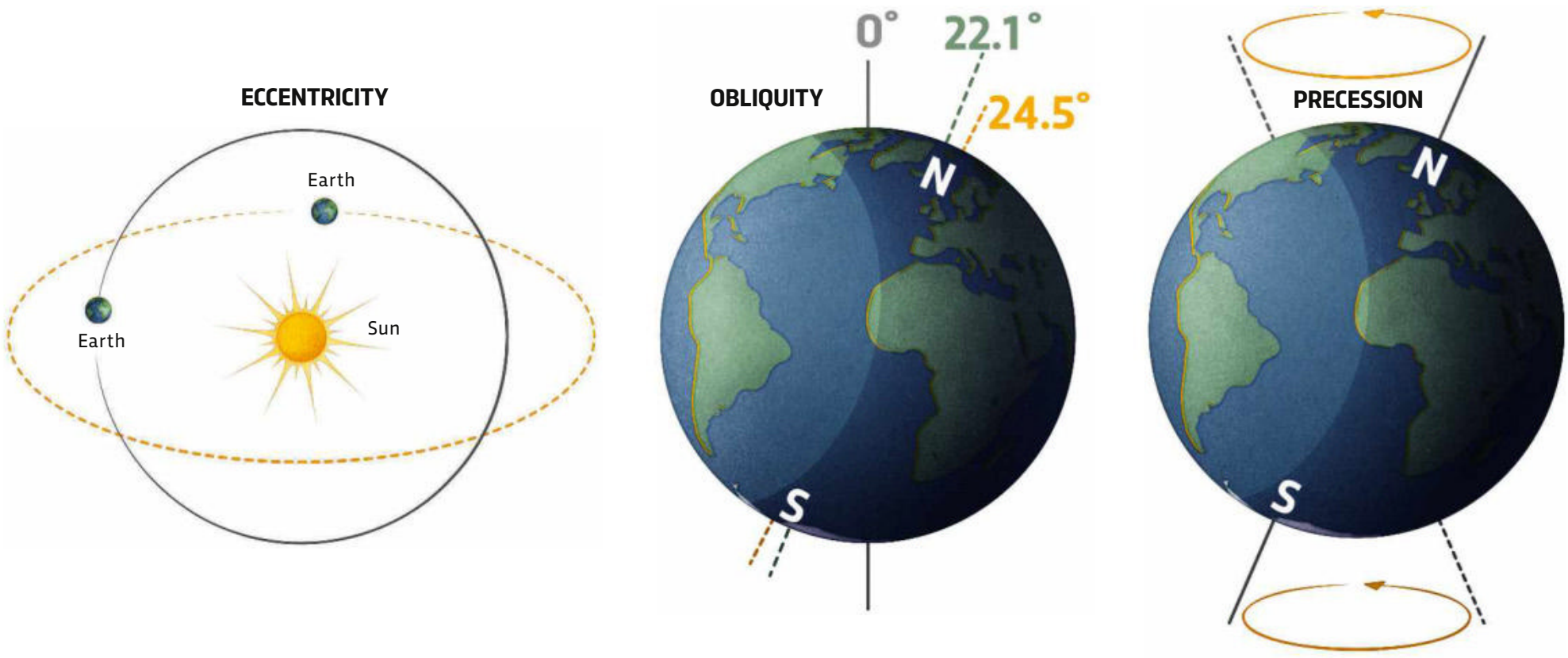
Some people seem to experience boredom more often than others. Psychologists use questionnaires to measure this 'boredom proneness', which they see as being akin to a personality trait. High scorers tend to agree that time passes slowly and that they find it hard to entertain themselves, among other similar statements. Unfortunately, the chronically bored are at heightened risk of depression and addiction – they will often turn to drink, drugs and digital devices to ease their discomfort and unease, though such strategies promise only temporary and superficial relief. To truly overcome boredom, the secret is to find pursuits that are personally meaningful that offer just the right mix of challenge and novelty. ***CJ***

GETTY IMAGES X3, ALAMY ILLUSTRATIONS: DANIEL BRIGHT

PHIL BLACK, OXFORD

WHY DOES LEFTOVER PIZZA TASTE SO GOOD?

A night in the fridge gives strong pizza flavours time to merge and mellow in a satisfying way. The pizza keeps its structure when cold, with the tomato layer preventing fat in the cheese topping from seeping into the dough base. Pizza temperature affects taste perception, with cold foods generally having less intense flavours than warm ones. At temperatures between 15 and 35°C, heat-sensitive channels in the tongue's sweet and bitter taste receptors open wide, setting off a chain reaction to send strong signals to the brain. At lower temperatures the channels barely open and the signals are weaker. Salty and sour taste receptors are not affected by temperature in the same way and cold pizza can actually taste saltier. ***ED***



JAMES EDWARDS

HOW DO MILANKOVITCH CYCLES AFFECT CLIMATE?

Earth has a long history of episodic alternation between glacial and interglacial periods. And so far, these alternations are best explained by periodic deviations in Earth's orbit around the Sun, called Milankovitch cycles. These cycles cause regular variations in the amount of heat we receive from the Sun.

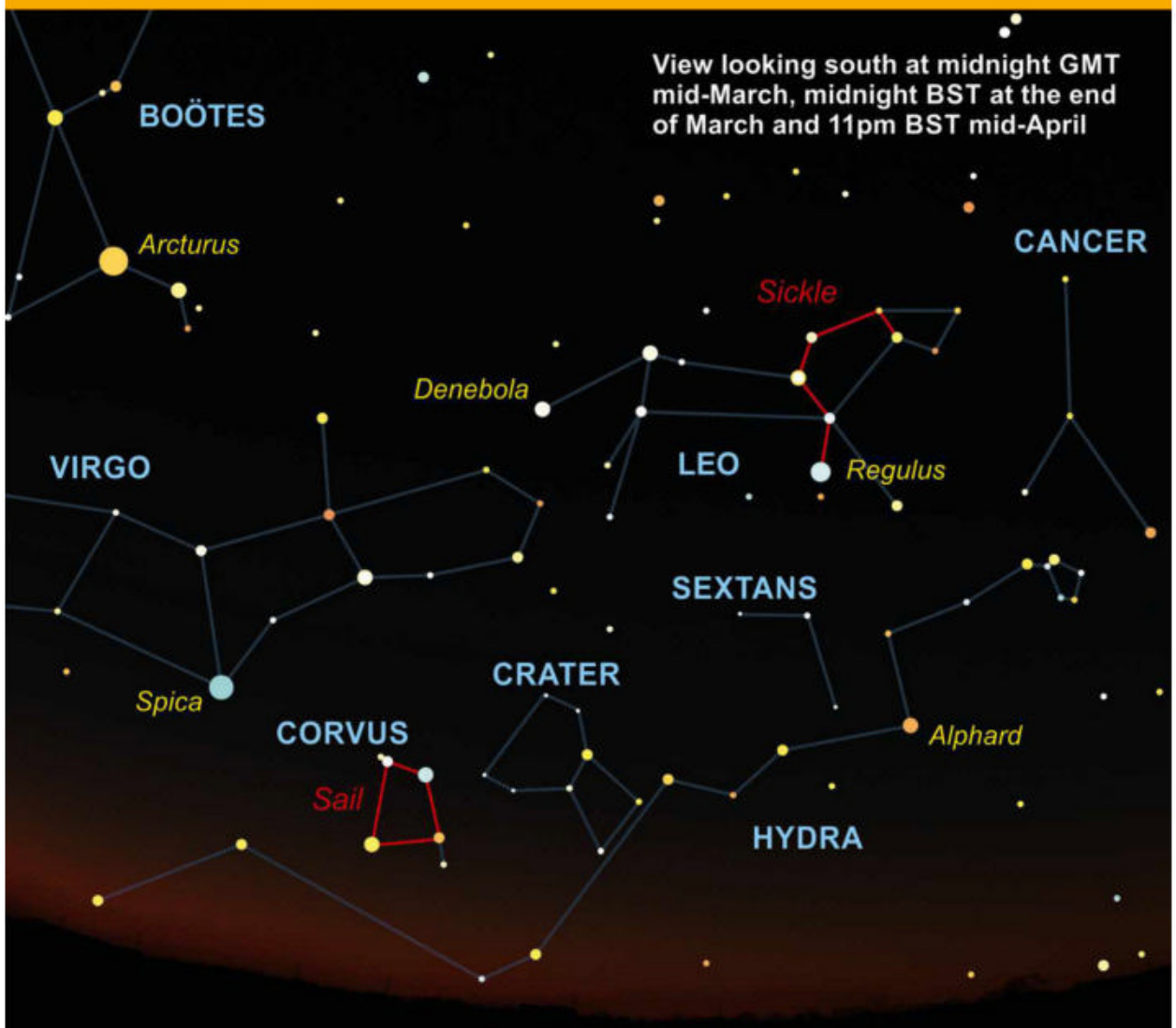
Changes in the shape of Earth's orbit around the Sun occur cyclically; the pull of gravity from other bodies in the Solar System causes our orbit to vary from nearly circular to more elliptical. When Earth's orbit is at its most elliptical, around 23 per cent more solar radiation reaches Earth during our closest approach to the Sun. Currently, Earth is near its most circular orbit (least elliptic). This cycle is known as eccentricity and occurs over a period of around 100,000 years.

Obliquity, also known as axial tilt, involves changes in the angle of tilt of Earth's rotation axis, and it's the reason why we have seasons. Over the last million years or so, it's varied between 22.1 and 24.5°, and as obliquity decreases, our seasons become milder.

In addition, Earth wobbles a little on its axis of rotation, like a toy spinning slightly off-centre. This gives rise to precession and is caused by the gravitational influence of the Sun and the Moon on the Earth's equator. Precession dictates when the perihelion (the closest approach to the Sun) will be, which currently occurs on 3-4 January when it's winter in the northern hemisphere, and summer in the southern hemisphere. Precession creates more extreme seasonal contrasts in one hemisphere, and less extreme in the other. So, in around 13,000 years, precession will cause our current conditions to switch, and the northern hemisphere will experience more extremes in solar radiation.

Milankovitch cycles do not, however, account for the current period of rapid warming, as they operate on much longer time scales than we are currently seeing. They range from tens of thousands, to hundreds of thousands of years, and without the influence of humans, our current orbital positions suggest that our planet should be cooling, rather than warming.

ASTRONOMY FOR BEGINNERS



HOW TO SPOT HYDRA IN THE NIGHT SKY

WHEN: MID-MARCH TO MID-APRIL

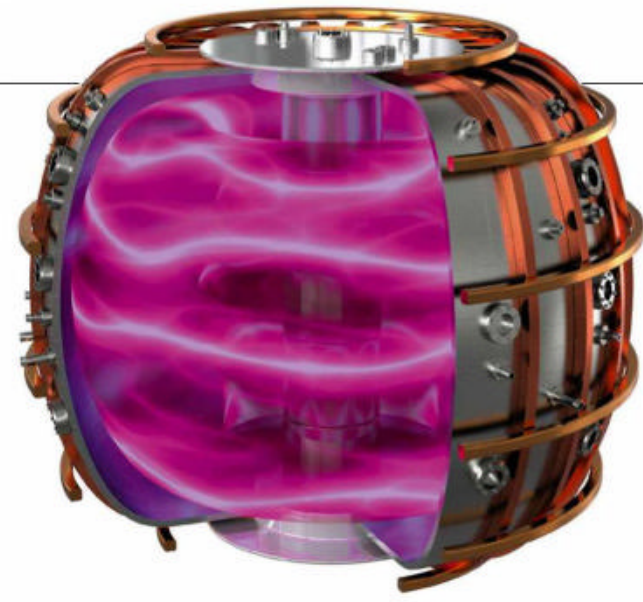
The largest constellation is also one of the most ill-defined. Hydra the Water Snake slithers onto the scene in spring, fully taking nine hours to completely appear above the UK's southern horizon. Tracing its full length takes some doing, but there are guides.

Hydra starts with a small sideways teardrop-shaped pattern. This is located below the faint, inverted-Y shape of Cancer the Crab. If you're struggling here, extend the side of the Plough's blade nearest the handle, down with respect to the plough, to reach bright Regulus in Leo the Lion. Above Regulus, identify the backward question-mark pattern called the Sickle. Look one-and-a-half Sickle heights right from Regulus. Just below where you end up is Hydra's sideways teardrop-shaped head.

From here, look down and left for a solitary, orange-hued star called Alphard. This is Hydra's alpha star, its name meaning 'the solitary one'. Hydra's body meanders left and down from Alphard but is not easy to identify.

Along the Water Snake's back sit three small constellations. Sextans the Sextant lies near Alphard but being made up of three barely visible stars, is also not an easy find! Keep going along Hydra's back and eventually you'll find the faint but distinctive outline of Crater the Cup. If you extend the curved handle of the Plough away from the blade this brings you to bright orange Arcturus in Boötes. Keep going and you'll arrive at white Spica in Virgo. Crater hangs down from the midpoint of the line between Alphard and Spica.

Left of Crater sits Corvus the Crow, a small but thankfully more distinctive pattern. The compact quadrilateral made from Corvus's brighter stars forms an asterism – an unofficial pattern – known as the Sail, so-called because it looks like the sail of an ancient boat sailing along the horizon. ***PL***



MARK BROWN, IPSWICH

HOW DOES NUCLEAR FUSION WORK?

Nuclear fusion is the process by which stars, including the Sun, generate their energy. In a fusion reaction, atomic nuclei 'fuse' together to form heavier nuclei. For this to happen, the nuclei need to have enough energy to overcome the repulsive force they experience because they are both positively charged. They also need a good chance of colliding with each other in the first place.

These conditions of extremely high pressure and temperature can be found in the cores of stars. The pressure at the centre of the Sun, for example, is a staggering 100 billion times atmospheric pressure while the temperature is a whopping 15,000,000°C. Under these conditions, fusion of hydrogen into helium can easily be sustained. In a fusion reaction, the resultant nucleus (if it is lighter than iron) has a slightly smaller mass than the nuclei that combined to form it. That excess mass is released as energy, and it is that energy which powers the stars.

Fusion reactions are different to the 'fission' reactions which power nuclear power stations. There, heavy and unstable atoms are split apart to produce energy (and radioactive by-products too). In contrast, fusion power could supply a clean, efficient and unlimited source of energy; it would require only water as a fuel (or lithium) and would produce only inert, non-toxic helium gas as a by-product.

The trouble is that initiating, containing, and sustaining nuclear fusion reactions offer significant engineering challenges. There are many research institutions working on the problem worldwide. Recently a laboratory in China achieved a fusion temperature of about 70,000,000°C for over 17 minutes – a fantastic achievement, but still some way off being a commercial source of energy. Even so, scientists estimate that nuclear fusion energy will become commonplace by the second half of this century. ***AG***

HOW IS COAL FORMED?

Coal is a non-renewable energy source that can be burned for fuel and is used to generate electricity. Burning it adds a huge amount of carbon dioxide to the atmosphere and it's the single biggest contributor to human-made climate change. Under current plans, the UK aims to phase-out unabated coal-fired power stations by 2025.

1 DECAYING ORGANIC MATTER CREATES PEAT
Around 300 million years ago, in the Carboniferous, plant matter from the dense, swampy forests accumulated and lay decaying in the bottom of the swamps. Burial and compaction under anaerobic conditions formed peat from this partially decomposed organic matter.

2 PEAT BECOMES LIGNITE
When this peat was buried at relatively shallow depths, continued heat and pressure compressed the peat between layers of sediment into lignite: a soft, brownish-black coal-like material with a high moisture content.

3 LIGNITE BECOMES COAL
With continued burial, heat and structural deformation, this lignite metamorphoses into sub-bituminous and bituminous coal, and then to anthracite (hard coal). The more metamorphism, the harder and more carbon-rich the coal becomes.

SCIENCE PHOTO LIBRARY, ALAMY, BRUCE MCADAM/WIKIPEDIA ILLUSTRATIONS: PETE LAWRENCE, DANIEL BRIGHT

CONNOR SYKES

WHAT IS WATERMELON SNOW?

Otherwise known as glacier blood, watermelon snow is found worldwide in mountains and polar regions. The pink-red snow has a faintly fruity smell but is reported to have laxative effects if eaten. The watermelon colour comes from freshwater green algae called *Chlamydomonas nivalis*. In summer, the algae produce a red pigment to protect themselves from the Sun's intense rays. This pigment belongs to a large group of carotenoid substances, many of which are found in brightly coloured fruits and vegetables such as tomatoes and carrots. Unfortunately, the pigment reduces snow's ability to reflect heat, leading to faster melting rates. ***ED***

ROWENA BROSNAN, MANCHESTER

HOW DID DINOSAURS SLEEP?

As strange as it might be to imagine, dinosaurs would have slept. Would they lie down, or sleep standing up? Would they take quick rests or long slumbers? We don't really know the answers. But there is one dinosaur whose sleep habits are well understood: the tiny puppy-sized troodontid theropod *Mei long*, a close relative of birds. Two skeletons of this 125-million-year-old dinosaur have been found fossilised in a sleeping position (pictured). It seems as if a volcanic eruption suffocated and buried these dinosaurs while they were napping, similar to how some humans were caught unaware at Pompeii by the eruption of Mount Vesuvius. The skeletons are in the same 'tuck in' sleeping posture of today's birds: the body sits on folded limbs and the head is tucked in between the arm and torso. Birds sleep this way to conserve heat in their heads – a necessity for warm-blooded animals. Perhaps this is a sign that some dinosaurs were warm-blooded too. ***SB***

DEAR DOCTOR...

HEALTH QUESTIONS DEALT WITH BY *SCIENCE FOCUS* EXPERTS

HOW DO I KNOW IF MY TOE IS BROKEN OR JUST BRUISED?

A broken toe is usually painful, swollen, red or bruised, and difficult to walk on. If the break is severe, the toe may stick out at an angle, or bone may poke through the skin.

In reality, it's quite difficult to know if a toe is broken, bruised or sprained without an X-ray. However, if the toe is in normal alignment (not bent out of normal position), and it's not your big toe that's affected, then an X-ray won't usually be done. In reality, the treatment isn't that different.

Whether the toe is bruised or broken, the key things you can do at home are: take regular painkillers to ease the pain and swelling; rest the foot and keep it elevated; avoid walking as much as possible; hold an ice pack or bag of frozen peas wrapped in a towel to the toe for up to 10 minutes every couple of hours; wear comfortable shoes; and strap the broken toe. This means putting a small piece of cotton wool between your injured toe and the toe next to it, then taping them together to support the injured toe. If it's your big toe that you suspect is broken, it's worth going to A&E as this may require an X-ray. *NM*

ISABEL BLACKMORE

HOW DO YOU READ BINARY NUMBERS?

We count in decimal – that's multiples of 10, or base 10. That means we use 10 distinct symbols to write down all numbers: 0,1,2,3,4,5,6,7,8,9. Perhaps having 10 digits on our hands helps with the maths. It was not always this way – duodecimal, or base 12, was a very popular system: 12 inches to the foot, 12 pence to a shilling, 12 zodiac signs, 12 months in a year and 2 x 12 hours in a day. In duodecimal maths we use 12 symbols to write down all the numbers: 0,1,2,3,4,5,6,7,8,9,A,B. Duodecimal is superior for mental arithmetic because it has four non-trivial factors: it is divisible by 2, 3, 4 and 6, compared to the decimal system, which has only two non-trivial factors: 2 and 5.

But computers don't count fingers or perform mental arithmetic, they operate using electricity, and so they need a simpler way to count. Their logic circuits just understand on and off, which means the native counting system for computers is binary, or base 2. So they have just two symbols to write down all numbers: 0,1. This is not a problem, because using the right combination of 1s and 0s we can represent anything – but it does mean that we need quite a lot of them.

To understand a number in binary, for whole numbers we need to recognise that the most significant binary digit (or bit for short) is on the left and least significant bit is on the right. As we look right to left, each bit represents a higher power of 2 (because binary is base 2). So the binary number 1101 is, looking at each bit from right to left: $\mathbf{1} \times 2^0 + \mathbf{0} \times 2^1 + \mathbf{1} \times 2^2 + \mathbf{1} \times 2^3 = 1 + 0 + 4 + 8 = 13$.

Or, the binary number 1,000 is $\mathbf{0} \times 2^0 + \mathbf{0} \times 2^1 + \mathbf{0} \times 2^2 + \mathbf{1} \times 2^3 = 0 + 0 + 0 + 8 = 8$.

As with any numbering system, use more digits and you can represent bigger numbers. We can also represent fractional or floating-point numbers by adding a notional point. So 0111.0101 becomes $\mathbf{1} \times 2^0 + \mathbf{1} \times 2^1 + \mathbf{1} \times 2^2 + \mathbf{0} \times 2^3 = 7$ for the whole part, and (this time working left to right from the point) $\mathbf{0} \times 2^{-1} + \mathbf{1} \times 2^{-2} + \mathbf{0} \times 2^{-3} + \mathbf{1} \times 2^{-4} = 1/4 + 1/16 = 0.3125$, making the number 7.3125.

However, representing negative numbers in binary can be more tricky – there are actually three different methods! The easiest is just to use a spare bit on the left, so if 00111 is 7, then 10111 is -7. But the most common approach in computers is called twos complement. In this approach to represent a negative number we invert all the bits and add 1. So if 00111 is 7 then 11000+1 = 11001 represents -7. To flip the sign we invert the bits and add 1 again: 00110+1 = 00111. Clever, eh? ***PB***

GEMMA LAWRENCE

HOW DOES WIRELESS CHARGING WORK?

Electrons are clever subatomic particles. Push them along a wire and you've got electricity. Coil that wire, and you get a magnetic field – that's how electric motors get their push. Put the coil near another one with a shared iron core to direct the magnetism, and power is induced in the second coil – that's how transformers change voltages. Pulse electrons through the coil and you can separate the other coil a little further away, enabling you to put the emitter in a charging pad, and receiving antenna in a phone. Bring the phone within range and it will have electricity induced in its coil by the electromagnetic pulses resonating from the charging pad. ***PB***

QUESTION OF THE MONTH

LUKE RUSSELL, WAKEFIELD

HOW WORRIED SHOULD WE BE ABOUT ANCIENT VIRUSES AND BACTERIA EMERGING FROM MELTING PERMAFROST DUE TO CLIMATE CHANGE?

Permafrost — ground that remains frozen for more than two years straight — underlies nearly one-quarter of the land in the northern hemisphere. The deepest parts extend a mile into the Earth, and the oldest parts are more than 600,000 years old. But as the world warms, the permanence of the permafrost is being undermined in many places, including Canada, Alaska and Siberia.

Technically, permafrost doesn't melt, it thaws. But you're right to be concerned; scientists estimate that by 2100, as much as two-thirds of the Arctic's near-surface permafrost could be lost. And yes, this could potentially unearth viruses and bacteria that have been sequestered for tens of thousands of years.

In 2016, a 12-year-old boy died and around 100 people became sick with anthrax poisoning in a region of Siberia that hadn't seen an outbreak in over 70 years. Scientists think the outbreak was caused by anthrax spores released from a decades-old reindeer carcass that was newly exposed by thawing permafrost.

A single gram of permafrost can contain thousands of dormant microbe species. Scientists fear that a thaw could not only unearth diseases we thought we had conquered — including smallpox and bubonic plague — but also release ancient pathogens against which we currently have no natural immunity and no effective antibiotics or vaccinations. The main mitigating factor will be the extent to which humans come into contact with these emerging threats. Today, fewer than five million people live in northern permafrost regions. But as the world warms, new shipping routes become viable, and resource extraction, commerce and tourism in the Arctic increase, we run the risk of people encountering ancient pathogens — and spreading them around the world. ***CP***

WINNER

The winner of next issue's Question Of The Month wins **two books from The Official Gerry Anderson Store**, worth £65. The prize includes Space: 1999 Moonbase Alpha Technical Operations and UFO Comic Anthology: Volume 1. **shop.gerryanderson.com**

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

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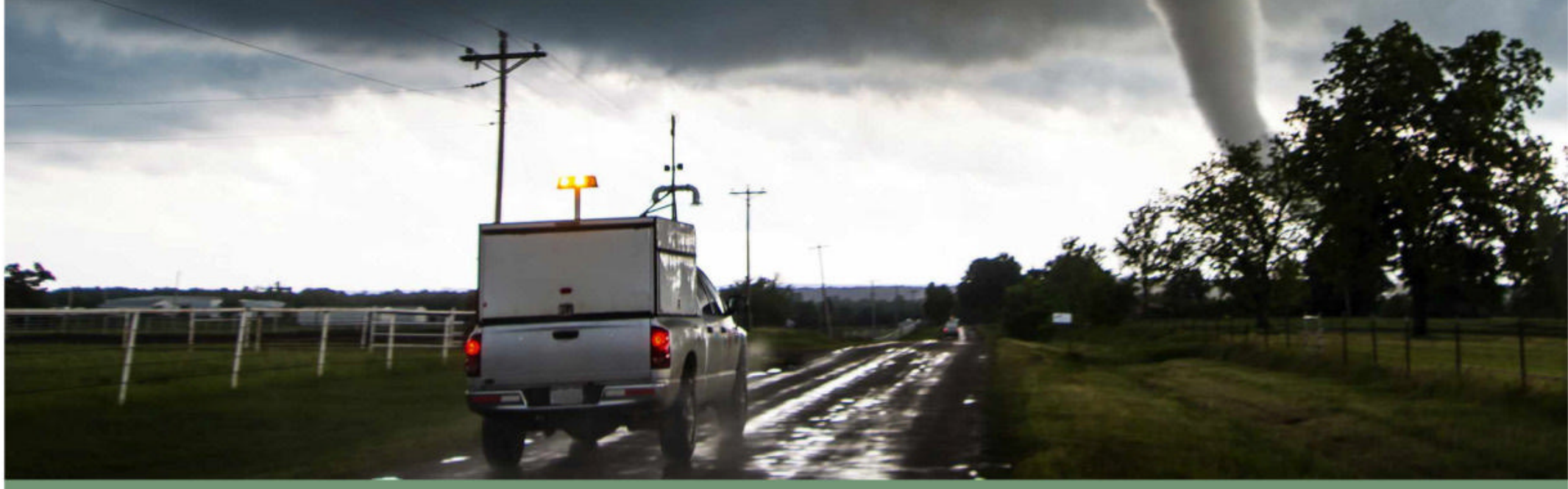
THE EXPLAINER

TORNADOES

WHAT IS A TORNADO AND HOW DOES IT FORM?

Tornadoes, sometimes called twisters or whirlwinds, are intense vortices stretching from the Earth's surface to the base of stormy, cumulonimbus clouds – these clouds extend deeply in the vertical and often have an anvil-shaped top. Typically, tornadoes measure around 100 metres in diameter, travelling on average around five kilometres before they dissipate. Tornadoes form from mesocyclones, large-scale regions of rapidly rotating air that flow within the cumulonimbus clouds. Cool, dry air can wrap around these mesocyclones, creating a strong temperature contrast which intensifies the spinning, drops the central pressure and extends the vortex to the ground, thus the tornado is born. As tornadoes are made up of air, they are invisible to the naked eye unless they are transporting some other material, such as condensed water in the form of water vapour, dust, or larger debris, so more often than not take on a dark appearance. Given the chaotic nature of tornadoes, they are a nightmare to predict, so often it is the original mesocyclone that will start to alert the forecasters on where to look.



WHAT ARE THE DIFFERENT TYPES OF TORNADO?

Weather agencies around the world include different phenomena in their classification of tornadoes. So for instance, intense waterspouts, which form over water from a mesocyclone, often only officially count as a tornado if they make landfall. An extremely rare subset of these are known as snowspouts – essentially the same type of circulation but formed in regions of snow. There are also a number of other tornado-like vortices, for instance dust- or fire-devils. The former being a small vortex consisting of dust that can form from updraughts without the need for storm clouds. The latter being a small vortex funneling fire, often formed in large wildfires. While these phenomena typically look much like tornadoes, they are generally not considered part of the grouping, because their formation is so different, and the vortex itself does not usually extend from the Earth's surface to a cloud base.

ALAMY X2, GETTY IMAGES X2, SHUTTERSTOCK

WHERE ARE YOU MOST LIKELY TO BUMP INTO A TORNADO?

Tornadoes occur where the atmospheric and land conditions for tornado-generation are most common, and nowhere are these ingredients more prominent than the Great Plains of the US, which gives rise to 'Tornado Alley'. Tornado Alley is generally accepted to extend from Texas to South Dakota and contains more violent tornadoes than anywhere else in the world. Canada, for instance, comes in at a distant second with an order of magnitude fewer tornadoes. While the most intense tornado activity is found on that continent, tornadoes also exist in a number of other places, namely in the mid-latitudes which have favourable conditions for the storm systems. Argentina and Brazil give rise to their own tornado alley around the Pampas Plains, but also parts of Europe, South Africa, Australia, New Zealand, and South and East Asia. Indeed, the country with the highest density of tornadoes for its area is actually the UK, where we see around 30 tornadoes each year.

WHEN IS TORNADO SEASON?

Tornadoes can occur at any time in the year if the conditions are favourable but are far more common during the stormy season. For most mid-latitude countries this is often spring or autumn, because tropical and polar frontal systems meet in these transitional seasons, giving rise to the storm weather. However, even within a continent there is variability in the most active months. For instance, in the US, dangerous tornado activity in the south maximises around March or April, but in the north, the activity maximises around June or July. Some of the stronger tornadoes even persist into southern Canada during this period. In South Asia, it is still the transitional months, but the wetter monsoon seasons also play a role, which run from March to May.

HOW TO SURVIVE A TORNADO

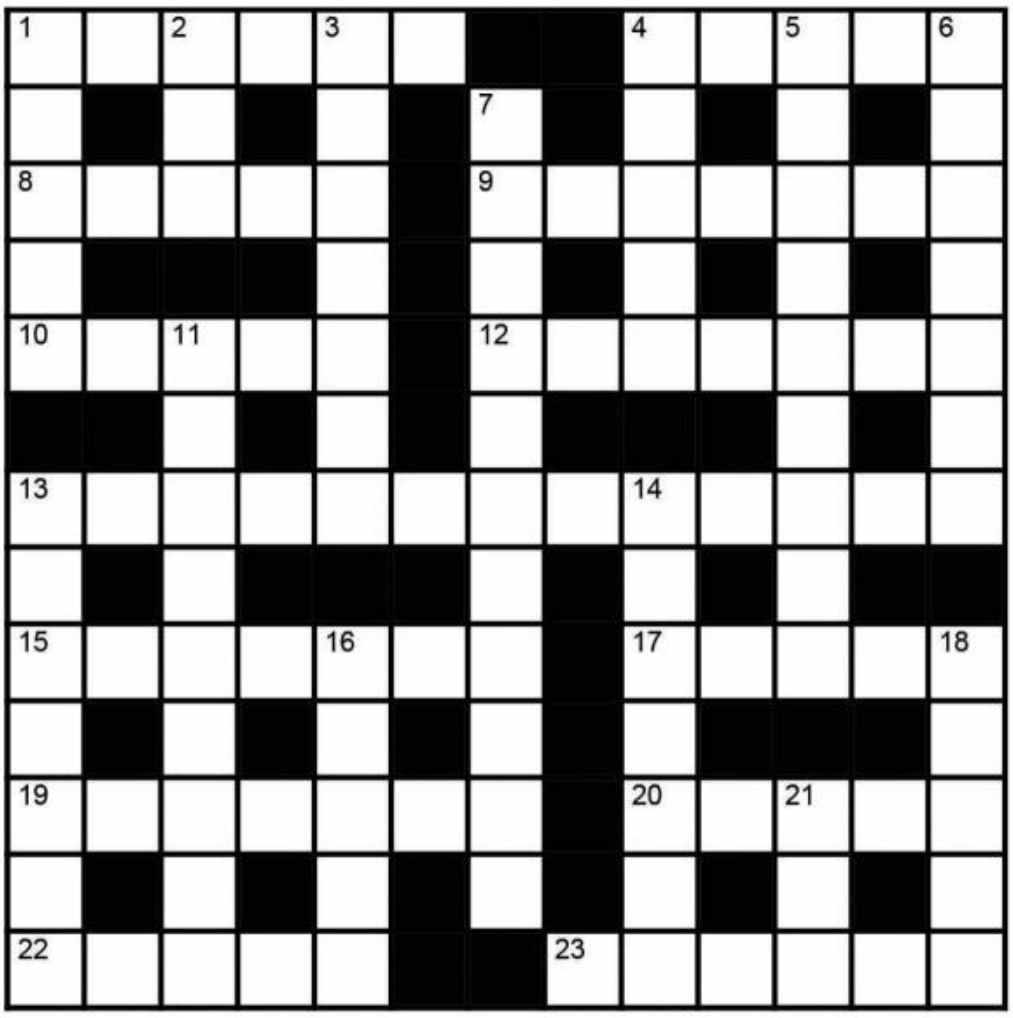
Loss of life during a tornado most often occurs from shelters collapsing, or debris turning into lethal projectiles. The split between these depends on the development of the country. So for instance, while America has the strongest tornadoes, the deadliest ones actually occur in Bangladesh, due to poor infrastructure and insufficient warming systems. The amount of devastation depends on the tornado strength, which is measured on the Fujita (F) scale. The weakest tornadoes, termed F0 tornadoes, have maximum winds around 113km/h (70mph) and are not strong enough to cause any real major infrastructural damage. However, they can uproot small trees, and turn small objects into dangerous projectiles, so staying in sturdy homes away from windows is a good idea during these events. On the other end of the scale, F5 tornadoes are devastating. There is no surviving these without adequate cover, such as a dedicated storm shelter, or a basement of a tornado-resistant building, and even then, getting yourself under a sturdy table is a good idea.

by PROF DANN MITCHELL

Dann is professor of climate science at the University of Bristol. His research focuses on climate change and how it affects atmospheric circulation and extreme events.

CROSSWORD

PENCILS AT THE READY!



ACROSS

1 Student without a single bad habit (6)
4 So Catherine sent back dish (5)
8 Convoluted position for a flower (5)
9 One earl running from Henry II's queen (7)
10 Lone arrangement with British peer (5)
12 Criticise youngster – sat around (7)
13 May possibly see a period of rent (8,5)
15 At home, complexity is comprehensive (2-5)
17 Carriage includes a quantity of diamonds (5)
19 Tricky question for someone like you (7)
20 Food producer finds tumbler, not English (5)
22 Terrible key included for sad song (5)
23 Work the other side of the river intensely (6)

DOWN

1 Material obtained from many Londoners (5)
2 Old soldier is a doctor (3)
3 Tank caught one at the back (7)
4 Some heat from another machine (5)
5 Dilapidated or ancient vessel (9)
6 Score unlikely to be of the highest quality (7)
7 Played Oh, Plain Area on stringed instrument (7,4)
11 Tractor? Nonsense – he's asleep (9)
13 Cut some terse pronunciation (7)
14 Horse taking taxi – that's gruesome (7)
16 Bean shows sign of life (5)
18 Sailor next to railway is to loiter (5)
21 Skipper has money in Laos (3)

ANSWERS

For the answers, visit **bit.ly/BBCFocusCW**
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POPCORN SCIENCE

Could a hedgehog run at the speed of sound?

As Sonic returns to cinemas, we find out what fate awaits a hedgehog that can top the speed of sound

The exact maximum speed of Sonic the Hedgehog is debatable (and trust me, there are many people on the internet debating it), but it's fair to assume that at the very least he is capable of running at 1,225km/h (761mph) – the speed of sound. The human world record, for comparison, is 44km/h (27mph), achieved by Usain Bolt during the 100m sprint at the 2009 World Championships in Athletics. But while Sonic would surely win every gold medal, would travelling faster than the speed of sound be survivable?

"Humans have flown in supersonic vehicles since the late 1940s and in hypersonic vehicles since the 1960s," says Richard Leland, president of the National Aerospace Training and Research (NASTAR) Center. For clarity, supersonic flight is defined as speeds up to Mach 4.9, which represents 4.9 times the speed of sound, while hypersonic flight is defined between Mach 5 and 10. "Neither supersonic flight nor hypersonic flight have an appreciable effect on the human body so long as the human is in a properly designed aircraft."

But Sonic does not travel in aircraft, which are designed to deal with heat buildup due to friction with the atmosphere. "In order to reduce these temperatures, supersonic vehicles typically fly at altitudes of 60,000 feet [18,288m] or higher where the atmosphere is thinner," says Leland, who speculates that on average Sonic travels between Mach 3 and Mach 5. "Since Sonic the Hedgehog runs at roughly sea level, wind blast and temperature buildup would not be survivable," he says. "To put it another way: he would break up and burn."

Another factor is how Sonic would be affected by g-force. Leland explains that, generally, the average human can withstand up to 15G for a short time, if they are travelling forward. "It would definitely not be comfortable, and would likely induce some degree of injury," he says. Still, this is more than can be handled by travelling backwards or vertically (like fighter pilots do) and is why astronauts face upwards, therefore travelling forward, when their shuttle is being launched into space.

G-force wouldn't be too much of an issue for Sonic during his run, as long it was at a consistent rate of motion and in one direction. Hence why, despite travelling at around 27,360km/h (17,000mph) in orbit, astronauts can move around more or less as easily as a passenger on an aeroplane. But Sonic's tendency to rapidly accelerate and decelerate – both of which are lethal to living organisms – is quite another matter.

"If Sonic the Hedgehog were to accelerate to Mach 1 in one second, he would sustain 34G," explains Leland. "If he were to accelerate to Mach 3 in one second, he would experience 114G. If he were to accelerate to Mach 5 in one second, he would experience 175G."

He brings up the example of John Stapp, who in the 1950s, during his studies on the effects of deceleration, showed that a trained human can withstand at least 46.2G while accelerating/decelerating on a rocket sled. During these tests he broke ribs, lost fillings and temporarily lost his vision due to bleeding in his retinas. "Suffice to say, accelerations or decelerations of 114G and 175G would not be survivable," Leland adds.

Not to mention the fact that if Sonic were to pass out or die while running, he would likely smash into another object. Leland cites a calculation conducted by **syfy.com**, who figured out that the kinetic energy of a 35kg hedgehog travelling at the speed of sound equates to 2,058,858 joules. That's a ridiculous amount of damage. And would no doubt make collecting rings while in mid-sprint a dangerous hobby. **SF**

VERDICT

Dr Robotnik can rest easy. Sonic is likely to splat into hedgehog mince once he starts accelerating or hits a golden ring.

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

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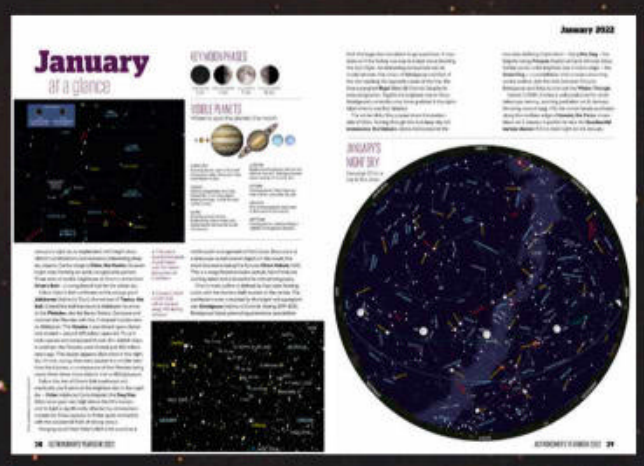

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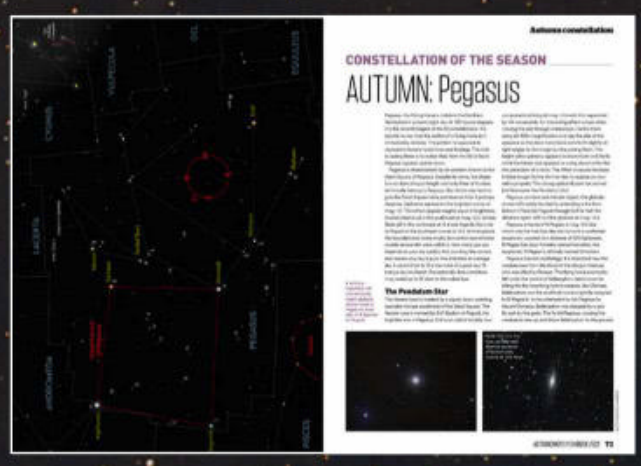

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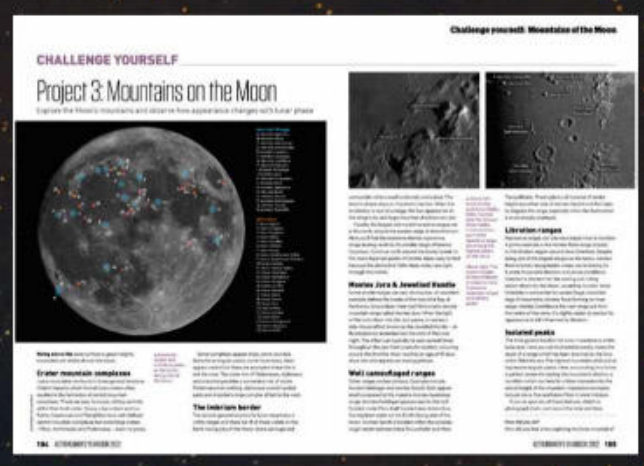

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