BBC 20 DISCOVERIES TO MAKE YOU FEEL BETTER ABOUT 2020

Science Focus

EUREKA!

THEORIES OF (NEARLY) EVERYTHING

THE IDEAS YOU NEED TO UNDERSTAND IN 2021

VIRTUAL REALITY THERAPY

CLONING GETS MAINSTREAM

WHY THE UNIVERSE DOESN'T ADD UP

SPACESHIP SWARMS STUDYING EARTH

THE TECH THAT WILL LET US SEE FURTHER INTO THE PAST

WHAT REWILDING THE PLANET WILL DO FOR THE CLIMATE

HOW VIRUSES CAN SAVE LIVES

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NEW YEAR 2021

IN THIS ISSUE

Health
How rapid vaccine development will change medicine

Mars
Curiosity rover discovers signs of ancient Martian floods

Tech
How to make the internet great again

Thank you, Sylvia

Sylvia left a gift in her Will to help conquer Stroke

The first we knew of Sylvia was when we received notification of the gift she'd left us in her Will. Shortly after, a beautiful story of a much-loved woman began to unfurl.

Friends remembered Sylvia's kind-heart and her wish to help others. She spent part of her adult-life caring for her mother, and developed a passion for medicine. Becoming a medical secretary was her next step and, in the course of her career, she discovered the devastating impact a stroke could have on people and their families. She saw that research and treatment were vastly under-funded, and she decided to remember the Stroke Association in her Will.

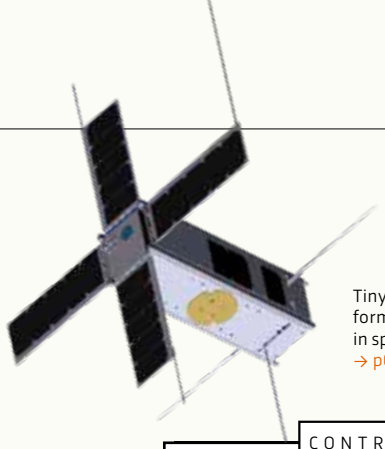
Sylvia's gift has helped fund our work to conquer stroke. She's supported research to prevent and treat stroke, and she's helped care for survivors. And that's something you can do too – in the same way.

If you would like to learn more about remembering the Stroke Association in your Will, please get in touch.

Call 020 75661505 email legacy@stroke.org.uk
or visit stroke.org.uk/legacy

Stroke association

FROM THE EDITOR



Tiny satellites are forming swarms in space
→ p68

There's a lot to say about 2020, but one moment sticks in my mind like a splinter. Back in January, the *BBC Science Focus* team was sitting in a room going through ideas. We plan our issues months in advance and we were trying to decide what should go in the March edition. Someone piped up with: "What about this new virus in China?" "How big will that get?" I asked. "Will we still be talking about it in March?"

Thankfully, we ran the piece and thus began our reporting on the biggest story of the year. But with 2021 about to begin, we all felt it was time to talk about something else for a bit. So, in this special issue we've cleared out the usual sections to take a look back at the big breakthroughs you might have missed over the last 12 months (p26) and give you a guide to some of the science that we think will make headlines in 2021 (starting on p34). And if you enjoy those, you should check out our podcast. We have a growing collection of episodes that dig into these ideas in further detail – you can hear Marcus Chown talking more about the wonders of cosmology (p34) or listen to Dr Steffanie Strathdee explain how she saved her husband from a superbug, using viruses harvested from sewage (p56). Subscribe to our podcast now to get all this and many more interviews with brilliant scientists.

Enjoy the issue,

Daniel Bennett, Editor

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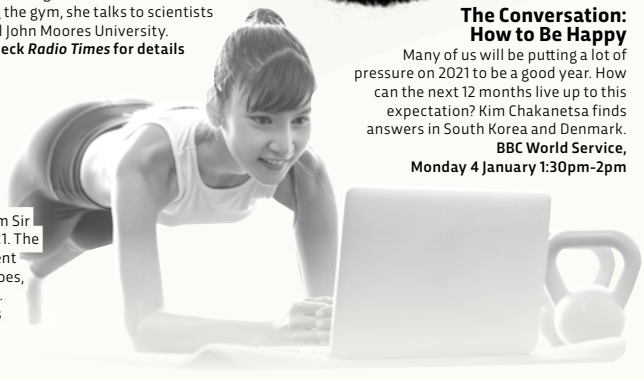
BBC, GETTY IMAGES X2

ON THE BBC THIS MONTH...

A Perfect Planet
The eagerly anticipated new show from Sir David Attenborough is due in early 2021. The five-part series will explore the different forces of nature shaping Earth: volcanoes, sunlight, weather, oceans and humans.
BBC One, check *Radio Times* for details

The Truth About... Getting Fit at Home
Like many fitness enthusiasts, journalist Mehreen Baig has taken to online workouts this year. To find out whether her new virtual regime is better or worse than hitting the gym, she talks to scientists at Liverpool John Moores University.
BBC One, check *Radio Times* for details



The Conversation: How to Be Happy
Many of us will be putting a lot of pressure on 2021 to be a good year. How can the next 12 months live up to this expectation? Kim Chakanetsa finds answers in South Korea and Denmark.
BBC World Service, Monday 4 January 1:30pm-2pm

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JOCELYN TIMPERLEY
Rewilding parts of the landscape improves its biodiversity, but should we go further and reintroduce predators like wolves to the UK? Jocelyn finds out. →p82

TOM IRELAND
Bacteriophages, viruses that eat bacteria, could help solve the problem of antibiotic-resistant bugs. Tom looks into where they come from and how they work. →p56

LUCY MADDOX
Lucy immerses herself in the world of virtual reality therapy and the ever greater role it's playing in helping people deal with mental health issues. →p48

MARCUS CHOWN
Marcus explains what cosmologists think might fill the puzzling gap that sits between our theories of the Universe and our observations of it. →p34

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BBC Science Focus (ISSN 0966-4270) (USPS 015-160) is published 14 times a year (monthly with a Summer issue in July and a New Year issue in December) by Immediate Media Company, Bristol, Eagle House, Colston Avenue, Bristol, BS1 4ST. Distributed in the US by Circulation Specialists, LLC, 2 Corporate Drive, Suite 945, Shelton, CT 06484-6238. Periodicals postage paid at Shelton, CT and additional mailing offices. POSTMASTER: Send address changes to *BBC Science Focus*, PO Box 37495, Boone, IA 50037-0495.

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ANNUAL SUBSCRIPTION RATES (INC P&P):
UK/BFPO £72.80; Europe & Eire £77.80;
Rest of World £82.80.

Audit Bureau of Circulations
44,687 (combined, Jan-Dec 2019)

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2020 IN IMAGES

THE COVID-19 PANDEMIC DOMINATED THE LAST 12 MONTHS AND HAS HAD A PROFOUND EFFECT ON ALL OUR LIVES. BUT IT WASN'T THE ONLY THING ALTERING OUR LANDSCAPE. HERE, IN PICTURES, IS A SELECTION OF SOME OF THE STORIES THAT SHAPED THE WORLD IN 2020

GETTY IMAGES

The new normal

NEW YORK, USA, **24 MAY**

A woman hugs her grandmother through a plastic sheet draped over a clothesline during Memorial Day weekend in New York. By May, the city had been in lockdown for around three months and the photographer caught the pair's first meeting since it began.

It's thought the first case of COVID-19 was recorded on 17 November 2019, according to documents discovered by the *South China Morning Post*. The discovery of a novel virus was only announced a month later. Just over a year later, scientists are poised to deploy a range of vaccines to fight the disease. This incredible feat is testament to how vital the science sector and universities are to our collective future.

Black summer

BLUE MOUNTAINS, AUSTRALIA, **11 JANUARY**

Much of the Australian bush started the year ablaze, as wildfires that began towards the end of 2019 continued to rage. This shot shows a van crawling through a mix of fog and thick smoke that engulfed the Ruined Castle area of the Blue Mountains, about 75km (45 miles) outside of Sydney.

The fires raged into March, burning an estimated 200,000km^2 of land, destroying nearly 6,000 buildings and killing more than 30 people. The environmental cost is more difficult to estimate, but countless animals lost their lives in the flames, with some species believed to have been driven to extinction.

Bush fires can be caused by lightning strikes, or sparks accidentally created by humans. But the hotter, drier climate experienced in Australia in recent years is contributing to the fires becoming more frequent and intense, scientists say.

Eye of the storm

BATANGAS, PHILIPPINES, **12 JANUARY**

Schools closed, flights cancelled and face masks called for. Sound familiar? This was the situation in January, when large amounts of volcanic ash covered the area surrounding the Taal volcano following its eruption.

A volcanic eruption creates columns of ash in the air, called ash plumes. These plumes contain particles – a mixture of rock, minerals and volcanic glass – which generate electricity when they collide with each other. This causes what's known as volcanic lightning.

The Taal Volcano Network continues to monitor the volcano's activity and is recording volcanic earthquakes on a regular basis.

GETTY IMAGES X2, ALAMY

Final checks

GUIZHOU, CHINA, **9 JANUARY**

China's Five-hundred-meter Aperture Spherical Telescope, or FAST, is the world's largest and most sensitive radio telescope. Though it saw its first light in September 2016, the enormous telescope was only declared fully operational on 11 January 2020.

In this picture, a worker studies the reflector panels at the end of its three-year trial period, just two days before FAST began observations.

With such a gargantuan dish, focusing the telescope isn't easy. Even the few millimetres that gravity pulls it out of shape can be enough to blur an image. To get around this, the dish is made up of individual metal panels that can be moved independently to adjust the focus.

Ready for launch

FLORIDA, USA, **30 MAY**

On 30 May, after a delay of three days, Elon Musk's company SpaceX launched the first crewed mission from US soil in nine years, following the end of the Space Shuttle programme in 2011. The Crew Dragon capsule successfully docked with the International Space Station approximately 19 hours later, making SpaceX the first private company to launch humans into orbit.

In this image, astronauts Doug Hurley (left) and Bob Behnken leave the Operations and Checkout Building and head towards SpaceX's Falcon 9 rocket.

Passing through

LHASA, TIBET, **21 JUNE**

A solar eclipse passed across Central and Eastern Africa and South Asia, just a day after the summer solstice. It was an annular eclipse, where the Moon blocks all but a narrow ring around the Sun's edge. This occurs because the Moon's orbit around Earth is elliptical, not circular, so sometimes it appears slightly too small to completely cover the Sun.

This shot was taken as the eclipse passed over Lhasa, the capital of the Tibet Autonomous Region. Not being directly beneath the eclipse's path meant the full ring wasn't visible. Instead the city was treated to a stunning crescent.

Rising tide

HUBEI PROVINCE, CHINA, **19 JULY**

A security guard checks his smartphone as floodwater is discharged from the Three Gorges Dam, on China's Yangtze River. The dam was built to alleviate flooding, generate hydroelectric power and create access for ships. But this summer, the structure was put to the test when the water rose to its highest levels since the dam was completed in 2006.

The rising water levels were due to an exceptionally wet rainy season across large areas of China, which affected millions of people and caused hundreds of deaths. News outlets reported that these were the worst floods experienced by the country since 1996.

GETTY IMAGES X2, SHUTTERSTOCK, PITT RIVERS MUSEUM OXFORD

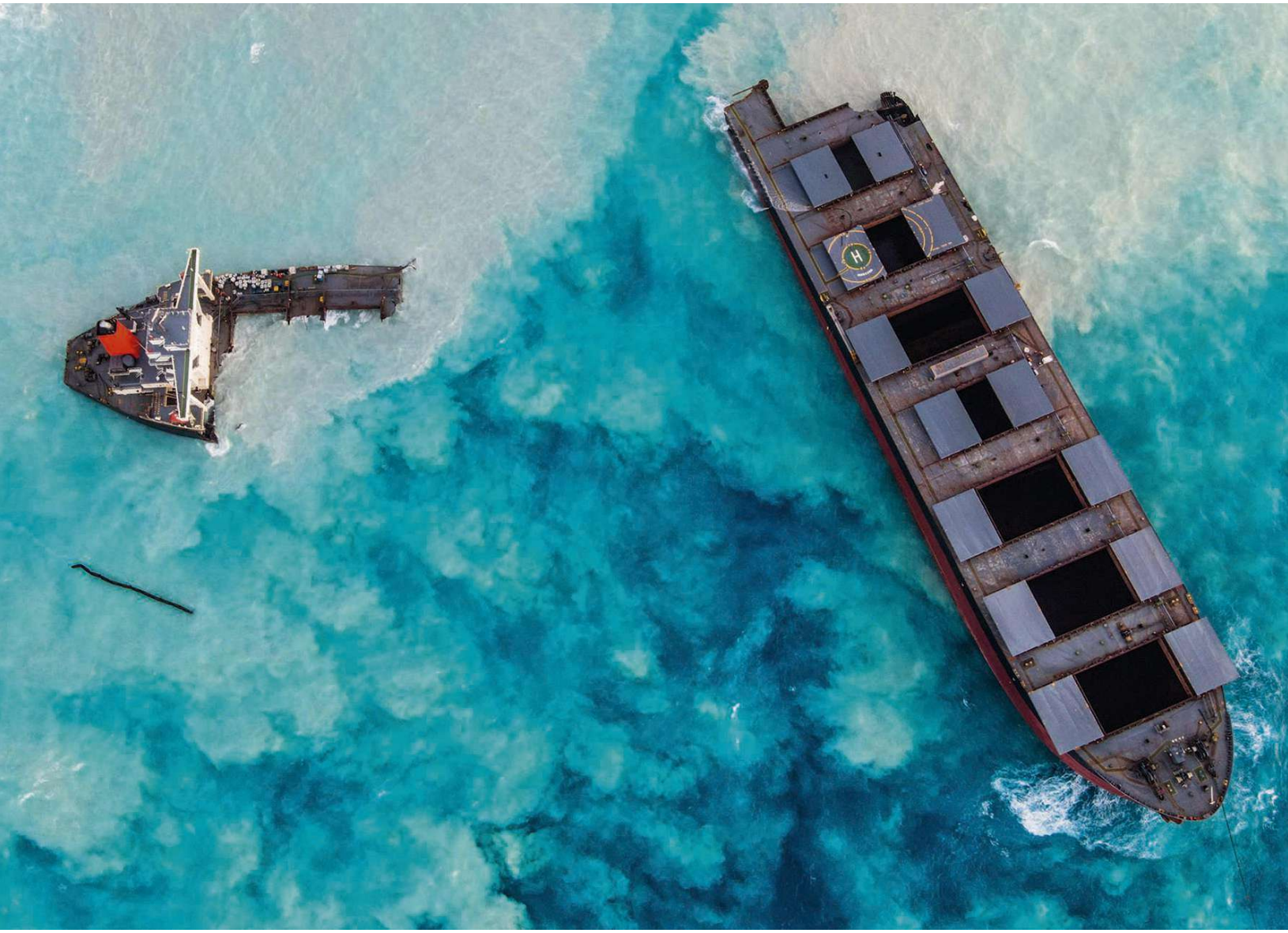
Handle with care

OXFORD, UK, **1 JULY**

The Black Lives Matter movement caused changes this year. Statues of figures associated with slavery were torn down, and buildings named after eugenicists and slave traders were retitled. The Pitt Rivers Museum in Oxford changed, too, agreeing to remove human artefacts from its visible collection.

"Rather than enabling our visitors to reach a deeper understanding of each other, the displays reinforced racist stereotypes," wrote the museum in a statement. "By removing human remains from display we seek to show our respect for the communities around the world with whom we work."

GETTY IMAGES X3



Flying visit

NEVADA, USA, **23 JULY**

Comet NEOWISE had stargazers eagerly searching the skies in July – including some frustrated members of the *BBC Science Focus* team who didn't manage to spot it.

Discovered in March by NASA's Near-Earth Object Wide-field Infrared Survey Explorer telescope (after which the comet is named), it made its closest approach to Earth on 23 July, before heading off on a highly elliptical orbit that won't bring it back into the inner Solar System for another 6,800 years. NEOWISE was the brightest comet in the northern hemisphere since Hale-Bopp in 1997.

The aftermath

BEIRUT, LEBANON, **5 AUGUST**

On 4 August, a blast from tonnes of ammonium nitrate destroyed a large part of Beirut. Ammonium nitrate is mostly found in fertilisers, but can be used to create explosives.

As it's relatively safe when stored securely, it's unclear exactly what caused the explosion. The material may have been contaminated over time and subsequent contact with a fire resulted in the massive blast.

Beyond the death toll (believed to be 204 people) and physical damage, the nitrogen oxide gases released by the blast could lead to respiratory irritation and air pollution.

Black and blue

POINTE D'ESNY, MAURITIUS, **17 AUGUST**

Oil leaks into the sea around Mauritius from the *MV Wakashio*, a Japanese-owned cargo ship that ran aground on a coral reef while en route to Brazil.

Mauritian seas host a wide range of unique species, so the resulting pollution from the oil released threatens thousands of animals and plants. Coral bleaching from hydrocarbons in the oil will also damage the species that rely on the coral reefs. As Mauritius's biodiversity attracts a large number of tourists, it is expected that that part of the economy will suffer as a result of the spill.

The fires rage

NAPA COUNTY, CALIFORNIA, **18 AUGUST**

The West Coast of America experienced the worst wildfire season in at least 70 years this summer. The blazes wiped out around three million hectares of forest (an area 1.4 times the size of Wales) and burned through residential areas like this one near Lake Berryessa in California.

Now the fires have subsided, scientists are working to understand their impact. Fires are not all bad news; some species thrive in the aftermath, as fresh growth and newly cleared areas provide feeding grounds for grazing animals. But invasive species can also creep in during a forest's recovery, preventing young trees and bushes from establishing, which will have knock-on effects for the region's wildlife.

SHUTTERSTOCK, GETTY IMAGES X2, GREAT NORTH AIR AMBULANCE SERVICE

Musk's moonshot

TEXAS, USA, **11 NOVEMBER**

SpaceX unveiled the Starship – a prototype reusable spacecraft – at its Texas launch facility in 2019. SpaceX founder Elon Musk stated his ambition for the vessel to carry crews of up to 100 astronauts first to the Moon, and then to Mars and beyond. In November this year, the craft was exposed to further testing, including the firing of its engines, ahead of undertaking a test flight.

The Starship spacecraft has been designed to carry passengers or cargo, such as satellites, into orbit depending on the mission. It's the second stage of a launch system that will sit on top of a Super Heavy booster stage for launch.

The first private Starship passenger, Japanese billionaire Yusaku Maezawa, is pencilled in for a trip around the Moon and back in 2023.

Fly to the rescue

LAKE DISTRICT, UK, **29 SEPTEMBER**

Difficult terrain and steep hills can slow down paramedics' response times. The Great North Air Ambulance Service wondered if jet suits could speed things up, so approached jet-suit manufacturer Gravity Industries to find out. In the test flight in the Lake District, a jet-suited paramedic flew from the valley floor to a 'patient' on the top of a fell in 90 seconds. The journey would have taken 25 minutes on foot.

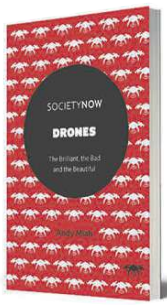
Making waves

PLYMOUTH, UK, **16 SEPTEMBER**

It took the *Mayflower* 66 days to cross the Atlantic when the pilgrims set off for the New World 400 years ago. In April 2021, a new ship sharing the name is aiming to complete the same journey in just two weeks. But this *Mayflower* (seen here being tested in the waters off Plymouth) won't be carrying anyone, passengers or crew, as the 15m (50ft) trimaran is piloted by artificial intelligence.

Image: Shutterstock

BOOKS OF 2020



Drones: The Brilliant, the Bad and the Beautiful
Andy Miah

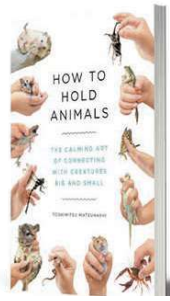
bit.ly/DronesAndyMiah

In this increasingly dynamic world, driven by rapid digital innovation and technological advances, drones are becoming prolific within society. Delving into philosophical discussions about the implications of drone technology, this book shines a light on their real-world applications, challenges and what they reveal about the human condition, when faced with a future of autonomous, intelligent robots.

The Medieval Internet: Power, politics and participation in the digital age
Jakob Linaa Jensen

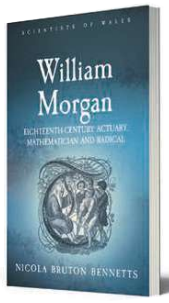
bit.ly/MedievalInternet

The Medieval Internet sheds light on the world of the Internet and social media through a historical prism drawn from the Medieval Age. This book argues that concepts originating in medieval society are suitable for discussing a plethora of social and political phenomena, all related to the massive rise and use of new digital media technologies and adherent societal paradoxes, dilemmas and challenges.



How To Hold Animals
Toshimitsu Matsuhashi

Should you hold a mouse by its tail? A grasshopper by its leg? A butterfly by its wing? Most of us don't have nearly enough experience with animals. We're apprehensive to touch them, scared we'll hurt them, or that they'll hurt us. But connecting with animals can make you feel at peace and aligned with nature. Animal photographer and former zookeeper Toshimitsu Matsuhashi has compiled a delightful treasure trove of tips on how to hold animals without hurting them.

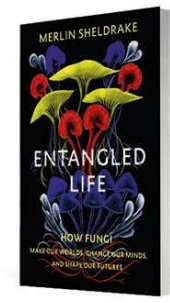


William Morgan: Eighteenth-Century Actuary, Mathematician and Radical
Nicola Bruton Bennetts

To meet William Morgan is to encounter the eighteenth-century world of finance, science and politics. His actuarial calculations underpin our present-day pensions; his scientific investigations are an early link in the chain of experiments leading to the discovery of X-ray; and his outspoken political writings, for which he risked imprisonment, call for universal suffrage and transparency in government finances.

Living Off-grid in Wales: Eco-Villages in Policy and Practice
Elaine Forde

Living Off-grid in Wales examines the new policy context for off-grid rural development by contrasting the policy approach with the activist version of going off-grid. The examples examined in the book feed into much broader debates about the possibility of planning for sustainable development. This book brings clarity to the notion of off-grid by examining two main case studies that do off-grid very differently to each other.



Entangled Life: How Fungi Make Our Worlds, Change Our Minds and Shape Our Futures
Merlin Sheldrake

The more we learn about fungi, the less makes sense without them. Entangled Life is a mind-altering journey into a spectacular and neglected world, and shows that fungi provide a key to understanding both the planet on which we live, and life itself.
'*A dazzling, vibrant, vision-changing book. I ended it wonderstruck at the fungal world. A remarkable work by a remarkable writer*' - Robert Macfarlane

DISCOVERIES

ANCIENT MEGAFLOOD HINTS AT POSSIBILITY OF LIFE ON MARS

Data beamed back by NASA's Curiosity rover tells of floods raging across the planet's surface four billion years ago

GETTY IMAGES

Surface formations on the bottom of Mars's Gale Crater indicate it was once submerged under water

If you were to travel back in time four billion years and headed to the surface of Mars, chances are you'd be greeted with scenes of flooding of biblical proportions, and maybe even some form of life.

According to data collected by NASA's Curiosity rover and analysed by scientists from Jackson State University, Cornell University, the Jet Propulsion Laboratory and the University of Hawaii, a raging megaflood was triggered by a massive meteoritic impact that created Mars's Gale Crater. Heat from the impact caused the mass melting of ice stored on the Martian surface around four billion years ago.

The flooding was so severe that it caused significant changes to the geological structure of the Red Planet's surface, carving out great ripples and waves in the sedimentary rock, the researchers say.

"We identified megafloods for the first time using detailed sedimentological data observed by the rover Curiosity," said Dr Alberto G Fairén, a visiting astrobiologist at Cornell University. "Deposits left behind by megafloods had not been previously identified with orbiter data."

"Early Mars was an extremely active planet from a geological point of view"

The data includes evidence of giant wave-shaped features in sedimentary layers of Gale Crater, often called 'megaripples' or 'antidunes', that stand about 10 metres high and are spaced approximately 130 metres apart.

The antidunes are indicative of floodwater flowing across the crater about four billion years ago. They are identical to the features formed by melting ice on Earth about two million years ago, the researchers say.

The flooding was most likely caused by the heat generated by the impact of a large meteorite, which melted the planet's frozen reservoirs and released the carbon dioxide and methane stored in them. The water vapour and gases probably combined to produce a short period of warm and wet conditions on the Red Planet.

Condensation that formed from the water vapour clouds in turn created torrential rainfall, possibly across the entire planet. That water entered Gale Crater, then combined with water coming down from Mount Sharp, a rock formation, to produce gigantic flash floods that deposited sediment, forming vast gravel ridges.

It has previously been established that Gale Crater had persistent lakes and streams in the ancient past. And these long-lived bodies of water are good indicators that the crater was capable of supporting microbial life, according to the researchers.

"Early Mars was an extremely active planet from a geological point of view. The planet had the conditions needed to support the presence of liquid water on the surface – and on Earth, where there's water, there's life," Fairén said. "So early Mars was a habitable planet. Was it inhabited? That's a question that the next rover Perseverance [which is scheduled to reach Mars in February 2021] will help to answer."

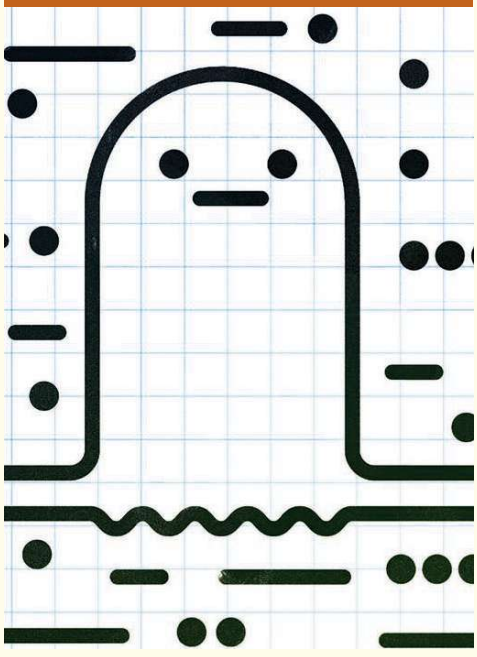
They did what?

Haunted house visitors monitored

WHAT DID THEY DO?
Researchers from Denmark fitted 110 volunteers with heart-rate monitors and filmed them on CCTV as they went around a multi-room 'live-action horror experience' in which they experienced a range of scare tactics, including being charged at by zombies. The researchers then asked the volunteers to rate their experiences.

WHY DID THEY DO THAT?
The team wanted to investigate the nature of recreational fear – the mixed emotional experience of feeling fear and enjoyment at the same time. While fear is generally considered to be an unpleasant emotion that evolved to protect people from harm, humans sometimes paradoxically seek out frightening experiences for purely recreational purposes.

WHAT DID THEY FIND?
Plotting the relationship between self-reported fear and enjoyment, as well as heart rate and enjoyment, the researchers discovered an inverted U-shape revealing an apparent sweet spot, or 'Goldilocks Zone', for fear where enjoyment is maximised.



GETTY IMAGES, UNIVERSITY OF PORTSMOUTH ILLUSTRATIONS: CATHAL DUANE

Dr Mike Simms holds the two dinosaur fossils found in County Antrim. The theropod tibia is on the left and the *Scelidosaurus* femur is on the right

PALAEONTOLOGY

Ireland's first-ever dinosaurs discovered

Despite its proximity to the fossil-rich Great Britain, the island of Ireland has never had any dinosaur fossils discovered on it. Until now.

Two 200-million-year-old bones were found by Roger Byrne, the late schoolteacher and amateur fossil collector, who donated them to Ulster Museum. The bones were discovered in early Jurassic rocks in Islandmagee, on the eastern coast of County Antrim. At the time of donation, they were not formally identified. But now, researchers at the University of Portsmouth and Queen's University Belfast have confirmed that the fossils came from dinosaurs.

"The great rarity of such fossils here is because most of Ireland's rocks are the wrong age for dinosaurs, either too old or too young, making it nearly impossible to confirm dinosaurs existed on these shores," said study leader Dr Mike Simms, a palaeontologist at National Museums Northern Ireland.

With the help of high-resolution 3D digital models of the fossils, the researchers were able to confirm that the remains came from two species. One is from a plant-eater called *Scelidosaurus*, while the other is from a two-legged theropod carnivore, similar to *Sarcosaurus*.

"*Scelidosaurus* keeps on turning up in marine strata and I'm beginning to think that it may have been a coastal animal, perhaps even eating seaweed like marine iguanas do today," said Prof David Martill from the University of Portsmouth.

This is a significant discovery for Ireland, but also for palaeontologists around the world. "Despite being fragmentary, these fossils provide valuable insight on a very important period in dinosaur evolution, about 200 million years ago. It's at this time that dinosaurs really start to dominate the world's terrestrial ecosystems," said University of Plymouth researcher Robert Smyth.

BIOMIMETICS

Camel fur inspires new gel-based cooling technology

Camels with more fur find it easier to keep cool. This counterintuitive discovery has enabled scientists at the Massachusetts Institute of Technology (MIT) to develop a new cooling material that could keep things like food and medicines chilled, without the need of a power supply.

Camels (and other animals, including humans) cool down by sweating. When their internal body temperature rises, sweat glands in their skin start to produce sweat. This salty secretion sits on the skin, and the humidity difference between that and the dry, desert air drives evaporation, turning the sweat into water vapour that transports the heat away from the body and keeps the camel cool.

Previous studies of this process have enabled scientists to develop a cooling material that mimics sweat glands. It uses a hydrogel, which is a gel-like substance designed to hold large amounts of water. A single layer of this hydrogel was able to keep something cool by releasing its water over the course of around 40 hours, after which it had to be replenished with more 'sweat'.

The scientists at MIT have come up with a way to increase the time that the hydrogel can keep something cool by mimicking another trick that camels use.

"Zoologists have reported that a shorn camel has to increase the water expenditure for sweating by 50 per cent in the daytime compared to one with a natural woolly coat," said Prof Jeffrey Grossman, a senior author of the study.

This means that a camel with less fur has to sweat more to stay cool. Similarly, a hydrogel without an insulating layer on top loses water faster than one covered with something that acts as 'fur'.

The MIT scientists decided to design an 'artificial fur' layer by using an aerogel that sits on top of the hydrogel and allows water vapour to pass through it. "By mimicking the dual fur/gland system in camels, we designed an evaporation-insulation bilayer, which, like for the camel, allows for a significant extension of the passive evaporative cooling time for the same amount of water consumption," explained Grossman.

> **"A shorn camel has to increase the water expenditure for sweating by 50 per cent"**

The MIT team's hydrogel/aerogel bilayer was less than 1.5 centimetres thick and was able to maintain a temperature 7°C lower than its surroundings for 200 hours before it needed to be 'recharged' with water. That's five times longer than the hydrogel layer on its own.

Unlike cooling systems based on air conditioners and refrigeration, the hydrogel/aerogel bilayer doesn't

A porous aerogel sits on top of a section of hydrogel to form the cooling bilayer

use electricity, making it better for the millions of people around the world without access to a power supply.

"We want this to be a green technology," said the study's lead author, Dr Zhengmao Lu. "Once the hydrogel is fully dried [out], it can be submerged in water – not necessarily clean water – to become hydrated and functional again, for multiple cooling cycles."

The manufacturing cost of the bilayer is the current obstacle to scalability. But with news that the Pfizer/BioNTech coronavirus vaccine might need to be kept at -70°C, low-cost, portable cooling technology is in demand.

"One major thing we learn in this work is the benefit of adding porous insulation, which I think can be useful for temperature regulation of the vaccine as well," said Lu. "Admittedly, with our current material set, where the major heat removal mechanism is still water evaporation, it is unlikely to reach such low temperatures."

Lu says a solution to the problem could be to pair dry ice with porous insulation. "To some extent, people already do this with existing dry ice packages. To reach even lower temperatures than those we need to optimise the design of the insulation material… This might take a few years' effort."

GETTY IMAGES X2, ZHENGMAO LU/NINGXIN CHEN

NUTRITION

Eating chilli peppers may help us to live longer

Large-scale study suggests consuming spicy peppers may reduce death by all causes by up to a quarter

Make mine a vindaloo! People who regularly chow down on chilli peppers may live for longer and have a significantly reduced risk of dying from cardiovascular disease or cancer, research from Cleveland Clinic's Heart, Vascular & Thoracic Institute suggests.

Previous studies have found that capsaicin, the compound that gives chilli peppers their characteristic kick, can have anti-inflammatory, antioxidant, anti-cancer and blood-glucose regulating effects when eaten.

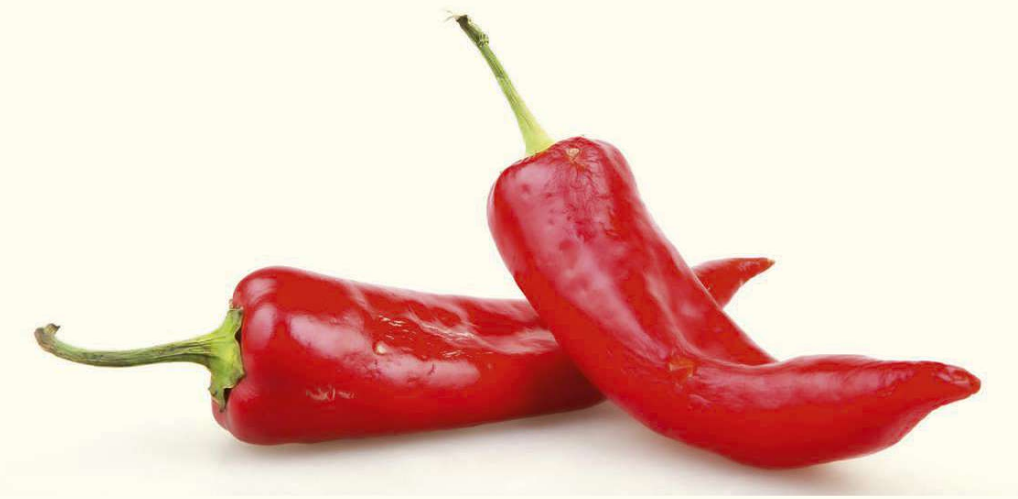
To further investigate the effects of consuming chilli peppers, the researchers gathered together the health and dietary records of more than 570,000 patients in the US, Italy, China and Iran, published in four previous large-scale scientific studies.

They found that those who ate chilli peppers regularly had a 26 per cent reduction in cardiovascular disease (CVD) mortality, a 23 per cent relative reduction in cancer mortality, and a 25 per cent relative reduction in all-cause mortality, compared to those who rarely or never ate them.

"We were surprised to find that in these previously published studies, regular consumption of chilli pepper was associated with an overall risk-reduction of all-cause, CVD and cancer mortality. It highlights that dietary factors may play an important role in overall health," said senior author Dr Bo Xu, a cardiologist at Cleveland Clinic's Heart, Vascular and Thoracic Institute.

"The exact reasons and mechanisms that might explain our findings, though, are currently unknown," he added. "Therefore, it is impossible to conclusively say that eating more chilli pepper can prolong life and reduce deaths, especially from cardiovascular factors or cancer. More research, especially evidence from randomised controlled studies, is needed to confirm these preliminary findings."

Additionally, as the precise amount and type of chilli pepper consumed varied across the four studies used in the research, it's tricky to determine exactly how much and what type of chilli peppers may provide the health benefits. However, the researchers are continuing to analyse the data in the hope of uncovering more concrete evidence.



DAYDREAMERS
Daydreaming boosts creativity, according to researchers at the University of California. Reveries about meaningful events help creative behaviour, while those of a fantastical nature can improve creative writing.

OPTIMISTS
Cheerful people are less likely to experience memory decline as they age, a study carried out at Northwestern University has found. The cause is unclear, but it may be linked to health and social relationships.

Good month

Bad month

THE DOGMATIC
People who are dogmatic about their views seek less information and make less accurate judgments as a result, even on simple matters unrelated to politics, according to a study led by UCL and the Max Planck Institute for Biological Cybernetics researchers.

FREQUENT FLYERS
'Super emitters', frequent flyers that account for just 1 per cent of the world's population, were responsible for half of aviation's carbon emissions in 2018, a study carried out at Linnaeus University in Sweden has found.

ENTOMOLOGY

Caterpillars can get even more 'hangry' than humans

Caterpillars: you won't like them when they're 'hangry'. That's according to a new study from Florida Atlantic University, which found that the insects may turn violent when food is scarce.

Researchers noticed that when monarch butterfly caterpillars were deprived of milkweed leaves, their favourite food, they behaved more aggressively towards each other. In fact, the less food there was, the more the caterpillars lunged and knocked aside other individuals, going as far as head-butting to reach food.

"Aggression is common in insects, including fruit flies, where single-pheromone receptors or single genes have been shown to trigger their aggression," said lead researcher Prof Alex Keene.

> "The less food there was, the more the caterpillars knocked aside others"

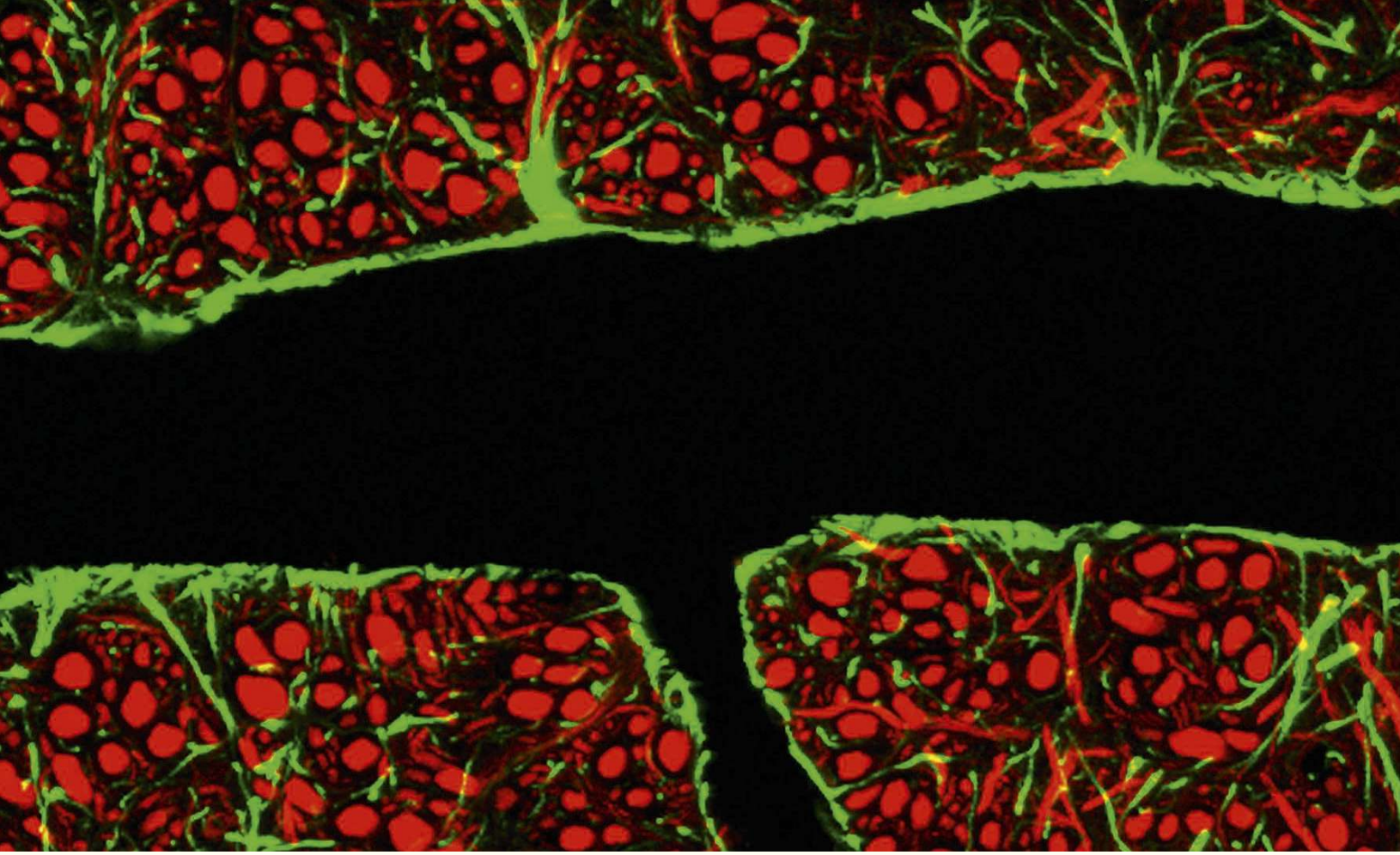
Caterpillars closest to the final stage of metamorphosis (those about to turn into butterflies) were found to be the most aggressive. And for good reason: a lack of nutrition in the insect's youth may reduce its size in adulthood, but also decrease its lifespan.

Although the study was undertaken in a lab, a lack of milkweed is a common issue in the wild. While this is chiefly because the plant only grows during select parts of the year, caterpillars' ravenous and territorial nature also has an impact.

"If you compare a monarch caterpillar to a fruit fly, when there are lot of larvae on a piece of rotting fruit, they feed socially with little evidence of territoriality," said Keene. "But each caterpillar will, at some point in its developmental cycle, encounter resource limitation because they can strip an entire milkweed of leaves."

Monarch caterpillars, common to the US, are known to consume an entire milkweed plant in two weeks. During their biggest and hungriest phase, a single caterpillar can eat an entire leaf in 300 seconds (five minutes).

Table manners go out of the window when a monarch caterpillar is hungry



MEDICINE

Scientists develop nanoparticles for treating Alzheimer's disease

Enclosing drugs in nanoparticles could allow them to cross the blood-brain barrier

Scientists have come up with a method for delivering drugs to the brain using nanoparticles, which could be used to treat neurodegenerative diseases such as Alzheimer's and Parkinson's. The technique, developed by researchers at Canada's Institut National de la Recherche Scientifique (INRS), has been shown to work in both cultured cells and zebrafish.

The biggest hurdle in treating neurodegenerative diseases is the blood-brain barrier (BBB), a border designed to protect the brain from potentially harmful substances in the blood. Pathogens, antibodies and large molecules are blocked by the BBB, while certain antibiotics and glucose (with the help of a specific transport protein) are allowed to pass through.

"The blood-brain barrier filters out harmful substances to prevent them from freely reaching the brain. But this same barrier also blocks the passage of drugs," said Prof Charles Ramassamy, a pharmacologist at the INRS who supervised the study that led to the breakthrough.

Usually, neurodegenerative diseases are treated by administering high doses of a drug, so that a small amount will succeed in crossing the BBB. But this leaves a large amount of the drug in the patient's blood, which can lead to significant side effects that discourage the patient from continuing with the treatment.

The team of researchers found a way to create nanoparticles that can cross the BBB. They made the particles out of polylactic acid, a bioplastic that's easily broken down in the body, and encapsulated them with the compound polyethylene glycol (PEG).

"A layer of polyethylene glycol covers these nanoparticles and makes them invisible to the immune system, so they can circulate in the bloodstream longer," Ramassamy said.

As well as enabling the drugs to cross the BBB, encapsulating them in PEG-covered nanoparticles could mean that patients can take much smaller doses, reducing the risk of side effects.

The researchers tested their method on cultured cells and then on zebrafish. "This species offers several advantages," said Ramassamy. "Its BBB is similar to that of humans and its transparent skin makes it possible to see nanoparticles' distribution almost in real time.

A cross-section of a blood vessel in the brain shows glial cells (in green), which are thought to help maintain the blood-brain barrier

ALAMY, SCIENCE PHOTO LIBRARY ILLUSTRATIONS: CATHAL DUANE

20 POSITIVE NEWS STORIES FROM 2020

Words:
Daniel Bennett, Jason Goodyer, Thomas Ling, Amy Barrett, Sara Rigby

1 A giant leap for womankind

In September, NASA announced its plans to land the first woman, and next man, on the Moon by 2024 as part of its Artemis missions.

The space agency is close to finishing work on its cutting-edge Space Launch System (SLS) and Orion spacecraft – the vessel that it hopes will take humans back to the Moon and then, later, on to Mars.

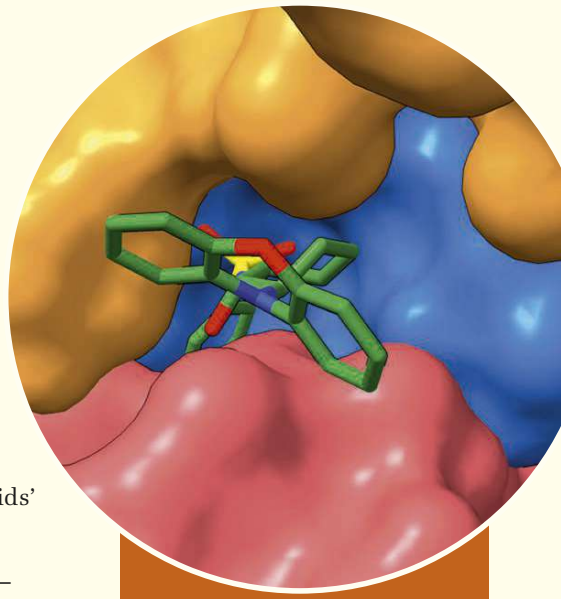
The missions will begin with Artemis 1, an uncrewed test flight of SLS and Orion currently planned for November 2021. The mission will last for 26 days and include six days in lunar orbit.

Artemis 2, the first crewed mission for Orion, is currently planned for August 2023. The spacecraft will perform a flyby of the Moon before returning to Earth. If successful, it'll be the first crewed spacecraft to leave low Earth orbit since Apollo 17 in 1972.

It's hoped that October 2024 will see the launch of Artemis 3 – the first crewed mission to the Moon for more than 50 years. Two of the mission's four astronauts will try to land on the Moon aboard the Human Landing System, while two remain in orbit on Orion.

"As we've solidified more of our exploration plans in recent months, we've continued to refine our budget and architecture. We're going back to the Moon for scientific discovery, economic benefits and inspiration for a new generation of explorers," said NASA Administrator Jim Bridenstine.

NASA engineer Kristine Davis models the spacesuit that will be worn for the forthcoming Artemis missions



2 How long is a sea creature that's like a piece of string? Very long, it turns out

The discovery of what could be the longest animal ever recorded was announced in April. The 46m-long siphonophore was found in a deep-sea canyon off the west coast of Australia by researchers from the Western Australian Museum, and a submersible robot called ROV SuBastian.

A siphonophore is a colonial organism made up of lots of individual animals called 'zooids' that reproduce asexually. Each zooid performs a particular function for the siphonophore – like the cells in our bodies – so that the colony acts together as one long chain.

The researchers also found what might be 30 other new species during their expedition, which took them to depths of 4.5km.

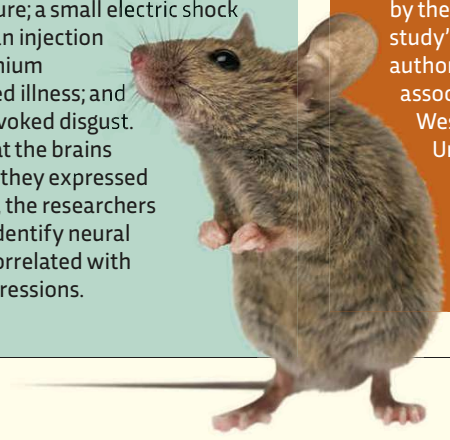
The record-breaking 46m-long siphonophore was found floating deep in the waters off Australia

3 AI TAUGHT TO SPOT WHEN A MOUSE IS HAPPY OR SAD

A study published in April revealed how neuroscientists at the Max Planck Institute of Neurobiology used machine learning, a type of artificial intelligence, to identify the emotions of mice. By monitoring patterns of muscle movements in a mouse's face and ears, an algorithm was able to pick out the expressions that corresponded to pleasure, pain, malaise and disgust.

The researchers generated these emotions by triggering different senses. The taste of a sweet liquid revealed the look for pleasure; a small electric shock elicited pain; an injection of the drug lithium chloride caused illness; and a bitter fluid evoked disgust.

By looking at the brains of the mice as they expressed each emotion, the researchers were able to identify neural circuits that correlated with particular expressions.



4 KEY TO CANCER'S EMERGENCY BRAKE UNLOCKED

The compound that activates an enzyme capable of suppressing tumours was discovered by a team at the University of Michigan in the early part of 2020.

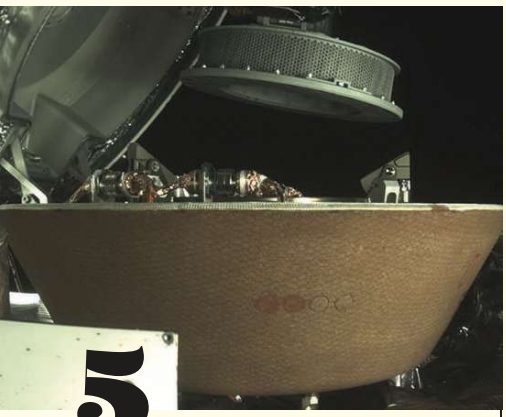
The breakthrough is centred on PP2A, a type of enzyme produced by the human body that stops a tumour growing by breaking down proteins used by the cancer to duplicate.

There are certain compounds that can increase the activity of PP2A, helping it to kill cancer cells, but scientists didn't understand how these compounds, or the enzyme, interacted with the tumour's proteins. Until now.

By designing a molecule that could attach to a PP2A enzyme and using a special type of microscope, the team was able to "see precisely how different parts of the protein were brought together and stabilised by the compound," said the study's co-senior author Derek Taylor, an associate professor at Case Western Reserve University, in Ohio.

The team is now working on turning this knowledge into a treatment for cancer.

GETTY IMAGES X2, DEREK TAYLOR LAB, SCHMIDT OCEAN INSTITUTE

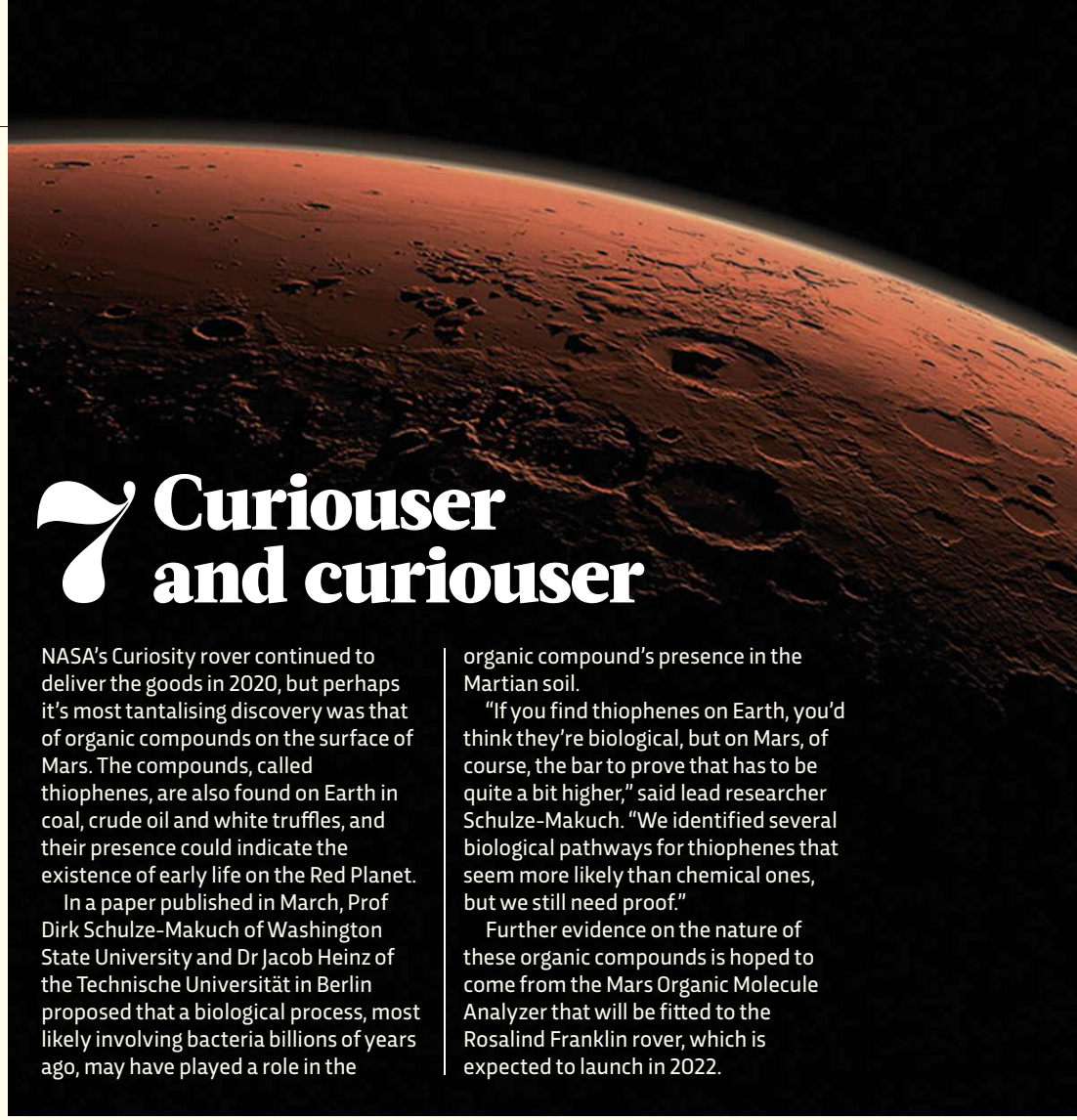


5 ASTEROID-GRABBING SPACECRAFT RETURNS WITH ROCK

NASA's OSIRIS-REx mission had three extraordinary goals when it launched in September 2016: land on an asteroid, collect samples and return them to Earth. By the end of October 2020, the first two had been successfully completed.

The mission's target was the asteroid Bennu, a lump of rock approximately 490m across that's shaped a bit like a spinning top. Though it's classed as a near-Earth asteroid, Bennu is currently over 300 million kilometres away from us and OSIRIS-REx is not expected to arrive back here until September 2023.

OSIRIS-REx's landing on Bennu went without a hitch, but NASA ran into a problem with the sample collection. A rock jammed open the door of the container and the sample started to leak out. Fortunately, the mission team managed to seal the container and leave the asteroid with at least 400g of material – well over the 60g they'd expected to return with.



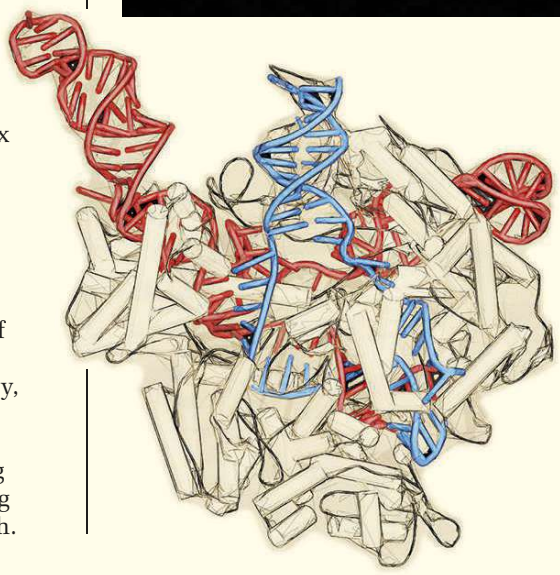
7 Curiouser and curiouser

NASA's Curiosity rover continued to deliver the goods in 2020, but perhaps it's most tantalising discovery was that of organic compounds on the surface of Mars. The compounds, called thiophenes, are also found on Earth in coal, crude oil and white truffles, and their presence could indicate the existence of early life on the Red Planet.

In a paper published in March, Prof Dirk Schulze-Makuch of Washington State University and Dr Jacob Heinz of the Technische Universität in Berlin proposed that a biological process, most likely involving bacteria billions of years ago, may have played a role in the organic compound's presence in the Martian soil.

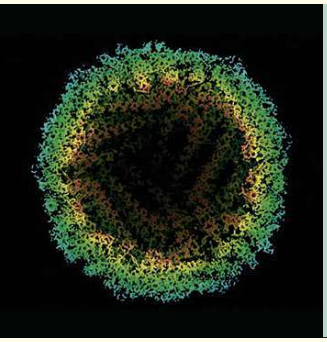
"If you find thiophenes on Earth, you'd think they're biological, but on Mars, of course, the bar to prove that has to be quite a bit higher," said lead researcher Schulze-Makuch. "We identified several biological pathways for thiophenes that seem more likely than chemical ones, but we still need proof."

Further evidence on the nature of these organic compounds is hoped to come from the Mars Organic Molecule Analyzer that will be fitted to the Rosalind Franklin rover, which is expected to launch in 2022.



8 Medicine made with CRISPR?

March saw the first trial of a CRISPR-created medical treatment. The low-cost gene-editing technology was used to make a potential treatment for Leber's congenital amaurosis 10, a leading cause of blindness in children. The CRISPR sequence has been designed to cut out the gene mutation that disables light-sensing cells. The trial, carried by pharmaceutical companies Editas Medicine and Allergan, hasn't yet published its results.

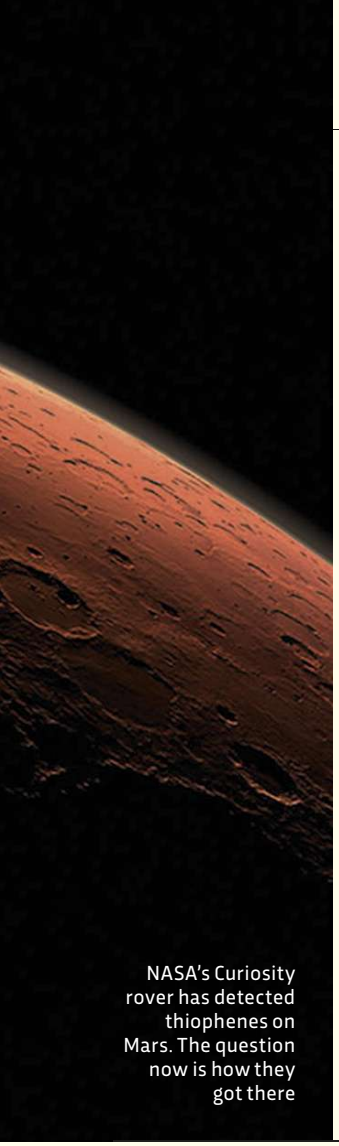


6 CLOSE UP AND ATOM

A gargantuan breakthrough in the world of the very small, June 2020 saw the development of technology that can picture individual atoms for the first time. Using a technique known as cryo-electron microscopy, scientists at the Max Plank Institute for Biophysical Chemistry fired electrons at frozen protein samples to picture structures 1.2-ångström (one ten-billionth of a metre) in size.

"It's really a milestone... There's really nothing to break anymore. This was the last resolution barrier," said Holger Stark, one of the project's researchers.

The imaging technique wasn't only created to boost scientists' Instagram profiles, though. Advances in cryo-electron microscopy will help experts learn how proteins work, providing insights that could lead to better disease-beating drugs with fewer side effects.



NASA's Curiosity rover has detected thiophenes on Mars. The question now is how they got there

10 Puppy love has ancient roots

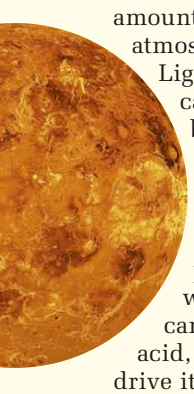
SCIENCE PHOTO LIBRARY, UNIVERSITY OF MINNESOTA, NASA/JPL X2, GETTY IMAGES X3, PAUL EMSLEY/MRC LAB

They say that dogs are our best friends – and it seems they have been our buddies for millennia. A study, published in October and led by scientists from the Francis Crick Institute in London, found that there were already five lineages of dogs nearly 11,000 years ago.

"Some of the variation you see between dogs today originated in the Ice Age," said Dr Pontus Skoglund, a co-author of the study.

Some ancient humans loved their dogs so much that they took them with them when they moved. By comparing human and dog genomes, the scientists found that ancient Swedish farmers brought their dogs with them when they left the Near East, while other farmers from the Near East settled in Germany and befriended local pups who were better adapted to the environment.

9 TANTALISING HINTS OF LIFE FOUND ON VENUS



The world was shocked in September when an international team of astronomers announced that they'd detected phosphine in the clouds of Venus. It's thought that the trace amounts of phosphine in Earth's atmosphere are created by microbes.

Lightning and volcanic eruptions can also produce phosphine, but not in the quantities found on Venus. The prospect of finding what could be a by-product of life on Venus was shocking, because the planet is a hellscape. It's wrapped in thick clouds of carbon dioxide and sulphuric acid, which trap the Sun's heat and drive its temperature up to 471°C.

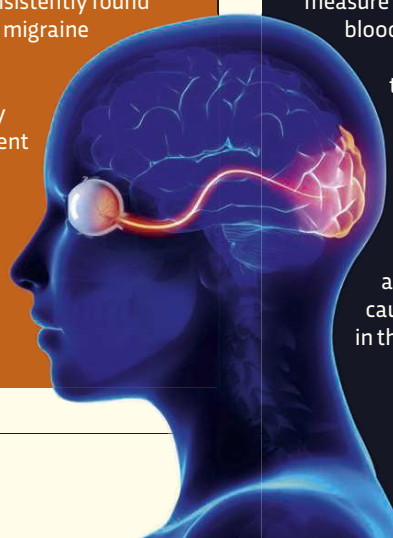
Another paper was rushed out in October suggesting that the phosphine discovery was a mistake. This paper was still under review at the time of writing, so the debate rages on.

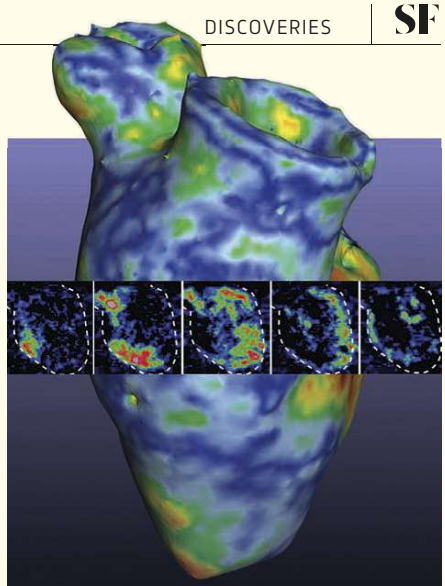
11 MIGRAINE BREAKTHROUGH

In February, a team from the Universities of Birmingham and Lancaster published a study that found migraine-sufferers appear to have a hyper-excitable visual cortex.

The team examined 60 volunteers who were asked to rate a pattern according to how uncomfortable it was to look at, and noted any associated visual phenomena they experienced. The volunteers' brain activity in response to the patterns was also monitored. The team found that a larger response was consistently found in the visual cortexes of migraine sufferers.

"Our study provides evidence there are likely specific anomalies present in the way the visual cortex of migraine sufferers processes information from the outside world," said senior author Dr Ali Mazaheri.





12 3D printing finds its heart

In a study published in July, researchers at the University of Minnesota reported that they'd successfully made a functioning, scaled-down, human heart pump using 3D printing.

The researchers 3D printed high densities of pluripotent human stem cells, which have the potential to develop into any type of cell, onto an extracellular matrix, then reprogrammed them to form heart muscle. Using this method, they were able to create a 1.5cm-long muscle that beats just like a human heart, in less than a month.

"I couldn't believe it when we looked at the dish in the lab and saw the whole thing contracting spontaneously and synchronously, and able to move fluid," said lead researcher Prof Brenda Ogle.

The mini heart is like a closed pouch, with both a fluid inlet and outlet, and allows researchers to measure how the organ moves blood within the body.

The team is now planning to use the model to study the effects of various types of damage and disease, as well as those of medicines and other therapies.

According to the British Heart Foundation, heart and circulatory diseases cause nearly 170,000 deaths in the UK each year.

13 Drop in dengue fever due to new mosquito

The infection rates of dengue fever in Yogyakarta, Indonesia, were cut by 77 per cent after scientists released modified mosquitoes into the wild, according to a paper published in August.

Dengue affects nearly 400 million people annually and kills 25,000. It is spread by the *Aedes aegypti* mosquito, which also carries Zika and other viruses. In the wild, mosquitoes that carry a bacterium called *Wolbachia pipientis* don't spread viral disease, as the bacteria seem to inhibit viral replication. The scientists created populations of *A. aegypti* carrying *W. pipientis* before releasing them into areas around Yogyakarta. The drop in infection rates is unprecedented and the World Mosquito Program is looking to get the World Health Organization's endorsement to roll out the intervention where it's most needed.

14 Neuralink goes the whole hog

Elon Musk and his company Neuralink trotted out a pig with a coin-sized computer in her head during August. Gertrude the pig was being used to demonstrate Neuralink's plans to build a brain-to-machine interface.

By emitting wireless signals, the implant can track the neural activity in the area of Gertrude's mind linked to her snout.

Dr Kathryn Sullivan in the submersible vehicle Limiting Factor, which she used to descend into the Mariana Trench

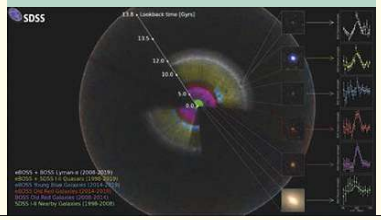
15 A deeply impressive woman

16 A NEW UNIVERSE A-Z

July saw the unveiling of the most detailed 3D map of the Universe ever created. Made by more than 100 astrophysicists, the Extended Baryon Oscillation Spectroscopic Survey (eBOSS) map used recent discoveries of faint galaxies to expand older charts.

Not only does eBOSS plot detailed measurements of over two million galaxies, but it also reveals how the Universe has changed over time. It indicates that the Universe's expansion accelerated six billion years ago, possibly due to the force physicists call 'dark energy'.

The map is expected to spur further research into the Universe's expansion, including by DESI, the Dark Energy Spectroscopic Instrument project, which involves many eBOSS researchers.



17 It's raining... iron

We might complain about the weather in the UK, but it's nothing compared to WASP-76b.

Astronomers analysing this tidally locked exoplanet, which lies 640 light-years from Earth, announced their findings in a study published in March. Among them was the astonishing fact that WASP-76b's star-facing side reaches soaring temperatures of 2,400°C, while its dark side 'only' reaches 1,500°C.

It's so hot on the day side that metals like iron separate into atoms and evaporate. The extreme temperature difference drives powerful winds to the night side, where the iron cools, condenses and rains down onto the planet's surface.

GETTY IMAGES, ENRIQUE ALVAREZ, ALAMY, SPACEX, NASA/JPL, ESO, NEURALINK, ANAND RAICHOOR/ASHLEY ROSS/SDSS

In June 2020, Dr Kathryn Sullivan, an American geologist, became the first woman to reach Earth's deepest point and only the eighth person to go there at all. Sullivan visited Challenger Deep, the deepest part of the Mariana Trench – nearly 11km below the surface of the Pacific Ocean – with underwater explorer Victor Vescovo. They travelled to the seabed in Vescovo's two-person submersible Limiting Factor. Sullivan is an explorer by nature. A former NASA astronaut, she became the first American woman to walk in space in October 1984.

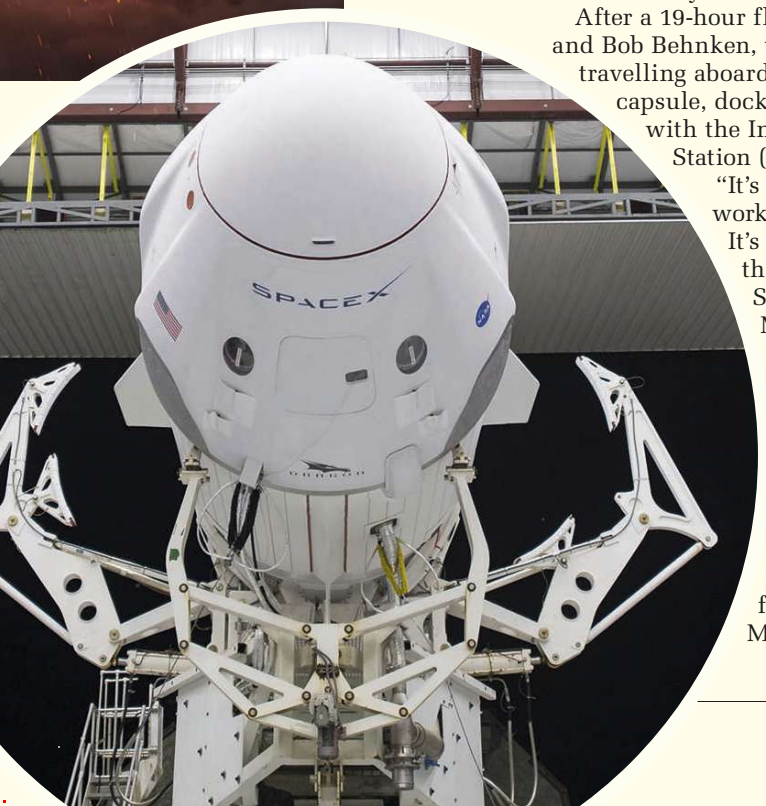
19 Oldest material on Earth discovered

In January, scientists analysing a meteorite that fell to Earth in the 1960s discovered that some of material inside was seven billion years old – the Sun is 'just' 4.6 billion years old.

The space rock contains what's known as pre-solar grains, fragments of stardust flung out by dying stars. The grains get trapped inside meteorites where they remain for billions of years, creating a time capsule of life before the Solar System formed.

To get to the pre-solar grains, the meteorite was crushed into a powdery paste, which smelt like "rotten peanut butter" according the scientists. The pungent paste is then dissolved in acid until all that's left is stardust. "It's like burning down the haystack to find the needle," explained lead researcher Dr Philipp Heck.

To calculate the dust's age, Heck and his team analysed how much cosmic radiation the material had been exposed to: the more cosmic rays it had been hit with, the longer it must have been in space. A substance this old will help scientists understand the early days of the Milky Way.



18 SpaceX flies crew to ISS

SpaceX became the first private company to send humans into orbit in 2020. After the close of the Space Shuttle programme in 2011, the Crew Dragon Demo-2 flight, which lifted off on 30 May, also marked the first manned mission to launch from US soil in nine years.

After a 19-hour flight, Doug Hurley and Bob Behnken, the NASA astronauts, travelling aboard the Crew Dragon capsule, docked successfully with the International Space Station (ISS).

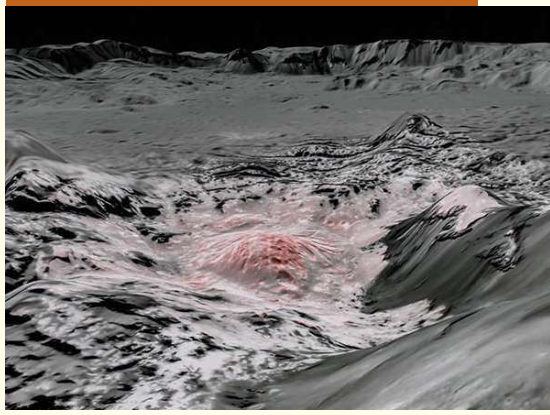
"It's been 18 years working towards this goal. It's really hard to believe that it's happened," SpaceX founder Elon Musk said after the capsule docked.

Following this flight, SpaceX launched a further four astronauts (and a Baby Yoda toy) to the ISS in November. Another manned Crew Dragon flight is scheduled for March 2021.

20 CERES CONTAINS RESERVOIRS

Studies published in August revealed the cause of the mysterious bright spots seen on Ceres. The white patches were spotted in images returned by NASA's Dawn probe when it visited the dwarf planet, the largest in the asteroid belt between Mars and Jupiter, between 2015 and 2018.

Scientists had determined the patches to be salt (sodium carbonate) deposits, but further analyses have now led them to believe that the salt percolated up in water from a reservoir 40km (25 miles) underground. The water evaporated once it reached the surface, leaving the thick, crusty deposits of highly reflective salt.



WELCOME TO THE *smarter home*

How smart meters and an intelligent energy system could help us to build the smart home of the future

In Britain, homes are responsible for 25 percent of the nation's Co_2 emissions, and while it's a combination of many changes that will help us achieve net zero by 2050, slashing that percentage is a big step toward that goal. The smart, connected home has many tools to help us do this, but the potential to intelligently run itself and save even more energy is the most exciting possibility, one that will transform it into the smarter home.

The first step toward creating this more energy-efficient home is to request a smart meter from your energy supplier. Electricity and gas usage equate to around one quarter of all carbon emissions from a typical home, and this no-additional-cost device allows you to see the energy your home is using in near-real time. This, combined with more intelligent, efficient tech enabled by smart meters, is the key to unlocking the way we use energy in our homes.

Once you can see the energy use, thanks to an in-home display that shows consumption in pounds and pence, you can then make changes to reduce it and save money. You can do simple things such as turn the thermostat down a bit, turn off some lights, run one less load of laundry. Currently, responding to this information can help save 5 to 15 percent of your energy consumption (typically equivalent to £50 a year). But if this sounds like a bit too much work, there's more good news around the corner. With the right home automation equipment installed, and with the energy data from your smart meter, your home's energy systems could soon be able to do some of this for you, automatically. Letting you save both time and money, while helping the nation achieve its quest for net zero.

Today, smart appliances and smart heating systems can intelligently control the way we use energy in our homes. Smart appliances could soon take advantage of time-of-use tariffs enabled by smart meters to run automatically when energy is cheaper and greener, and smart thermostats can use motion sensors to know when you're out and adjust accordingly, then communicate with your smartphone to know when you're coming back. But tomorrow, they will be able to do so much more.

Time to look forward

In the near future, those smart appliances and that smart heating system – and any other connected equipment you have, such as electric vehicles and energy storage systems – could all talk to each other, aided by your smart meter and new technologies like a Consumer Access Device (CAD).

And, once your smart meter is connected to the intelligent tech in your house, this lays the groundwork for a future interactive smart home. While innovations like CAD technology are still in their early stages, they are part of a wide range of ways we will soon be able to realise the potential of smart meters. The connected appliances in our smart homes and home automation systems will be able to securely tap into the near-real time data from smart meters and respond instantly to save even more energy.

New technology and services will be able to use this data to manage connected appliances in the home (such as running them when energy is cheap), and even access online services to increase the efficiency and cost effectiveness of how your connected appliances heat and light your home. For example, they could access weather information and calendar data to help appliances determine when they will be needed.

Home is where the smart is

The possibilities for the future smart home – when powered by the near-real time data that smart meters, along with new technology and services, can provide – are exciting. Innovations around the efficiency and smart functionality of energy systems in our home, such as heating and hot water, could be a reality in the near-future. Then will come the real potential to develop a home automation system that – using artificial intelligence – can learn your habits and energy use over time and intelligently balance those needs with times when demand is lowest, and energy is cleanest.

This will mean that your smart, connected home will be able to make small, yet significant adjustments to save energy in ways you won't even notice, but which cumulatively have a significant impact. Ultimately, this will make your home so much more attuned to your own everyday needs.

See for yourself

Sometimes, the numbers speak for themselves. Here are some important stats you need to know about smart meters.

We could achieve

11%

of the UK's **2050 carbon emissions target** just by taking household energy efficiency measures.

64%

of people with smart meters feel more in control of the energy they use at home.

Britain could save a total of **£5.6bn** on energy bills in the next 20 years.

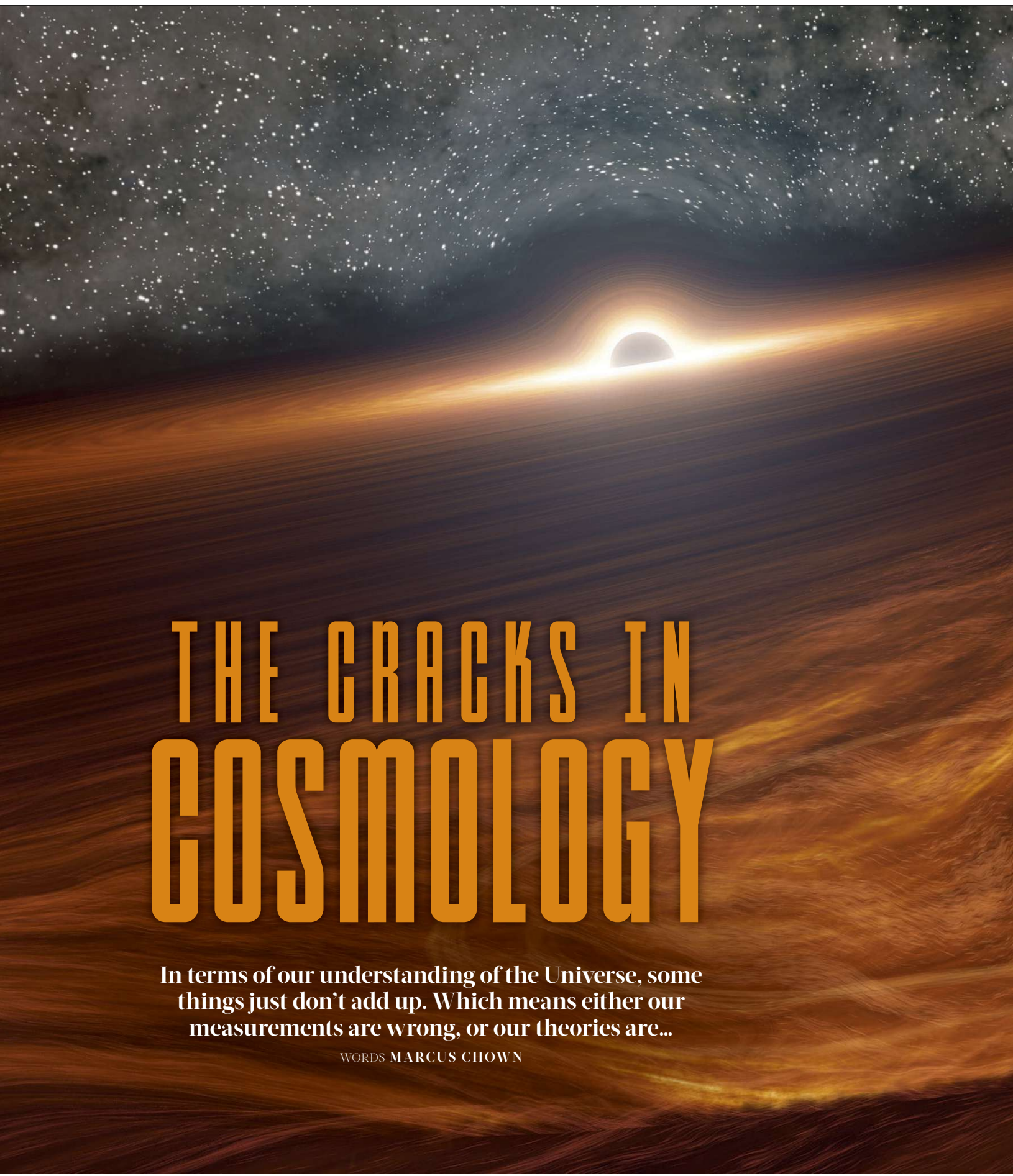
If every UK household took action on energy efficiency now, we could save up to **54 million tonnes** of carbon dioxide.

The smart meter in-home display, allowing you to track your energy expenditure in near-real time

Contact your energy supplier now to request a **smart meter** installation

Eligibility may vary

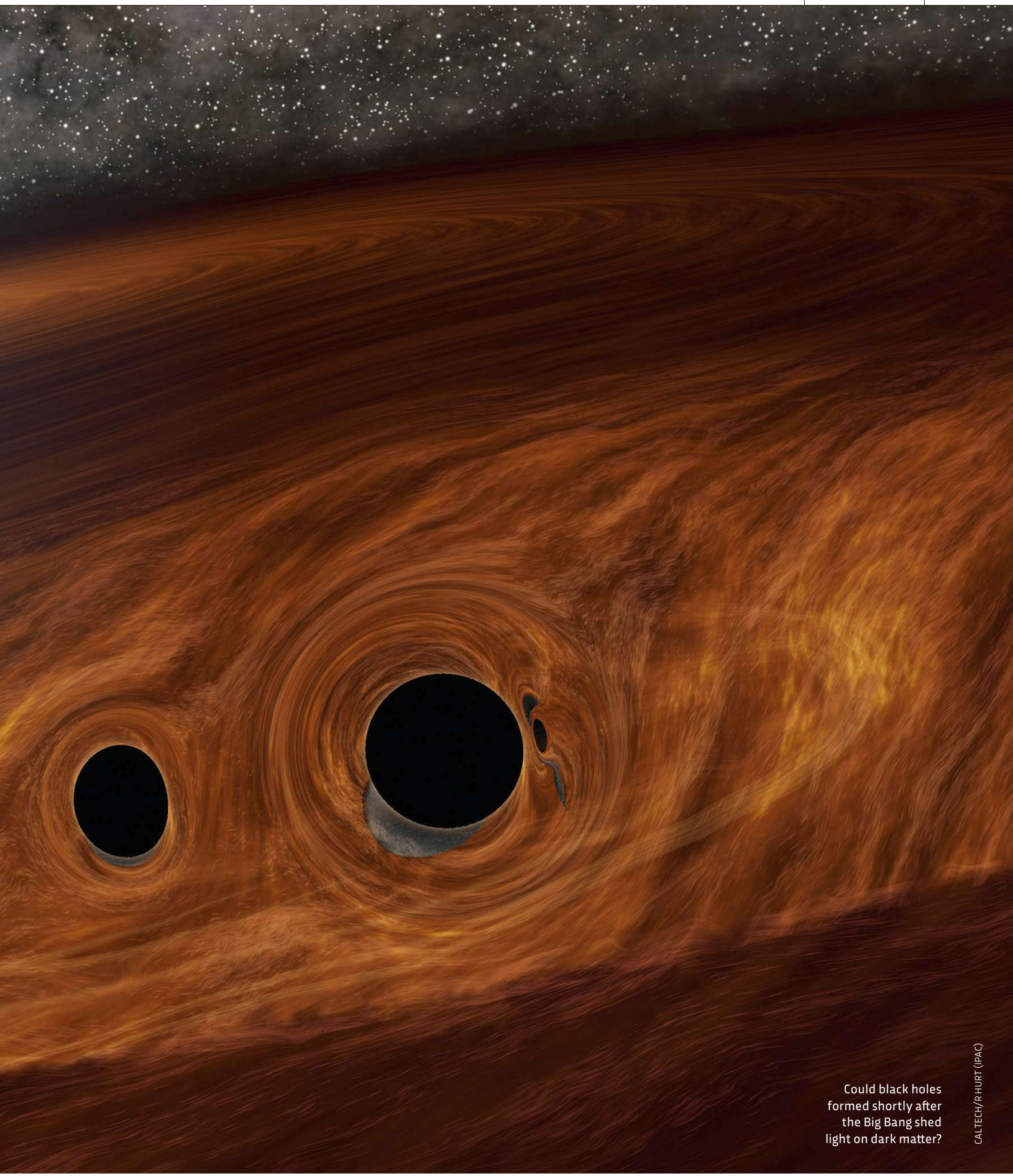
Smart Meters
Join the quiet revolution



THE CRACKS IN COSMOLOGY

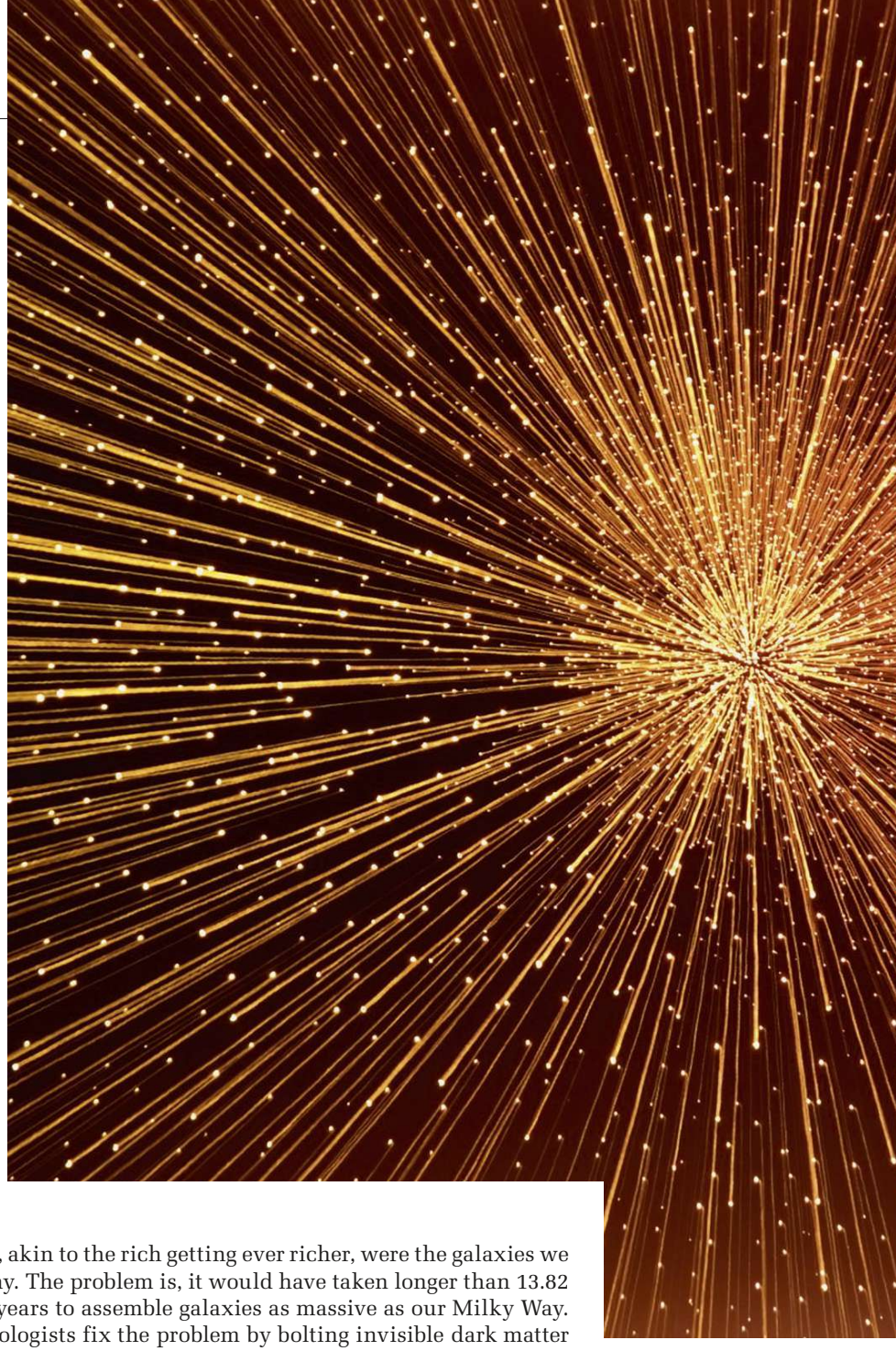
In terms of our understanding of the Universe, some things just don't add up. Which means either our measurements are wrong, or our theories are...

WORDS MARCUS CHOWN



Could black holes formed shortly after the Big Bang shed light on dark matter?

CALTECH/R HURT (IPAC)



The standard model of our Universe may be showing some cracks. Several fundamental cosmological observations are contradicting each other. For instance, the Universe appears to be expanding 10 per cent faster than it should be, according to observations of the leftover heat from the Big Bang.

It's perfectly possible that the contradictions will disappear as our estimates of cosmic parameters improve. But it's also possible that the contradictions won't go away and that our fundamental picture of the Universe is about to undergo a radical revision, perhaps to include invisible, 'dark' components as complex as atoms, stars and galaxies.

ADDITIONAL INGREDIENTS

Cosmology is the ultimate science. It deals with the birth, evolution and fate of the Universe. The standard model consists of several ingredients: the Big Bang, dark matter, dark energy and inflation.

First, take the Big Bang. Astronomers can see that the galaxies – the basic building blocks of the Universe of which the Milky Way is one – are flying away from each other in the aftermath of a titanic explosion. They also observe that the Universe is permeated by relic heat – the cosmic background radiation. Together, these two observations tell astronomers that the Universe was smaller and hotter in the past. In fact, according to the standard picture, the Universe was born in a blisteringly hot fireball 13.82 billion years ago and has been expanding ever since, with the galaxies congealing out of the cooling debris.

But the basic Big Bang picture requires a few extra ingredients, because it conflicts with observations. First, and most seriously, it predicts that we should not exist.

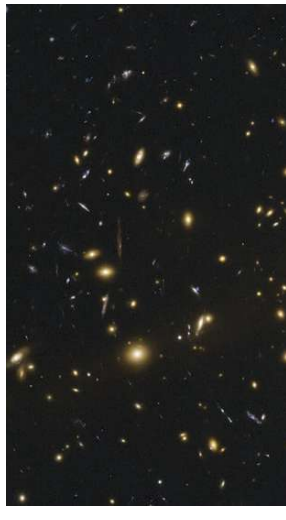
According to the basic Big Bang, when matter emerged from the primordial fireball it was spread extremely smoothly. Thereafter, regions that were slightly denser than average pulled in matter faster with their stronger gravity. The result of this process, akin to the rich getting ever richer, were the galaxies we see today. The problem is, it would have taken longer than 13.82 billion years to assemble galaxies as massive as our Milky Way.

Cosmologists fix the problem by bolting invisible dark matter on to the basic Big Bang. Invisible dark matter outweighs the visible stars and galaxies by a factor of six, and its extra gravity speeded up galaxy formation.

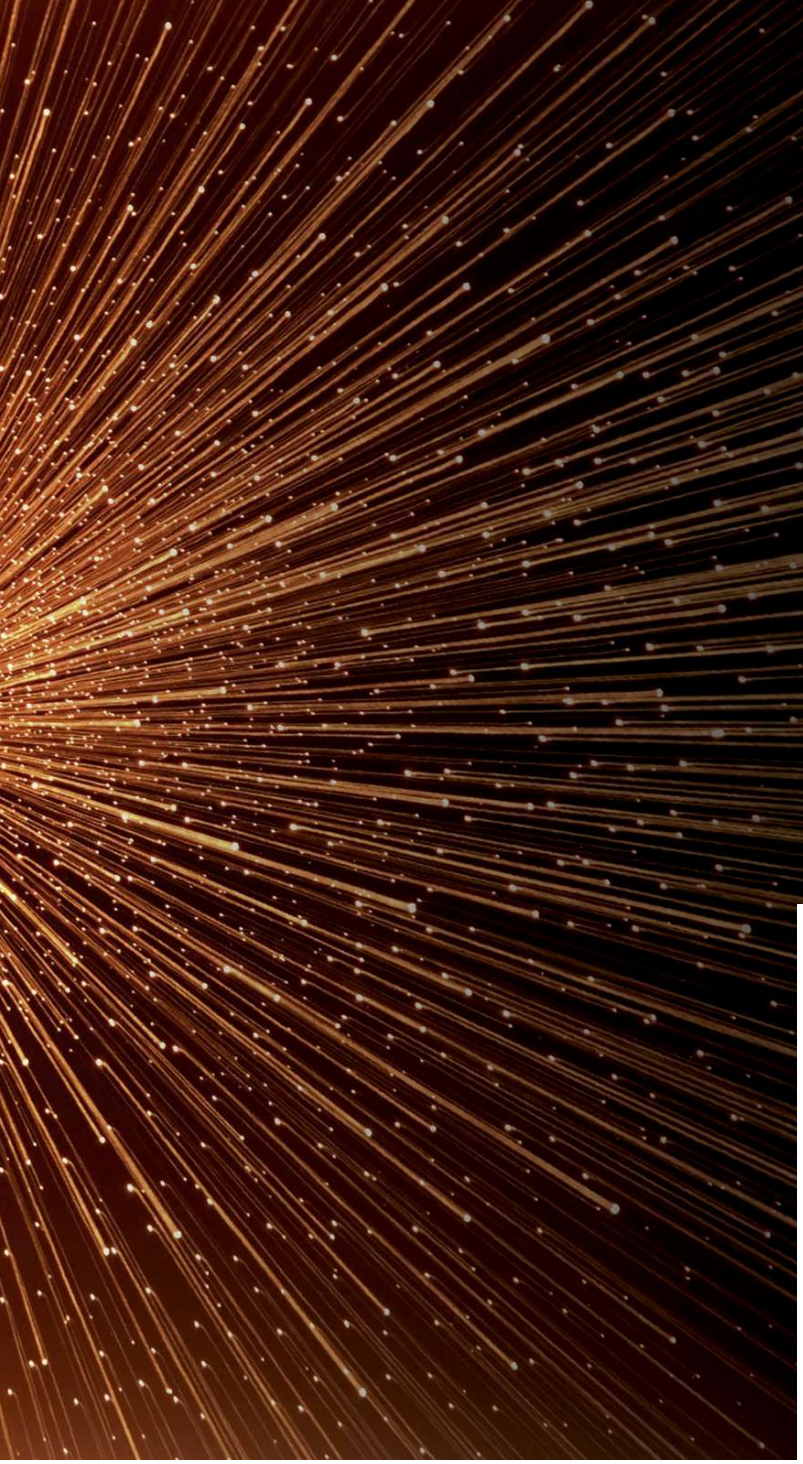
The second way in which the basic Big Bang picture conflicts with observations is that it predicts that cosmic expansion should be slowing down. Gravity acts like a web of elastic between the galaxies, braking their rush from each other. But in 1998, astronomers discovered that, contrary to all expectations, the expansion is speeding up.

They fix this by bolting dark energy onto the basic Big Bang, something that's invisible, fills all of space and has repulsive gravity. It's dark energy that's speeding up cosmic expansion.

The third way in which the Big Bang picture conflicts with observations is that Universe has the same temperature everywhere – the temperature of the cosmic background radiation. That temperature is 2.726K (absolute zero is 0K). Early on in the Big Bang, regions that are today on opposite sides of the sky were too far apart to equalise their temperatures.



GETTY IMAGES, NASA/JPL



"BUT THE BASIC BIG BANG PICTURE REQUIRES A FEW EXTRA INGREDIENTS BECAUSE IT CONFLICTS WITH OBSERVATIONS"

ABOVE The Big Bang on its own isn't quite enough to explain the Universe as we see it today

LEFT Distorted light from distant galaxy clusters can be used to detect invisible dark matter subhalos, which appear to be more compact than predicted

Cosmologists fix this by postulating that, early on, the Universe was far smaller than expected. It must therefore have expanded faster to achieve its current size in 13.82 billion years. In fact, the Universe, in its first split-second, is believed to have undergone an expansion so violent that it's been likened to the explosion of an H-bomb. This is compared with the stick of dynamite of the Big Bang expansion, which took over when the initial 'inflation' ran out of steam.

There you have it. The standard model of cosmology = the Big Bang + inflation + dark matter + dark energy. Technically, it goes by the name of 'Lambda-CDM'. Whereas the Big Bang + inflation is implicitly assumed, Lambda is shorthand for dark energy and CDM for cold dark matter, with the 'cold' meaning that its components move sluggishly so gravity can concentrate them into clumps.

SOMETHING'S WRONG

The first way Lambda-CDM conflicts with observations involves clusters of galaxies. According to the cold dark matter model, gravity will cause dark matter to clump on a range of scales, including those smaller than a galaxy cluster. Later, ordinary matter (which forms into stars) is pulled in. These 'subhalos' may have plenty of stars, but some subhalos may have no stars, or so few stars that they're invisible. There is a way to reveal them, however.

A team led by Dr Massimo Meneghetti of the National Astrophysics Institute in Bologna, Italy, observed 11 galaxy clusters with the Hubble Space Telescope and the European Southern Observatory's Very Large Telescope in Chile. They examined the light of more distant galaxies and how it was distorted, or 'gravitationally lensed', due to passing by the invisible subhalos. To the team's surprise, the lensing by subhalos was much stronger than expected, indicating that they're very compact. This conflicts with the cold dark matter model, which maintains the subhalos should be much puffier.

"We need to know if this anomaly can be caused by the way we analyse our data or the way we make our theoretical predictions," says Meneghetti. "If we fail to explain it, the only option will be to revise the model." One possibility is that the dark matter isn't made of what we think it's made from. Favoured candidates are massive, weakly interacting particles that interact with ordinary matter only through gravity. Such weakly interacting massive particles, or WIMPs, aren't part of the Standard Model of particle physics but are predicted by a speculative theory called 'supersymmetry'.

"Maybe the dark matter consists of particles that interact in different ways to WIMPS," says Meneghetti. "Possible alternatives include a new type of neutrino called a 'sterile neutrino', another class of particles called 'axions', or even primordial black holes, formed just after the Big Bang."

TOO SMOOTH

The second conflict between Lambda-CDM and observations concerns the clumpiness of matter on a large scale. A team led by Prof Koen Kuijken at the Leiden Observatory in the Netherlands looked at the distribution of 31 million extremely faint galaxies in the latest data release of the European Kilo-Degree Survey (KiDS). The KiDS collaboration used the Very Large Telescope's Survey Telescope in Chile to observe two large swathes of sky.

Specifically, Kuijken's team looked at how the light of these galaxies was gravitationally lensed by the matter between them and Earth, enabling its distribution. It discovered that matter was spread 8.3 per cent smoother than predicted by the cold dark matter model, which takes the very small variations in the density of the Universe shortly after the Big Bang – revealed by the cosmic background radiation – and calculates how these would have been enhanced by gravity over the past 13.82 billion years. Once again, the anomaly might go away with a better analysis of the data or a modification of the cold dark matter model. Or it could be telling us the model is fundamentally wrong.

The third conflict between Lambda-CDM and observations, known as the 'Hubble tension', concerns the Hubble constant, a measure of the current expansion rate of the Universe. There are two ways to measure it and they're contradicting each other.

One way is to look at subtle variations in the temperature of the cosmic background radiation across the sky. These were imprinted on the radiation by the 'fluid' of matter and radiation at the beginning of time as it sloshed about like water in a Universe-sized bath. It's possible to extract from these sloshing modes all the key cosmological parameters. The European Planck satellite, for instance, found that the Universe is 4.9 per cent atomic matter, 26.8 per cent dark matter and 68.3 per cent dark energy.

Crucially, such observations also reveal the Hubble constant in the early Universe and this can be extrapolated to the present time. And herein lies the problem: the extrapolated value is about 10 per cent smaller than the Hubble constant observed today.

A key thing to bear in mind is that the Hubble constant deduced from the cosmic background radiation is very precise because the physics is simple and well understood. But measurements

ABOVE The gravity of invisible dark matter, highlighted in pink, is used to explain the unexpected speed of galaxy formation

ABOVE RIGHT Gravitational waves could provide a way to explain the inconsistencies between our theories and the Universe

"WE NEED TO KNOW IF THIS ANOMALY CAN BE CAUSED BY THE WAY WE ANALYSE OUR DATA OR THE WAY WE MAKE OUR THEORETICAL MODELS"

ESO, GETTY IMAGES

of the Hubble constant in today's Universe are cruder and fraught with problems.

Such measurements involve finding objects that are believed to always have the same intrinsic luminosity, such as Cepheid variables and Type 1a supernovae. Like standard 100W lightbulbs strung across a field at midnight, such 'standard candles' reveal their relative distance by their relative faintness. The trouble is that the physics of such stars is not well understood and may not be as standard as we hope. So, it could be that these measurements of the distance of standard candles as they're dragged away from us by cosmic expansion are in error and will eventually yield a Hubble constant in line with that from the cosmic background radiation.

On the other hand, it could be that nature is telling us something new about the Universe. "The 'standard model of cosmology' is an admission of ignorance," admits Prof Abraham Loeb of Harvard University. "We label components whose nature we don't know as 'dark matter' and 'dark energy'. Since we don't know what they are, it's a very crude model that could easily be an oversimplification of reality."

Loeb points out that dark matter might not be a fluid of one type of dark matter particle. "There may not be a single dark matter particle but rather a mix of particles of different masses and interactions," he says. Dark matter could be complex, just like ordinary matter, which is composed of quarks and electrons that are assembled into 92 naturally occurring elements.

In addition, dark matter particles might behave in complex ways. For instance, they might decay over the age of the Universe, reducing their gravitational pull and thus taking the brakes off cosmic expansion. Such a boost to the cosmic expansion rate would relieve the Hubble tension.

One possible way to confirm or refute the Hubble tension is with 'standard sirens' rather than standard candles. Gravitational waves are vibrations of space-time akin to sound waves and the merger of neutron stars is believed to create standard sirens, like the foghorns of lighthouses. The quieter the sound, the further away the siren. "Gravitational wave sources offer the most robust method to resolve the uncertainties we currently have," says Loeb. The hope is that such techniques will show whether the current contradictions between different observations are real.

The standard model of cosmology is relatively simple, despite its multiple invisible components. But its simplicity may be blinding us to reality, which may be more complex. "Nature," cautions Loeb, "is under no obligation to comply with the simplest version." **SF**

—

by **MARCUS CHOWN**

Marcus's latest book is The Magicians: Great Minds And The Central Miracle Of Science *(£14.99, Faber & Faber).*

RISE OF THE CLONES

ANIMALS – FROM PETS AND LIVESTOCK TO WORKING DOGS AND EXTINCT SPECIES – ARE BEING CLONED FOR A VARIETY OF PURPOSES. BUT COPYING ANIMALS FROM THEIR GENETIC MATERIAL IS CREATING PROBLEMS AS QUICKLY AS IT'S SOLVING THEM

by DR HELEN PILCHER

It's almost 25 years since the most famous clone on Earth, Dolly the sheep, was born on a farm in Scotland. It was one small step for lamb, one giant leap for lambkind. Along with the celebrity bleater came promises of innovative applications, but at the time, no one really knew how cloning would come to be used.

Now, cloning is finally finding its niche. As a growing number of species are cloned, including camels, cats and cattle, companies are springing up to offer commercial cloning services. The practice has become big business.

Around the globe, hundreds of domestic and agricultural animals are cloned every day. As wild species start to be cloned too, it's thought the technique could even help conservation. But the ethical issues remain as large and divisive as the day that Dolly was born. So how is cell biology's *bête noire* making a difference and what should we make of these genetic doppelgängers?

WE'RE ALREADY CLONING ENDANGERED ANIMALS...

In August 2020, a healthy clone of the endangered Przewalski's horse (pronounced shuh-VAL-skees) was born in Texas. Przewalski's horses, which are native to the steppes of central Asia, are the last truly 'wild' horse species. Around 2,000 remain, but they lack essential genetic diversity because they're all descended from just 12 wild-caught individuals.

The little foal, called Kurt, was cloned using 40-year-old frozen cells from a stallion whose genes aren't well represented in today's population. Because Kurt is genetically identical to the stallion, the hope is that when he grows up and breeds, Kurt will restore this lost genetic diversity via his descendants. "The colt is expected to be one of the most genetically important individuals of his species," says Bob Wiese, chief life sciences officer at San Diego Zoo Global, who was involved in the project.

Kurt was cloned to increase the genetic diversity of Przewalski's horses

Other wild species have also been successfully cloned, including the coyote, the African wildcat and a rare Southeast Asian cow called the banteng. But many conservationists oppose cloning because they see it as an unproven, expensive distraction from tried and tested conservation methods, such as protected areas and anti-poaching initiatives.

Mammoth researcher Prof Adrian Lister with Lyuba, a baby woolly mammoth that died around 40,000 years ago

...AND EXTINCT ANIMALS TOO (BUT NOT DINOSAURS)

There'll be no real-life *Jurassic Park*. Sorry. Dinosaurs are off limits because their DNA is too long gone. But more recently extinct animals, such as the woolly mammoth, could theoretically be on the cards. 'All' that's needed is a source of DNA (from say, the cells in a frozen carcass or a museum specimen) and a closely related living species to help nurture the cloned embryo.

For the woolly mammoth, this would mean transferring a clone into the womb of a surrogate Asian elephant. The problem is Asian elephants are endangered. It's a major sticking point for critics, who also question the value of 'de-extincting' species whose natural habitats disappeared a long time ago.

Advocates, however, suggest that certain animals, dubbed keystone species, could engineer their own ecosystems. If the woolly mammoth were released into northern Siberia, for example, its actions could potentially create a lush grassland that could benefit many other species.

GETTY IMAGES, SCOTT STINE, SHUTTERSTOCK

Little Juice, seen here at 24 days old, is a clone of Juice, a star of film and TV in China

ALAMY X2, GETTY IMAGES

CLONING YOUR PET ISN'T SUCH A GOOD IDEA...

At least three pet-cloning companies now exist and for upwards of $40,000 (just over £30,000) they'll create a genetic replica of your beloved pet dog or cat. Singer Barbra Streisand and fashion designer Diane von Furstenburg have both bought clones of their pet dogs, for example, but the practice is fraught with ethical concerns.

In one cloning advert, from the Chinese company Sinogene, a grieving pet owner finds solace when a guardian 'pooch angel' beams her doe-eyed ghost dog back to Earth in new puppy form. It's a carefully choreographed tear-jerker, but cloning can't even guarantee to produce faithful lookalikes, let alone animals with identical personalities. "When people are faced with losing a pet, they're so vulnerable," says bioethicist Jessica Pierce, from the Center for Bioethics and Humanities, University of Colorado, Denver. "Jumping into that abyss and saying 'we can fix it for you; you don't have to say goodbye' is just so wrong."

In addition, cloning is a notoriously inefficient process, whatever the species. It takes multiple dog surrogates to achieve a single, successful pregnancy and dozens of cloned embryos to achieve a single, healthy puppy. Dogs die as bundles of cells in the culture dish, embryos in the womb and, more rarely, as puppies after birth. "It's creating a whole canine underclass that's invisible," says Pierce. "Why go down this route when there are millions of deserving dogs in shelters?"

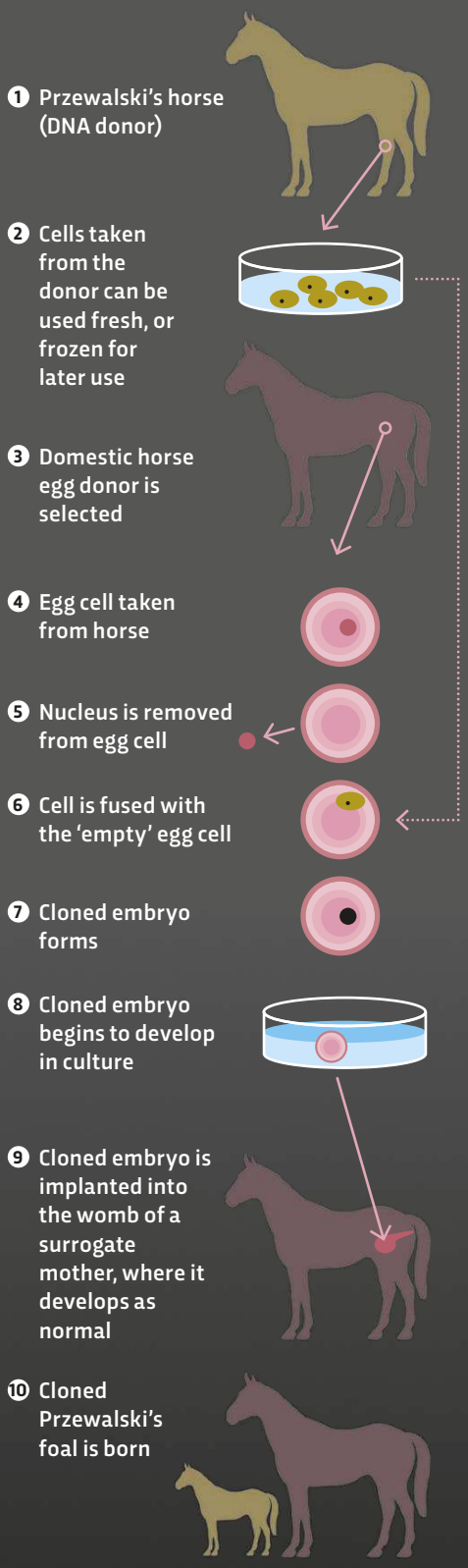
...BUT CLONED SNIFFER DOGS ARE ALREADY PATROLLING SOME AIRPORTS

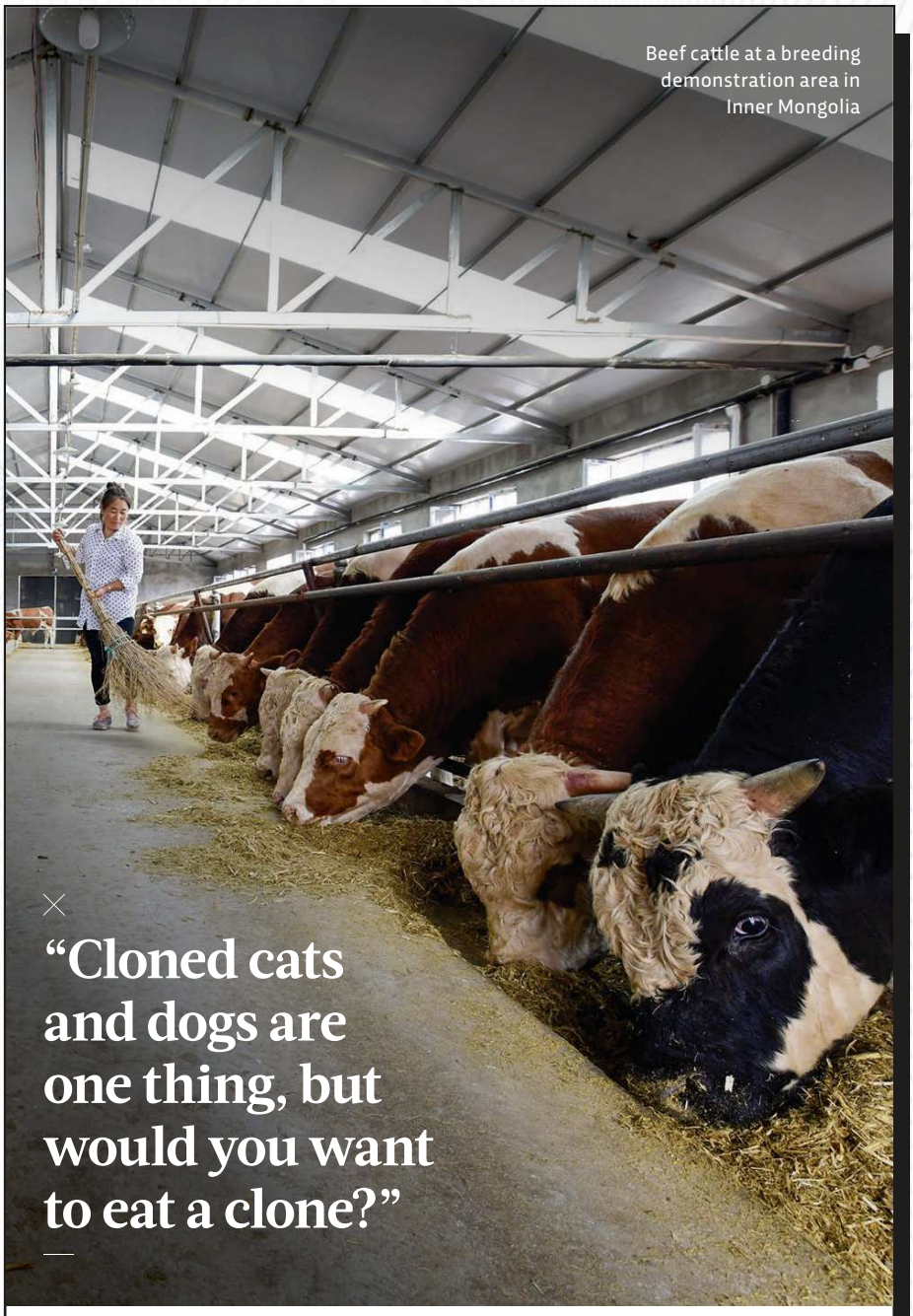
Some of the companies that clone pet dogs also clone working animals, such as drug-detection dogs. "That's the number one thing we're doing with dog cloning," says cell biologist Dr P Olof Olsson, at the Abu Dhabi Biotech Research Foundation in South Korea. Also known as Sooam Biotech, the company has produced hundreds of canine clones and many are now in active service. If you've ever collected a suitcase from the carousel at Seoul's Incheon Airport, chances are it was checked by a cloned sniffer.

The idea is to produce animals that are genetically predisposed to learn well. It takes time and money to train a sniffer dog, but even with the best training and the brightest animals, only around half of conventionally bred dogs manage to qualify. Cloned dogs do much better. "80 to 90 per cent end up going into service," says Olsson, "and we've been told multiple times that our clones respond better to training." Here, the method has become a way to minimise doggy dropouts and reduce costs.

Staff from the Russian Military Historical Society collect dogs cloned by Sooam Biotech

HOW CLONING WORKS





Beef cattle at a breeding demonstration area in Inner Mongolia

"Cloned cats and dogs are one thing, but would you want to eat a clone?"

YOU MIGHT SOON BE EATING CLONES

Cloned cats and dogs are one thing, but would you want to eat a clone? In China, where demand for prime-quality beef is rocketing, another cloning company thinks its customers will.

Boyalife Genomics, which works with the Abu Dhabi Biotech Research Foundation, is building a $30m (approximately £23m) cloning facility in the coastal city of Tianjin where it plans to clone some of the world's finest beef cattle. The goal, according to the company's chief executive Xu Xiaochun, is to start by producing 100,000 cloned cattle embryos annually, then increase that to a million. Eventually the firm hopes to be responsible for 5 per cent of China's premium slaughtered cattle and by scaling production up, Boyalife hopes to bring the cost of cloning down.

SEMEN FROM CLONED STUD ANIMALS IS AVAILABLE TO BUY ONLINE...

In agriculture, clones of high-value breeding animals are being produced for breeding purposes. For example, Final Answer was a naturally conceived bull so buff he became one of the most prolific sires of the Angus cattle breed. During his life, he produced more than 500,000 units of semen, which were used to father hundreds of thousands of offspring via artificial insemination.

Cloning is relatively routine in the cattle industry, so as Final Answer entered his twilight years, breeders made a copy. In 2014, when Final Answer finally died, Final Answer II took over. His sperm is no different from that of the original, and now a single shot retails online for around $22 (almost £17). Hundreds of other, similarly valuable cattle have also been cloned, so here the technique is being used as an insurance policy. "Having an heir and a spare is not a bad concept," says agricultural geneticist Alison van Eenennaam, from the University of California, Davis.

Semen samples collected from stud bulls in Preska, Slovenia

...WHILE CLONED PONIES ARE BEING RIDDEN ON THE POLO FIELD

In 2016, Adolfo Cambiaso – the Lionel Messi of the polo world – made history when he rode not one, but six cloned polo ponies, in the final of the prestigious Argentine Open Championship. The ponies were all copies of the same animal, an exceptionally agile mare named Cuartetera, and they were produced by Cambiaso's own cloning company, Crestview Genetics.

The practice has fuelled concerns that it offers an unfair advantage to those with the funds to afford it, but the body that governs Argentinian polo is remarkably relaxed. It basically permits any breeding technique that elevates the level of play, cloning included.

Meanwhile, other sporting equines have been cloned, including thoroughbreds and jumping horses, and the relevant governing bodies all have their own rulings. There is, for example, no reason why a cloned horse couldn't compete in the Olympic Games, although this has yet to happen.

CLONING - THE STORY SO FAR

1952
There were clones before Dolly. Robert Briggs and Thomas King in Philadelphia, Pennsylvania clone frogs (*Rana pipiens*) using cells from tadpoles and adult intestine. They show that the DNA inside specialised cells can direct embryonic development.

1996
Scotland's Roslin Institute announces the birth of Dolly the sheep, the first mammal to be cloned from an adult cell.

1998
Japanese scientists clone eight calves using adult cells collected from abattoir entrails, raising speculation that high-end beef cattle could be cloned for the quality of their meat.

2002
The world's first cloned cat, CC (short for Copy Cat) confounds people because her coat is a different colour to the original's. The effect is caused by environmental differences in the surrogate's womb.

2003
Spanish scientists use frozen cells from the world's last Pyrenean ibex, taken before she died, to create a clone. It dies soon after birth.

2003
Prometea, the first cloned horse, is born. Commercial equine cloning follows and clones are used in sports, such as polo and rodeo.

Four of the six clones of the star polo pony Cuartetera, produced by Crestview Genetics

ALAMY X2, ALAN MEEKER, GETTY IMAGES X3

But no one knows just how identical or otherwise these clones will really be. Every living thing is subject to the same interacting forces of genetics and the environment or 'nature and nurture.' So, although clones may have the same nuclear DNA as the animal they're derived from, this isn't enough to guarantee an exact replica. Some characteristics, such as muscle mass, are more heritable than others, such as personality. The environment that an animal is raised in, before and after birth, can affect the activity of key genes with dramatic repercussions. This is why some of Cuartetera's clones have different markings, why some cloned sniffer dogs never graduate from training and why cloned pets will never 'be' the same as the original. Just like identical human twins, cloned non-human animals may be similar, but they'll never be truly identical to each another. SF

> "There is no reason why a cloned horse couldn't compete in the Olympics"

by **DR HELEN PILCHER**
Helen is author of Life Changing: How Humans Are Altering Life On Earth *(£16.99, Bloomsbury).*

2004
Genetic Savings & Clone becomes one of the first companies to offer commercial pet cloning, despite the fact that dogs have yet to be cloned.

2005
The first dog is cloned – an Afghan called Snuppy (for Seoul National University puppy, where it was made).

2009
Seven clones of an elite drug-detection dog are produced in South Korea. One breaks its leg, but the others complete their training successfully and go off to work.

2015
A Japanese cancer-detection dog is cloned. It excels at sniffing out colorectal cancers, just like the original.

2018
Monkeys are cloned. It's hoped primate cloning will offer insights into human diseases, such as Alzheimer's.

2020
A newly born clone of the endangered Przewalski's horse raises hopes that cloning could be used in conservation.

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Virtual reality creates a safe environment for therapy patients to experience, and learn to deal with, situations that would cause them anxiety in real life

JOSEPH EDDINS/US AIR FORCE

MIND GAMES

Virtual reality is being used to treat a wide range of mental health problems. Meet some of the scientists who are pioneering VR therapy and the people who are benefitting from it

WORDS **DR LUCY MADDOX**

Do you ever have days when you can't seem to do anything right? Days when you're fed up with yourself? Days when you berate yourself for things you've said or done with the sort of angry monologue that you wouldn't subject a friend to? From time to time, we all do. But while it's common to sometimes struggle to be kind to ourselves, for some people, especially those with depression, relentlessly picking at their own worst traits can become an endless cycle of self-bullying.

Therapy seeks to break that cycle through various approaches and one of the newest involves virtual reality (VR). At University College London, Prof John King and Dr Emma Jayne Kilford are working on a VR intervention to use as an adjunct to face-to-face therapy for depression. They hope the new therapeutic angle VR provides can help people increase their ability for self-compassion.

Their system uses a virtual room in which there are two avatars: a child and an adult. Before participants enter the room, they're trained in how to use a compassionate script to lift the mood of someone who's distressed. There are three parts to the script: validating experience, redirecting attention and activating a positive memory. As the participant enters the virtual room they're confronted with the distressed virtual child and their task is to comfort the child using the script until its distress lessens. The next time the participant enters the room, they're the child and they get to see their adult avatar (themselves from the previous session) performing the compassionate script. "They sit there as a child," explains King, "and they literally have the experience of compassion. It's a form of very souped-up imagery." The adult avatar can even be made to look like the participant, although not all of them opt for this.

Initial results in one sample of self-critical students and another of people experiencing depression show significant reductions in measures of self-criticism and depression, as well as improvements in self-compassion. A larger trial has begun, with hopes that the intervention will become an option for people undergoing treatment for depression.

> "For simple phobias where someone has one predominant fear, VR can be used to expose the person to that fear gradually and safely"

FACE YOUR FEARS, VIRTUALLY

This is just one of many VR interventions for mental health problems that are currently in development or already in the clinic. VR in mental health treatment has been around since the mid-1990s, but recent advances in headset capabilities and reductions in cost have made it more feasible and accessible, and research in VR-assisted therapy is booming.

The most-established use of VR-assisted therapy is for anxiety disorders. For simple phobias where someone has one predominant fear, VR can be used to expose the person to that fear gradually and safely.

"I was plagued with a fear of heights for years," says Judith Keeling, who heard about a research trial into VR therapy for height phobia in her hometown of Oxford and decided to try it. "I was intrigued, but dubious."

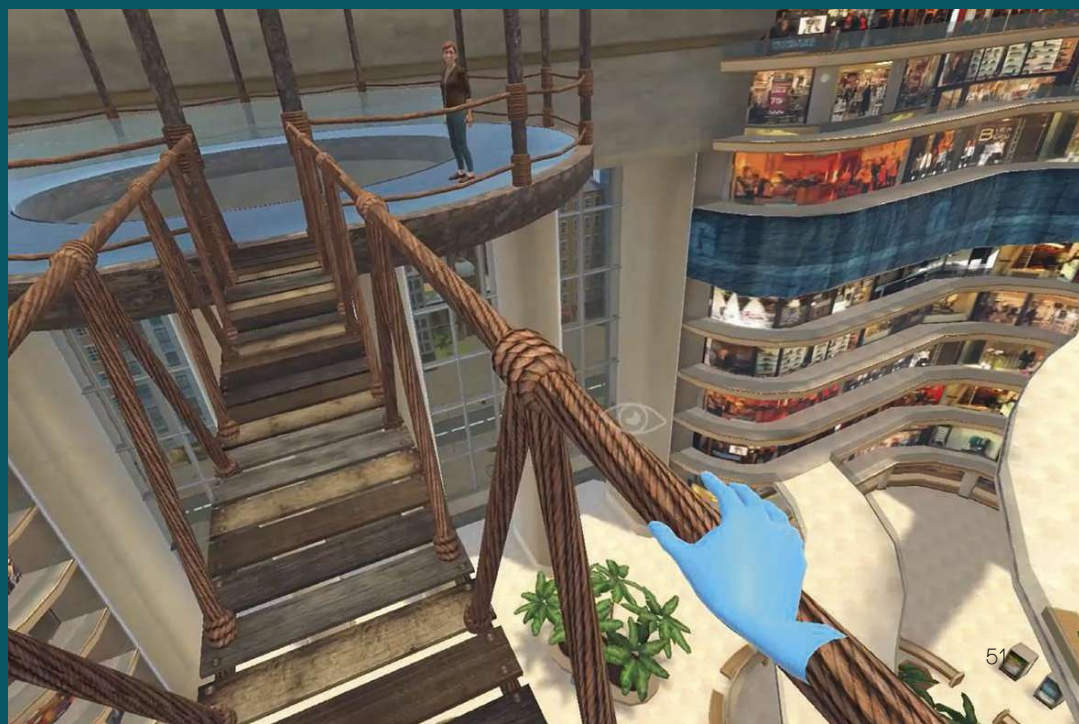
Judith remembers the experience: "You put the [headset] on and you find yourself in the atrium of a shopping mall. You can choose what floor you start at, then you go to that floor

GETTY IMAGES, UCL X2

ABOVE A therapist guides a patient through a VR experience

LEFT Avatars can be made to resemble the person receiving VR therapy

RIGHT A VR environment is a safe way to help someone find ways of dealing with a fear of heights



ABOVE The Bravemind VR package has been specifically developed to treat US soldiers suffering with PTSD after serving in Afghanistan

RIGHT A VR pub allows people with social anxieties and paranoid thoughts to experiment with coping strategies in a safe environment

in a lift. [The doors open, you walk out] and there's a glass barrier between you and the drop, as if you're looking down into the atrium. And then the barrier is removed. I jumped back when that happened."

Even though Judith knew it wasn't real and she found the VR setting somewhat cartoony, she still felt as if she was up high. For Daniel Freeman, a professor of clinical psychology at the University of Oxford, that's no surprise. "Whatever the computer shows you, that's your reality… The beautiful bit of the therapy is that there's also a conscious bit of your brain saying it's not real, therefore I can try things differently. It doesn't break the spell; it just enables you to make the learning."

In this intervention, people complete increasingly tricky tasks on each floor until they reach the top floor, where there's a wobbly bridge to walk across, which they can see through. If they accomplish that, they get to ride on the back of a surreal blue whale that's been floating around inside the shopping mall. "It feels unreal," says Judith. "So although I was uncertain, I could make myself do it."

After three sessions Judith wasn't sure whether the treatment had done much, but she noticed the difference when she went on a once-in-a-lifetime family holiday. "I was at Angkor Wat, in Cambodia, where there are a lot of rickety outdoor ladders and I was walking up and down them without any problems."

IMMERSIVE THERAPY

Freeman sees a key role for VR in automating some aspects of therapy to improve access. "There are some very powerful psychological therapies, but far too few people get them," he says. Freeman also thinks VR therapy can be more powerful than traditional therapy. "You can do things you can't do in face-to-face therapy… The ultimate aim is using the tech not just to replicate successful therapies… but to push them even further."

One example of pushing the therapy further is in the treatment of post-traumatic stress disorder (PTSD). PTSD involves a trio of symptoms: hyperarousal (feeling extra anxious to threat), avoidance (not wanting to think or talk about traumatic memories) and re-experiencing symptoms, such as intrusive images, nightmares or flashbacks. PTSD is common in war veterans and a VR package called Bravemind has been designed specifically for soldiers who served in Afghanistan by Dr Albert 'Skip' Rizzo at the University of Southern California. "We use the best technology to train soldiers for war; we should use the best technology to fix the… mess afterwards," he says.

Bravemind simulates war situations using 14 customisable virtual worlds. A therapist controls what happens, tailoring content to the memories of the person reliving the trauma, allowing those memories to be processed and the re-experiencing of symptoms to resolve. The principles are identical to traditional cognitive behavioural therapy for PTSD, so the treatment still needs a therapist but the imagery is more immersive. "It's a real-time clinical tool," says Rizzo. "Technology doesn't fix anyone; it extends the skills of a well-trained clinician."

"You can do things [in VR] that you can't do in face-to-face therapy… The ultimate aim is using the tech to push the therapies even further"

When Bravemind is used in conjunction with a trained therapist, its results are equivalent to, or better than, traditional therapy. A small fMRI study showed changes in the brain areas associated with PTSD too.

A SAFE ENVIRONMENT

It's not only depression and anxiety that can benefit from VR therapy. At the Institute of Psychiatry, Psychology & Neuroscience (IOPPN) at King's College London, Dr Lucia Valmaggia and her colleagues are working with individuals who experience psychosis, which is characterised by a loss of contact with reality that often involves hearing or seeing things that others can't, strong feelings of paranoia or delusional thoughts. VR can simulate situations where paranoia might be problematic.

"We use the VR as a first experience of something," Valmaggia explains. "For example, someone walks into a VR pub and the first thing they do is tense up when someone says hello. You see if they're aware or not that they're doing it. You teach them to breathe, to become aware of their jaw, to do all of that. And then they try it. Not straightaway in a real pub, but in a VR situation around other people.

"The person experiencing it knows that it's not real so they'll try to do more things and they're more able to get new experiences and physiologically new responses," she says. "It's a trick to have experimental control in an ecologically valid environment and, at the same time, [for] the person experiencing it to be able to try something new."

Jemma* has tried the intervention. Diagnosed with psychosis in 2019, Jemma has a background in video game experience design and her psychotic experiences left her feeling convinced that she was living inside a game. As these beliefs subsided, Jemma found she became uneasy in

BRAVEMIND, KINGS COLLEGE LONDON *Jemma has requested that only her first name be used.

RIGHT A smartphone and a few carefully shaped pieces of cardboard can be combined to bring VR technology to a much broader range of people

TECH IN THERAPY: WHAT'S ON THE HORIZON

APPLICATIONS

Most adults have a smartphone now and apps are easily accessible. There's a wide range of psychology apps with variable evidence-bases behind them. One highly evidence-based blended therapy for psychosis is the SlowMo programme (pictured right) from the Institute of Psychiatry, Psychology & Neuroscience, which uses a combination of face-to-face therapy and an app co-designed by clinicians, app developers and people with psychosis, to help people see their thoughts as separate from them and more controllable. The app allows people to visualise thoughts and manipulate their size, shape and colour, or replace them with more helpful ones that their therapist helps to generate. Initial studies have been encouraging and the results of a large clinical trial are imminent.

AUGMENTED REALITY

If you've played *Pokemon Go!* then you've used augmented reality (AR) – the overlaying of virtual images onto a real background, through the screen of your smartphone. At the Moffitt Cancer Center in Florida, AR is being used to help people practise tolerating cravings for substances that they're trying to give up. For example, a virtual ashtray and cigarette can sit on the arm of your actual sofa so you can practise tolerating the craving without the risk that you'll smoke a cigarette.

DIGITAL THERAPY WORKBOOKS

Digital therapy has been researched in different ways for many years now, including computer programs that don't require a therapist or digital workbooks that a patient can work through between phone sessions with a therapist. The blended options tend to have better results, which have been impressive for a range of problems, including post-traumatic stress disorder and social anxiety.

VIDEO CALLING

Video calling has become so ubiquitous during the COVID-19 pandemic that this hardly feels like a new technology. But although it's been around for a while, it has taken off dramatically in the wake of lockdown and social distancing. Research suggests that it's similar in efficacy to face-to-face therapy and offers another option to it, as long as people have a suitable Wi-Fi connection and the ability to be somewhere quiet and private, which should never be taken for granted.

social situations and was uncomfortable being seen by others.

"I had a visceral reaction to [the VR therapy]. It was kind of amazing," says Jemma, who froze as she went into the virtual pub, due to feeling intense fear. "I just totally shut down and couldn't say anything… There's no hiding from it… It's very honest and transparent."

With practice and therapeutic support, Jemma overcame her fear and became more comfortable and confident. She was also recommended a relaxation programme available on YouTube (**bit.ly/dolphins_swim**) that lets her swim with dolphins in a virtual sea by using a cardboard VR headset into which she slots her mobile phone. "It's very relaxing," she says.

COMING TO A CLINIC NEAR YOU?

VR therapy is not without its challenges. While the headsets are vastly cheaper than they once were, accessibility still depends on clinics being able to purchase them for patient use. There's also a strong need to understand the ethical complexities around digital security to ensure sensitive data can't be harvested. "I do see that as being a critical issue," cautions Kilford. "The tech always moves so much faster than the regulatory body."

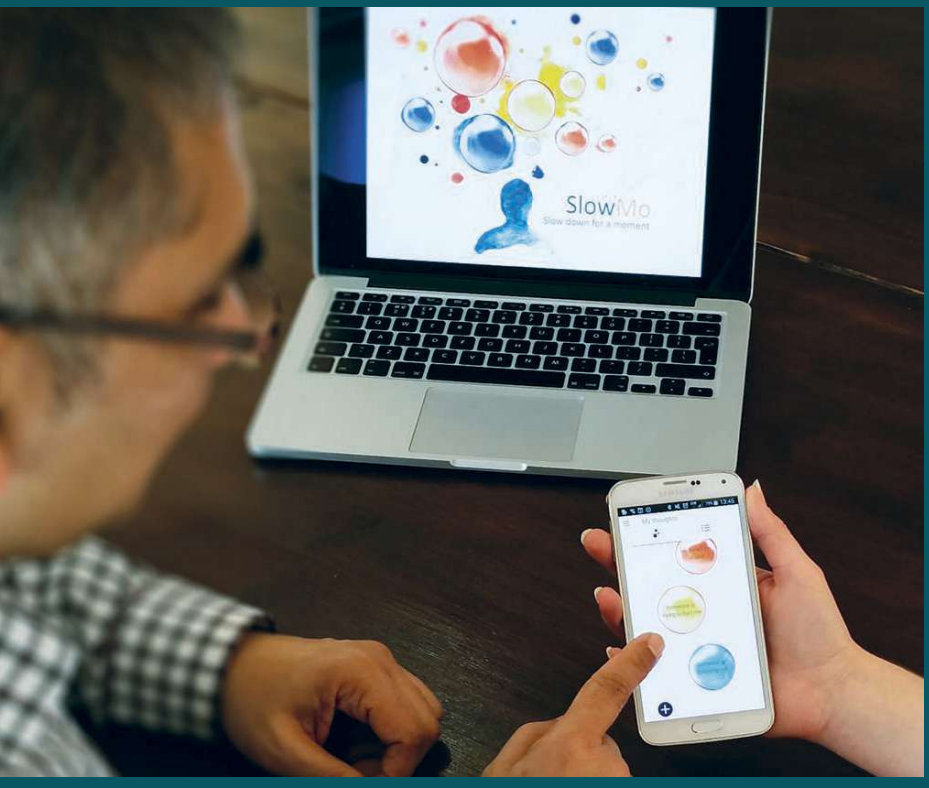
The inevitable lag between technological progress and good-quality research means studies can be out of sync with the technology by the time they're completed. Plus, VR only works for certain types of talking therapy (usually those belonging to cognitive behavioural schools).

> "Headsets in the home will be like toasters. You know, you don't use it everyday, but every home has one"

Nevertheless, the tech and research advances mean VR therapy is finally coming of age. Rizzo thinks we're not far off the day when "headsets in the home will be like toasters. You know, you don't use it everyday, but every home has one… It'll get to a point where every clinician has a VR headset in their drawer and they'll have had some training [on how to incorporate its use into therapy] at some point." Rizzo also thinks 5G will help clinicians access VR interventions.

The variety of VR-assisted therapies being researched covers a huge range of disorders and settings. There are VR kitchens to help people with eating disorders, relaxation programmes for people in inpatient care, and programmes for schoolchildren to help them handle their assumptions of what others think of them (especially helpful for children who've been bullied or had experiences that can affect future relationships). Whatever you can imagine a use of VR for, it can be programmed.

VR therapy won't replace human therapists, but it's a powerful adjunct and access to it is going to grow. VR therapy for fear of heights is already available in a number of UK NHS Improving Access to Psychological Therapy clinics, and several of the VR research trials are available in NHS Trusts too. As VR therapy grows, it'll be key that the programmes we choose are ones with established efficacy, and are co-designed by clinicians and people with experience of mental health problems. And there is no shortage of those to choose from. **SF**



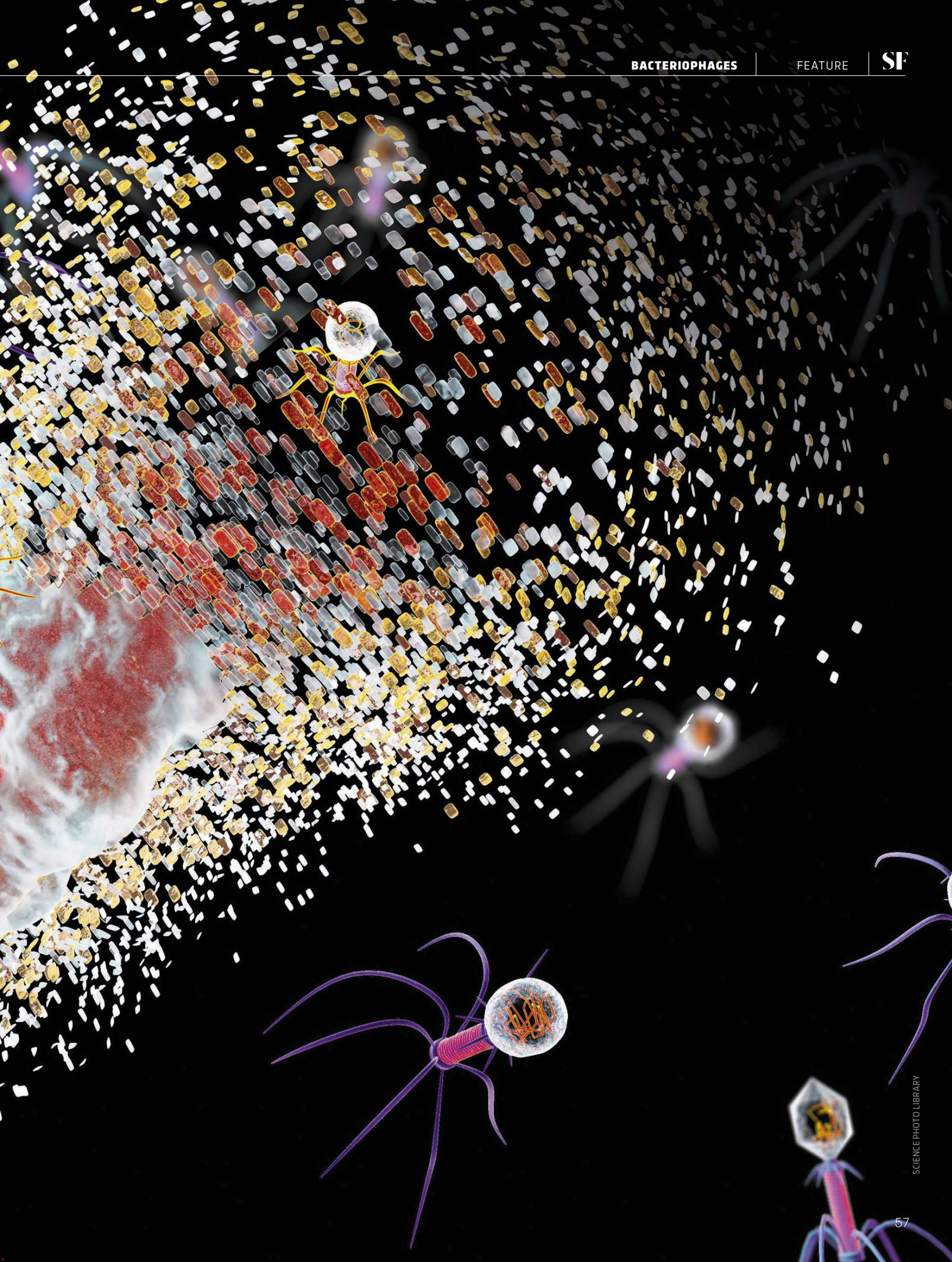
GETTY IMAGES

by **DR LUCY MADDOX**
Lucy is a consultant clinical psychologist and the author of What Is Mental Health? *and* Blueprint: How Our Childhood Makes Us Who We Are.

With the medical world struggling to treat antibiotic-resistant infections, could scientists turn to a group of viruses that explode bacterial cells from within?

WORDS **TOM IRELAND**

MEET THE BACTERIA KILLERS



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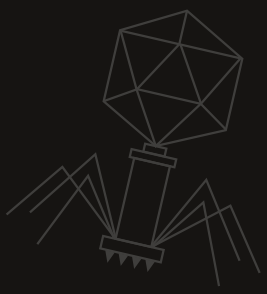

Trials of an exciting new way of treating dangerous drug-resistant infections will start to report results in 2021. These treatments involve patients being injected with billions of virus particles that specifically infect and kill bacteria.

Such viruses – known as bacteriophages (or just 'phages') – are found everywhere there are bacteria and replicate by inserting their genes into bacterial cells. Once infected with the virus genes, the bacterial cell goes awry and starts producing viral proteins, which assemble into new viruses. Within as little as half an hour, the cell bursts and tens or hundreds of new viruses are released to repeat the cycle in another host. They're remarkably effective at this: some studies suggest that for every grain of sand on Earth there are over a trillion phages in existence at any one time.

Given their natural bacteria-killing abilities, these nanoscopic predators could be key in the fight against the growing problem of antimicrobial resistance. And the idea of using them in medicine isn't really new at all.

Over 100 years ago, in 1919, an eccentric scientist called Félix d'Hérelle breezed into a children's hospital in Paris and told doctors that he had found a way to treat dysentery (an infection of the intestines). This was decades before antibiotics such as penicillin were available, when common bacterial infections killed millions of people a year.

While studying colonies of bacteria, d'Hérelle realised that some kind of disease was spreading through his bacterial plates. Although barely anything was known about viruses at the time, d'Hérelle came to the extraordinary conclusion that he had found a virus that preyed on bacteria, not humans – a microbe of a microbe. He named the virus a bacteriophage ('bacteria-eater') and began using it to kill off bacterial infections in animals.

This was long before the existence of regulators like the Federal Drug Administration (FDA) in the US or the Medicines and Healthcare products Regulatory Agency (MHRA) in the UK, who rigorously test new drugs and therapies before they're approved for use in patients. So to prove his experimental treatment was safe to use on children with dysentery, d'Hérelle simply drank a vial of the phages in front of the hospital doctors. The doctors agreed that if he was alive the next day, they'd try the treatment at the hospital.

The next day, d'Hérelle was fine (he'd already tested the phages on himself and his family). When several desperately ill children arrived suffering from dysentery, they were each given a vial of the pure bacterial viruses to drink. The treatment was a success. The children quickly recovered and left hospital within days. His phages were soon being touted as the latest wonder drug and by the 1930s were being shipped around the world to treat all manner of different bacterial infections.

ABOVE LEFT The Franco-Canadian microbiologist Félix d'Hérelle is one of the scientists credited with discovering viruses that feed on bacteria

ABOVE RIGHT A bacteriophage infects an *E. coli* cell

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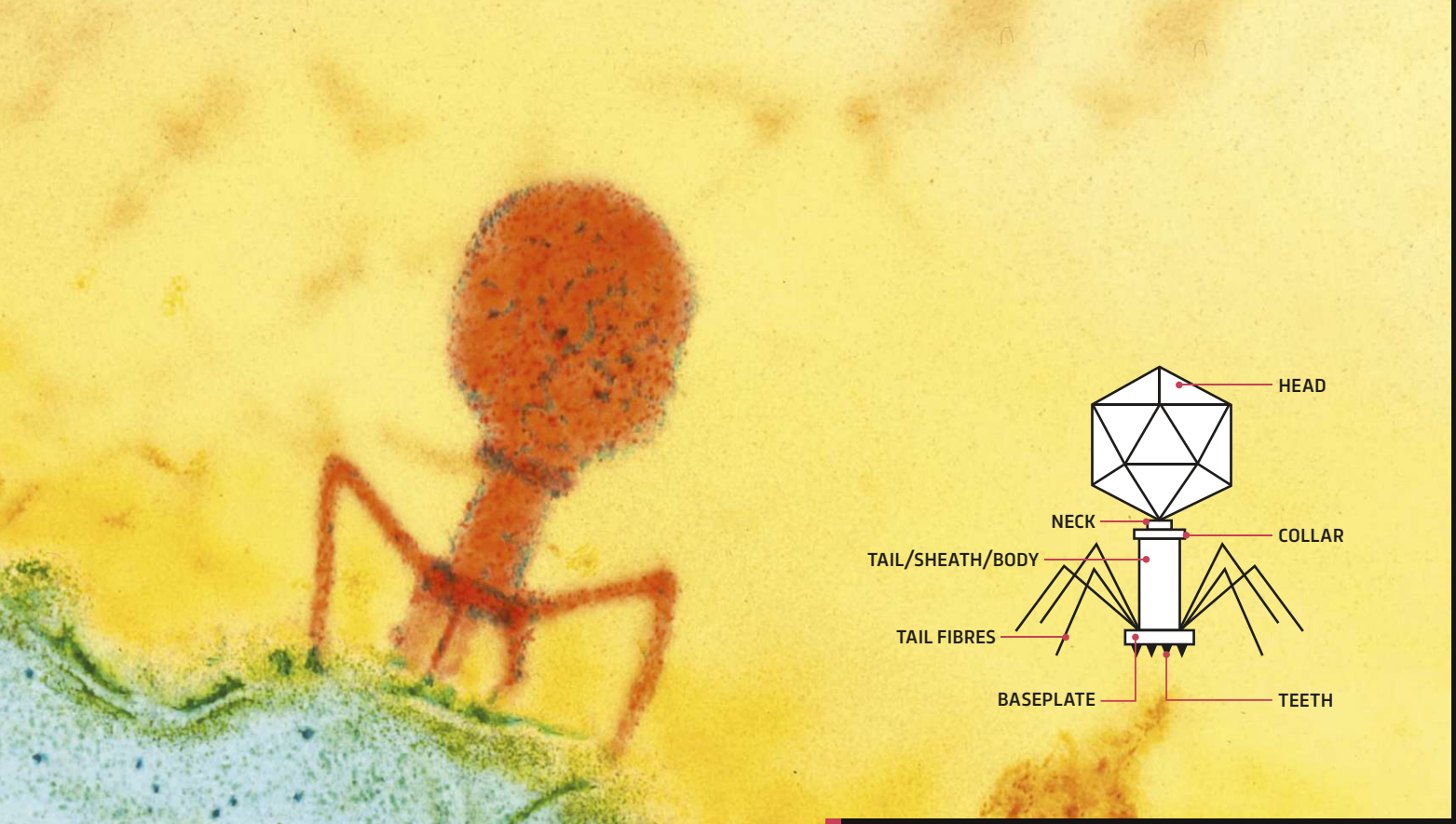
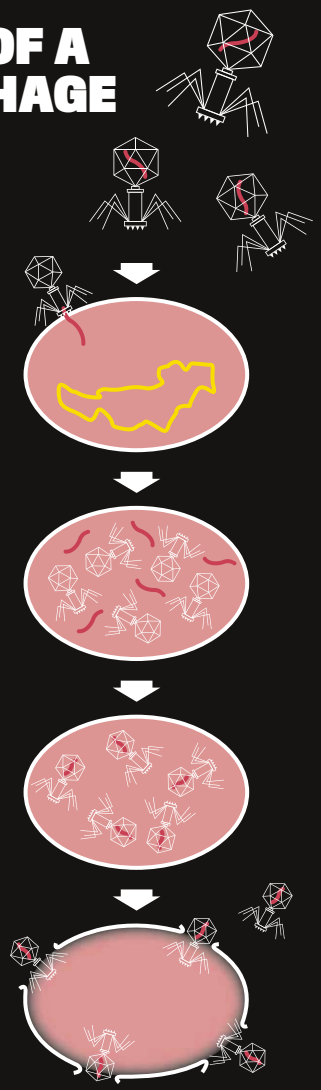
THE FORGOTTEN TREATMENT

How come then, in 2020, so few people have heard of phage therapy? And why, given that the world is so desperate for new antibiotics, are we not using it in hospitals all the time? It's a long story, but by the 1950s the Western world had largely forgotten ▶



"SOME STUDIES SUGGEST THAT FOR EVERY GRAIN OF SAND ON EARTH THERE ARE OVER A TRILLION PHAGES"

LIFE CYCLE OF A BACTERIOPHAGE



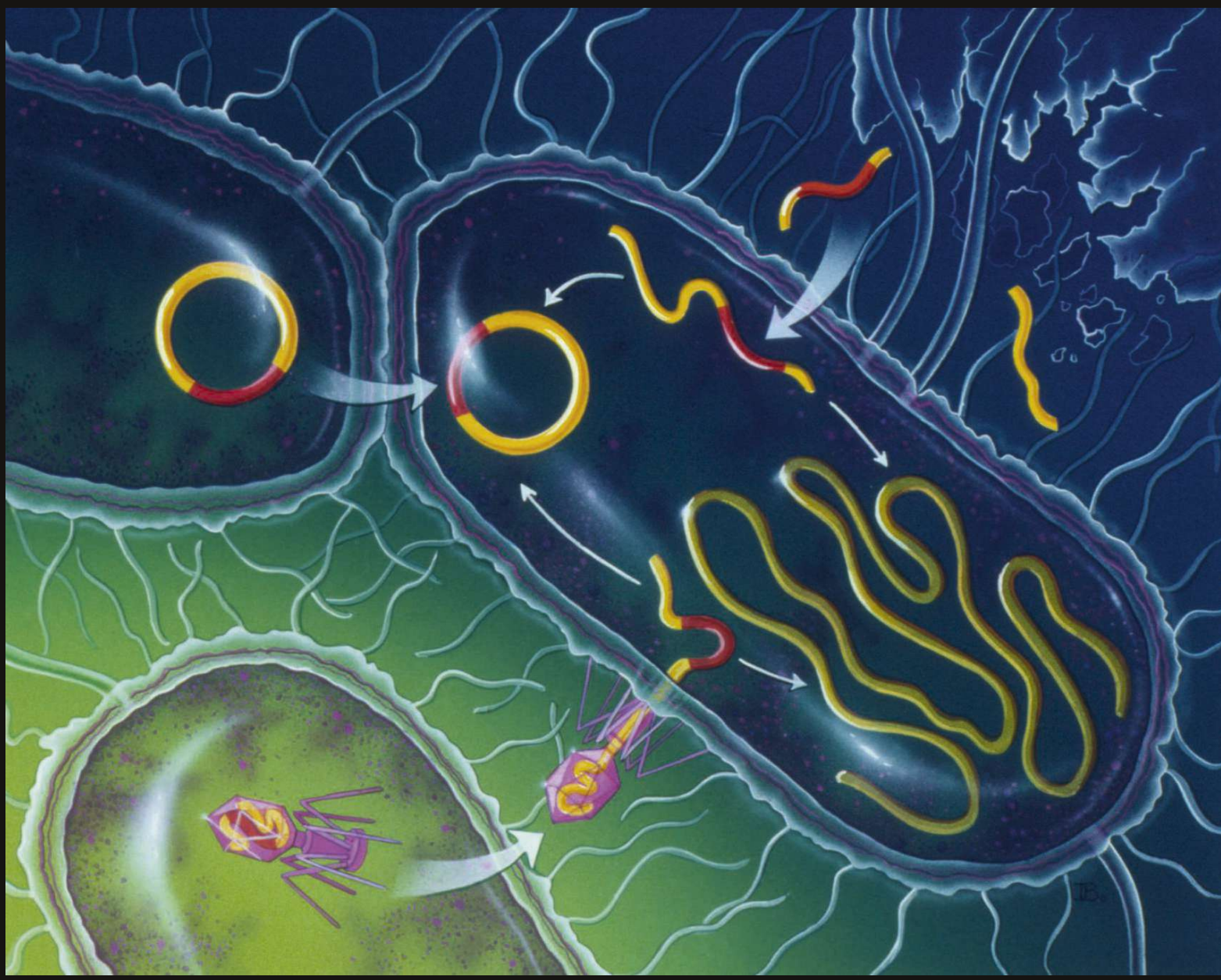
1 Free-floating phages drift around in the environment, hoping to encounter a bacterial host.

2 Once the phage binds to a suitable host, it injects its genetic material into the cell.

3 If the phage's genetic material evades the cell's defences, the cell will start manufacturing the proteins encoded in the virus genome.

4 This causes a build-up of viral proteins inside the cell, which assemble into hundreds of new bacteriophages.

5 The phage eventually instructs the cell to produce a protein that bursts it open. The bacterium is dead and the new phages are released to repeat the cycle in another host cell.



A HISTORY OF PHAGE THERAPY

1917
Félix d'Hérelle controversially declares he has found a bacteria-eating virus – a bacteriophage. Others claim an English scientist, Frederick Twort, observed the same phenomena two years earlier.

1919
Félix d'Hérelle (below) uses phages to treat children with dysentery in a Paris hospital.

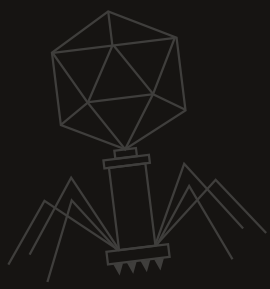
1920s-40s
Phages are shipped around the world to treat infections. Huge trials to test if they work are chaotic and poorly devised, and drug companies begin selling mixtures of phages for diseases that they couldn't possibly cure.

1940s
Penicillin and other chemical antibiotics become commercially available. Doctors prefer to use these cheaper and more reliable treatments for infections.

1950s
Phages are used as tools in molecular biology (above), but their use in medicine is largely abandoned.

1950-1990
Shortages of antibiotics in areas of the USSR means phage therapy continues behind the 'Iron Curtain'.

"DRUGS, SUCH AS PENICILLIN, HAD COME ON THE MARKET, AND WERE FAR CHEAPER AND EASIER TO MASS PRODUCE THAN LIVE VIRUSES"



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all about phages. Drugs such as penicillin had come onto the market, and were far cheaper and easier to mass produce than live viruses. In most parts of the world, medical research focused on developing new classes of antibiotics and the idea of using viruses to treat infections was gradually abandoned.

The only countries that still used phages to treat infections were Soviet countries, where there was a shortage of drugs like penicillin. But the Cold War prevented any communication between Soviet scientists and the rest of the world, so their improvements in using phages went unnoticed. By the 1980s, Western medicine had almost entirely forgotten phage therapy had ever existed.

Now, as drug-resistant bacteria becomes a bigger and bigger problem in hospitals around the world, the idea of using viruses is attracting attention once again. Desperate patients in the US and Europe now travel to 'phage clinics' in former Soviet countries, such as Georgia, to try and cure infections that are no longer treatable with antibiotics.

Despite the renewed interest, outside these regions phage therapy has only been used successfully in a few experimental cases. In 2015, scientist Tom Patterson fell ill with pancreatitis while on holiday in Egypt. The cause turned out to be a multiple-drug-resistant strain of bacteria. With doctors unable to control the infection, Tom quickly fell into a coma. Almost a year of conventional treatments failed, but as a last resort, Tom's wife Steffanie Strathdee, an HIV researcher, decided to do her own research and stumbled upon the idea of using phages to kill the bacteria that was killing her husband.

LEFT An artist's impression of a bacteriophage infecting a bacterial cell with its genetic material

She spent months trying to connect Tom's doctors with scientists all over the world who might be able to source the right phages to control the infection (as well as completing the piles of paperwork required to gain legal approval for a treatment that doctors effectively had to make up as they went along). Thanks to injections of an experimental cocktail of phages – sourced from Russia, the US Navy and raw sewage – Tom was eventually brought back from the brink of death.

TAILORED COMBINATIONS

Phages are not easy to work with. Every different strain of bacteria – of which there are millions – has a particular strain of phage that preys on it. So every patient needs to be treated with exactly the right strain of phage for the bacteria causing their infection.

The body also removes phages from the bloodstream quickly and, just like antibiotic drugs, bacteria can quickly develop a resistance to them. This is why a combination of phages often must be used to ensure that any bacteria with resistance to one phage are killed by another.

1990s
The break-up of the USSR allows communication between Soviet scientists and the West for the first time in decades, just as the World Health Organization was addressing the problem of antibiotic resistance.

2000s
Americans and Europeans begin to travel to Eastern Europe to receive phage therapy.

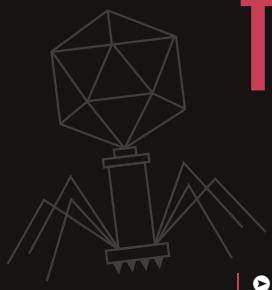
2015
Steffanie Strathdee uses phage therapy in the US to cure her husband Tom Patterson (below).

2018
A cocktail of three genetically engineered phages are used to treat a teenage patient in the UK who had contracted a life-threatening infection after a double lung transplant.

2020
Clinical trials of new phage therapies begin.

2021-22
Clinical trials of new phage therapies expected to conclude. If the results are positive enough and application can be made to regulatory bodies for the treatment to become a medical practice.

"SEVERAL CLINICAL TRIALS ARE UNDERWAY THAT HOPE TO PROVE THAT PHAGES CAN BE A RELIABLE METHOD OF TREATING INFECTIONS"



RIGHT At a Naval medical research unit in Texas, Dr Yoon Hwang checks on the development of genetically modified bacteriophages being developed to treat gum infections

BELOW RIGHT A bespoke cocktail of phages is formulated to treat each specific infection

This adds to the complexity of developing a treatment regime. There's also the fact that up to half of all phages are what are known as 'temperate phages'. These viruses don't always burst the bacterial cell open and kill it. Instead, they prefer to lie dormant in the cell's genome or replicate slowly without killing their host. Scientists can get around this by genetically altering phages so that they use the more violent 'bursting' strategy, rather than lurking.

In 2018, at London's Great Ormond Street Hospital, a cocktail of three genetically engineered phages were used to treat a young patient who had suffered from breakouts of multiple-drug-resistant infections throughout her body for years. The teenage patient had undergone a double lung transplant due to cystic fibrosis, a condition that causes a build-up of mucus in the lungs. Soon after the procedure, despite several courses of antibiotics, infections spread from her lungs to her liver and, eventually, there were even pockets of bacteria pushing up through the skin on her arms, legs and buttocks.

Again, the development of a phage-based treatment required an international collaboration of doctors and phage researchers to find, purify and engineer the right phages for the particular strain of bacteria in the patient – as well as the laborious bureaucratic hurdles required to give an entirely new and unregulated medical treatment to a child. But it was a success – the treatment brought the infection under control and saved the girl's life.

PHAGE LIBRARIES

These success stories have helped accelerate efforts to develop phage therapy in the US and Europe, with similar good news from experimental treatments and trials in animals in other countries. Yet despite these positive examples, there are still major obstacles to phage therapies becoming cost-effective and reliable mainstream treatments.

The main obstacle is that every patient is likely to be infected with a unique mix of bacterial strains, so every treatment must be bespoke. This means drug manufacturers can't mass-produce doses and it has also made it impossible for drug regulators to approve phage therapies: every case is likely to involve a completely different mix of viruses.

Thankfully, collaborative efforts between researchers, public health bodies and regulators are helping to overcome these hurdles. The idea is that by using modern DNA-sequencing technology, enormous libraries of phages could be quickly scanned to find a suitable match. Matches could then also be screened to ensure they don't contain any genes that might cause toxicity in the patient.

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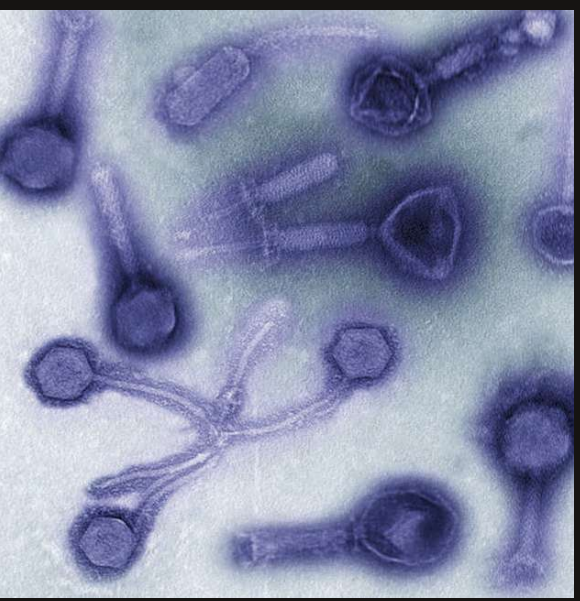

Drug regulators would assess the safety of the library as a whole, the methods of purifying the phages and the method of administration, rather than trying to assess every individual treatment. When a patient had a drug-resistant infection, information on the exact strain of bacteria would be sent to a phage library, which would be scanned for suitable matches. The matches would then be sent out in a vial to the hospital where the patient was being treated. With this method, a lifesaving and bespoke cocktail of viruses could be produced in a matter of days.

That's the plan, at least. Several clinical trials are underway that hope to prove, once and for all, that phages can be a reliable method of treating infections, and the collaborative efforts of authorities, scientists and doctors continue in the hope of setting up regulatory systems that can green-light bespoke phage therapies in a cost-effective way.

Hopefully none of us will ever face the terrifying prospect of an infection with bacteria that are resistant to conventional antibiotics. But if we do, it's good to know that these ancient bacterial killers can be called upon to help us out. SF

by TOM IRELAND
Tom is editor of The Biologist, *the magazine of the Royal Society of Biology.*

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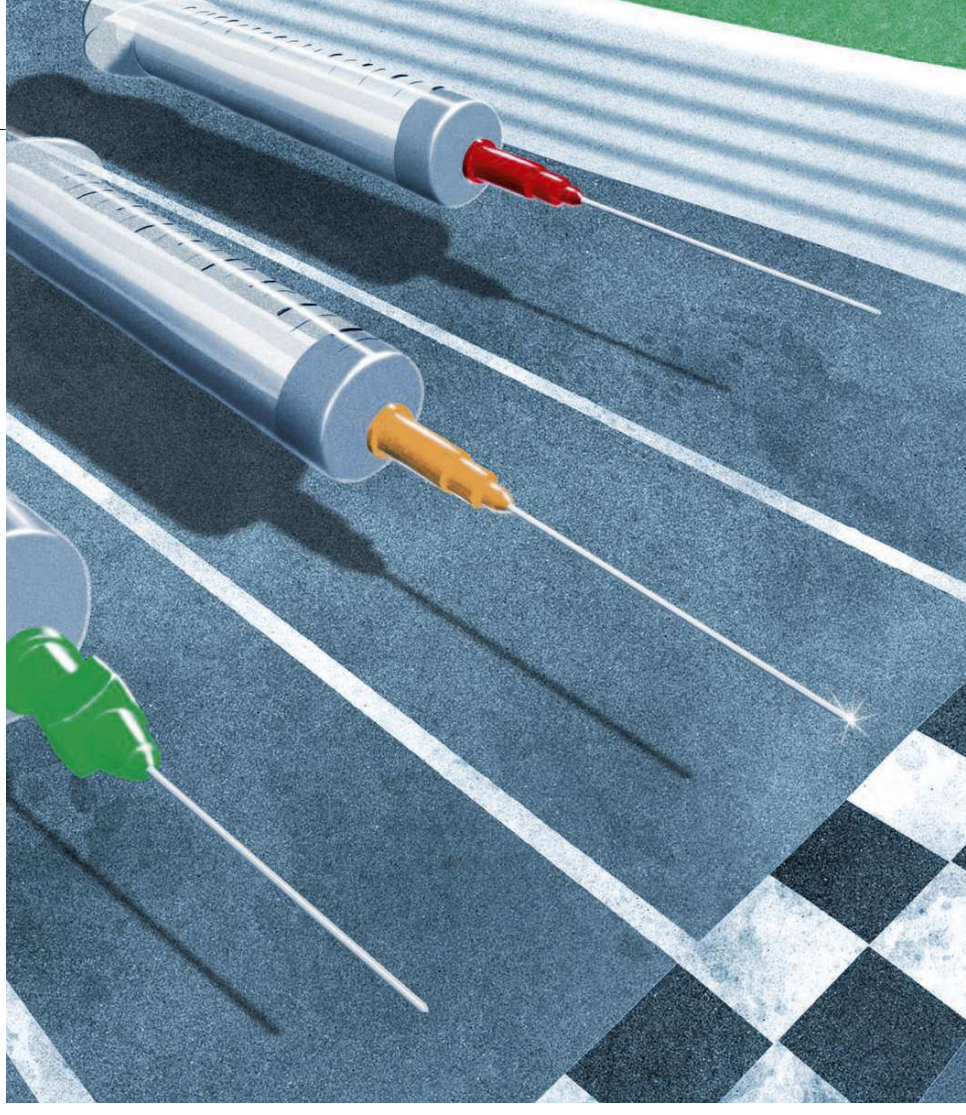
COMMENT

THE YEAR OF THE VACCINE

The race to protect us from COVID-19 has led to next-generation vaccinations



Just as 2020 was the year of COVID, I expect 2021 to be the year of the COVID vaccine, as the race to develop a vaccine has been truly extraordinary.

Last March, I was lucky enough to be making a *Horizon* programme all about COVID-19 when I managed to get an interview with Prof Robin Shattock, who heads the Department of Infectious Disease at Imperial College. When we spoke, he and his team were well underway developing their own novel COVID vaccine.

Shattock, unlike many other experts I spoke to at the time, was optimistic that a vaccine could be developed, tested and produced in quantity by the end of 2020.

More traditional vaccines involve growing whole viruses, and you make your vaccine from killed or weakened versions of them. But Shattock's vaccine is based on mRNA, the molecule that your cells use to create specific proteins. This is the same approach used by the Pfizer and Moderna vaccines.

The new vaccines are based on injecting mRNA that specifically produces the coronavirus's 'spikes', not the whole virus. The idea is that these spikes will provoke an immune response, in the same way the real virus would, but without the resultant infection.

Unlike the Pfizer and Moderna vaccines, the Imperial one is self-amplifying, meaning that it should go on provoking an immune response for longer. It also means we should need far less for a single dose and it could, potentially, be much less expensive.

"We think there's a very high scientific probability that the vaccine will work and go on working"

As Shattock said at the time, although he was concerned about potential side effects, he expected them to be less of a problem with this approach than with a standard vaccine. "Remember, we're not growing whole viruses and we're not using cells or animal material," he told me. "The vaccine is an extremely pure product. That's one of reasons we think the risk of side effects is very low."

Another concern some people have is that this novel coronavirus could mutate, like the flu and HIV, making the vaccine useless. Having worked for years on HIV vaccines, Shattock is well aware of the challenges. But, unlike AIDS, the virus that causes COVID-19 isn't mutating fast.

"There is never any guarantee that things will work, but we know that as a target this is much easier than some of the vaccines we've been trying to make because it's a relatively stable target to go after," he told me. "So we think there's a very high scientific probability that a vaccine will work and go on working."

He seems to have been right, on all counts, and though the Imperial vaccine has yet to complete full clinical trials, I expect that, like other COVID vaccines, it'll be available in 2021. By then we should have a range of vaccines to choose from and a brand new approach to vaccination, based on mRNA technology, which will transform this branch of medicine. **SF**

MICHAEL MOSLEY

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

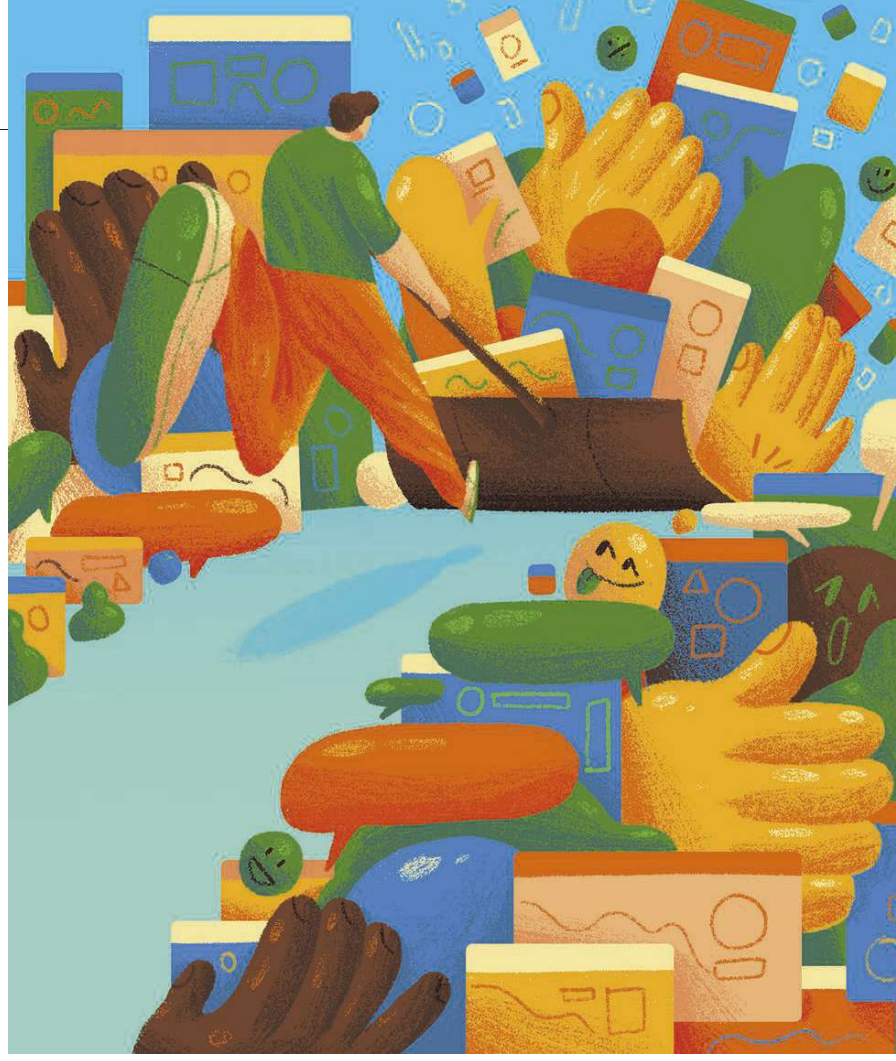
BBC TWO

PORTRAIT: KATE COPELAND ILLUSTRATION: JASON RAISH

COMMENT

GOODBYE CLICKBAIT, HELLO COMMUNITY

Algorithms have turned the online world into an echo chamber. Let's welcome back diversity, critical thinking and a sense of community



ALEKS KROTOSKI

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

BBC RADIO 4 92–95 FM & 198 LW

PORTRAIT: KATE COPELAND ILLUSTRATION: SCOTT BALMER

Since the Czech playwright Karel Čapek invented the word 'robot' 100 years ago, we've been anticipating machines taking over our lives. That's now happened.

Our functional lives are ruled by machines, whether it's the card readers we use to pay for our food or the microwaves we use to heat it. But after 2020's lockdowns, machines became the intermediaries in our emotional lives too – allowing us to see and speak to family, friends and colleagues via Zoom, FaceTime and similar apps.

Given the ubiquity of machines, it's no surprise there are concerns that our actions, and increasingly our thoughts, are at the mercy of algorithms. To avoid this we have to evolve our relationship with machines, and the next 12 months gives us a chance to do that in two important ways.

"First, we must develop ways to survive in the artificial emotional environment we're in. When we become conscious of the fact that we're part machine and part organic entity, we become aware that it's possible to be emotionally manipulated by a machine."

"Critical thinking is more robust than anything a computer can come up with"

That last paragraph was written by an artificial intelligence. AIs are evolving at such a rate that, with the click of a mouse, they can spin up 1,000 websites, a Facebook page and a YouTube channel, and populate them with videos and posts that justify and reinforce a message that someone wants you to believe. It could be about the health benefits of wearing masks, or it could be about QAnon.

It's our job to look at what we're consuming online and determine whether it's using our words to mimic us and spread misinformation. We have the tool to do this; we learned it at school. It's critical thinking and it's more robust than anything a computer can come up with.

The second way is to find and populate spaces that welcome a diversity of voices. Some believe the internet has made this harder – ironic, given its original intention. Yet such spaces are there to be found.

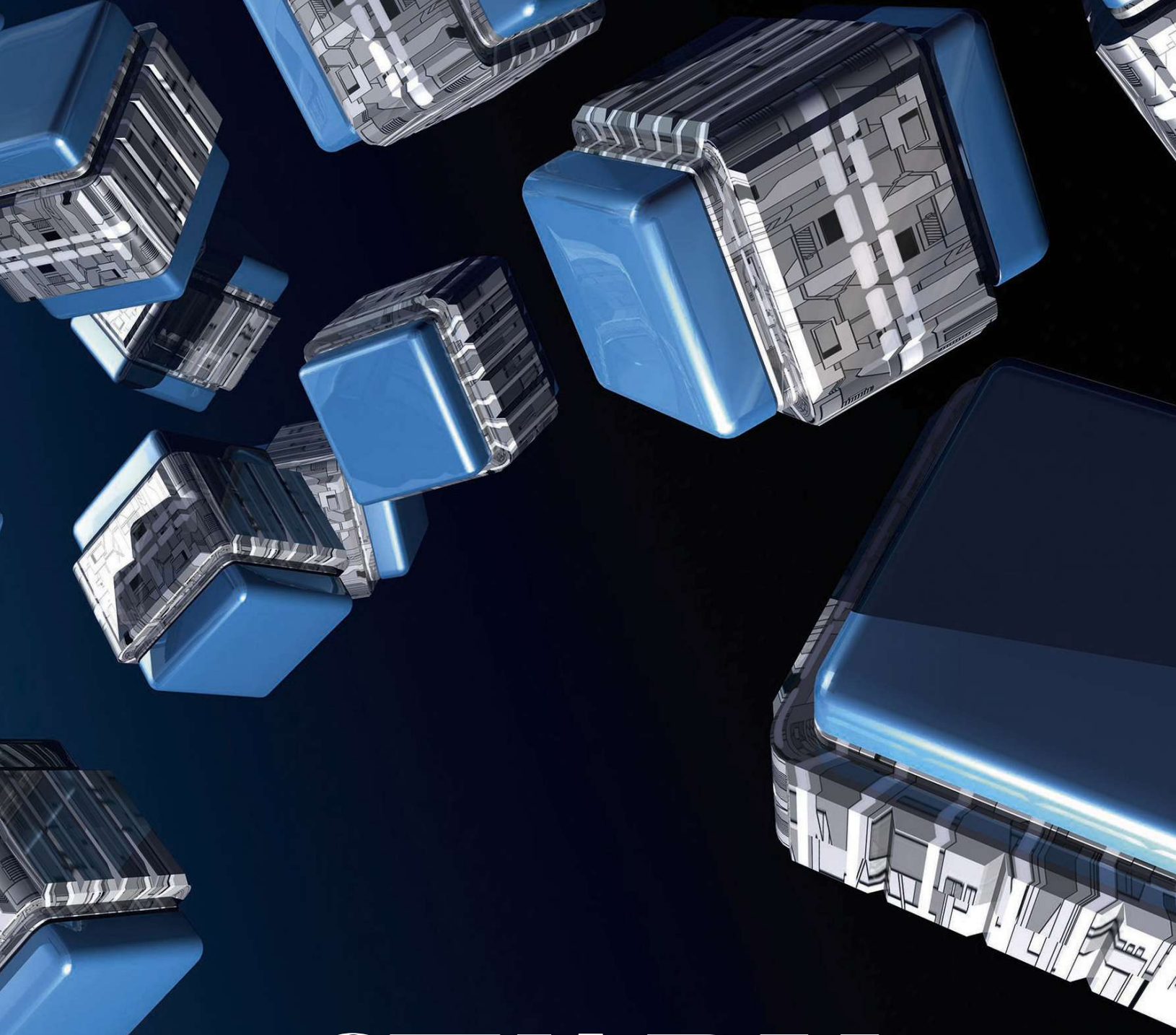
We live among intelligent technology that thinks it knows what we want and gives it to us. The outcome, as Eli Pariser wrote in his book *The Filter Bubble*, is the soma we need to fill our psychological happy places with stuff that confirms our beliefs instead of challenging them.

Too much of our technology builds walls, instead of bridges. Yet growing quietly are sites that have been designed to inspire visitors to leave their ideologies at the door. Not unlike parks, libraries or city streets, they encourage diversity because no one owns them, yet people want to be in them. Pariser's Civic Signals project (**civicsignals.org**) is one.

We need to give these projects the audiences they need. 2020 made the internet more mundane than ever. But 2021 gives us the chance to change that by taking responsibility for our digital future. **SF**

'Megaconstellations' of CubeSats could be deployed in Earth orbit to monitor the health of the planet. But scientists have even bigger plans for the tiny satellites

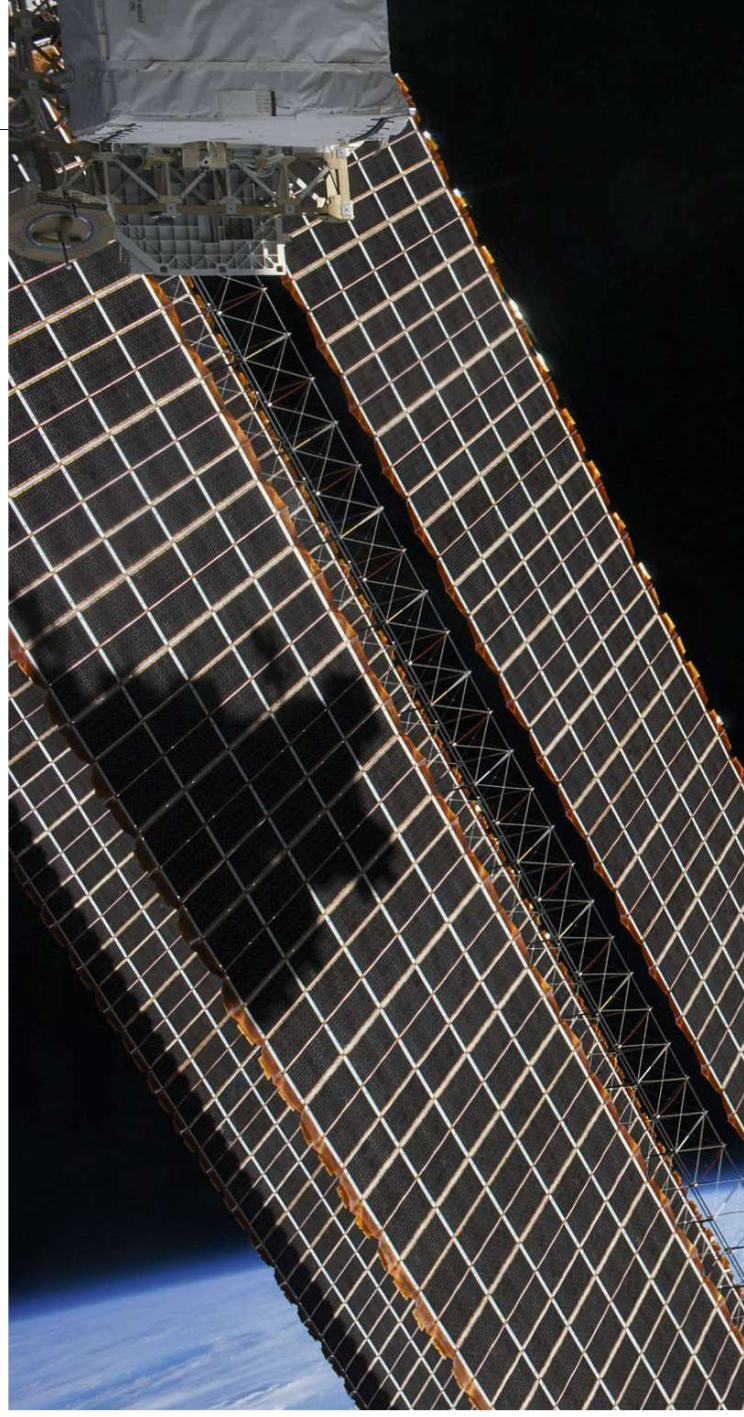
SCIENCE PHOTO LIBRARY



SWARM INTELLIGENCE

Small, simple, cheap satellites are being developed to explore and study space in new ways. If we deploy them in vast swarms, these 'CubeSats' could change the way we see and protect our planet

WORDS **DR STUART CLARK**



The roar of engines from the Rockot launch vehicle split the air as it lifted off from the Plesetsk Cosmodrome in northern Russia on 30 June 2003. The rocket was 30m tall and had been chartered by the German company Eurockot Launch Services. But instead of carrying one large satellite into orbit, the Rockot was carrying eight smaller ones.

At the time, no one paid it much attention. After all, it wasn't the launch of a flagship, billion-dollar mission. Yet in hindsight we can see that's exactly what made the launch so important – perhaps even a watershed in the way we use and explore space.

Some of the satellites lofted into orbit that day were tiny CubeSats, with dimensions of just 10 x 10 x 10cm. Made of standardised parts, CubeSats are relatively quick and simple to construct. When they were conceived in the late 1990s, they were thought of as educational tools to teach students the basics of how to build satellites. The idea was that the students would take the knowledge they gained on CubeSats and apply it to the large spacecraft of the traditional satellite industry. And while some did just that, others used their experience to take on an entirely different challenge: to use the miniature satellites for something more than just education.

"There are now some very smart people in Europe and around the world who have set themselves a challenge to miniaturise technology such that it can fit into a very small volume. People refer to it as thinking inside the box," says Roger Walker from the European Space Agency (ESA).

That kind of thinking is starting to pay off. The CubeSat standard is cheap and it's allowing many more missions to be developed than ever before. And as technology continues to shrink and new techniques are developed, more types of missions become possible – some of which were practically unimaginable until recently, such as satellite swarms.

Satellite swarms are dozens, hundreds or even thousands of tiny spacecraft all working together to do something that's impossible or impractical with traditional spacecraft. Swarms containing such huge quantities of CubeSats can be envisioned because each one is so cheap to build.

Scott Williams is a programme director at SRI International, who was involved in the early development of CubeSats. He remembers thinking: "Okay, how

NASA/JPL X2

The Nanoracks CubeSats Deployer has been in operation since 2014 and is one of two systems aboard the International Space Station capable of releasing CubeSats into Earth orbit

THE BIRTH OF CUBESATS

The first CubeSat was developed by Bob Twiggs of Stanford University and Jordi Puig-Suari of California Polytechnic State University in the 1990s. According to the story, they decided that a CubeSat should be just 10 x 10 x 10cm because sitting close by was a box for a Beanie Baby toy. Their goal was for a team of students to learn to construct a CubeSat that could transmit a radio signal like Russia's Sputnik 1, the first satellite launched into space in 1957. But others were thinking bigger.

Scott Williams, now a programme director at SRI International, was also developing smaller satellites with his colleague Victor Aguero. Both were at Stanford University, California, at the time. They'd witnessed the impact the microcomputer revolution had and could see the chance to do something similar for the aerospace industry.

"Victor and I both owned some of the early IBM PCs. We had lived through that disruptive technology event when we were in college. We had computers on our desktop that were unthinkable a mere few years earlier," says Williams. Indeed, Aguero would talk about space satellites being a disruptive technology for the aerospace business.

After completing their PhDs, Williams and Aguero went to work for SRI International, where Williams has been ever since, developing small satellites in general and CubeSats in particular.

By 2012, more than 120 small satellites had been launched. Over the next two years, however, that figure more than doubled. Now, the tally now runs at around 500 a year, although most of these are Starlink satellites. The figure is only set to rise in the future.

many can we fly? What can we do with them? If we can get lots of measurement points in space, don't we create a similar, or perhaps in some ways better, capability than a single, exquisite measurement from a trillion-dollar satellite?"

Williams realised that for many applications, the answer was a resounding yes. But how do you control a swarm of, say, 1,000 CubeSats?

"What you can't do is have 1,000 operators in ground stations, individually keying in commands to each of the satellites," he says. "It doesn't scale financially; you have to be able to treat the network as a single entity. Once you have a single operator that runs your hundred-million-dollar constellation, then you achieve a real economy of scale and you've got an excellent economic advantage." In practice, that means developing some level of artificial intelligence for the CubeSats so that they can guide themselves.

SMALL SATELLITES, BIG POSSIBILITIES

The public has only really had its eyes opened to satellite swarms, or 'megaconstellations' as they're often called, in 2020 because of the numerous launches of Elon Musk's Starlink satellites. Launched in batches of 60, they captured popular attention because shortly after reaching orbit, they became visible as bright 'trains' moving across the sky. Almost 800 are now circling Earth, with plans calling for a total of almost 12,000 in order to deliver fast internet everywhere on the planet. Although the Starlink satellites aren't CubeSats, they apply many of the same principles, such as miniaturisation and mass production, that keep the costs down.

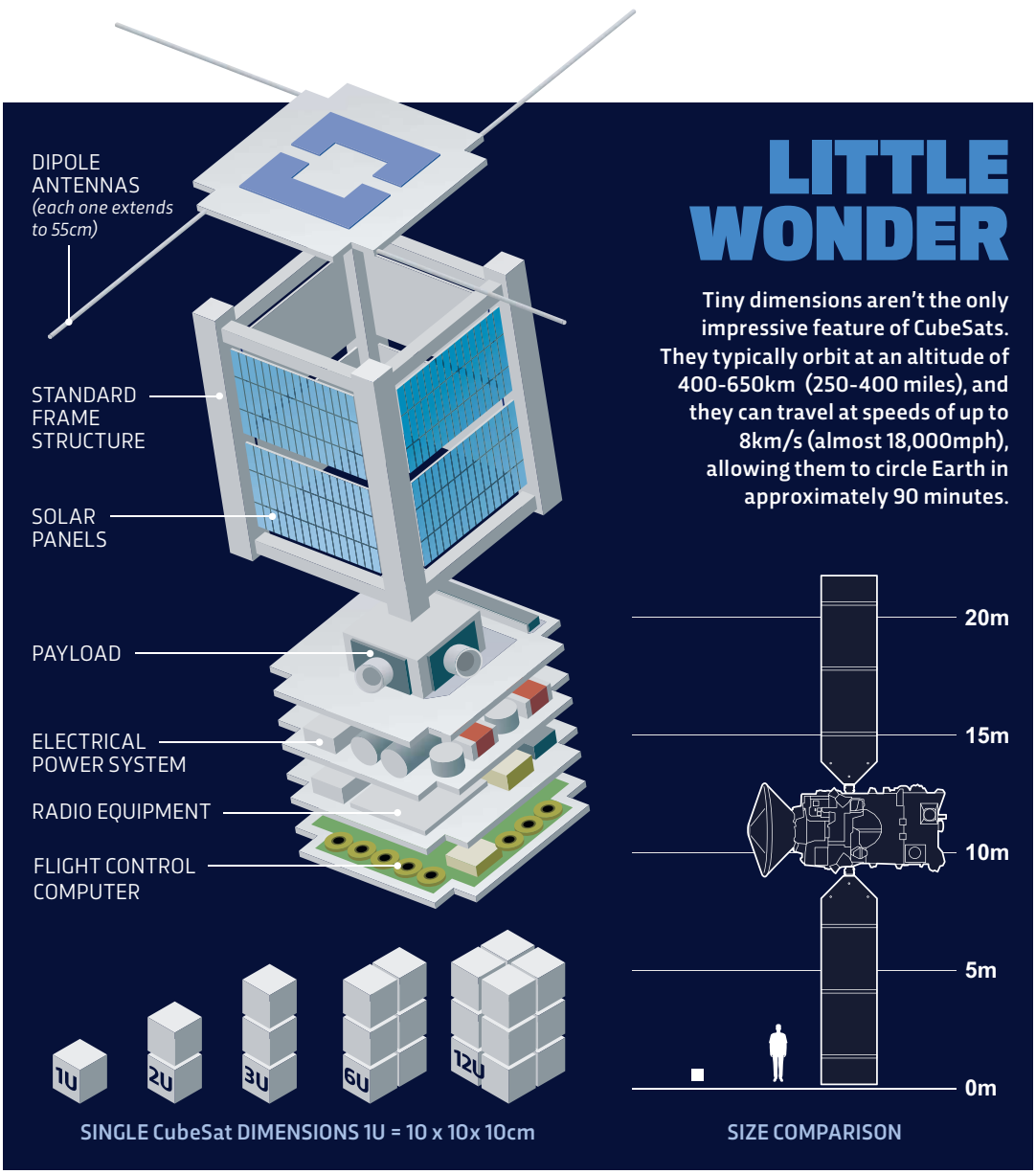
ESA sees CubeSats as such a promising way forward that it has set up a dedicated part of the agency to develop them, demonstrate their capability and roadmap the sorts of things they make possible in terms of space missions.

Roger Walker is the head of the CubeSat systems unit. "Our job is to coordinate the technology developments that are needed to enable new capabilities of these very small satellites," he says.

Many applications revolve around Earth observation. For example, Walker's unit has

ABOVE Long camera exposures reveal the trails of Starlink satellites visible in the night sky

RIGHT A trio of CubeSats form ESA's PICASSO satellite, designed to investigate Earth's upper atmosphere. It launched on 3 September 2020



realised that a small fleet of CubeSats could precisely measure the nitrogen dioxide emissions produced by road traffic and burning fossil fuels in cities and smaller settlements.

Another application is 'hyperspectral imaging' of Earth. This involves a fleet of CubeSats constantly taking images of Earth in dozens of colours and other spectral bands, such as infrared and ultraviolet. "This would allow people to track changes in vegetation for instance, or moisture and flooding on Earth's surface," says Walker.

Another idea is a fleet of CubeSats that pick up the stray reflection of sat-nav signals from Earth's surface in order to measure the movement of ice at the poles and ocean currents around the globe.

ASTEROIDS UP CLOSE

As well as telecommunications and remote sensing, there are also new kinds of science and exploration that can be done with CubeSats. Patrick Michel, director of research at CNRS at the Observatoire de la Côte d'Azur in Nice, France, is the principal investigator of NEO-MAPP (Near Earth Object Modelling And Payload for Protection), a European Commission project to study asteroid deflection techniques and research other methods of preventing an asteroid hitting Earth.

One of the biggest unknowns in this research is the surface properties and compositions of asteroids. Without knowing an asteroid's physical and chemical properties we can't accurately predict how it would respond to the impact of a projectile designed to nudge it off a collision course with Earth. And we can't gain this information from Earth because the asteroids are so small that ground-based observatories can't see them in sufficient detail. "This is an example of where CubeSats can be very useful," says Michel.

His idea is simple. Send a fleet of CubeSats into space, each one designed to rendezvous with a different near-Earth asteroid. Even if the CubeSat is only equipped with a camera, researchers can start to look at the different surfaces and categorise them.

ALAMY, ESA, ACUTE GRAPHICS

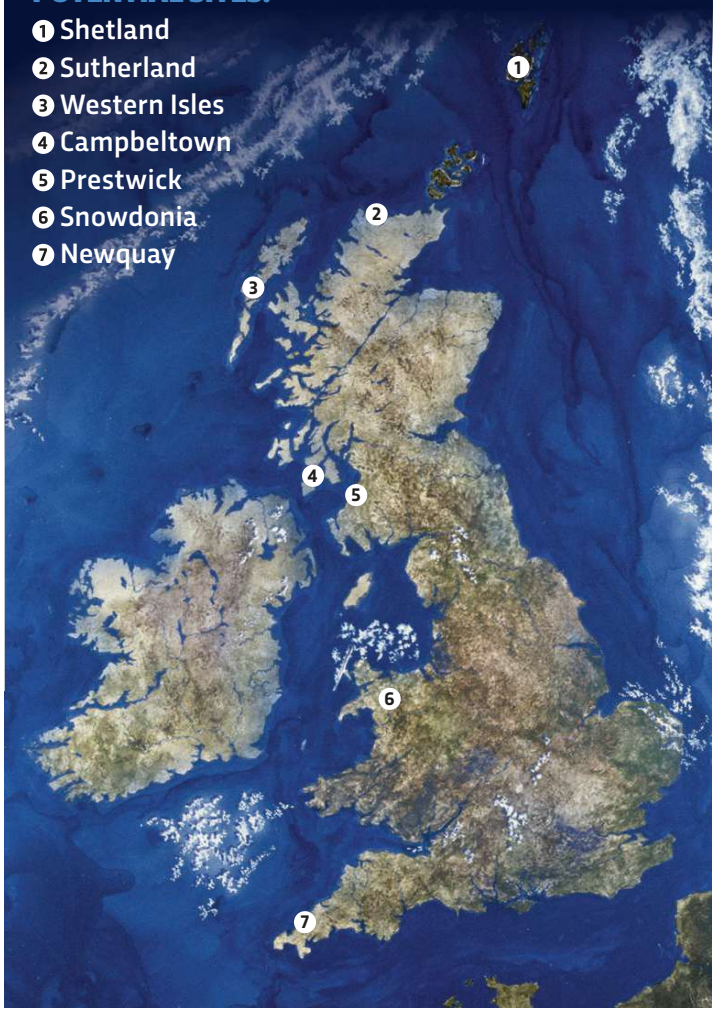
LAUNCHED FROM THE UK

The UK is currently working towards establishing a number of launch sites across the British Isles. From a range of potential locations, planning is currently underway to establish them in Sutherland, Prestwick and Cornwall. These are capable of hosting a variety of spaceflight activities, including both horizontal and vertical launches.

Horizontal launches will use aeroplanes that take off from conventional runways to fly a rocket part-way up into the atmosphere before the rocket is deployed and ignited. Vertical launches involve traditional rockets, but because CubeSats are so small they don't need to be the towering behemoths that took people to the Moon. This brings launching small satellites into the realm of private businesses.

POTENTIAL SITES:

1. Shetland
2. Sutherland
3. Western Isles
4. Campbeltown
5. Prestwick
6. Snowdonia
7. Newquay



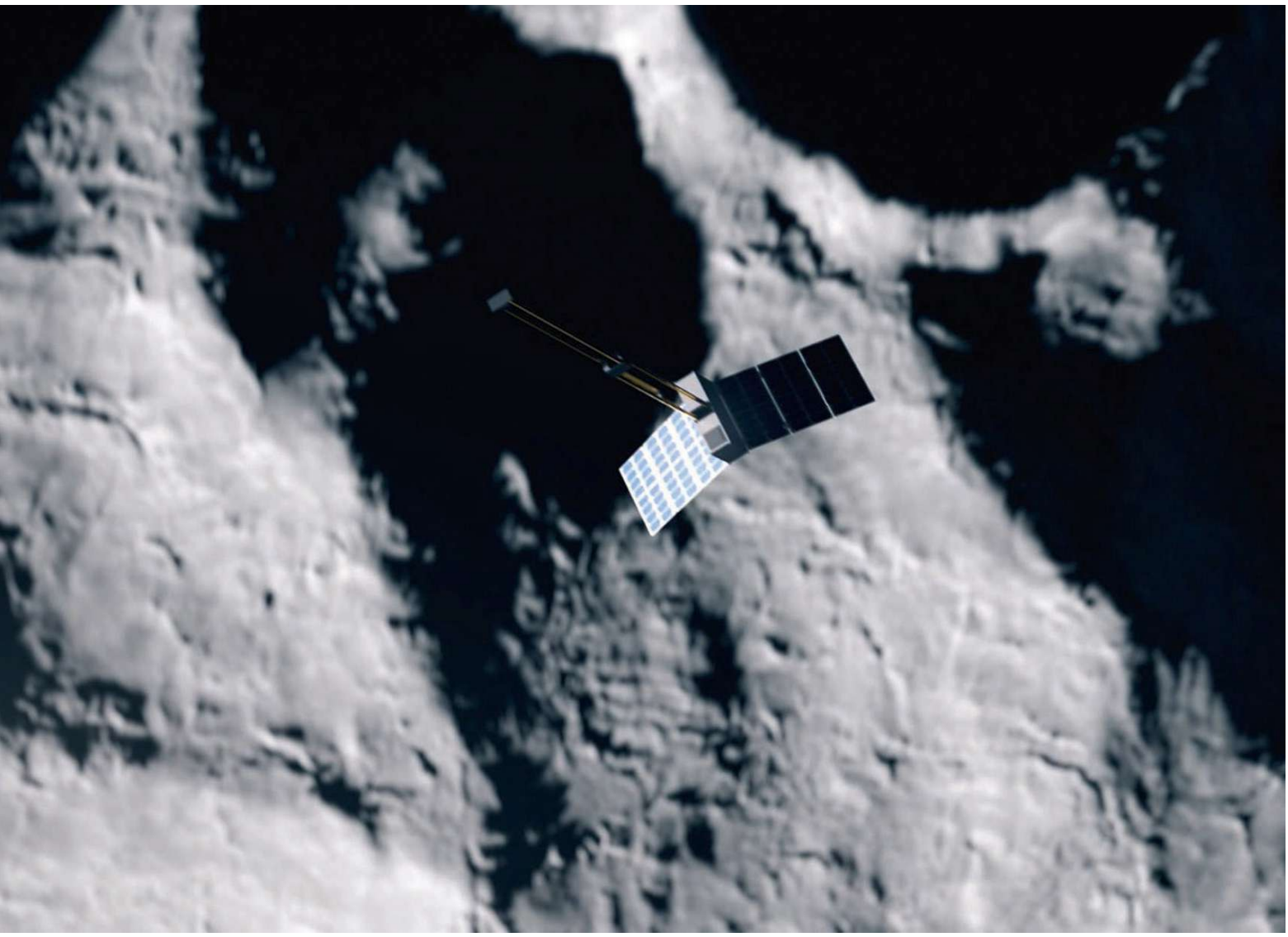
"The CubeSat standard is cheap and it's allowing more missions to be developed than ever before"

"We may see some commonalities for some kinds of asteroids. Then we can [classify them]. So I think that's a very good approach," he says.

It's also possible that the distortion of each CubeSat's radio signal caused by the asteroid's gravity could be analysed to give each asteroid's mass. But that's not all; Williams has been working on the idea of analysing other distortions in a CubeSat's radio signals to more precisely predict the changeable radiation environment in space. Known as space weather, the radiation comes in the form of subatomic particles given off by the Sun. It can cause electronics to malfunction and, at its most serious, can jeopardise the health of astronauts.

Williams and colleagues have taken their inspiration from the way mobile phones are being used to improve terrestrial weather prediction. Meteorologists on Earth have

GETTY IMAGES, ESA, PERFECT CIRCLE PV



ABOVE LEFT An artist's impression of a vertical-launch spaceport in Sutherland

ABOVE Visualisation of ESA's Asteroid Prospection Explorer (APEX), a briefcase-sized satellite made up of six CubeSats, is being designed to survey the Didymos binary asteroids as part of the HERA mission, planned to launch in 2024

begun to measure the 'noise' in individual microwave signals being transmitted across mobile phone networks, because the noise is determined by the atmospheric conditions the microwave is travelling through.

"All they have to do is collect the data on the noise and suddenly they've got weather information, and they're building much more accurate weather forecasts by doing that. We're going to do the same thing in space," says Williams.

NEXT STEPS

As well as being cheap to build, CubeSats are also cheap to launch because they're so small and this is driving a new industry of commercial rocket companies.

When it comes to satellite swarms, the limits are only really defined by the imaginations of the engineers and scientists, and the computing power that can be packed into these tiny spacecraft.

Samson Phan is senior research engineer at the Signals and Space Technology Laboratory, SRI International. It's his job to develop the next generation of CubeSats, including swarms, and he's got big ideas. "For me, it's all about robotics and manipulation," he says.

In Phan's vision, CubeSats won't be passive collectors of data; instead, they'll be individual robots capable of working together with artificial intelligence to build new space hardware, such as giant telescopes that are too large to be launched whole. "I have these visions of large swarms of small, sat-based robots assembling a 5,000km-long array so that we can visualise what Alpha Centauri's planets look like," he says with a smile, before clarifying that his vision is an eventual goal rather than a project he is currently working on. But such visions are what drive innovation. **SF**

—

by **DR STUART CLARK**

Stuart is an astronomy writer. His latest book is Beneath The Night: How The Stars Have Shaped The History Of Humankind *(£14.99, Faber).*

ON THE ORIGIN OF US

by ANDY RIDGWAY

PALAEOPROTEOMICS, A NEW TECHNOLOGY THAT STUDIES THE PROTEINS OF ANCIENT REMAINS, IS SHAKING UP HISTORY. NOT ONLY CAN WE NOW PEER FURTHER BACK IN TIME, BUT THE TECHNIQUE IS ALSO LETTING US SEE OUR PAST IN A NEW WAY...

SCIENCE PHOTO LIBRARY

Extracting DNA from fossils has shed light on our ancient ancestors, but proteins preserved within the remains could reveal more about our relatives from further back in time

Ancient DNA teased out from the fossilised bones and teeth of human species has transformed what we know about our ancestors. Over the past two decades, analysis of genetic material has not only revealed new human species, but it's also allowed archaeologists to recreate what our ancestors looked like, thousands of years after they went extinct. But it can't give us the whole story because DNA is fragile – it breaks down over time to the point where its code becomes unintelligible. This has meant that many ancient bones can't be analysed genetically, therefore much of the human family tree has remained hidden from view.

But over the past few years, new insights into our ancient ancestors have come from the proteins locked inside fossilised remains. Proteins can survive much longer than DNA, and advances in lab techniques, such as mass spectrometry, have increased researchers' ability to detect and characterise tiny amounts of them.

Most promising of all is 'shotgun proteomics', a technique that creates a profile of all the proteins inside a fossilised bone or tooth. These 'protein fingerprints' have already proven their ability to identify which species of ancient human fossilised bones belonged to, even when DNA evidence has been lost. It means we're on the cusp of a 'palaeoproteomics' revolution that promises to provide an unprecedented view of who our ancient relatives were and how they lived.

DIGGING DEEPER INTO THE DENISOVANS

Anthropologists are particularly keen to learn more about the Denisovans, a mysterious tribe of humans who lived at least 200,000 to 50,000 years ago. So far, their genetic material has only been recovered from one site: the Denisova Cave in the foothills of Siberia's Altai Mountains. But there's evidence that they were much more widespread. People alive today in Asia, Australia and Papua New Guinea have Denisovan DNA in their genetic code.

"Almost every [question we have] about the Denisovans is unanswered," says Dr Frido Welker at the University of Copenhagen in Denmark who's a leader in the field of ancient proteins. "It's not only that we need to know where they lived, we also don't know what kinds of stone tools they made, we don't know their hunting behaviour."

The most complete remains of a Denisovan found so far is half a lower jawbone with two teeth attached that was discovered by a monk in Baishiya Karst Cave high on the Tibetan Plateau in China. The DNA inside the jaw, thought to be at least 160,000 years old, was too degraded to ➲

"New insights into our ancient ancestors have come from the proteins locked inside fossilised remains"

SCIENCE PHOTO LIBRARY, DONGJU ZHANG/LANZHOU UNIVERSITY, PROF JOSE MARIA BERMUDEZ DE CASTRO X2

ABOVE The Denisova Cave in Siberia is the only site where Denisovan DNA has been recovered, so far

BELOW LEFT Proteins in the teeth attached to this jawbone, found in China, identified it as belonging to a Denisovan

BELOW RIGHT Examples of the jewellery made by Neanderthals some 42,000 years ago

LANDMARKS IN THE PROTEOMICS REVOLUTION

Homo antecessor fossils are some of the oldest human remains ever found in Europe

OLDEST HUMAN PROTEIN SEQUENCE

The oldest human fossil to have its protein sequenced is 800,000 years old – nearly twice the age of the oldest fossil to have its DNA sequenced. In April 2020, researchers at the University of Copenhagen in Denmark announced that they had sequenced proteins from the dental enamel of a male *Homo antecessor* that once lived in Atapuerca, Spain. When the amino acids in the tooth enamel's proteins were compared with sequences from other hominins, it showed that *H. antecessor* is a close relative of the last common ancestor of modern humans, Neanderthals and Denisovans. The oldest human DNA sequenced is from the 430,000-year-old fossilised teeth and bones of early Neanderthals.

OLDEST OF ALL PROTEIN SEQUENCES

Ancient ostrich eggshells found in northern Tanzania provide evidence that we haven't even got close to reaching the limits of how far back protein analysis can allow us to see. In 2016, archaeologists at the University of York, the University of Copenhagen and elsewhere extracted proteins from eggshells that are 3.8 million years old. The eggshells were found in the Laetoli archaeological site, the same site where the oldest known human footprints were discovered. What's particularly impressive is that the proteins in the eggshells survived the sun-baked conditions of equatorial Africa for all that time.

EVIDENCE NEANDERTHALS MADE JEWELLERY

Jewellery made 42,000 years ago from animal teeth, shells and ivory discovered in a cave in central France have been the subject of intense debate for decades. They were dug up from the same soil layer at Grotte du Renne as bones that were believed to belong to Neanderthals. But some researchers argued that Neanderthals weren't capable of such 'symbolic expression'. In 2016, researchers at the Max Planck Institute for Evolutionary Anthropology in Germany analysed the amino acids in the bones, showing them to be from Neanderthals. It provides evidence that the Neanderthals *did* make the jewellery and so were more intelligent than they're often thought to be.

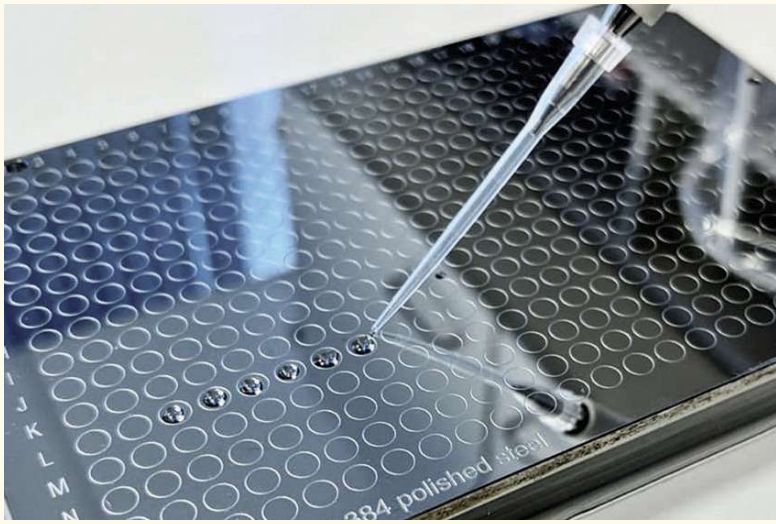
INSIGHTS INTO DIET FROM TOOTH TARTAR

On our teeth, tartar is an unwanted build-up of plaque that we brush away. Yet tartar that's on the teeth of people who lived thousands of years ago is a treasure trove of information. Researchers at the Max Planck Institute for the Science of Human History in Germany and the University of York scraped plaque from the teeth of people who lived in Mongolia around 5,000 years ago. In 2020, the researchers announced that when proteins from the plaque were sequenced, they were identified as being from the milk of ruminants, such as sheep – providing evidence of milk drinking. Plotting the history of milk drinking is important as dairy consumption is integral to many modern diets.

"Many of the shards of bone that researchers work with only have a limited number of proteins in them"

analyse. But in 2019, a team that included Welker managed to analyse the collagen protein in the teeth and it was a match for the Denisovans found at Denisova Cave. It was the first time an ancient human had been identified only from its proteins.

Protein analysis is now being used to comb through thousands of bone fragments dug up from archaeological sites across Europe and Asia to identify which belonged to ancient humans, and which belonged to animals such as hyenas and mammoths. By doing this, the FINDER research project at the Max Planck Institute for the Science of Human History in Jena, Germany, is increasing the number of bone samples known to be from ancient humans. This will provide a much larger range of ancient human bones for analysis.



TOP A representation of *Homo heidelbergensis*, a presumed ancestor of *Homo sapiens*

ABOVE Protein analysis is allowing scientists to identify bones that in the past they'd have discarded

OLD BONES, NEW VALUE

As well as using DNA, archaeologists have studied the shapes and dimensions of bones to identify species and consider where they might fit into our evolutionary past. But much of what they find is just small shards that can't be identified. "Back in the 1950s, or even earlier, [archaeologists] would chuck these bone fragments away because they'd be of no value to them," says Dr Katerina Douka, who is leading FINDER.

Douka is using a technique called Zooarchaeology by Mass Spectrometry (ZooMS) to identify the bone shards. In ZooMS, collagen protein is extracted from the bones and broken down with trypsin, an enzyme that helps to digest protein in our stomachs. Trypsin chops the collagen into peptides (chains of amino acids), which are then placed in a mass spectrometer so their masses can be measured. The peptides are present in different ratios in human remains compared to those of animals, allowing human bones to be identified.

So far 11,000 bone fragments from the Denisova Cave have been analysed using ZooMS, and 10 human bones identified. Some of them are almost 250,000 years old, so likely beyond genetic analysis. After all, DNA has only been sequenced from three hominin groups; Neanderthals, Denisovans and *Homo sapiens* – and mostly from the past 100,000 years.

DNA's tendency to break down over time is a problem Welker is familiar with from his days as an undergraduate. He was trying to sequence genetic material trapped within the fossilised dung of an extinct mountain goat (*Myotragus balearicus*) to find out what it ate by identifying the genes of any plants it had digested. "It didn't work because [the DNA] was absolutely knackered in terms of preservation," he says. "The next best thing seemed to be proteins."

In December 2020, Welker started work on a major new research project sequencing the proteins in hominin fossils from the past million years, that had been collected across Africa, Europe and Asia. He has received €1.5m (£1.35m approx) from the European Research Council to analyse bone and teeth samples from museums and universities. "Between 700,000 and 200,000 years ago is an exciting period for understanding where we, as a species, originate and what the hominin species at the time were doing, behaviourally speaking," says Welker.

It's the period when *Homo heidelbergensis*, the species that we, *Homo sapiens*, are thought to have descended from, first came about, having evolved from *Homo erectus*. "There are several species designations out there, like *Homo heidelbergensis* where either people disagree on how it should be placed in relation to us, or whether it exists or not," says Welker. "The good thing is that, for that time period and

Homo heidelbergensis specifically, proteins can be very informative in the coming years to resolve some of those questions."

The shotgun proteomics technique Welker will be using starts by drilling into bone or tooth to create a breadcrumb-sized amount of powder. Typically, the powder is placed in hydrochloric acid to release the proteins, which are then sliced into peptides using trypsin. Just as in ZooMS, the peptides' masses are measured in a mass spectrometer. But shotgun proteomics differs from ZooMS in that the data from the mass spectrometer also allows researchers to determine the sequence of amino acids within the peptides – and it does this for all the proteins in the sample, rather than just one.

So while ZooMS can tell whether a bone came from an ancient human or something else, a protein sequence from shotgun proteomics can be compared with those already known to occur in hominin species to identify the specific species. Furthermore, as the amino acid sequence of a protein is determined by the genome, variation in the sequence that might exist between species tells researchers something about the evolutionary relationship between the fossil being studied and other hominin species.

LOOKING FORWARD TO LOOKING BACK

Over the next few years, it's expected that shotgun proteomics will allow researchers to identify the species present at more archaeological sites, providing a clearer picture of where the likes of the Denisovans lived. Also, by identifying the species present at a location, archaeologists can use the artefacts there to piece together more information about them, such as the prey they hunted and whether or not they used fire.

But it won't be easy. Many of the shards of bone that researchers work with only have a limited number of proteins in them – they are, after all, a tiny fragment from one part of the skeleton. So they contain much less information than an entire genetic code. Proteins are also 'evolutionarily conserved', meaning they often don't change a great deal between species because they're doing the same job. This limits the extent to which they can be used to link a bone sample to a specific species.

But proteins have already shown themselves to be much more resilient than DNA, allowing us to peer further back in time than ever before. Right now, we just don't know how far back proteomics will allow us to see. "It's exciting to have been part of what has happened in the field in the past couple of years," says Welker. "Even now, I still don't know what its limits are. That's only a good thing, because it means we still have lots of things to explore." **SF**

ABOVE A technician drilling a fossilised Neanderthal bone to extract a DNA sample

SCIENCE PHOTO LIBRARY X2, DR KATERINA DOUKA

by **ANDY RIDGWAY**
Andy is a lecturer and freelance science writer based in Bristol.

Parts of the Caledonian woodland in the Abernethy National Nature Reserve date back to the last ice age

ALAMY

REWILDING

CAN IT SAVE OUR WILDLIFE AND TEMPER CLIMATE CHANGE?

We've pushed nature to the brink, but it may be capable of repairing the damage, provided we step aside and let it go back to doing what it does best

WORDS: JOCELYN TIMPERLEY

Dotted through the Scottish Highlands there remain fragments of Caledonian pine woodland whose origins can be traced back to the temperate rainforest that covered much of the country after the last ice age. Often surrounded by Scots pine plantations and land overgrazed by deer, they're a last refuge for many threatened species.

Abernethy National Nature Reserve includes one of the largest remnants of this ancient woodland. Decades of work by RSPB Scotland and others is restoring and expanding it.

The project, which now has a 200-year plan, is based on carefully encouraging natural processes to flourish, making it perhaps Britain's most successful example of the 'rewilding' concept so far. "With the [ancient] pine wood expanding, that's allowing other species to expand their range and spread as well," says Tors Hamilton from Cairngorms Connect, a large-scale 'habitat restoration' partnership between Abernethy and neighbouring land managers. "There's been a lot of work and research going on – and it's still continuing today – looking at how we enable those natural processes to expand and continue."

With this focus on restoring natural processes, such as allowing trees to seed and spread themselves, the Abernethy reserve encompasses many of the aims of the rewilding movement. At the same time, Abernethy's hesitancy to call itself a rewilding project gives an inkling of the underlying tensions that often surround this approach to regenerating wilderness.

DEFINING REWILDING

In the years since the term 'rewilding' was first coined by US environmentalist Dave Foreman in the early 1990s, people have struggled to agree on what it means.

Pine cones are collected from one area of the Abernethy Nature Reserve so they can be used to grow new native trees in other parts of the reserve

ALAMY X2

When it began the movement focused on the 'three Cs'. "Core protected areas (kind of no-go zones for people), then large carnivores and the connectivity between those habitats," says Dr Andrea Perino from the German Centre for Integrative Biodiversity Research. The aim of rewilding was to create self-sustaining ecosystems that could return to pre-human levels of biodiversity, but the idea evolved as it spread. In 2015, environmental historian Prof Dolly Jørgensen found six uses of the word, from 'productive land abandonment' to 'releasing captive-bred animals into the wild'.

In Britain, writer and environmentalist George Monbiot helped to popularise the term with his 2013 book *Feral*, which advocated for allowing nature to re-establish itself and the reintroduction of large wild animals, such as lynx, beavers and wolves, to Britain. More recently, Sir David Attenborough adopted the term in the documentary *A Life On Our Planet*, his much-lauded 'witness statement' for the environment. "So what do we do?" he asked, after an hour journeying through the enormous biodiversity loss the world has experienced during his 94 years. "To restore stability to our planet we must restore its biodiversity, the very thing that we've removed… We must rewild the world."

In their 2019 paper on rewilding, Perino and her colleagues outlined a framework for how they thought it could be implemented in a way that also considers ongoing human interaction. "We started to try and find the different components that need to be there to help an ecosystem to be resilient," she says.

The researchers landed on three key components that allow ecosystem functions to regenerate and sustain themselves. The first, says Perino, is to have enough species at different levels of the food chain, from predators to decomposers, and enough 'redundancy' so that several species are available to play similar roles. Secondly, connections between ecosystems are also needed, she says, so species can move between them. Finally, allowing natural disturbances, such as floods or fires, to occur increases the resilience of wildlife and helps to ensure one species doesn't dominate.

Rebecca Wrigley is the chief executive of Rewilding Britain, a charity formed in 2015 following the success of Monbiot's book. For her, rewilding means a large-scale restoration of ecosystems that reinstates natural processes to the point where nature can take care of itself, meaning everything from ensuring rivers are free-flowing to restoring "natural levels" of herbivores and predators.

BRINGING BACK THE ANIMALS

The reintroduction of large animals is what most often leads to controversy around rewilding projects, as many focus on predators, such as wolves and lynx. This can generate strong opinions from all quarters and tensions with farmers, who can see these reintroductions as both affront to their heritage and a threat to their livelihoods.

This is one reason why Cairngorm Connect prefers to use the term 'habitat restoration' to describe what's being done in the Abernethy National Nature Reserve, even while others celebrate it as a successful example of rewilding. "Within rewilding and a lot of rewilding projects worldwide, the

"TO RESTORE STABILITY TO OUR PLANET WE MUST RESTORE ITS BIODIVERSITY, THE VERY THING THAT WE'VE REMOVED... WE MUST REWILD THE WORLD"

Sir David Attenborough

Eurasian beavers have been reintroduced to the UK as part of rewilding projects in Argyll, Tayside and Devon

reintroduction of apex predators in particular is often quite high on the agenda. [But] isn't within our plans at the moment," says Hamilton.

Rewilding projects focus on reintroducing wolves, lynx and other predatory animals because they're often 'keystone species' that occupy an essential role in the natural ecosystem. Apex predators, such as lynx, keep the numbers of herbivores, such as deer, down, which triggers a 'trophic cascade' (see 'The wolves return', page 86) that indirectly benefits a wide variety of other plants and animals.

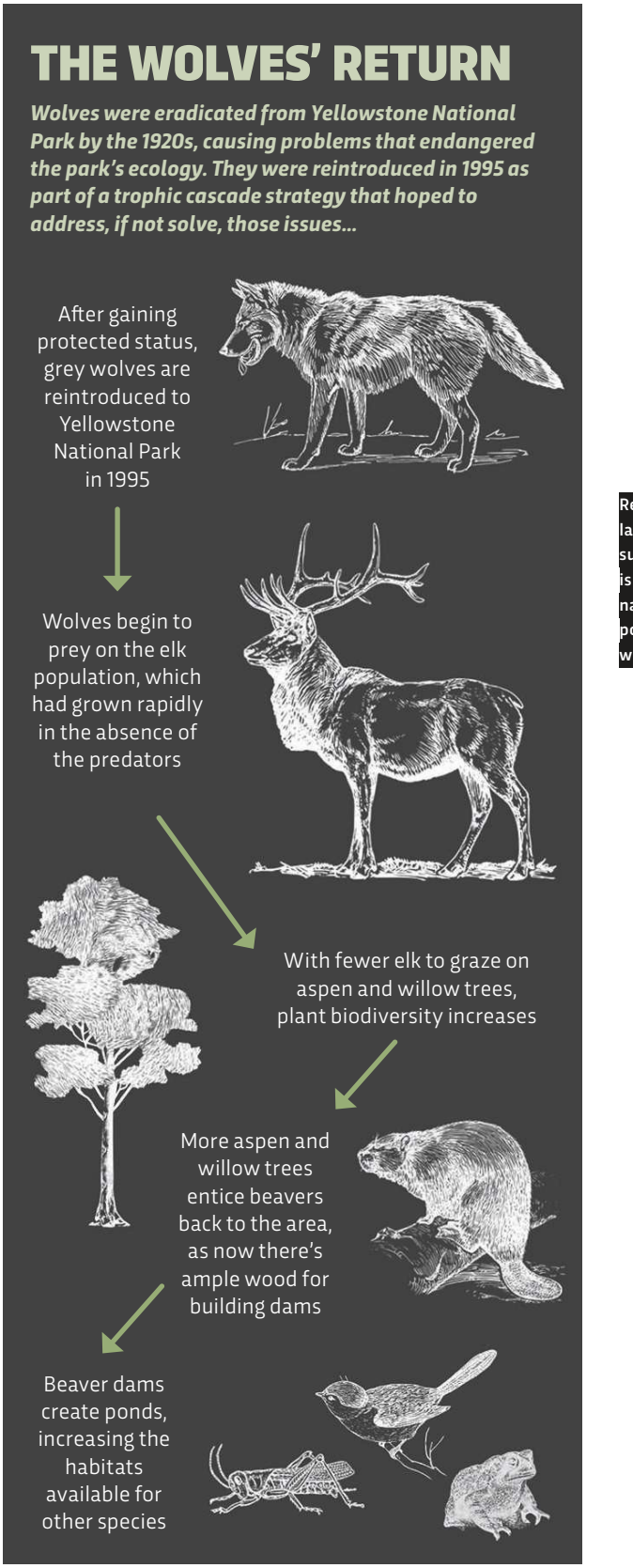
In practice, in Britain at least, rewilding projects have so far tended to focus on returning herbivores, such as beavers and more recently bison, to the landscape, rather than predators. But groups such as the Lynx UK Trust are pushing to release Eurasian lynx, following reintroductions in Germany, France and Switzerland. "There's no point [introducing predators] against public opinion because they'll just end up getting shot," says Wrigley. "But I think public opinion is changing."

The connectedness of the European mainland means reintroductions by humans are not always necessary for predators to return to an area,

Reintroducing larger predators, such as wolves, is one way to naturally manage populations of wild deer

THE WOLVES' RETURN

Wolves were eradicated from Yellowstone National Park by the 1920s, causing problems that endangered the park's ecology. They were reintroduced in 1995 as part of a trophic cascade strategy that hoped to address, if not solve, those issues...



though. "For Europe's mainland, carnivores are just coming," says Frans Schepers from Rewilding Europe, noting the recent return of wolves to the Netherlands. "If you provide the safety and the habitat, species will come – most of that happens on its own."

In France, wolf populations have grown rapidly since they returned from Italy in 1992, with sheep and goat farmers saying their herds are suffering rising attacks. "Of course, it can be controversial because people are just not prepared for it," says Schepers.

But there are other ways to compensate for a lack of apex predators, although it's not the hands-off approach favoured by rewilding. In Abernethy, for example, an essential part of the restoration project has been establishing a management plan to address the high numbers of deer that were preventing young tree seedlings coming up. The deer are now culled and sold for venison, both providing jobs and bringing in revenue for the project, says Hamilton.

REWILD FOR THE CLIMATE

Rewilding is also increasingly receiving attention for its potential to help mitigate climate change. Research has shown that degraded landscapes that have been restored have huge potential for sequestering carbon and can play a part in protecting people from the impacts of a changing climate. Planted – or rewilded – trees, for example, absorb and store carbon as they grow, and can also reduce the risk of flooding.

"RESEARCH HAS SHOWN THAT DEGRADED LANDSCAPES THAT HAVE BEEN RESTORED HAVE HUGE POTENTIAL FOR SEQUESTERING CARBON"

Scientists in Brazil recently found that restoring the most promising 15 per cent of ecosystems, including former forests, degraded grasslands and wetlands, could sequester 30 per cent of all CO_2 released since the Industrial Revolution, and avoid 60 per cent of expected extinctions. Restoring tropical forests tended to bring the most carbon benefits, the researchers found.

Another paper found that simply stopping disturbances (by getting rid of grazing cows, for example) and letting pastures regrow naturally as forests could absorb the equivalent of a quarter of global fossil fuel emissions per year up to 2050, while maintaining current levels of food production.

A key message was the huge differences in how much carbon could be captured. "The highest [amounts] are in the places that you'd expect, so the tropics are much higher than the more temperate forests," says lead author Dr Susan Cook-Patton, from The Nature Conservancy. "But what's really cool is the variation at smaller scales. It's really good for helping to find those locations with the greatest potential carbon on a per-hectare basis."

In the UK, for example, carbon absorption rates could more than double depending on the location. "Our map can help people determine whether there are locations that will optimise biodiversity benefits and carbon benefits at the same time," says Cook-Patton. Research like this could be useful as countries attempt to balance different priorities for land use. But even small areas of rewilded land – such as an untouched garden – can add up to make a big difference climate- and biodiversity-wise.

A programme of tree planting, with species native to the area, saw the fells around Cumbria's Thirlmere Reservoir acquire 50,000 new trees to provide flood protection and increase biodiversity

ECO SAPIEN/YOUTUBE CHANNEL/DAVID BODENHAM, ALAMY X2

HOW TO BRING BACK THE TREES

The UN aims to reverse the loss of forest cover and to increase forest area by 3 per cent worldwide by 2030. Other organisations are calling for higher amounts of forest gain. But how could they be achieved?

NATURAL FOREST REGROWTH
Letting forests grow back on their own, often by removing disturbances that were preventing growth.

REWILDING
Restoring ecosystems by enabling natural processes to take over, often with a focus on re-establishing lost species.

TREE-PLANTING
This can encompass anything from commercial tree plantations to urban parks, to planting a small number of seed trees to start a forest going.

REFORESTATION
The restoration of an area that had, until recently, been forested.

AFFORESTATION
New forests are planted across land that has never had trees, or not recently had them.

A single square metre of grassland can contain over 40 plant species, compared to the one or two found on garden lawns, leading to a cascade of benefits for insects and other animals. Reducing fertiliser and herbicide use in your garden and leaving even small areas to grow naturally (or mowing less often) can do wonders for local wildlife, such as hedgehogs and birds. Meanwhile across Britain, stretches of roadside are being turned over to wildflowers under different, more effective, management approaches than the usual 12 or so verge-cuttings per year.

A larger change in animal fauna around the world could also make a difference for the climate. Replacing the huge numbers of methane-emitting cattle globally with lower-emitting large herbivores, such as horses and rhino, would significantly reduce overall methane emissions, according to a 2018 scientific review. And rewilding the world's tropical forests with large, fruit-eating mammals, such as elephants and American tapirs, could have a greater impact on the climate than tree-planting schemes, it said, because these animals are crucial to the seed dispersal of hardwood tree species.

Even smaller spaces, like roadside verges, can have a positive impact on biodiversity if they're turned over to nature

PLANTING VS REWILDING

Whether on a large or small scale, rewilding focuses on how to restore ecosystems, rather than individual species. Advocates argue its low-cost, widespread benefits are often a better bet than concentrating on a single species or meeting fixed tree-planting targets.

In the UK and elsewhere tree-planting has captured the public imagination. The UK government's target to plant 30,000 new hectares of trees per year is a key part of its climate strategy and has public support. A global initiative to plant one trillion trees within the decade, launched at the World Economic Forum in January 2020, is another of a whole host of tree-planting initiatives.

There's certainly a place for tree-planting where natural forest regeneration is unlikely to work, such as in urban parks or areas far from natural seed sources. "If you have really degraded conditions, or no seed sources, you're not going to get a forest coming back," explains Cook-Patton. "And you'd need to actively plant at that point."

But many argue tree-planting isn't always the best approach. For one thing, research has shown that natural forest regrowth tends to result in better biodiversity outcomes. Cook-Patton says

"REDUCING FERTILISER AND HERBICIDE USE IN YOUR GARDEN AND LEAVING EVEN SMALL AREAS TO GROW NATURALLY CAN DO WONDERS FOR LOCAL WILDLIFE"

The Knepp Estate in West Sussex was once a dairy farm, but its owners have found new ways to generate income since they rewilded the land

ALAMY, KNEPP WILDLAND

that's because people often plant just a handful of tree species, representing only a fraction of what a forest would have previously contained. "The more tree species you have, usually the more animal species you can support," she says.

Other research has found commercial tree plantations are much poorer at storing carbon than natural forests. Scientists are also concerned that a fixation on tree-planting could result in non-native trees being planted on savannahs or grassland, causing disruption for local species.

There's also the cost of planting trees compared to letting nature to do the job. "We like to think that we need to plant trees, but nature has been planting trees forever, all on its own," says Cook-Patton.

Supporters of rewilding say regenerated land can also be used to generate income. But this relates to what we, as a society, choose to value. Some governments are already changing how they subsidise land, following the example set by countries such as Costa Rica, which has been paying landowners to protect their forests for decades.

In Britain, the departure from the EU has opened up a space to rethink how to spend the £3bn a year in UK agricultural subsidies previously distributed by the EU's Common Agriculture Policy (CAP). The UK government has proposed a 'public money for public goods' policy, with funds rewarding carbon sequestration, air and water quality, and improved access to the countryside. "If that's implemented as it's proposed we think that could be a great incentive for change," says Wrigley.

Meanwhile, some landowners are experimenting with how to generate income from private rewilding schemes, such as the 1,416-hectare (3,500-acre) Knepp Estate in West Sussex. Previously an arable and dairy farm, it was turned over to wildlife in 2001. Fences were removed, allowing the estate's cattle and pigs to roam freely, and deer and Exmoor ponies (acting as proxies for the extinct wild horse) were introduced to cause helpful natural disturbance through their grazing and trampling. Knepp Estate's owners, Charlie Burrell and Isabella Tree, now earn money by running a glamping site and ecotourism business, as well as selling animal products made from the free-roaming livestock.

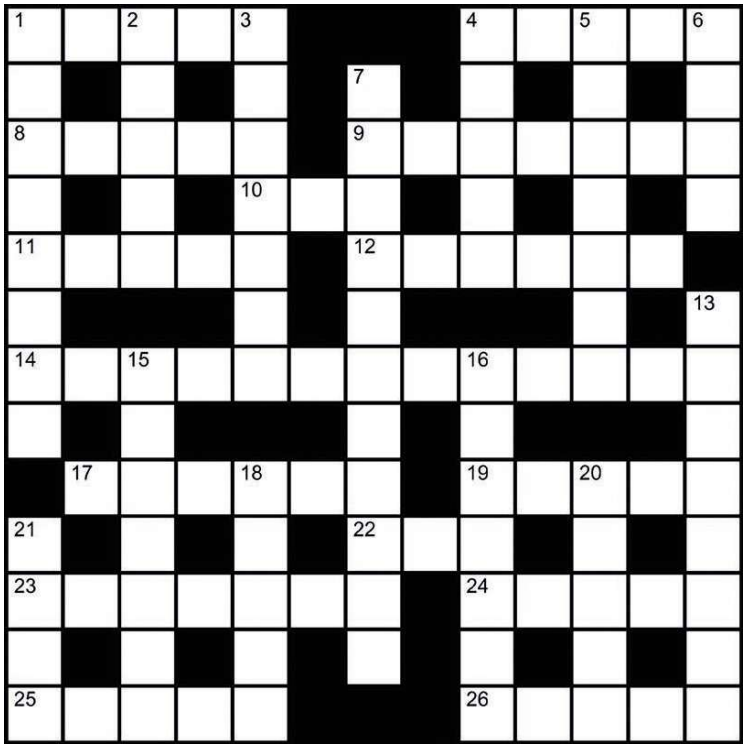
An important part of rewilding that has changed, at least for some, from the initial concept is the inclusion of people. A criticism often levelled at rewilding is that it focuses on returning to landscapes untouched by people and so risks disempowering local communities. But Wrigley argues rewilding must include people. "It's not to take people out of the landscape and forbid them from touching or entering it," she says, pointing to how low-impact agroforestry and agriculture can be compatible with rewilding. "There's a spectrum of restoring those natural processes and we see some forms of landscapes that are productive as part of that."

To its advocates, rewilding goes further than traditional conservation to recognise the vast scale of the ecological disaster the world is now facing. It aims to bring back nature as much and as fast as possible. But it's also about trusting nature, according to Schepers. "We should stop treating nature as a sick child," he says. "Nature is our ally." SF

by **JOCELYN TIMPERLEY**
Jocelyn is a freelance climate journalist.

CROSSWORD

GIVE YOUR BRAIN A WORKOUT



ACROSS

1 Airwoman in secret plan to capture his heart (5)
4 Blade that's reversible (5)
8 Philosopher quietly changes a lot (5)
9 Improve nowadays in organised purge (7)
10 Poor balance around a sphere (3)
11 Diminishing lute composition by head of performance (5)
12 Gold transaction is a very unpleasant experience (6)
14 Sporting award brings city down (9,4)
17 Life's fashionable for an enzyme (6)
19 Old-fashioned appointment with daughter (5)
22 Canasta certainly includes a card (3)
23 Old colour around top of chart, no longer found (7)
24 Man has planted first tree (5)
25 Agent didn't finish without money (5)
26 Trainee acted in a strange way (5)

DOWN

1 Residents almost well liked by church (8)
2 Left direction to a minimum (5)
3 Soldier gets poorer, sadly, after time (7)
4 Equipment I would find unyielding (5)
5 Follow, acquiring a victory that's hard work (7)
6 Stagger for part of the film (4)
7 Inferior military craft gets rationed a new way (11)
13 Layabout is utterly exhausted (8)
15 Friend removed tempo – new sort for conductor (7)
16 Point denim out to conservative native (7)
18 Feeling that may be common (5)
20 Indifferent to pressure in new diet (5)
21 Overburdened with a word (4)

ANSWERS

For the answers, visit **bit.ly/BBCFocusCW**
Please be aware the website address is case-sensitive.

GETTY IMAGES

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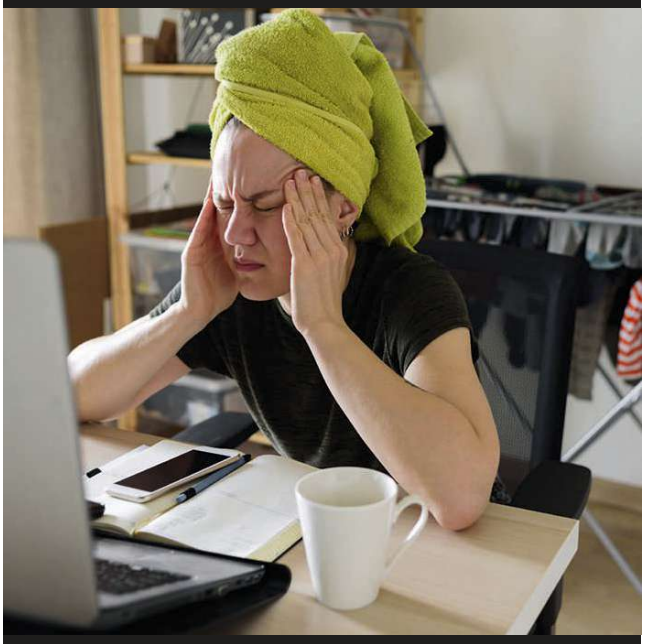
Get the better of pandemic fatigue with the help of science.



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Are the seasons hardwired into our biology?

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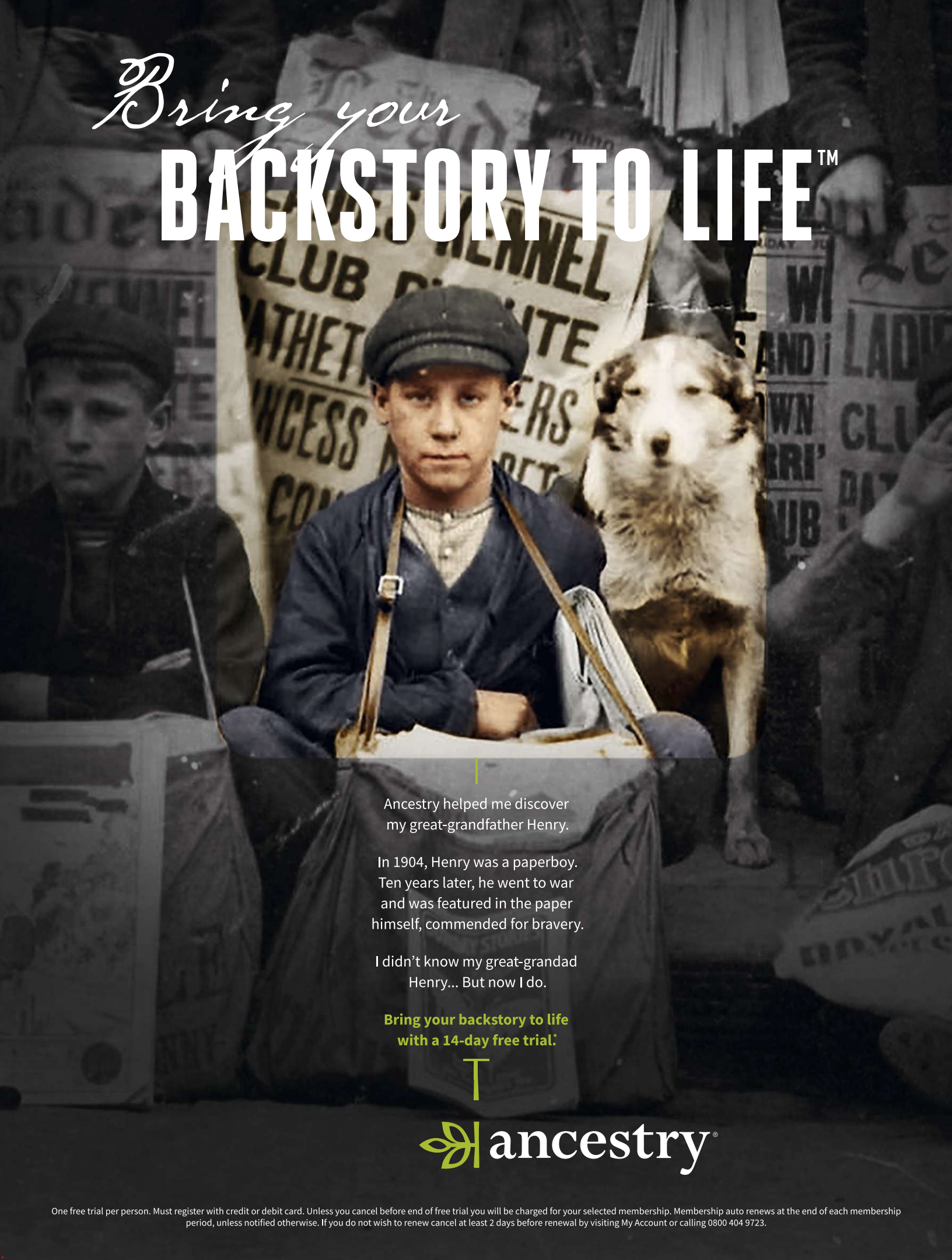

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