New Scientist

WEEKLY August 1–7, 2020

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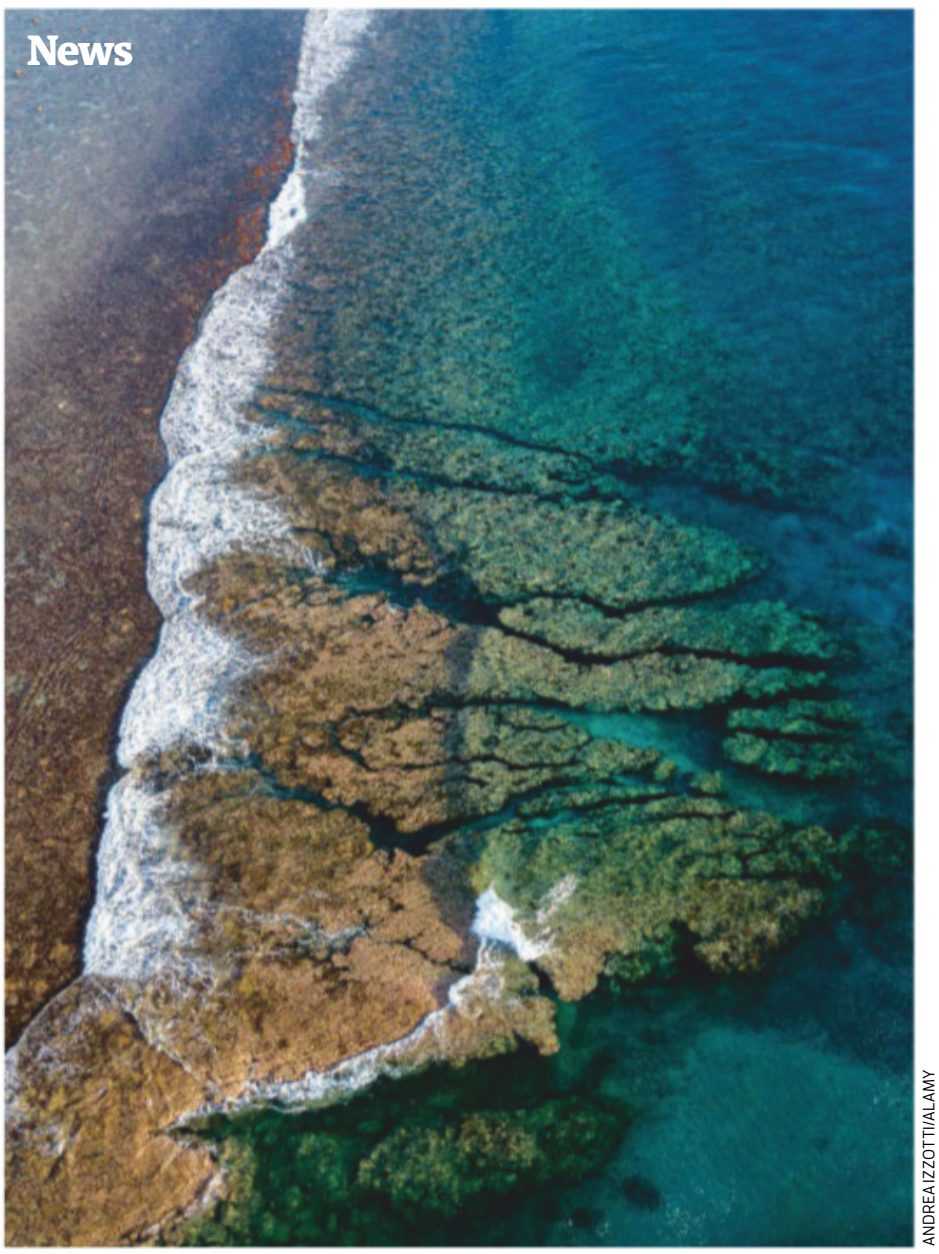

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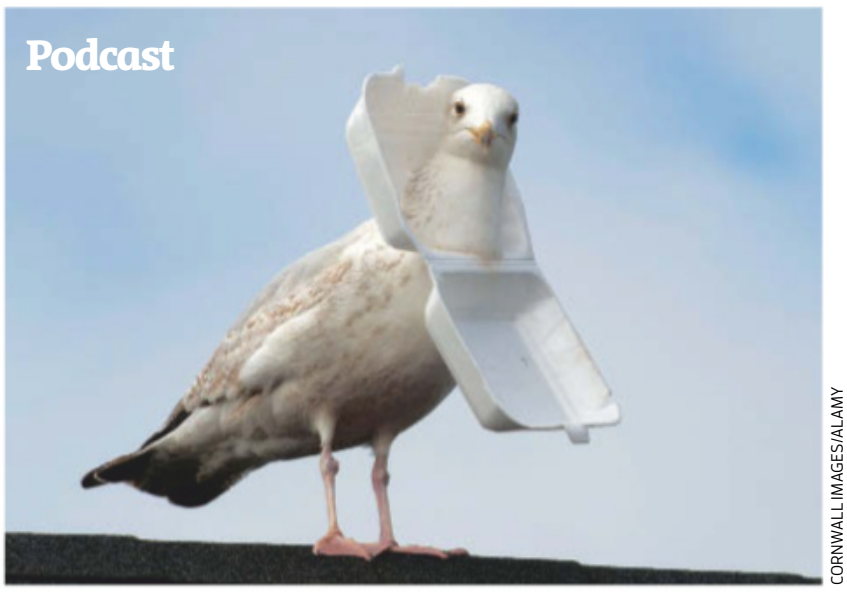
The end of everything Astrophysicist Katie Mack on our cosmic fate



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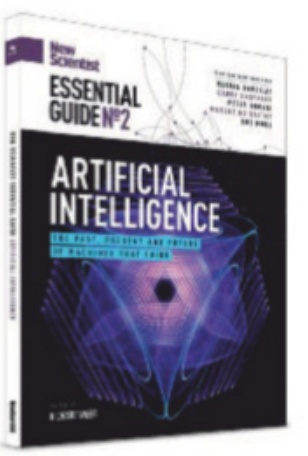

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Cosmic visions

Astronomical breakthroughs show the age of scientific discovery is far from over

PHOTONS travel light. They have been zinging around the cosmos largely unimpeded since around 380,000 years after the big bang, when atoms formed and the universe became transparent to them. Astronomy is essentially the act of capturing as many photons as possible; cosmology that of translating this act into a coherent picture of the universe.

News this week that we have made our best ever map of the cosmos, depicting some 11 billion years of its history, is a milestone on both counts (see page 12). It is the result of two decades of light gathering by astronomers at the Apache Point Observatory in New Mexico involved in the Sloan Digital Sky Survey (SDSS). For cosmologists, the map is the best confirmation yet that their standard model of the universe is correct – albeit with one big caveat that suggests our understanding is far from complete.

If you leaf through the SDSS paper you might think that, for such a grandiose view of the universe, it rather lacks in visual appeal. Not so for the image that is the centrepiece of our cover story this week. Rarely have photons been combined to such iconic effect than in the first direct picture of a black hole, reproduced once again on page 34.

"Future generations will have the chance to look further, and sharper, into the universe than we can"

There is a tendency with such a momentous breakthrough as this – made by the Event Horizon Telescope in April last year and, again, one decades in the making – to walk away thinking "job done". But the power and beauty of scientific discovery is that it builds on itself. As often as not, such events represent the closing of a chapter and the opening of many new ones.

In this case one new chapter is the mind-bending, yet simultaneously awe-inspiring, thought that the black hole's orange glow hides infinite rings of photons that it captured at different times – a movie of the universe as seen from its perspective (see page 30).

Does it matter that we lack the capability to see much of that cosmic footage yet? Not really. We should see these insights, and those of SDSS, as investments for the future. They remind us that if we preserve ourselves, and the planet we live on, future generations will have the chance to look still further, and sharper, into the universe than we can. ▮

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CONTACT US

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General & media enquiries
US PO Box 80247, Portland, OR 97280
UK **Tel** +44 (0)20 7611 1200
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Australia 418A Elizabeth St, Surry Hills, NSW 2010

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Healthcare workers check temperatures in Mumbai, India

Global cases rise and rise

The world is facing a resurgence of covid-19 cases as the pandemic continues to accelerate, reports **Adam Vaughan**

CASES of the coronavirus hit a new daily high of around 300,000 globally on 27 July, with more than half occurring in the Americas – the US alone has been reporting a seven-day average of 67,000 daily cases since 21 July. The virus is also spreading rapidly in India, Brazil and South Africa, which haven't yet suppressed their first peaks.

There has also been a worrying uptick of cases in Asia. On 26 July, China, where the outbreak began, saw its highest number of new daily cases since March. The next day, Hong Kong announced new restrictions to curb infections, as did the city of Danang in Vietnam, which reported the country's first community transmission since April.

Speaking during a World Health Organization press conference on 27 July, Maria Van Kerkhove said the global picture is complicated, but countries where transmission is growing fall into two camps.

"Many countries are really in the thick of it, they are really seeing intense transmission," she said. "Other countries which have already passed through their first peak, many of them are keeping transmission low. [However] in some of those countries, they're starting to see a resurgence, clusters of cases and outbreaks in certain geographic areas or areas associated with certain types of industries, such as nightclubs."

Worldwide, the cumulative number of cases has roughly doubled in the past six weeks, which WHO director general Tedros Adhanom Ghebreyesus cited as a sign that the pandemic is continuing to accelerate. In total, there have been more than 16 million cases and more than 650,000 deaths. The US is approaching the milestone of 150,000 deaths.

New Zealand, Cambodia, Rwanda, Germany, China, Canada and South Korea were among countries that had done well at controlling transmission, Tedros told the press conference. "Our world has changed, the response has not," he said, listing strong political leadership, testing and tracing, social distancing, hygiene and wearing masks as important factors in controlling the virus.

"Many countries are really in the thick of it, they are really seeing intense transmission"

While most of Australia is largely free of covid-19, hotspots in the state of Victoria led to the highest daily increase in cases on 27 July. That prompted warnings from authorities of an extension to a six-week lockdown.

New cases in the European Union and UK overall have remained stable. However, the cumulative number of cases over a fortnight per 100,000 people is considerably higher in some countries, at 40.1 in Sweden, 35.1 in Spain, 35.5 in Portugal and 63.2 in Romania, compared with 14.7 in the UK and eight in Germany.

Concerns over outbreaks in Spain saw the UK impose a 14-day quarantine on people returning from Spain, to limit potential spread to the UK. Michael Ryan at the WHO said: "The fact is the virus is pretty much everywhere and it can move between areas. Where we need to look at is what is the risk of the disease moving from an area of high transmission to areas where it's under control. I think that's what's worrying governments now."

Nonetheless, he added that keeping international borders sealed wasn't sustainable. Spain has said the country is safe for tourists, but the UK government defended its decision as a necessary step to avoid a second spike. ▮

Daily coronavirus news round-up
Online every weekday at 6pm BST
newscientist.com/coronavirus-latest

Interview: Sarah Gilbert

Inside the race for a vaccine

Sarah Gilbert, the driving force behind the much-publicised Oxford vaccine, tells **Michael Le Page** what her life is like right now, and why we should be optimistic

LAST week was a big one for Sarah Gilbert at the University of Oxford, leader of the team that created the "Oxford vaccine", a front runner in the race for a coronavirus vaccine. On 20 July, her team published results showing that the vaccine produces the desired immune responses in people.

Gilbert says she took a moment to pause ahead of the announcement – she had most of the day before, a Sunday, off.

That is a rare luxury these days. She normally works long hours, including on weekends. "There is a lot going on during the week, so weekends are a time to catch up on more substantial pieces of work with fewer interruptions," she says.

Gilbert gradually moved into vaccine development after joining Oxford in 1994. Even so, she never imagined working on a vaccine to tackle a massive global pandemic. "We had been starting to prepare for a 'disease X' vaccine, but that was always envisaged as a novel pathogen that would cause an outbreak rather than a pandemic."

"We all want the best vaccine we can get, but we will accept one that is safe and reduces mortality"

The type of vaccine she has been working on against coronavirus is known as a viral vector vaccine. The key component is DNA coding for a surface protein – which would normally trigger an immune response – from the virus you want to protect against.

Like a Trojan Horse, this is put inside the shell of an adenovirus that causes colds in chimpanzees, which delivers it to human cells, where the protein is made.

In response, the body produces both antibodies that circulate in the blood and bind to any matching viruses they encounter, and T-cells that destroy infected cells before they make more virus.

JOHN CAIRNS

Profile

Sarah Gilbert is professor of vaccinology at the University of Oxford, leading its research on flu vaccines and emerging pathogens

To create the coronavirus vaccine, which is being developed in collaboration with drugs firm AstraZeneca, the researchers simply had to put DNA coding for the virus's surface protein into the adenovirus "cassette" they had already created for other vaccines.

That meant they could produce small batches of the vaccine for initial tests in just weeks. It can take several years to get to this point in vaccine development.

A chimp adenovirus shell is used instead of a human one because it doesn't get mopped up by our immune system before delivering its cargo. "Vaccines based on human adenoviruses don't work quite so well in people who have some immunity to the adenovirus," says Gilbert.

So far, things look good. The results published last week show that the Oxford vaccine produces good antibody and T-cell responses after two doses and only minor side effects, including pain at the injection site, tiredness, aches and fever in some cases.

In Brazil, large trials of the Oxford/AstraZeneca vaccine are under way

The big question is whether it really protects people from infection. To find out requires phase III trials in which thousands of people are given either the vaccine or a placebo. They aren't told which, so they don't change their behaviour. These trials are now under way (see page 10 for more on vaccine trials).

If the vaccine works, fewer people given it should end up catching the coronavirus compared with those who got the placebo. Ideally, there would be no cases at all among those vaccinated, but even a vaccine that provides only partial protection would be better than nothing.

"We all want the best vaccine we can get, but will accept one that is safe, despite some tolerable side effects imme diately after vaccination, and reduces mortality," says Gilbert. "There aren't any vaccines against coronaviruses that infect humans, so there is nothing to compare with."

Normally, human trials of vaccines take a decade or more. "The reasons for being slow usually are financial," says Gilbert.

If all goes well, the Oxford vaccine might get the go-ahead from regulators this year. This would be an amazing achievement, but Gilbert thinks we might have done even better. "We could have been quicker to get started if we had been better prepared. We need more investment in pandemic preparedness to do better next time."

How much protection?

One of the biggest worries around the promise of a vaccine to end the pandemic is that our immune response to the virus might only provide short-lived protection. However, that issue doesn't necessarily translate to vaccines,

says Gilbert. "Immunity to pathogens and vaccines is not necessarily the same," she says. "The vaccine may provide longer-lived immunity." Fears of decreasing immunity after infection are probably overstated too, she says: "It's usual for antibodies to reach a peak level and then decline over time."

Once we have one or more effective vaccines, Gilbert thinks it should be given first to healthcare workers, both to protect them and to prevent transmission within hospitals and care homes. "That is where the vaccine can have most impact," she says.

The hope of many is that normal life can resume once a vaccine is available, but this will take time. "It won't be available to everyone at the same time and the vaccine may not work very well in older people. If that is the case, we need the rest of the population to be vaccinated to prevent transmission and protect the vulnerable." ▮

AMANDA PEROBELLI/REUTERS/PA IMAGES

The hunt for treatments

What are the most promising medicines?

Adam Vaughan

AS THE World Health Organization (WHO) baldly reminds us, "there are no specific vaccines or treatments for COVID-19". However, trials of treatments are taking place. Some have shown promise in helping those infected by calming an overreacting immune system or targeting the coronavirus – either by destroying it or stopping it from replicating.

Dexamethasone, a widely available steroid that dampens the immune response, became the first medicine shown to reduce deaths in covid-19 patients. The RECOVERY trial of more than 2000 people found that it reduced deaths in people on mechanical ventilators by a third – and by a fifth in those who received oxygen but not ventilation.

"The trial showed it is beneficial to those who are severely affected," says Sheuli Porkess at the Association of the British Pharmaceutical Industry. It is now being used by the National Health Service in the UK to treat covid-19.

1/3

Reduction in deaths of ventilated patients given dexamethazone

In June, the US bought up virtually all global stocks of the drug remdesivir, an antiviral that suggested promise against Ebola. The move came after one trial found that it reduced recovery time by four days in covid-19 patients.

However, other studies have yielded mixed results: one in April showed no clinical benefit, while an analysis last month by Gilead, the company behind the drug, indicated a reduced risk of death in those severely affected by covid-19. Gilead cautions that more rigorous trials are needed. The drug has received emergency or conditional approval in a number of countries. The litmus test will come in a few weeks with the results of the international Solidarity trial.

Trials are also looking at whether the anti-inflammatory tocilizumab, which is already used to treat arthritis, could be beneficial against covid-19.

Another recent development relates to an inhaler-based treatment that delivers a protein called interferon beta to the lungs. A preliminary finding showed that it reduced the risk of patients going on to develop severe covid-19 by 79 per cent, compared with a placebo group. However, this was a small, early trial of the drug, called SNG001, developed by UK firm Synairgen.

The blood plasma of covid-19 survivors offers another possible treatment because it contains antibodies to the coronavirus. An alliance of companies formed in May to pool research on its use as a therapy for the disease. There are no trial results so far.

New drugs might still emerge. Last week, an analysis of thousands of known drugs that have been approved or are under clinical investigation found 13 that inhibited the coronavirus's replication in cultured cells.

As well as trying to use existing drugs to tackle covid-19, some pharmaceutical companies are exploring entirely new ones.

In addition, researchers have started to rule out certain drugs. For example, hydroxychloroquine and lopinavir-ritonavir haven't been shown to provide any benefit, at least in hospital settings.

For now, the focus remains on treating the most severe, short-term problems caused by the illness. But with growing evidence pointing to longer term symptoms, treatments will be needed to tackle those too. ▮

JON SUPER/XINHUA NEWS AGENCY/PA IMAGES

Dexamethasone was the first drug shown to cut covid-19 deaths

Vaccine trials

Vaccine effort yields a flurry of positive trial results

Adam Vaughan

AMID rising global numbers of daily coronavirus infections, a fresh flush of vaccine trial results is offering hope for the longer run.

There are more than 160 coronavirus vaccines in development around the world. About 140 of these are at the preclinical stage, meaning they are still being looked at in laboratories and in animal tests. Another 25 are already being tested in people.

The rate at which the tally has risen to 160-plus is unusually fast. "What is phenomenal is the numbers changing over the past few months. The amount of research is incredible," says Sheuli Porkess at the Association of the British Pharmaceutical Industry.

As the candidates advance, the World Health Organization (WHO) last month started to convene a working group to prioritise the most promising vaccines. "Practical realities will require a process that focuses global efforts on a small handful of candidates that may have the highest impact," the WHO said.

Four vaccines have made big steps in development in the past few weeks. Initial trials show that they can trigger an immune response and appear safe – but it is too early to say if they will protect against coronavirus and whether they will work across many different groups of people, including older individuals and those with chronic health issues.

On 20 July, a team led by Sarah Gilbert at the University of Oxford (see interview, page 8) and pharmaceutical company AstraZeneca showed that their ChAdOx1 nCoV-19 vaccine produced the desired immune responses without showing serious adverse reactions. That was in a combined phase I/II trial of 1077 volunteers (see "Trial phases", left). It is now being tested in many thousands more people.

Six days earlier, US company Moderna and the US National Institute of Allergy and Infectious Diseases revealed that 45 people had received their mRNA-1273 vaccine and shown an antibody response. On Monday, they began a phase III trial intended to have 30,000 participants.

The other two most promising candidates are from CanSino Biologics in China, which published encouraging phase II trial results on the same day as the Oxford team, and another from German company BioNTech with pharmaceutical giant Pfizer, which published a promising preliminary report on 14 July.

At this stage, we don't know which, if any, of the vaccines will succeed. "The eyes of the world are on these that are closest. But without being pessimistic – I'm being realistic – drug development is a risky business," says Porkess.

The much larger phase III trials in coming months, involving thousands of people, will give a better idea of which vaccine might be deployed first. "This is the pointy end, this is when you are getting into real-world testing of a vaccine," says Margaret Harris at the WHO.

Any vaccines that are successful in clinical trials will still need to be manufactured at scale, which will affect the time it takes to get a vaccine for general use. "We are seeing things happening at unprecedented speeds. Maybe something could [be licensed for use] within 18 months from now," says Porkess. ▮

Trial phases

Phase I
A vaccine is given to a small number of healthy people to see whether it is safe to use

Phase II
A greater number and diversity of people are tested, to see if it triggers an immune response

Phase III
Involves hundreds or thousands of people, including a control group to see if the vaccine works in the population at large

Combined phases
Because of the urgency of the current pandemic, some phases are happening in parallel

TED S WARREN/AP/SHUTTERSTOCK

A volunteer in Seattle takes part in a trial for a vaccine developed by Moderna

Where are all the vaccines?

Scores of vaccine candidates are in development around the world, but only a handful have made it to the final stages of testing, and none has so far been approved for general use.

139
Vaccines in preclinical trials, not yet tested in humans

25
Vaccines being tested in humans, some of which are in more than one trial phase

18
Vaccines in small-scale phase I safety trials

11
Vaccines in large phase II safety trials

5
Vaccines in large phase III trials

SOURCE: WHO, 27 JULY 2020

Risk factors

Can blood type alter covid-19 risk?

Blood type may affect whether you catch the coronavirus or the severity of your symptoms

Graham Lawton

YOU may have heard that your blood type can protect you against covid-19, or make you more vulnerable. The science suggests that it can do both, a bit, but researchers say that it is too soon to make decisions about personal risk based on your blood group.

The idea that blood type might affect susceptibility to infection by the coronavirus that causes covid-19 began circulating in March after a team led by Jiao Zhao at the Southern University of Science and Technology in China posted preliminary results online.

The team's starting point was the fact that susceptibility to the SARS coronavirus is affected by blood group, with type O somewhat protective against catching it. Other viruses are also blood-group dependent: people with type A blood have been found to be more susceptible to hepatitis B and HIV.

The Chinese team blood-typed 2173 people in hospital with covid-19. They found more in blood group A and fewer in blood group O than in the general population, suggesting type A was associated with a higher risk of infection and type O with lower risk.

Michael Zietz and Nicholas Tatonetti at Columbia University Irving Medical Center in New York found a similar pattern, but only among patients whose blood type was rhesus positive (see "What is a blood type?", right).

The earlier work on the SARS virus had shown that protection enjoyed by people with type O blood was due to them already having protective antibodies, which may have been a response to immunogenic molecules, or antigens, from other pathogens. These antibodies stopped the SARS virus latching onto a cell receptor called ACE2, which it uses to break into human cells.

Those antibodies seen in people with type O blood appear to have been elicited by antigens very similar to those on type A blood cells. This could explain why people in the type A blood group don't have these antibodies: even if they had been exposed to the same pathogens as those people with type O blood, their immune systems would recognise the antigens as "self".

"Susceptibility to the virus behind SARS is affected by blood group, with type O somewhat protective"

Given the biological similarity of the SARS virus and the novel coronavirus, both teams of researchers speculate that the same mechanism is behind the protective effect. However, susceptibility to infection doesn't necessarily equate to risk of getting seriously ill.

"There are two separate questions," says Anahita Dua at Massachusetts General Hospital. "Number one, is blood type related to susceptibility to the virus? The second is, once you've got it, does your blood type make you have a worse outcome?" On the second question, the evidence is "all over the place", she says, and mostly in non-peer-reviewed research. The New York team, for example, found no association.

Last month, an international collaboration published a peer-reviewed study of 1590 people from Italy and Spain who had gone into respiratory failure while being treated for covid-19 (*NEJM*, doi.org/gg2pqx). Genome scans showed two variants associated with the severity of their disease.

One was a cluster of six genes with several possible links to the disease, including genes that regulate ACE2; the other was the ABO blood group system. The result is "striking", says Mark Caulfield at the William Harvey Research Institute in the UK, but needs to be replicated.

The latest research by Dua's group hasn't helped to clear up the confusion. They analysed medical data from thousands of people with covid-19 in the Boston area (*Annals of Hematology*, doi.org/gg4sc7). "We looked at blood type and severe disease and death, and we found no association," says her colleague Christopher Latz. However, says Dua, the possibility cannot be ruled out and, if it is real, would be a useful tool in assessing patients' prognoses. "But more research is needed to come to a thorough conclusion," says Latz.

ROBIN UTRECHT/ABACA/PA IMAGES

Blood vials in a Dutch lab being tested for coronavirus antibodies

What is a blood type?

There are two main blood groupings in humans, called ABO and rhesus. Both are genetically determined. The ABO system has three gene variants known as alleles: A, B and O. Each of us inherits two, one from each parent. A and B are dominant and O is recessive, so people who inherit two Os are blood group O and everybody else is either A (AA or AO), B (BB or BO) or AB.

Rhesus is similar, but has only two alleles, Rh+ (dominant) and Rh- (recessive). The groupings are independent of each other so somebody who is A can be either rhesus positive or rhesus negative, for example.

Blood types are expressed as molecules on the surface of red blood cells. There are four types of these molecules: O, A, B and Rh+ (Rh- is simply the absence of Rh+). Everybody has the O type regardless of their blood group, which is why O-negative blood can be transfused into anyone. But the wrong blood type – say, somebody who is O or B being given type A blood – will provoke a violent immune response.

Cosmology

Best map of the universe created

It charts 11 billion years of the cosmos and deepens a long-standing mystery

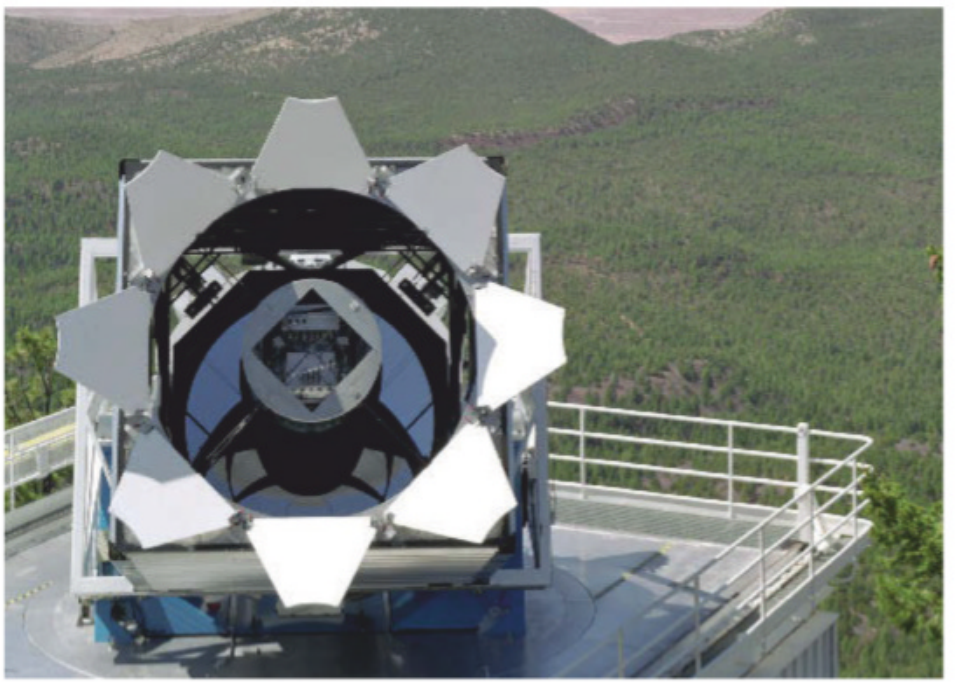
Leah Crane

A HUGE 3D map depicts 11 billion years of cosmic history and places the tightest constraints ever on our best model of the universe. Captured by the Sloan Digital Sky Survey (SDSS), it has bolstered our leading picture of the cosmos, even though it deepens one enduring mystery.

Light travels at a finite speed, so looking into space also means peering back through time. This new survey looks deep enough to map 80 per cent of the universe's 14-billion-year history. "There isn't anything else with that range of coverage and that allows us to fill this 11-billion-year gap between the ancient and recent universe," says Kyle Dawson at the University of Utah, who leads the extended Baryon Oscillation Spectroscopic Survey (eBOSS) team at SDSS.

The team observed galaxies and quasars, which are the bright centres of some galaxies, and used their red shifts – changes in light due to them moving away from us – to measure distances and the rate of expansion of the universe. This lets us watch giant structures such as galaxy clusters forming.

"The universe now is very clumpy: there can be large things like galaxies or planets in one place, or nothing in another place," says Scott Dodelson at Carnegie Mellon University in Pennsylvania. That wasn't always the case. "It used to be that if you went to one random place and counted 1000 atoms and then went to another random place, you might count 1001 but probably not even 1002."



SLOAN DIGITAL SKY SURVEY

The Sloan Digital Sky Survey uses a 2.5-metre telescope in New Mexico

Our leading approach to understand how the universe went from mostly homogeneous to clumpy is a model called lambda-CDM. Some past measurements have hinted that what we see in the universe may not match that model's predictions, but the eBOSS map shows no conflict at all (arxiv.org/abs/2007.08991). So lambda-CDM is holding up well.

The development of large-scale structure is partly dependent on the behaviour of particles known as neutrinos in the early universe; eBOSS was able to constrain their mass, which is a big outstanding problem in physics. It didn't quite nail it down, but the measurement was as precise as the best ground-based neutrino experiments.

The team also constrained the shape of the universe 10 times more tightly than our next best set of observations. As predicted by lambda-CDM, space-time as a whole seems to be flat, not curved.

However, one existing conflict has been exacerbated by the survey. "Things are fitting together remarkably well, with the exception of the Hubble constant," says Wendy Freedman at the University of Chicago. This is a measure of the rate of expansion of the universe. Our two main ways of calculating it – using the ancient cosmic microwave background (CMB) versus a local measurement of the movement of nearby objects – always disagree.

The eBOSS study agrees with the CMB method, which deepens the puzzle. "There's probably some missing physics somewhere, but nobody has been able to come up with it yet," says Freedman. ▮

Machine learning

AI learns to recognise individual birds from behind

ARTIFICIAL intelligence has been trained to identify individual birds. The system is being developed for biologists studying wild animals, but could be adapted to help people recognise birds in their surroundings.

André Ferreira at the Center for Functional and Evolutionary Ecology in Montpellier, France, started the project while studying how sociable weavers contribute to their colonies. This is normally done by putting coloured tags on their legs and sitting by nests to watch them, which is very time-consuming.

So Ferreira and his colleagues turned to AI. The difficult part is getting the photographs required to train the system. "We need thousands of pictures of the same individual," says Ferreira. The researchers solved this problem by putting RFID tags on the birds, which triggered cameras at bird feeders.

The system has so far been tested on captive zebra finches, wild great tits and wild sociable weavers. Tests with photographs that weren't used for training reveal its accuracy is around 90 per cent for a single image (*Methods in Ecology and Evolution*, doi.org/d438).

For now, the system is still quite limited. It has only been trained on pictures of the back of birds, as that is the view biologists usually get when observing behaviour. It might also fail if the appearance of a bird changes, such as during moulting.

"The system could be adapted to help people recognise individual birds in their surroundings"

However, Ferreira thinks that all these issues can be overcome if given large-enough data sets. He and his team are now setting up cameras to take pictures from multiple angles, not just the back. The plan is to release the software for others to use as it is further developed. ▮

Michael Le Page

Life

Revived bacteria may be 100 million years old

Colin Barras

MICROBES that have been hibernating deep below the Pacific Ocean since the reign of the dinosaurs have been revived in the lab. Some may be 100 million years old, perhaps making them the longest-lived life forms on Earth.

We already know that microbes can survive deep below our planet's surface, even though nutrients are generally scarce. Biologists suspect that the microbes enter a minimally active mode to stay alive. But whether they can emerge unscathed has been unclear.

Now a team led by Steven D'Hondt at the University of Rhode Island and Yuki Morono at the Japan Agency for Marine-Earth Science and Technology has studied about 7000 individuals of a bacterium found living in mud 75 metres beneath the sea floor, 5700-metres-deep in the South Pacific Ocean.

"We didn't know whether we had fully functioning cells or zombies capable of doing very few things," says D'Hondt.

Bacteria were retrieved from the South Pacific Ocean

CHRIS NEWBERT/NATUREPL

In the lab, the researchers gave the microbes nutrients laced with distinctive isotopes of carbon and nitrogen. Within 10 weeks, these isotopes began showing up inside the microbes, indicating that they had begun to feed like typical bacteria (*Nature Communications*, DOI: 10.1038/s41467-020-17330-1).

That is remarkable considering what the bacteria have been through, says Jens Kallmeyer at the GFZ German Research Centre for Geosciences in Potsdam. He says the mud in which the bacteria were found is capped by layers of silicon dioxide that no microbe could penetrate. This implies that the microbial populations have been trapped since the mud was buried under the silicon dioxide an estimated 101.5 million years ago. Given that this mud contains few nutrients, survival must have been challenging. "Nowhere else on Earth do you find sediment as close to totally dead as this," says Kallmeyer.

7000

Microbes taken from beneath the ocean floor to be studied

The microbes may be even more astonishing than that. Although they can probably gather sufficient nutrition from the mud to repair cellular damage, it isn't clear if the mud contains enough nutrients to fuel cell reproduction. "They may have divided since they were buried, or they may not," says Virginia Edgcomb at the Woods Hole Oceanographic Institution in Massachusetts. "I don't think anyone knows."

If cell division is difficult there, some of the bacterial cells might be as old as the mud itself. "I mention this possibility in talks and it drives some researchers nuts," says D'Hondt. Many biologists are unsettled by the idea that individual bacterial cells could survive for 100 million years.

There have been a handful of claims for even older microbes on Earth. One team claimed in 2000 to have resurrected microbes trapped inside 250-million-year-old salt crystals, but some researchers suspect that the microbes were seen as a result of sample contamination, which is unlikely to be the case in the new study.

Because the deep-sea microbes must have patched and repaired themselves countless times, it is perhaps down to philosophers to decide whether any individual cell really is 100 million years old. D'Hondt believes they qualify. "I sometimes use the metaphor of my grandfather's hammer," he says. "My grandfather gave a hammer to my father and my father gave it to me. We've replaced the head twice and the handle three times, but it's still the same hammer." ▮

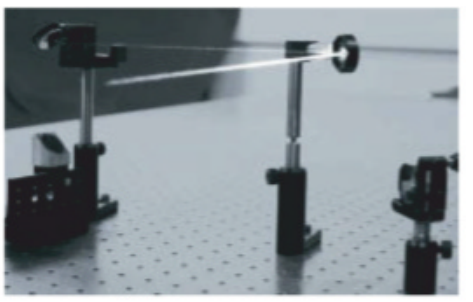
Physics

Light caught on camera as it flies through the air

Leah Crane

AN ULTRA-FAST camera has captured a video of light as it bounces between mirrors.

Although light isn't normally visible in flight, some photons from a laser pulse will scatter off particles in the air and can be picked up by a camera. Using these photons to recreate the pulse's trajectory is difficult, because by the time they reach the camera, the pulse has moved to a new location.



KAZUHIRO MORIMOTO ET AL.

This laser pulse appears as a white line following a path between mirrors

Edoardo Charbon at the Swiss Federal Institute of Technology in Lausanne and his colleagues used a camera with a shutter speed of about a trillionth of a second to take pictures and video of a laser beam following a 3D path.

Knowing exactly how long the pulse took to get to the camera, along with the pulse's trajectory in a flat plane, allowed a machine learning algorithm to reconstruct the entire 3D path of the burst of light (arxiv.org/abs/2007.09308).

This could be useful in chemistry, says Marty Baylor at Carleton College in Minnesota. "You could watch light interacting with a molecule in real time", giving a more detailed understanding of certain chemical reactions, she says.

A similar method could also be used to see around obstacles, says Charbon. If you bounced a laser pulse off a wall, then off an obscured object around a corner and back off the wall again before capturing it, the algorithm could potentially reconstruct an image. ▮

Genetics

How the slave trade left marks in the DNA of people in the Americas

Michael Marshall

A STUDY of the DNA of people in the Americas with African heritage has revealed overlooked details about the transatlantic slave trade.

"This gives some clarity and some sense of individual history," says historian Linda Heywood at Boston University in Massachusetts, who wasn't involved in the research. DNA evidence means African Americans can pinpoint where their ancestors were abducted from and reclaim aspects of their heritage that were hidden by the slave trade, she says. "It broadens the way in which identity and personal history can be thought about."

An estimated 12.5 million people were taken from Africa to the Americas between the 1500s and 1800s, according to historical texts like shipping documents and records of people being sold.

To fill out the picture, Steven Micheletti of consumer genetics firm 23andMe in Sunnyvale, California, and his colleagues looked at DNA from 50,281 people, including 27,422 people from across the Americas with a minimum of 5 per cent African ancestry, 20,942 Europeans and 1917 Africans. This allowed them to identify stretches of DNA that are unique to people from particular regions of Africa (*American Journal of Human Genetics*, doi.org/d4sc).

In line with historical records of where slaves were taken from, the African DNA in people in the Americas was most similar to that of people living in western and central African countries like the Democratic Republic of the Congo, Senegal and Angola.

However, most people in the Americas with African ancestry won't have DNA from a single region of Africa, says Micheletti. That is partly because slave traders disregarded ethnic identities, mixing people from different groups, and partly because African Americans moved around within the US.

Because so many people were abducted as slaves, much of the genetic diversity in Africa was carried to the Americas, says Eduardo Tarazona-Santos at the Federal University of Minas Gerais in Belo Horizonte, Brazil. "But within the Americas, this diversity was more homogenised between populations."

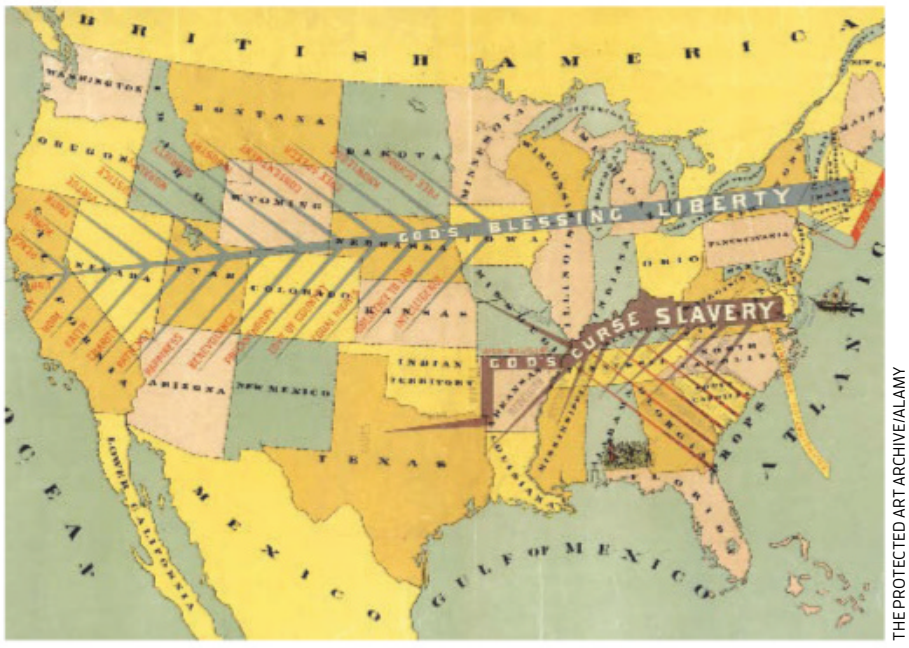
The analysis points to overlooked details of the slave trade. For instance, the team found less DNA from Senegal, Gambia and regions in other neighbouring countries than would be expected given the huge numbers of people taken from there. This may be because those slaves were often taken to rice plantations in the US, where the death rate was high due to malaria, says the team.

"The transatlantic slave trade carried much of the genetic diversity in Africa to the Americas"

Meanwhile, many people in Central and South America and on many Caribbean islands today carry little African DNA – despite the fact that 70 per cent of slaves who survived the trip to the Americas were sent there.

This may reflect a form of racism once practised in Brazil, says Joanna Mountain, also of 23andMe, in which women of African descent were raped or forced to marry Europeans to promote "racial whitening". In contrast, in the US, African Americans were often segregated from white people by law, and racial intermarriage was illegal or taboo.

The analysis also confirms that female slaves have passed on much more of their DNA than male slaves – even though historical records show the majority of people taken from Africa were male. This is probably because female slaves were subjected to rape and sexual exploitation. ▮



THE PROTECTED ART ARCHIVE/ALAMY

This 1888 map of the US was drawn up by an abolitionist

Space

Chernobyl mould tested as radiation shield on ISS

Alice Klein

A RADIATION-absorbing fungus found at the destroyed Chernobyl nuclear reactor has been shown to absorb harmful cosmic rays on the International Space Station, and could potentially be used to protect future Mars colonies.

Exposure to cosmic rays poses a major health risk to astronauts leaving Earth's protective atmosphere. Shields can be made out of stainless steel and other materials, but must be launched from Earth, which is hard and costly.

Xavier Gomez and Graham Shunk saw research showing that a fungus called *Cladosporium sphaerospermum* found in the ruined Chernobyl nuclear reactor could absorb high levels of radiation, and wondered if it could function as a space radiation shield.

They were able to send a Petri dish containing the fungus to the ISS in December 2018 for 30 days to test their idea. They could only send a thin layer of the fungus – just 2 millimetres – but it still blocked about 2 per cent of incoming radiation (bioRxiv, doi.org/d4vm).

This suggests a 21-centimetre-thick layer of the fungus would be enough to effectively shield people on Mars, says Gomez, who is now a student at the University of North Carolina, and Shunk, who is at the North Carolina School of Science and Mathematics.

"What makes the fungus great is that you only need a few grams to start out, it self-replicates and self-heals, so even if there's a solar flare that damages the radiation shield significantly, it will be able to grow back in a few days," says Nils Averesch at Stanford University in California, who is collaborating with the pair.

The fungus couldn't be grown outdoors on Mars because it gets too cold, but it may be possible to incorporate it inside insulated building walls, says Averesch. ▮

Space exploration

China launches mission to Mars

It is one of three spacecraft heading to the Red Planet this month

Leah Crane

THIS year's hottest destination is Mars. On 23 July, China launched the Tianwen-1 mission to the Red Planet – one of three spacecraft slated to head there in 2020.

This is China's second interplanetary mission, but the first that the nation has launched on its own. The other, Phobos-Grunt, was a collaboration with Russia that didn't make it out of Earth's orbit after blasting off in 2011.

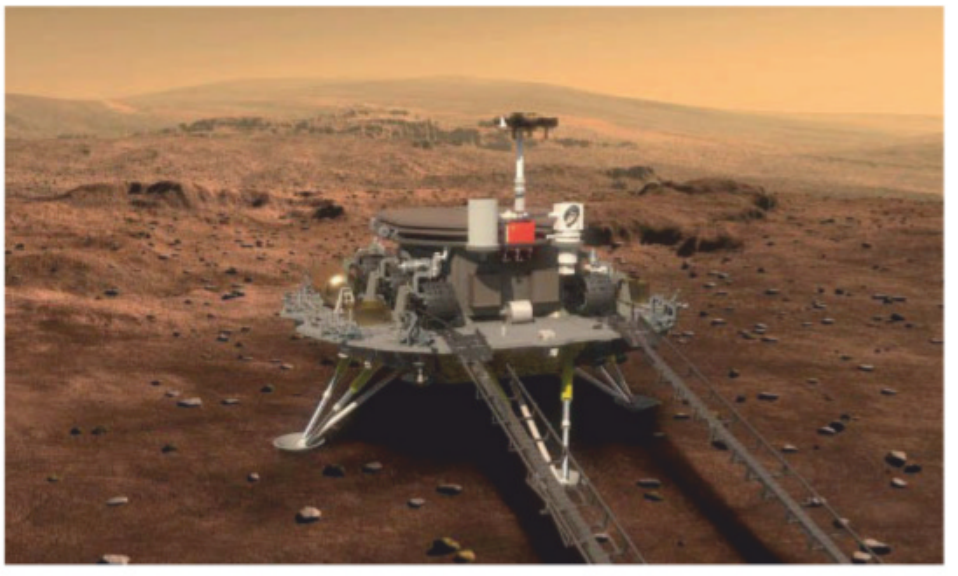
The new mission, called Tianwen-1 – which translates as "questions to heaven" – consists of an orbiter, a lander and a rover, the last of which will be named via a public competition.

"It's very ambitious because it's a four-part mission: there's the launch, getting into orbit, the landing and the rover, and every single step has to go right," says space consultant Laura Forczyk.

All those steps must work on the first try, a feat no other space programme has accomplished on a Mars mission because of the difficulty of landing there. "No planetary missions have ever been implemented in this way," wrote the mission's scientists in *Nature Astronomy* (doi.org/d4vg).

If all goes well, Tianwen-1 will arrive at Mars in February 2021 and the lander and rover will touch down two or three months later. They will take pictures from the surface, measure the soil composition, make radar observations of the planet's underground structure and observe Mars's magnetic field.

The Tianwen-1 mission includes a Mars lander and a rover



CNSA

Due to the harsh environment on Mars, the rover is expected to last about 90 Martian days. It weighs around 240 kilograms, about the same as China's Yutu-2 rover, which is currently roaming the moon. "The Chinese mission to the far side of the moon has been hugely successful, so they're building on that success now," says Forczyk.

The orbiter, which will relay data from the lander and rover back to scientists on Earth, also carries a suite of scientific instruments. It has two cameras and a spectrometer, which it will use to create a map of the mineral composition of Mars's surface, as well as radar and detectors to examine particles in the Martian atmosphere. It will also look for deposits of water ice that could be helpful for future explorers.

90

Number of Martian days that China's rover is expected to last

Tianwen-1 won't be alone in Mars orbit. The United Arab Emirates has just launched its first mission to Mars, and NASA's Perseverance rover is set to launch on 30 July. These missions are all leaving now because Mars is at its closest point to Earth, which happens once every two years. They will arrive at Mars around the same time and help us understand the planet and its history.

"If we learn what Mars is truly like and how we can operate there robotically, then those lessons can be applied to future human missions," says Forczyk.

Biodiversity

Spiderwebs can help us monitor forest life

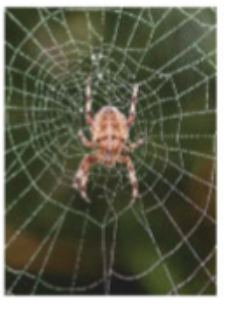
SPIDERS may build their webs to catch prey, but trials in Slovenian forests show they can also serve as a way for humans to monitor the biodiversity of ecosystems.

There has been growing interest in detecting species by collecting the fragments of DNA they shed in an environment, a method that can be less invasive and quicker than surveying with nets and trays.

Matjaž Gregorič at the Slovenian Academy of Sciences and Arts turned to an unusual tool to collect such environmental DNA: the orb webs of garden spiders (*Araneus diadematus*) and sheet webs of common hammock-weaving spiders (*Linyphia triangularis*).

The webs act as a passive air filter, capturing DNA from insects, fungi and bacteria – and providing an elegant alternative to the air filtering machines ecologists use, which need to be powered by heavy generators (bioRxiv, doi.org/d4xn).

"The results are fantastic, much more than I hoped for. From 25 webs, I found [DNA from] 50 families of animals: nematodes, butterflies, moths, wasps, bees, beetles and flies, everything. The richness of information surprised us a lot," says Gregorič.



PIX/ALAMY

Orb webs like these can catch DNA from insects in the surrounding area

He and his colleagues got the idea from a 2015 trial in a zoo, but Gregorič says this is the first proof of concept in the wild. The approach could complement traditional surveying of pollinators, which are suffering major declines, or to detect pests or invasive species.

The use of environmental DNA to monitor ecosystems is growing, with the technique being deployed by regulators in English rivers and lakes. It doesn't require years of taxonomical knowledge to identify species, which instead have their DNA matched against databases. "You don't have to be a spider expert to use spiderwebs," says Gregorič.

Adam Vaughan

Viruses

The Vikings may have had a milder version of smallpox

Michael Le Page

THE DNA of ancient smallpox viruses has been found in the bones and teeth of people who died in northern Europe during the Viking age. Unexpectedly, these smallpox strains are quite different to the strain that was eliminated in the 20th century, and possibly far less deadly.

Historical accounts and lesions on Egyptian mummies suggest that the *Variola* virus, which causes smallpox, has plagued people for thousands of years. Barbara Mühlemann at the University of Cambridge and her colleagues now have the first unambiguous evidence.

They started by looking for viral genetic code in previously sequenced DNA from nearly 2000 individuals who lived in Eurasia and the Americas between 30,000 and 150 years ago. "Presumably many people died of the virus," says Mühlemann.

In these people, viral DNA might be present in their remains and could have been sequenced along with their own DNA. Sure enough, the researchers found signs of *Variola* DNA in 26 individuals. They then looked for more viral DNA in the original samples. They found it in 13 individuals, 11 of whom died between AD 600 and 1050. This overlaps with the Viking age from AD 793 to 1066 (*Science*, DOI: 10.1126/science.aaw8977).

Most of these people died in Scandinavia or what is now western Russia. Three were found on Öland island in the Baltic Sea, one in a boat burial from around AD 700 and two others in burials from around AD 1000, who may have died in the same outbreak.

The *Variola* virus was also found in a man from a mass grave in Oxford, UK, which is odd because all 35 men in the grave are thought to be Viking warriors killed in a massacre in AD 1002.

In four cases, Mühlemann's team recovered near complete viral genomes. These reveal that the ancestor of the *Variola* virus probably had about 200 genes, similar to some pox viruses still circulating in animals. The strain eliminated by vaccination in the 20th century – which killed 1 in 3 people – had lost about 30 genes.

The strains that Mühlemann sequenced had lost only half of these 30 genes. They derive from the same ancestor as the 20th-century virus, but didn't give rise to it. Instead, they are a now-extinct side branch.

"It's more complicated than anyone imagined," says team member Terry Jones, also at the University of Cambridge.

THAMES VALLEY ARCHAEOLOGICAL SERVICES

Skulls of Vikings buried in a mass grave in Oxford, UK, in AD 1002

Strains with the full 200 genes typically cause only mild disease, says Antonio Alcamí at the Autonomous University of Madrid, Spain. He thinks the Viking age virus type was less deadly than the 20th-century one. "It was probably able to kill but was not as terrible," he says.

This flies in the face of current thinking, which is that viruses are most deadly when they first jump to humans and evolve to become less deadly, because viruses that kill hosts are less likely to spread.

One explanation for the diversity of strains is that smallpox jumped to people from animals more than once. That might mean it is more likely to happen again than we thought, says Jones.

Increasing numbers of people are being infected by monkeypox virus – whose normal host is unknown despite the name – but so far there has been no sustained human-to-human spread. The increase in cases could be due to the fact that people are no longer being vaccinated against smallpox following its eradication, says Mühlemann. ▮

Wearable technology

Colour-changing hair dye shows your exposure to UV rays

STICKERS and hair dye that change colour in response to ultraviolet light could help people gauge when they are at risk of sunburn.

Alex Mariakakis at the University of Washington in Seattle worked with a team at Microsoft to develop printable stickers that change colour from purple to light pink throughout the day to indicate cumulative exposure to UV light. The patches contain a reference colour scale to show UV exposure, as measured by UV index (UVI) hours, a standard measure of UV radiation.

They also accommodate for different skin tones, which have different minimum UV-exposure points for sunburn, says Mariakakis. The stickers display thresholds corresponding to 0, 3.33, 6.67 and 11.11 UVI hours, which roughly match the minimum amount of UVI hours that can cause sunburn in people of differing skin tones.

After being taught how to compare the colour-changing section with the reference colours, 35 people were able to glance at the patches and determine whether the reading would indicate sunburn risk for three different skin tones with an accuracy of 73 per cent. The work was presented virtually at the 2020 ACM Designing Interactive Systems Conference last month.

The stickers are made from UV-sensitive ink and can be printed in an inkjet printer. The ink uses a photoacid generator – a compound that produces acid when exposed to UV light – as well as a pH-sensitive dye that responds to that acid.

"As you're more exposed to UV, it generates more acid and the dye changes colour," says team member Bichlien Nguyen at Microsoft Research in Redmond, Washington.

"As you are more exposed to UV light, it generates more acid and the dye changes colour"

The team also made hair dye with pigments that change colour in the presence of UV light – from clear to pink, for example. It changes colour irreversibly, so it can only indicate UV intensity at a given moment rather than cumulative exposure throughout a day, like the patch. ▮

Donna Lu

Solar system

Giant impact may have left cracks all over Ganymede

Jonathan O'Callaghan

JUPITER'S moon Ganymede is covered in cracks that may be evidence of a huge collision, making them the largest known impact structure in the solar system.

Ganymede is the solar system's biggest moon, and its ninth biggest object at more than 5000 kilometres across. It is larger than the planet Mercury. Multiple spacecraft have visited it, including NASA's Voyager 1 and Voyager 2 probes in 1979, and the Galileo spacecraft from 1996 to 2000.

Images from these visits revealed cracks or furrows on the surface, each up to several kilometres wide, which appeared to be in concentric rings. Researchers thought they might have been caused by an impact that rocked half the moon, but the true extent of the collision or its location wasn't clear.

Now Naoyuki Hirata at Kobe University in Japan and his team re-examined the images, finding the impact structure may stretch nearly 16,000 kilometres across the surface, meaning it wraps around almost the entire moon, narrowly avoiding meeting up on the other side, and was caused by an impactor 300 kilometres across (*Icarus*, doi.org/d4sn).

This dwarfs the next biggest known impact structure in the solar system, the South Pole-Aitken basin on Earth's moon, which is 2500 kilometres across.

The size of the impact structure had been difficult to constrain until now, says Paul Schenk at the Lunar and Planetary Institute in Houston, Texas, because it didn't form in a normal way. "The icy shell of Ganymede was too thin to form a classical rim like you see on other large craters elsewhere," he says.

Future missions, most notably the European Space Agency's JUICE spacecraft scheduled to orbit Ganymede in 2032, should tell us even more. ▮

Analysis Plastic

How do we clean up planet plastic? The problem is ubiquitous and growing, but knowing the best way to fix it has largely been a guessing game so far, says Adam Vaughan

SOULSURFING - JASON SWAIN/GETTY IMAGES

Plastic pollution washed up on the coast of the Isle of Wight, UK

EVEN if we took every feasible action to cut plastic pollution, we would still only manage to get rid of 78 per cent of it by 2040 compared with a business-as-usual scenario, according to a new analysis. This huge effort would still leave us with an extra 710 million tonnes of pollution by 2040. Are we in a hopeless predicament?

No, says Richard Bailey at the University of Oxford, who worked on the study. While a complete ban on plastics is unrealistic, there is still much we can do, he says.

Pollution aside, a war on plastic makes financial sense. The team found that its ambitious scenario would be about a fifth cheaper than business as usual, as the cost of more waste and recycling facilities would be offset by lower production and selling recycled material (*Science*, doi.org/d4vc).

Yet no single silver bullet, such as mass recycling, is enough. "What we found was there isn't a single thing that we can say we can, 'let's just do loads of X'. We've got to do it all," says Bailey.

Despite it varying by region, the biggest savings at a global level come from curbing plastic use and substituting it for other materials, rather than from better recycling and disposal or from reducing mismanagement of waste, though they are essential too. All the approaches and technologies covered by the study exist today. "We are not asking for something new to be created," says Winnie Lau at the Pew Charitable Trusts in Washington DC, who was part of the research team.

710m

Extra tonnes of plastic pollution by 2040, even with large cuts

Julian Kirby at Friends of the Earth in London points to existing examples of plastic reduction, such as UK football club Arsenal saving 500,000 cups by switching from single-use cups to reusable ones. He believes approaches that depend on consumer demand, like refillable products, could scale-up due to changing public attitudes.

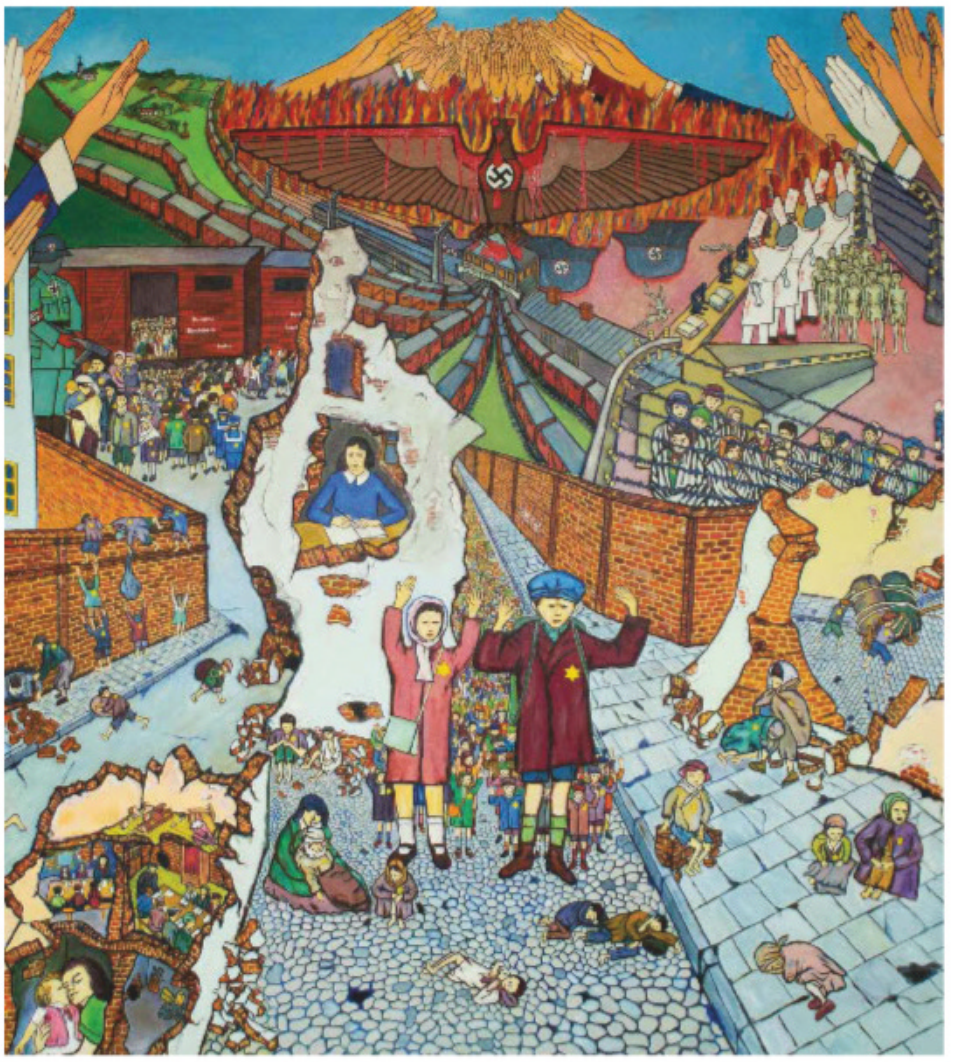
"There is a sense of momentum we've got with plastics now that means the Loop system has a chance of working," says Kirby, referring to the US firm that delivers and takes away reusable containers and has just partnered with Tesco, the UK's biggest supermarket chain.

When it comes to recycling, plastics split roughly into three groups. In the UK, bottles are mostly recycled because it is easy to do and there is an end market for the material. By comparison, pots, tubs and trays are tricky because they are made from so many polymers. Meanwhile, plastic films get contaminated, clog machines and have little end market.

Jacob Hayler at the Environmental Services Association in London says chemical conversion to break polymers down to individual compounds could help with pots, tubs and trays in the future, but is too expensive for now. The study's ambitious scenario assumes that 6 per cent of plastic waste reduction would come from this process, so investment would be required to meet that goal.

Despite innovations and policy changes, some problems will remain. For instance, Lau says that there isn't yet an obvious fix for microplastics from car tyres, about a third of which were recently found to be ending up in oceans.

What's more, the coronavirus pandemic could prove to be either a blessing or a curse. Plastic face masks are already turning up in oceans, and coffee shops have halted the use of reusable cups. "It feels like it's going to make the problem worse in the short run because of more plastic use and potential for waste," says Bailey. "The silver lining is it's an enormous opportunity to change the system, to rebuild things in a different way." ▮



MONTCLAIR STATE UNIVERSITY PERMANENT COLLECTION

Infectious disease

How a Jewish ghetto beat a typhus epidemic in WW2

JEWISH people confined in a Nazi ghetto during the second world war curbed a typhus outbreak through similar control measures to those being used now against covid-19.

Typhus, an often-fatal bacterial disease spread by body lice, swept through Europe in the second world war. Nazi propaganda portrayed Jewish people as major spreaders of the disease to garner public support for imprisoning them in ghettos.

In November 1940, the Nazis walled more than 400,000 Jewish people in a 3.4-square-kilometre ghetto in Warsaw, Poland. The terrible conditions led to typhus rapidly infecting about 100,000 people and causing 25,000 deaths.

But new infections suddenly ground to a halt by October 1941. This was unexpected because typhus usually accelerates at the start of winter. "Many thought it was a miracle," says Lewi Stone at RMIT University in Australia.

To find out how the Warsaw ghetto (depicted in this painting by Israel Bernbaum) stamped out typhus, Stone and his colleagues trawled through historical documents, including some kept by doctors who lived in the ghetto. They found that doctors helped lead efforts to halt the disease, including public lectures on the importance of personal hygiene, social distancing and self-isolation if infected.

Mathematical modelling by the team suggests that these measures prevented tens of thousands of deaths (*Science Advances*, doi.org/d425).

Tragically, almost all the residents were later sent to die in Nazi extermination camps. **Alice Klein**

Environment

Fleet of illegal fishing vessels detected

SATELLITE imaging has revealed hundreds of boats from China fishing off the coast of North Korea, violating UN resolutions prohibiting such activity. It is the largest known case of vessels from one country operating unlawfully in another country's waters.

More than 800 vessels were seen in 2019, say researchers at the non-profit Global Fishing Watch, which traced the boats to Chinese ports and waters. Similar numbers were seen in 2017 and 2018.

It estimates that the vessels, about a third of China's long-range fishing fleet, caught more than 160,000 tonnes of flying squid, rivalling the Japanese and South Korean totals. Stocks of the squid, the main commercially fished species in the area, have fallen sharply in recent years.

"These novel insights are now possible thanks to advances in machine learning and the rapidly growing volume of high-resolution, high-frequency imagery that was unavailable even a couple of years ago," says David Kroodsma at Global Fishing Watch.

Vessels are usually tracked using a transponder identification system, which can be detected by satellite. Boats fishing illegally often turn this off, but satellite-based radar can see all vessels. Combining this with transponder data can reveal which boats aren't reporting their position.

The researchers used satellite images to spot vessels and a machine-learning system to scan images and pick out the distinctive technique of pair trawling, in which two vessels work together (*Science Advances*, doi.org/d4vq).

China's Bureau of Fisheries didn't respond to a request for comment. In response to allegations of illegal fishing in 2019, China told the UN it was already doing everything possible. **David Hambling**

Zoology

Foxes raided ancient humans' rubbish too

WE SHOULDN'T be surprised at how well foxes can survive by scavenging from our food leftovers – the behaviour is around 42,000 years old.

Chris Baumann at the University of Tübingen in Germany and his team analysed animal bones, including those of foxes, bears and wolves, found at sites in Germany. The sites had been dated to three periods: older than 42,000 years ago, when Neanderthals were the only humans in the region, and two later periods when modern humans had moved in, lasting until 30,000 years ago.

GRAHAM RACHER/ALAMY

By measuring different carbon and nitrogen isotopes in the bones, the team worked out what the animals had eaten (*PLoS One*, doi.org/d4wj). In the oldest period studied, the ancestors of today's foxes had fed on a mix of animals, and these were likely to have been killed by bears, wolves and lions.

But after about 42,000 years ago, some foxes had switched to eating mainly reindeer. None of the other carnivores were mostly eating this animal, so the foxes couldn't have been scavenging their kills.

While the humans at that time ate a range of animals, "in cave sites, we find a lot of reindeer bones, because they are easy to transport as whole bodies to the caves", says Baumann. "And if humans butchered them there, it would have produced food waste." **Clare Wilson**

Really brief

JENS WOLF/DPA/AFP VIA GETTY IMAGES

Recent floods are among the worst

The years 1990 to 2016 rank among the worst periods of flooding in Europe in five centuries, according to a study of historical letters, annals and legal records (*Nature*, doi.org/d4sb).

Rats modified to hear the light

Cochlear implants that restore hearing could be improved by genetically modifying the nerve cells in people's ears to respond to light instead of electricity, a study in rats has shown. Optogenetics, as this is called, appears to be safe judging by animal and human studies done so far (*Science Translational Medicine*, doi.org/d4r9).

Coronavirus made the world fall silent

Lockdowns to contain the coronavirus led to drastic falls in the vibrations of Earth's surface, as people significantly curtailed their activity. Records from 268 seismometer stations around the world revealed a sudden quietening of seismic noise that began in China in late January, then spread to Europe and the rest of the world in March and April (*Science*, doi.org/gg5txj).

Parasites

Why dry mosquitoes prefer human blood

MOSQUITOES living in places with intense dry seasons evolved to bite humans, according to a study of African mosquitoes. The insects need water to breed and may have latched onto us because we often create standing water.

Many mosquitoes feed on a wide range of animals, yet some only bite humans and nobody knew why until now. *Aedes aegypti* mosquitoes often specialise in humans, bringing diseases like Zika and yellow fever with them. But some African populations of the species have a wider diet.

"No one had actually gone through and systematically characterised behavioural variation in Africa," says Noah Rose at Princeton University.

He and his colleagues captured *A. aegypti* eggs from 27 sites in sub-Saharan Africa and raised them in a lab. The mosquitoes were put in a chamber where they could catch a whiff of either a human or an animal – a guinea pig or a quail – to see which they would move towards to attempt to bite.

The researchers then built mathematical models to work out which factors affected the insects' preferences. Those in areas with a long, intense dry season were much more likely to prefer humans (*Current Biology*, doi.org/d4vd).

A long dry season is a problem for *A. aegypti* because it needs standing water to rear its young, says Rose. But humans often create this, whether by storing rainwater or irrigating crops. Mosquitoes that lived thousands of years ago may have been drawn to these places and thus evolved to bite humans. **Michael Marshall**

Animal behaviour

DOUGLAS GIMESY

Night lights may cause major sleep disturbance for birds

CITY lights could seriously disrupt the sleep patterns of birds, according to the first study to look at neurological activity in animals thought to be affected by light pollution.

Researchers used tiny sensors to record brain activity in pigeons and magpies on three nights in an indoor aviary. On the second night, they were exposed to lights with a similar intensity to street lights. As well as white light, the study looked at amber light, which previous studies have suggested may have less impact on sleep.

The lighting had an effect on both rapid eye movement (REM) sleep and non-REM sleep. Magpies were more affected by white light than amber light, losing 76 per cent of their non-REM sleep, while pigeons lost about 4 hours of sleep in total, regardless of the type of light (*Current Biology*, doi.org/d4wm).

"Sleep loss can cause problems for behaviour, health and development, so if birds can't adapt or tolerate light at night, they might suffer poorer health, produce fewer offspring or have to find new habitats," says co-author Anne Aulsebrook at the University of Melbourne and La Trobe University, Australia. Sam Wong

Robots

Flapping drone can hover like a bird

A DRONE that flaps its wings and can make quick turns like a bird could one day be used to monitor crowds or check on crops.

It consists of a battery and motor attached to a set of X-shaped wings made from polyurethane film and carbon fibre. It has rear stabilising fins of expanded polystyrene.

Other robots with flapping wings can't hover because it takes too much energy, says Yao-Wei Chin at Nanyang Technological University in Singapore, who built the drone with his colleagues.

"Being able to hover and make quick turns requires excess thrust," says Chin. "Our prototype has an excess thrust of about 40 per cent of its body weight, which allows it to climb fast."

This is achieved by maximising the drone's energy efficiency. The nylon hinges of its wings minimise wobbling and help recover kinetic energy lost during flapping.

The 27.5-gram robot can fly at up to 8 metres per second and stay in the air for up to 8 minutes on a single battery charge (*Science Robotics*, doi.org/d4wq).

"Its wings are slow and flexible and so do not risk cutting people," says Chin. It could also monitor crops without fear of damaging them. **Jason Arunn Murugesu**

Annalee Newitz is a science journalist and author. Their latest novel is *The Future of Another Timeline* and they are the co-host of the Hugo-nominated podcast *Our Opinions Are Correct*. You can follow them @annaleen and their website is techsploitation.com

Annalee's week

What I'm reading
Our History is the Future *by Nick Estes, a deeply researched history of uprisings by indigenous people in the US.*

What I'm watching
The surprisingly smart and sweet time-loop movie Palm Springs.

What I'm working on
I'm researching the history of psychological warfare.

This column appears monthly. Up next week: James Wong

Columnist

Fake news forecasting

A social media weather report that predicts outbreaks of propaganda is on its way. It can't arrive soon enough, says **Annalee Newitz**

A FEW weeks ago, I noticed that a foul and offensive hashtag was trending on Twitter. Like a horror movie character who goes into the basement after hearing monster noises, I clicked on it.

Every post on the hashtag was like a parody of a political debate, with each side making the same screaming accusations. It was almost as if these people had learned to argue from bad algorithms.

That is when it hit me. Maybe these angry tweets were generated by algorithms. Or by operatives at a place like the Internet Research Agency in Russia, where they make memes to fan the flames of the political trash fire in the US. Not for the first time, I wished that I could check some kind of social media weather report on outbreaks of propaganda.

That dream isn't so far from being turned into reality, it turns out. Meysam Alizadeh at Princeton University is making an automated system for identifying trolls on social media – and predicting what they will say next. He and his team say they want to create a public dashboard that shows "what's happening on social media and whether there is coordinated activity sponsored by foreign states".

To do that, they have trained a set of algorithms to spot the telltale signs of so-called influence campaigns. The group started by working with data sets released by Twitter and Reddit, which contained distinct troll activities originating in Russia, China and Venezuela between 2015 and 2018.

The campaigns were all aimed at the US, but they had very different approaches. Trolls from China seemed mostly to target people in the Chinese diaspora, especially ones with an interest in Islam. Venezuelan trolls tended to be bots spouting political news and links to fake news websites.

> **"These weren't bots spewing automated hate; they were Russian operatives, reacting to US news in real time"**

The Russian trolls were the craftiest. They responded quickly to current events in the US. Their posts about Black Lives Matter spiked during protests, and ones about Islam peaked during President Donald Trump's various travel bans on Muslims entering the US.

Alizadeh says there was a distinct, week-long Russian influence campaign aimed at actor Alec Baldwin, who has done many satirical impressions of Trump on *Saturday Night Live*. Alizadeh speculates that these weren't bots spewing automated hate; they were trained Russian operatives, reacting to US news in real time.

Once the algorithms had learned these distinct patterns, Alizadeh and his colleagues set them loose on data sets that contained some troll posts and some "control" posts from typical users. After several tries, the algorithms were able to predict whether or not a post was from a troll most of the time. The Venezuelan trolls were easiest to identify, with 99 per cent accuracy on some tests. When it came to Chinese and Russian trolls, the algorithms got it right between 74 and 92 per cent of the time (*Science Advances*, doi.org/d4p7).

That isn't perfect, but it is a lot better than I can do with my armchair speculation about how a nasty hashtag might be an influence campaign.

The real question is, how do you separate real social media nonsense from fake, when the fake accounts are so nimble and constantly changing what they are discussing? Alizadeh says the answer is to train these troll-seeking bots on new data every month. Based on the previous month's activity, he believes it is possible to generate accurate propaganda weather reports for the next month.

Here's hoping that Alizadeh's algorithms are coming to a social media platform near you. I can't wait for the warnings: "An 80 per cent chance of foreign government-sponsored disinformation about Islam this week, with a 40 per cent chance of conspiracy theories about voting." ▮

Editor's pick

I have witnessed bias in my work at university

27 June, p 14

Name and address supplied

You report on institutional racism in science. I am a white woman in a fairly senior support role at a university, but I have seen racism and sexism in my own institution.

It isn't just the hurdles that BAME students have to overcome or the more obvious forms that discrimination can take, but also the daily small-scale occurrences of bias that can make life unbearable for both BAME people and women in science. It is even worse if you happen to be a BAME woman.

I am not a social scientist, so I don't know how we might change these behaviours other than by challenging them when they happen in front of us. We have compulsory online training about unconscious bias, equality and diversity, but I suspect it needs something more personal and provocative. Consistent efforts to ensure a better attitude by senior staff, plus disciplinary action in some cases, will be required to bring about change. It is, however, the responsibility of those of us in the privileged groups to work for and aspire to real change.

Immunity may still have some benefits

11 July, p 9

From Tony Cains, Northampton, UK

When discussing why there hasn't yet been another wave of the coronavirus in the UK, you say one explanation that can be ruled out is herd immunity as the level required for this virus has been estimated at 60 per cent, while studies suggest that "just 1 to 10 per cent of people have antibodies to the virus".

This misses two critical points. Firstly, some parts of the UK have a much higher antibody prevalence than this – London as a whole is close to 20 per cent, for example, and some boroughs presumably have even higher levels than this.

Logically, the places most vulnerable to a resurgence of the virus are those where it spread the fastest before – areas with high housing density and high use of public transport, for instance. These places are exactly where immunity is at its highest. Secondly, even at immunity levels well below 60 per cent, there could be a significant reduction of spread.

So while the main reasons for the lack of a second wave are probably the continuing precautionary behaviours and the remaining restrictions, as Clare Wilson suggests, the possible contribution from existing immunity shouldn't be ignored.

We must do more about indoor airborne transfer

Letters, 4 July

From Nick Baker, Rowhedge, Essex, UK

I share Peter Borrows's feelings on inverse square laws applying to social distancing. But there is another mechanism beyond direct transfer that is relevant to stopping the coronavirus. The question of indirect transfer – inhaling contaminated air that has been circulated from a distant person – seems relatively neglected.

In anything but still conditions, the respiratory plume from an infected person who is outdoors will quickly be carried away. Even in still outdoor conditions, the temperature difference between the plume and the ambient air should ensure that it is convected upwards away from head height.

This useful effect, which might also occur in large indoor spaces like supermarkets, can be nullified by ceiling fans. Even desk fans only serve to move virus-laden air laterally, rather than dilute it.

When investigating indoor air quality, it is common practice to monitor carbon dioxide levels. Since CO_2 is also a respiratory product that responds to occupancy density and to dilution caused by ventilation, this could be used as a surrogate for microdroplets and as an indicator of risk. Advice for indoor gatherings should include "open all the windows, turn down the heating and turn off the fans".

Reasons why distant oceans may be lifeless

20 June, p 40

From Ben Haller, Ithaca, New York, US

Kevin Hand, in reference to moons in our solar system with ice-capped oceans, says the presence of microbial life in a range of extreme environments on Earth suggests that "if life emerges easily wherever the conditions are right, then these alien oceans beyond Earth should be inhabited".

This would seem to conflate two things: where life can originate and where it can evolve and adapt to survive after it has originated. We don't really know much about the beginnings of life, but it seems likely that the range of habitats in which life can originate is much narrower than the range it can subsequently adapt to. The oceans that Hand discusses may have never had conditions under which life could begin, even if it could have ultimately adapted to them.

We may be seeing the first TV signals of alien worlds

11 July, p 14

From Ian Simmons, Thorpe Bay, Essex, UK

Jason Wright may not be able to think of a reason why the Odd Radio Circles (ORCs) recently found by astronomers might be created by aliens, but there may be one. We know that when our civilisation began broadcasting radio waves, these also spread out from our planet in an expanding sphere that, in theory, could be detected by alien civilisations. It seems to me that, seen from a great distance, such a sphere might look something like an ORC.

This would also account for the edges of the ORCs being brighter than their interiors. When we began broadcasting, we needed to use very highly powered transmitters to distribute the signal, but as technology improved, the same effect was achieved at lower power.

Recently, more and more signals have been distributed via cables rather than by broadcasting. This would result in a very radio-bright edge with a less bright interior. As these signals are only now coming within the sensitivity range of our telescopes, it could well be that we are making our first observations of the TV and radio signals from alien civilisations.

What happens to water-filled windows in a fire?

11 July, p 15

From Scott McNeil, Banstead, Surrey, UK

Regarding the use of water instead of argon in double-glazing, two thoughts come to mind. Firstly, wouldn't water add a fair amount of weight to each window? This wouldn't just be from the weight of water, but also from the frame and seals, which would have to be upgraded. Would building designs need to be modified to take this additional weight into account?

Secondly, how does this window react in the event of a serious fire? Is there a pressure release system? Otherwise, if the water has been heated to over 100°C before the window breaks, this would result in an instantaneous (and possibly explosive) release of steam when the pressure is released – which is unlikely to please any firefighters in the vicinity. ▮

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The end of the universe

There are many ways that the universe could come to an end. A book that explores them is a fascinating tour of physics, says **Leah Crane**

Book

The End of Everything (Astrophysically Speaking)
Katie Mack
Scribner

DETLEV VAN RAVENSWAAY/SCIENCE PHOTO LIBRARY

A "big rip" could cause galaxies to be torn apart in billions of years' time

"PHYSICS is wild." Katie Mack repeats this on at least two occasions in *The End of Everything*. It is a mantra for her book, which guides readers on a tour of some of the wildest areas of physics and how they will someday contribute to the end of the universe.

For a book on a seemingly grim subject, it made me chuckle on many occasions, particularly the footnotes, which read like a director making snarky asides about her own film. The main text is more like an animated discussion with your favourite quirky and brilliant professor. Its references range from William Shakespeare and Nicolaus Copernicus to Friedrich Nietzsche and modern science fiction.

What stands out most is Mack's pure enjoyment of physics, and it is contagious. She describes primordial black holes as "awfully cute in a terrifying theoretical kind of way", antimatter as "matter's annihilation-happy evil twin", grand unified theories as "all-in-one particle physics part[ies]" and the universe as "frickin' weird". All of these are true, and Mack entertainingly explains why.

The frame for Mack's rollicking tour through the nooks and crannies of physics is an exploration of the ways our universe might end, from the relatively mundane (everything just keeps getting further apart forever) to the mildly terrifying (a bubble of death that expands at the speed of light until it devours everything without warning).

We don't know for sure which of these dooms will occur because some of the biggest questions in the universe, such as the nature of dark matter and dark energy, remain unanswered.

Mack acknowledges that many of these concepts are hard to explain without heavy use of mathematics, and then goes on to explain them expertly with no equations whatsoever.

"The book is like an animated discussion with your favourite quirky and brilliant professor"

As I spend a lot of my time reading about cosmology and speaking to cosmologists about these issues, I didn't expect to learn too many new facts and concepts. I was pleasantly surprised. I learned a great deal, including how white dwarf stars work, how extra dimensions might affect our own universe and the ominous nature of the big crunch, in which the entire universe contracts and returns to its beginning state.

Mack's explanations range from the colossal (galaxies colliding) to the seemingly humdrum (why air conditioners are bad for the environment), and she seems to have unending curiosity and enthusiasm for all of it.

Like any physics book, there are areas that are somewhat confusing – Mack could no more get me to understand "large" or "small" extra dimensions than the cosmologist I once asked to confirm that a small extra dimension wasn't "small like a jelly bean". But overall, the clarity was refreshing, even when the state of physics theory on the matter is somewhere between "we are still trying to understand" and "we will probably never know".

Unlike any other astrophysicist or cosmologist I have asked, she manages to coherently explain the big rip, in which dark energy tears asunder everything from clusters of galaxies down to single atoms, without using the word "virialised" (physics jargon that basically means "gravitationally bound and stable").

It is also refreshing, the state of the world being what it is right now, to read about something larger.

Every one of the scenarios in the book is only likely to take place billions of years in the future, long after Earth has been vapourised in the expanding sun.

As the final chapter acknowledges, there are infinite ways to feel about the end of the universe, and you may feel differently about different sorts of end. No matter how hard things are here on Earth right now, at least the universe hasn't become so hot that even stars "catch fire".

What all the endings have in common is to highlight the vastness of the universe, and the banality of our everyday existence.

If you need a moment to be distracted from everyday life and journey to the deep cosmic future, I highly recommend *The End of Everything*.

In it, Mack seems unable to help describing complex physics concepts as "fun" and "cool". She is right, and her book is also fun and cool. ▮

Realities of space travel

Proxima shows the difficulties of balancing family life with a career as an astronaut, finds **Simon Ings**

Film

Proxima

Alice Winocour

In UK cinemas from 31 July

THE year before Apollo 11's successful mission to the moon, Robert Altman directed James Caan and Robert Duvall in *Countdown*. The 1968 film stuck to the technology of its day, pumping up the drama with a somewhat outlandish mission plan: astronaut Lee Stegler and his shelter pod are sent to the moon's surface on separate flights and Stegler must find the shelter once he lands if he is to survive.

The film played host to characters you might conceivably bump into at the supermarket: the astronauts, engineers and bureaucrats have families and everyday troubles not so very different from your own.

***Proxima* is *Countdown* for the 21st century. Sarah Loreau, an astronaut played brilliantly by Eva Green, is given a last-minute opportunity to join a Mars precursor mission to the International Space Station. Loreau's training and preparation are impressively captured on location at European Space Agency facilities in Cologne, Germany – with a cameo from French astronaut Thomas Pesquet – and in Star City, the complex outside Moscow that is home to the Yuri Gagarin Cosmonaut Training Center. She is ultimately headed to launch from Baikonur in Kazakhstan.**

Comparing *Proxima* with *Countdown* shows how much both cinema and the space community have changed in the past half-century. There are archaeological traces of action-hero melodramatics in *Proxima*, but they are the least satisfying parts of the movie. Eva Green is a credible astronaut and a good mother, pushed to extremes on both fronts and painfully aware that she chose this course for herself. She can't be all things to all people all of the time and, as she learns, there is no such thing as perfect.

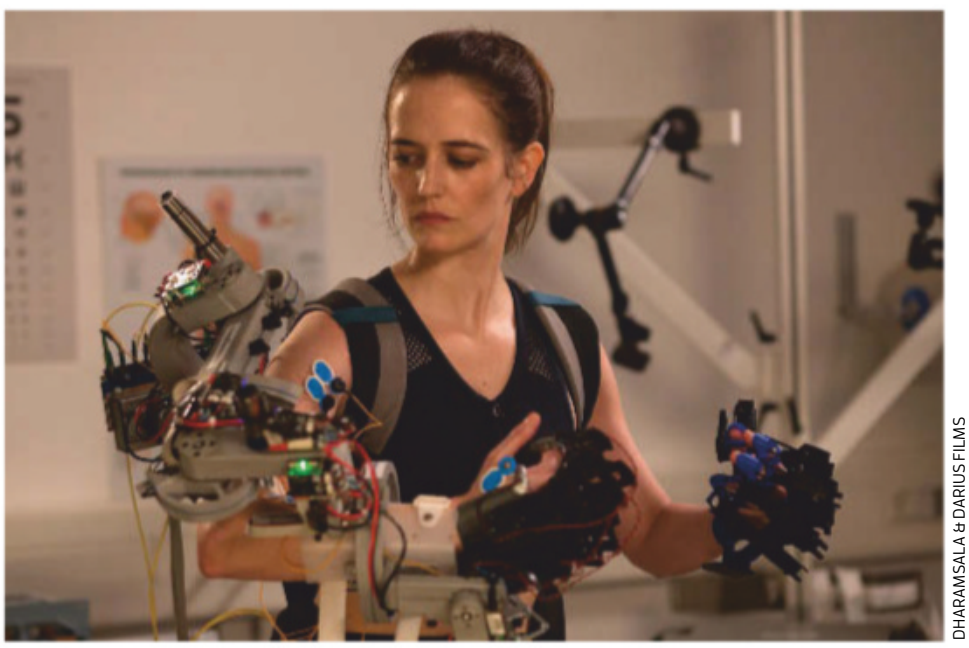
Because *Proxima* is arriving late – its launch was delayed by the covid-19 lockdown – advances in space technology have already somewhat gazzumped Georges Lechaptois's metliculous location cinematography. I came to the film still reeling from watching the Crew Dragon capsule Endeavour lift off from Kennedy Space Center on 20 May.

That crewed launch was the first of its kind from US soil since NASA's space shuttle was retired in 2011 and looked, from the comfort of my sofa, about as eventful as a ride in an airport shuttle bus. So it was hard to take seriously those moments in *Proxima* when taking off from our planet's surface is made the occasion for an existential crisis. "You're leaving Earth!" exclaims family psychologist Wendy (Sandra Hüller) at one point, thoroughly earning the look of contempt that Loreau shoots at her.

***Proxima*'s end credits include endearing shots of real-life female astronauts with their very young children – which does raise a bit of a problem. The plot largely focuses on the impact of bringing your child to work when you spend half your day in a spacesuit at the bottom of a swimming pool. "Cut the cord!" cries the absurdly chauvinistic NASA astronaut Mike Shannon (Matt Dillon) when Loreau has to go chasing after her young daughter.**

Yet here is photographic evidence that suggests Loreau's real-life counterparts – Yelena Kondakova, Ellen Ochoa, Cady Coleman and Naoko Yamazaki – managed perfectly well on multiple missions without all of *Proxima*'s turmoil. Wouldn't we have been better off seeing the realities they faced rather than watching Loreau, in the film's final moments, break Baikonur's safety protocols in order to steal a feel-good, audience-pandering mother-daughter moment?

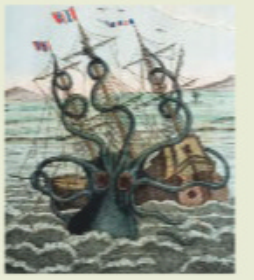
For half a century, movies have struggled to keep up with the rapidly changing realities of the space sector. *Proxima*, though interesting and boasting a tremendous central performance from Green, proves to be no more relevant than its forebears.



DHARAMSALA & DARIUS FILMS

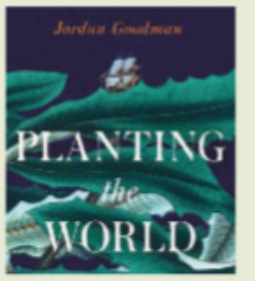
Astronaut Sarah Loreau (Eva Green) prepares to leave Earth in *Proxima*

Don't miss



Visit

Monsters of the Deep finally emerges from the covid-19 deep freeze at the reopened National Maritime Museum Cornwall in Falmouth, UK. The exhibition explores the fact, fiction and future of the planet's strangest sea creatures.



Read

Planting the World: Joseph Banks and his collectors traces how the influential naturalist and patron's 18th century plant-hunting expeditions transformed Europe, from its industry and medical practices to its diet and even its fashion.

Watch

The Rain returns for a third and final season on Netflix from 6 August. There are many mysteries to wrap up in this highly praised post-apocalyptic drama about a rain-borne virus that nearly wipes out humanity.

TOP: PAUL D STEWART; BOTTOM: HENRIK OHSTEN/NETFLIX

Marine mosaic

Photographer **Georgette Douwma**
Agency **naturepl.com**

HAILED as the rainforests of the sea, coral reefs support almost a quarter of all marine species, from turtles and fish – like the clownfish peeking out of its anemone that is seen repeatedly in this image – to snails and worms.

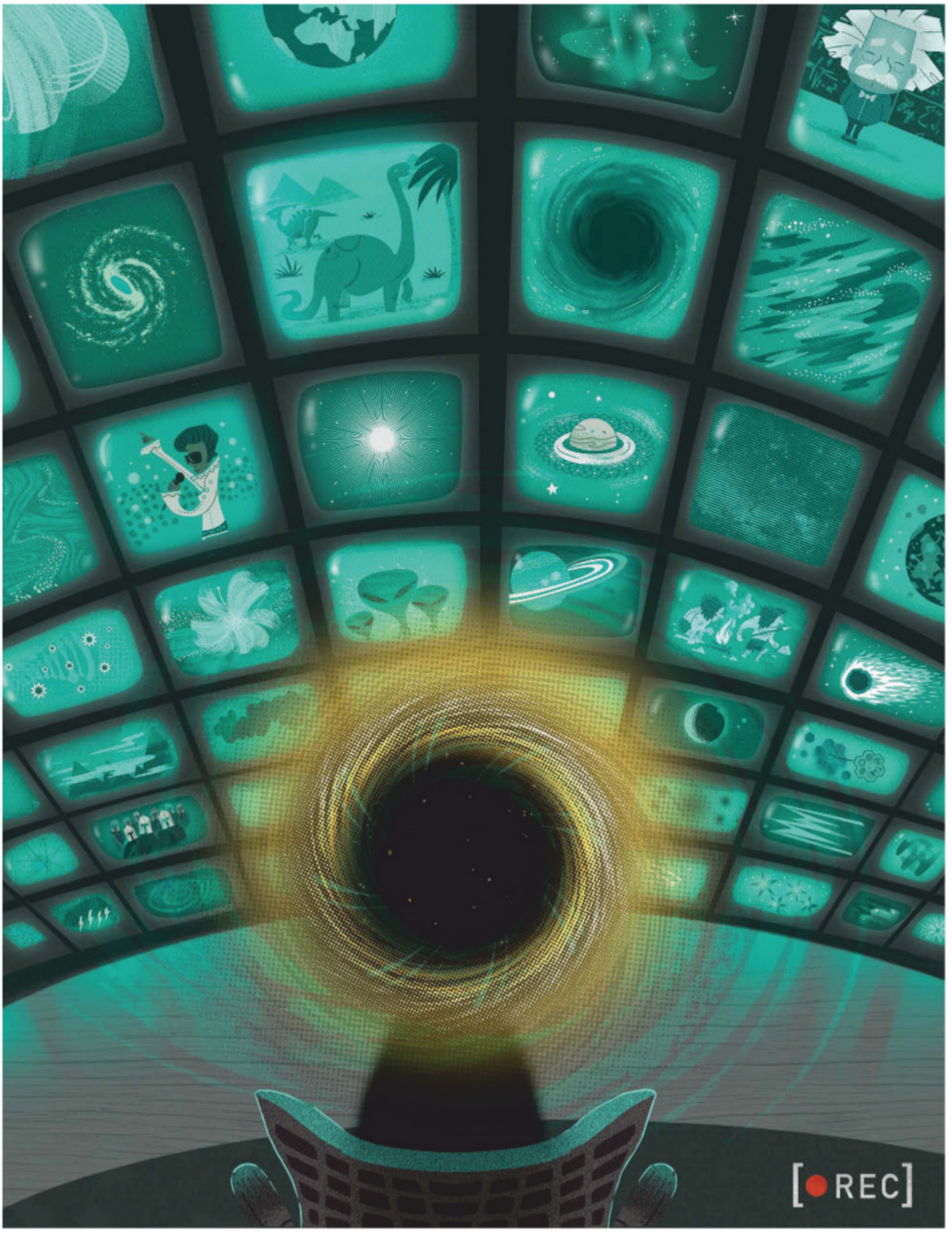
Dutch photographer Georgette Douwma's work reflects the ability of corals and some anemones to clone themselves from broken fragments. Here, she has combined mirrored shots of the clownfish and its home to create the impression of a natural kaleidoscope.

Due to a deadly combination of ocean acidification and warming from climate change, destructive fishing practices and pollution, coral reefs could soon cease to exist. Researchers at the University of Hawai'i in Manoa recently estimated that coral reefs could decline by up to 90 per cent by 2050.

Warmer waters have already triggered mass bleaching events of corals, including of the Great Barrier Reef in Australia. Bleaching strips corals of their protective algae as well as their bright colours, leaving them at risk of starvation and disease.

"My ultimate aim is to capture something that can communicate the vibrancy and colour of healthy reefs, before the next big bleaching event happens," says Douwma. "To watch them die would be a tragedy."

Gege Li



GRAHAM CARTER

Black hole movies

Einstein's monsters are broadcasting footage of the universe's history – and there are ways we could get a clearer view, says **Stephen Battersby**

THE picture was seen by billions: a hazy ring, glowing orange-bright, surrounding a heart of darkness. The work of many minds over decades, it was above all a tribute to the brilliance of one. Yet as the world marvelled at the first ever direct image of a black hole – one of the cosmic monsters predicted by Albert Einstein's theories – the researchers behind it found themselves confronted with a rather basic puzzle.

"After the result was published, we were all getting together and asking: what does this thing mean?" says radio astronomer Michael Johnson at Harvard University. They had been so wrapped up in turning their data into a picture that no one had really stepped back and tried to digest what it was telling them.

Over the past year, their quest to find answers has led them into a cosmic hall of mirrors, where the black hole's gravity takes light from all directions, warps it and beams it to us as an infinitely recast image of the hole's surroundings. The result is an epic movie of the history of the universe, as witnessed by a black hole, playing on a dramatically curved screen tens of billions of kilometres across.

From way back here in the cheap seats, about 55 million light years away, we will never be able to see the action's full sweep, but we can catch glimpses. They could be enough to unlock the true history of giant black holes, put Einstein to the test like never before and maybe even lead to a deeper understanding of space and time.

Black holes are perhaps the most breathtaking prediction of Einstein's general theory of relativity, the description of gravity he presented in 1915. No cosmological observation has been found to contradict its depiction of massive objects warping space and time around them. A black hole takes that idea to the extreme: it is a concentration of mass so great that space-time is warped to an infinite degree. Anything venturing too close is drawn across its event horizon, beyond which we can never see.

Although Einstein doubted that they actually existed, observations in recent decades have persuaded us that black holes are real. Small ones, just 10 or 20 times the mass of our sun, form when huge stars collapse at the end of their working lives. The gravitational waves detected by the LIGO collaboration in 2015 were ripples in space-time caused by two such objects merging. These are dwarfed by supermassive black holes of millions to billions of solar masses that appear at the heart of almost every galaxy, including our own Milky Way.

The image presented in 2019 was of M87, a giant elliptical galaxy in the Virgo cluster. It houses a beast of a supermassive black hole, with a mass probably 6.5 billion times that of the sun. The international Event Horizon Telescope team, which includes Johnson, used sophisticated signal processing to combine data from radio ›

telescopes from around the world into one image of M87's core. The resulting resolution matched that from a single radio dish the size of our planet.

The darkness at the image's centre is a shadow of the black hole; an image of the event horizon, magnified and distorted by the hole's gravity. But what exactly is that surrounding glow? That was the question that initially no one could really answer.

To help decode the image, Johnson reached out to some more theory-minded researchers, including Alex Lupsasca, also at Harvard. "We had been colleagues side by side for many years," says Lupsasca. "They were listening to us, but only with half an ear because they were busy doing their experiment."

"My role was finding the common language," says Johnson. "We have black hole observers, black hole simulators, black hole theorists... It sounds so silly. But actually it is extremely difficult to communicate between these subfields; they are all very technical."

Space opera

Since the image came out, physicists have run many models of the maelstrom around M87's black hole. Called GRMHD simulations, these combine general relativity with magnetohydrodynamics, which describes the behaviour of the hot, ionised gases that surround the hole. Each simulation starts with some assumptions about what might be producing the radio waves – for example, matter spiralling inwards – and follows the waves that would be produced by such a source as the hole's gravity bends their path, to predict what we would see on Earth.

It turns out that a wide range of possible sources lead to a fuzzy glow like the one seen by the Event Horizon Telescope: the black hole stamps its form with such force that the emission's true origin is hidden. But although the models weren't useful in distinguishing between the sources, they revealed something unexpected and intriguing. They all predicted that there should be a very bright, thin ring embedded in the broad fuzzy orange one. "To start with, there was a lot of confusion about what this meant," says Lupsasca.

It turned out that we had been here before, some time ago. Back in 1959, Charles Darwin had predicted something very similar – not that Charles Darwin, but his grandson, physicist Charles Galton Darwin. He showed how light from the surrounding universe passing very close to the black hole might take a swing around it before heading our way. Photons passing even closer would be caught for more orbits. Later work suggested that light taking a given number of orbits would be squeezed down into a thin ring.

That all assumed a black hole that isn't rotating, whereas real ones are expected to spin to some degree, preserving the angular momentum of material they have sucked in. "When a black hole spins, it literally drags space-time into a kind of whirlpool around it," says astrophysicist Janna Levin at Barnard College in New York. Anything nearby is dragged around with it, including light. "Nobody had studied this case," says Lupsasca. "It is way more complicated."

But the basic picture was confirmed by finer-grained GRMHD simulations. They show that, if you look closely, the thin bright photon ring should be made up of infinite, nested subrings, each corresponding to photons taking a certain number of turns

"When a black hole spins, it drags space-time into a kind of whirlpool around it"

around the black hole, getting exponentially fainter and thinner as they get closer to the edge of the black hole's shadow. Because the inner subrings are made of light that has made more orbits, this light was captured earlier on. As the team write in their paper, published in March this year: "Together, the set of subrings are akin to the frames of a movie, capturing the history of the visible universe as seen from the black hole."

Admittedly, this movie is highly biased to stuff near the black hole. Each subring is also only around six days older than the last, so there is a limit to how much of the reflected universe just a few frames show us. "We're not going to see dinosaurs," says Johnson.

But there is treasure in these golden rings, nonetheless. For a start, their size and shape don't depend on where the photons came from, but on the properties of the black hole alone. That could allow us to pin down these properties like never before. Our current best figure for the M87 black hole's mass, 6.5 billion solar masses, is only accurate to within 15 per cent or so. But the thickness of its rings is highly dependent on its mass. "If you can resolve the super thin photon ring and put a ruler across it, now you are talking precision measurement," says Lupsasca – perhaps to better than 1 per cent.

The spinning space-time around the hole should also squash the rings a little, so they aren't perfect circles. By tracing their shapes, we could get an accurate figure for the black hole's spin. That could tell us about the history of M87's monster. Did the black hole form in a series of random collisions between smaller ones, probably giving it a low overall spin? Or did it grow by hoovering up gas spiralling in from its host galaxy, consistently cranking up its rotation?

Elusive theory

Measuring black hole spin could also hold the answer to how black holes send out powerful jets of material, travelling at close to the speed of light. These jets can travel for hundreds of thousands of light years, blasting out of a host galaxy and ending in enormous plasma plumes that shine across the cosmos. One leading theory is that a black hole's spin combines with surrounding magnetic fields to act as a dynamo. This generates an electric field so intense that it wrenches electrons and positrons out of the vacuum, accelerating them into two jets, each speeding away from a pole of the black hole.

The photon rings could also provide our most stringent test of general relativity yet. We know the theory works very well in Earth's gentle gravitational field; it is verified billions of times a day, because satnav can only work by precisely allowing for relativity's time warps. Thanks to Gravity Probe B, a NASA satellite launched in 2004, we have even seen the frame-dragging caused by Earth's spin, our planet's feeble version of the space-time whirlpool around a rotating black hole.

As for the extreme gravitational fields where relativity really gets to work, the echoes of colliding black holes now routinely picked up by gravitational wave detectors square with the predictions of Einstein's theory. But the spacing between black hole photon rings would be a far more precise test.

"I think it's a great way to test relativity because it is very difficult to see those kinds of inner orbits in any other way," says Levin. Any deviation from general relativity's predictions could help physicists to finally devise a long-elusive quantum theory of gravity, which promises to tell us what space and time are made of, what really happened in the first moment of the big bang – and indeed what lies in the heart of a black hole.

With such promise, the prospect of actually seeing these photon rings is exciting. But it won't be easy. Discerning such fine features will require a radio eye even better than the existing Event Horizon Telescope, which is already opened as wide as Earth will allow.

One option would be to use shorter wavelengths, which potentially provide sharper vision. The original image of M87's black hole was based on radio signals at a wavelength of 1.3 millimetres, and Johnson suggests that moving to a quarter of this ›

wavelength might be enough to see the first, most distinct photon subring. Earth's atmosphere blocks this short-wave radio signal, except in very high, dry locations, such as the South Pole and Chile's Atacama desert. These two sites are already home to facilities that are part of the Event Horizon Telescope, but it isn't clear if they can produce the necessary resolution on their own.

Instead, we probably need to add a radio telescope in space. "The further away it can go, the more precisely we could image the subrings," says Lupsasca. A good location would be the second Lagrange point, or L2. Here, the gravity of Earth and sun combine in such a way that a spacecraft can maintain its position relative to Earth with minimal effort. L2 is a handy 1.5 million kilometres away in the opposite direction to the sun. A telescope there, coupled with others on Earth, should provide sufficient resolution to image the first three photon subrings around M87's black hole, as well as those around Sagittarius A*, the smaller supermassive black hole at the centre of the Milky Way.

This isn't as far-fetched as it might sound. Russia has already launched a space-based radio telescope, the now-defunct Spektr-R, that looped out to a distance of 300,000 kilometres from Earth. An improved version, Spektr-M, also known as the Millimetron Space Observatory, is due to launch out to L2 around 2029. And a proposed US mission, the Origins Space Telescope, is also intended for L2. If approved, it could launch around 2035.

Origins would need a few upgrades from its original specifications to perform the measurements required to see the photon rings, including an accurate onboard clock to synchronise observations with those on Earth. "The main difficulty I foresee is the sheer amount of data," says co-leader of the Origins project Asantha Cooray at the University of California, Irvine. Raw data would have to be beamed back for processing with data from the telescopes on Earth, and it would stack up to 230 terabytes for 6 hours of observations. That is far too much to send by radio networks, the usual means of transferring data from a spacecraft, so an optical downlink will be required instead. That has been achieved from low Earth orbit, but not from the great distance of L2.

EVENT HORIZON TELESCOPE COLLABORATION ET AL.

The fuzzy glow of M87's black hole is masking infinite sharp rings of light

Local screenings

The rewards could be huge. The higher resolution of the space set-up could see the shadows of many more supermassive black holes – perhaps a million of them, stretching across the observable universe. This could finally resolve many of the mysteries that swirl around Einstein's monsters, including how they managed to grow so quickly in the early days of the cosmos.

As for that black-hole's-eye movie of the universe, even the million-mile-wide radio array made possible by a dish at L2 would only be enough to show us a trailer, just three frames long. For a feature-length version, it is hard to imagine what kind of distant-future technology would be good enough. "Since the subrings get exponentially thinner, you need to increase your telescope size by roughly a factor of 10 for each additional subring that you want to see," says Lupsasca. A radio array spanning from here to our next nearest star Alpha Centauri, over 4 light years away, would get us up to about 10 subrings.

So perhaps we will have to get closer to the action, and visit a screen showing a good picture nearer by. Our nearest supermassive black hole, at the centre of our galaxy, is still rather inaccessible; but the nearest known black hole, discovered this year, is only around 1000 light years away. Being only about 4 solar masses, its screen size spans only tens of kilometres. Just a little fleapit of a cinema, compared with the movie-palace grandeur of M87's black hole – but at least the programme will have a lot more local interest. ▮

"To see the black hole rings, we probably need to put a radio telescope in space"

Stephen Battersby is a consultant for *New Scientist* based in London

The unlikely rise of the dinosaurs

Dinosaurs started off as pipsqueaks in a world of heavyweight competitors. How they ascended to glory is a mystery we're only just starting to unravel, says palaeontologist **Steve Brusatte**

RONALD KURNIAWAN

ABOUT 250 million years ago, a creature raced along the edge of a lake in what is now Poland, leaving prints behind it in the mud. It was a meek and forgettable animal called *Prorotodactylus*, about the size of a pet cat and with slender limbs. But those prints weren't the only legacy it left: its descendants somehow became the rulers of Earth.

Those descendants were the dinosaurs. The very word invokes majesty. These were among the most successful groups of animals ever, dominating the planet for more than 100 million years. They proliferated into creatures of all shapes and sizes, some even larger than a jet plane, and filled the land.

Palaeontologists like me were long obsessed with understanding why these mighty animals were snuffed out 66 million years ago. We now know the answer: their days were ended by an enormous asteroid impact. Today, the greatest mystery of dinosaur evolution is how they rose to glory in the first place.

The early descendants of *Prorotodactylus* would have stuck to the shadows, skulking away from much larger and more fearsome animals. So what was it that allowed them to take centre stage? Piecing together the answer is no easy matter. But over the past few years, a surprising new idea has gained traction. Perhaps the reason for the dinosaurs' ascendency lies not in their teeth or claws or muscles. It may instead be thanks to a series of strange anatomical adaptations invisible from the outside – adaptations that allowed them to thrive in one of the most extreme periods of climate change the planet has seen up until now.

The world was almost unrecognisable back when *Prorotodactylus* made those lakeside prints. Our planet had just experienced one

of the worst mass extinctions ever. A blast of global warming, fuelled by volcanic eruptions of unimaginable scale in Siberia, had caused more than 95 per cent of Earth's species to die. From this catastrophe sprang the dinosaurs' ancestors and closest cousins, including *Prorotodactylus*. Within 20 million years, they had evolved and diversified into the three main subgroups of dinosaurs: the meat-eating theropods, the long-necked, plant-guzzling sauropodomorphs and the beaked, herbivorous ornithischians. Much later, these lineages would spawn recognisable dinosaurs: *Tyrannosaurus*, *Brontosaurus* and *Triceratops*, respectively (see "An interrupted reign", page 38).

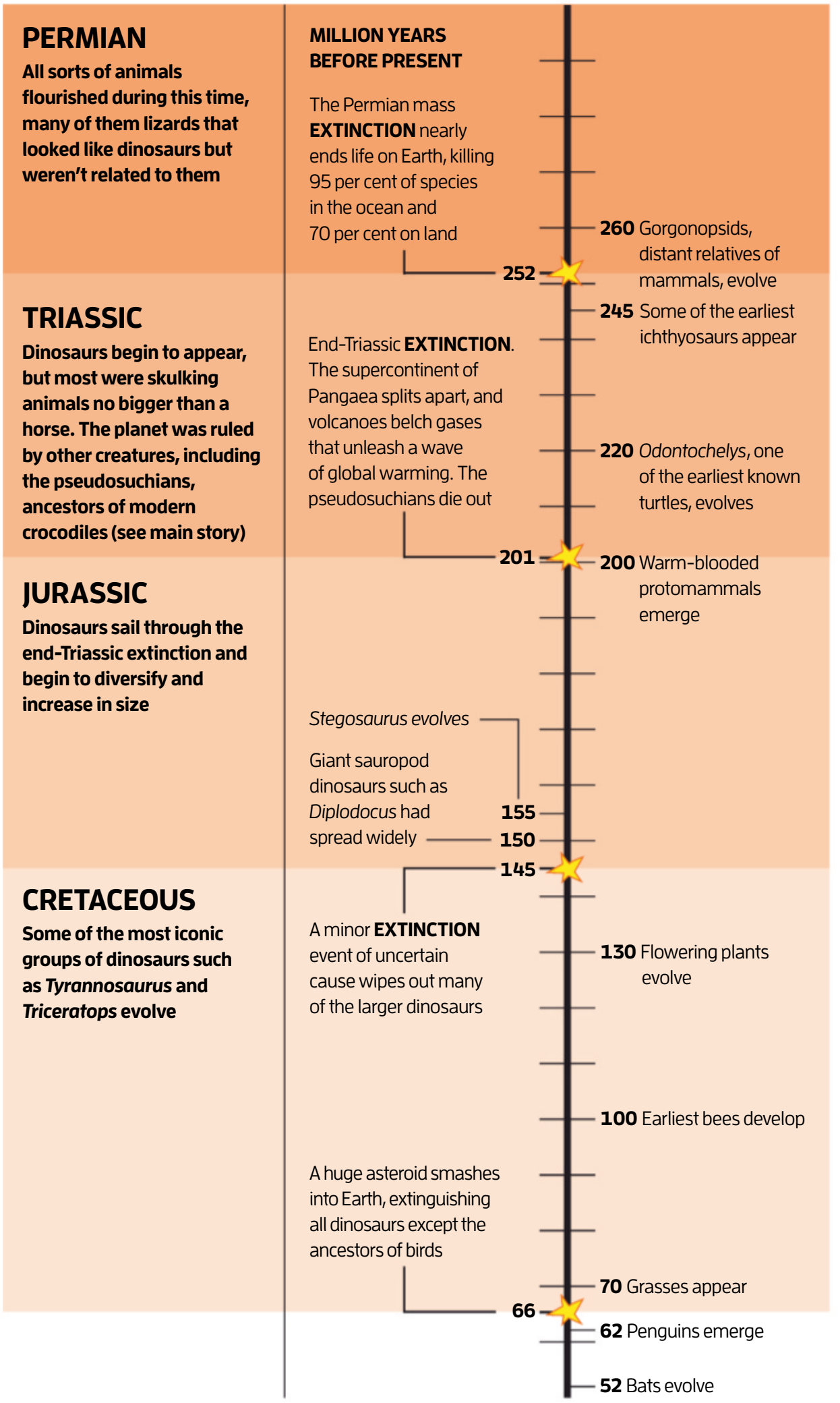
Before this, in the Triassic period, most dinosaurs were horse-sized or smaller. And they weren't alone. Proliferating alongside them were all sorts of other reptiles, including a particularly successful group called the pseudosuchians. This is the lineage to which modern crocodiles and alligators belong. They are a paltry bunch today, about 25 species all told, living in warm, semiaquatic environments. But back in the Triassic, there were scores of them, including armoured ones that ate plants, toothless omnivores that sprinted on their hind legs and apex predators called rauisuchians that were 9 metres from nose to tail and had teeth like steak knives.

See you later, alligator

If the pseudosuchians sound impressive, that's because they were. So how did dinosaurs replace them as the dominant creatures on land? Back in the 1970s, some palaeontologists thought that early dinosaurs were unusually well-adapted to rapid running compared with their close relatives, says John Hutchinson, an expert on animal muscles and locomotion at the Royal Veterinary College in London. They tended to walk on long, erect legs and were often bipedal. This view was articulated by leading dinosaur experts such as Robert Bakker, then at Harvard University, and Alan Charig at London's Natural History Museum. ›

An interrupted reign

The era of the dinosaurs that began around 250 million years ago was punctuated by epic extinction events that helped shape their evolution



Basically, dinosaurs were faster than the crocs and, over time, they outcompeted them.

It is an elegant story, but as a graduate student it didn't sit well with me. And during the first decade of the 21st century, it began to seem increasingly untenable. A wealth of new Triassic pseudosuchian fossils had been discovered and many of them were dead ringers for dinosaurs, a sign that both groups were converging on the same diets and lifestyles. In 2008, I reviewed these new fossils to trace the evolution of both groups and came to a startling conclusion. During the entire Triassic, the pseudosuchians were completely outpacing the dinosaurs. They had more species, were more abundant in their ecosystems and had a greater variety of body plans, anatomical features and diets.

Earth unzipped

These findings helped reframe the question of how the dinosaurs became the world's pre-eminent beasts. It must have happened, not gradually through the Triassic, but relatively quickly, towards the end of that period, when we know the pseudosuchians definitely did begin to decline. This actually makes a lot of sense because, at just this time, something epic happened to planet Earth.

In the days of *Prorotodactylus,* nearly all land was part of a supercontinent called Pangaea (see "Triassic world", page 40). Then, 200 million years ago, Pangaea started to crack. The fracture began in the centre of the land mass and unzipped it down the middle. North America separated from Europe; South America from Africa. As they parted, Earth haemorrhaged lava from volcanoes in what is now the bottom of the Atlantic Ocean for more than 500,000 years.

Released with the lava were huge volumes of carbon dioxide and sulphur dioxide. These gases continually warmed the atmosphere, while bursts of ash from the eruptions shut out the sun's light. This meant hot spells "alternated with intense volcanic winters that brought freezing for decades at a time", says Paul Olsen at Columbia University in New York. At least 30 per cent

CECILIA APALDETTI

The bones of *Ingentia prima*, found in Argentina, are full of tiny holes

of Earth's species were killed as a result.

Yet the pattern in the fossil record unmistakably reveals that the dinosaurs sailed through this period. The pseudosuchians, on the other hand, were devastated. Nearly all of their rich Triassic diversity was extinguished, leaving only a few twigs on the family tree.

There are many hypotheses that attempt to explain this, all of which fall into one of two camps. One says that the dinosaurs really did have some advantage over the ancient crocs – be it speed, agility or intelligence – and, although this didn't allow them to gradually outcompete them in the Triassic, it did finally give them the edge after Pangaea split. The other says that there is no single reason why the dinosaurs won. The rise in global temperatures was so quick and so brutal that animals survived mostly or only by chance.

Emma Schachner at Louisiana State University doesn't think dinosaurs survived by mere chance. She has proposed an interesting idea that has been getting plenty of attention: that dinosaurs had a hidden superpower that helped them cope with the toxic atmospheres of the late Triassic.

To understand the idea, you need to know a little about how lungs work. In mammals, including us, muscles stretch the lungs out, which pulls air into them. This means the membrane of the lung can't be too thin or else it would degrade as it moves and rubs against the ribs. But lungs work differently in some other animals, including birds, the direct descendants of dinosaurs. So let's turn to bird lungs, and, as Schachner has put it, "it gets crazy, so hold on to your butts".

In the chests of birds, the gas exchange portion of the respiratory system is like a dense sponge that doesn't move. Because of this, its membrane can be extremely thin without rupturing, increasing the efficiency with which oxygen passes from the lungs to the blood. What's more, several separate air sacs that aren't part of the gas exchange system expand and contract to funnel air through the air exchange part of the lungs in one direction only. This also means that oxygen is drawn through the lungs during both inhalation and exhalation, so birds get more out of every breath.

"During the entire Triassic, pseudosuchians were completely outpacing the dinosaurs"

In short, birds' lungs are hyper-efficient, and Schachner has published a series of papers arguing that Triassic dinosaurs had similar lungs to modern birds, and that this helped them thrive.

Lungs are fleshy things that don't tend to fossilise, but they can leave telltale signs behind. In birds, the air sacs often protrude into the vertebrae, creating indentations and sometimes hollows – so-called pneumaticity – in the bones. Do we see this in dinosaur bones? We sure do. Some sections of the back bones of Triassic dinosaurs are commonly pneumatised, indicating they probably had avian-style lungs. "This respiratory anatomy had the potential to give dinosaurs a major competitive advantage," says Schachner.

In truth, the jury is out on whether the lungs alone made the difference for dinosaurs. In the past, we thought that air had much less oxygen during the Triassic than it does today, in which case more efficient lungs would have been obviously beneficial. But the latest thinking is that there was plenty of oxygen around in the Triassic.

We also aren't sure if the pseudosuchians had their own special lung adaptations. They certainly don't have the same pneumaticity marks on their bones as early dinosaurs. But Richard Butler at the University of Birmingham, UK, has shown that they have depressions on the sides of some vertebrae. These might be signs of air sacs that were ›

a tad different from those of modern birds.

Cecilia Apaldetti at the National University of San Juan in Argentina is contemplating an idea that takes pneumaticity to a whole new level. Over the past decade, her team has unearthed a bounty of new dinosaurs from the late Triassic rocks of the Marayes-El Carrizal basin in Argentina. Among these is a species she and her colleagues named *Ingentia prima*. This may be the oldest known dinosaur to get bigger than an elephant. And its skeleton is riddled with holes, suggesting the air sacs proliferated widely. Essentially, this animal's lungs ran through its whole body. It is as weird as it sounds.

"These dinosaurs had an improved breathing system that provided them with numerous advantages," says Apaldetti. With air sacs spread throughout most of their bodies, they were able to take in oxygen super-efficiently and circulate air through their innards, helping them keep cool. This, in turn, would have supported a fast metabolism and rapid growth. Their bones were also light. All of these factors together would have set dinosaurs up to get gigantic without running into problems, like getting too heavy to support themselves or overheating.

It is easy to imagine how any one of these things might have helped dinosaurs ride out a few hundred thousand years of global warming, foul atmospheres and ecosystem breakdown. Add them together, and they may have been almost indestructible.

Where does that leave Bakker and Charig's hypothesis that dinosaurs were better runners than the crocs? Hutchinson's group is revisiting this through an ongoing project. "Past ideas about locomotion were based almost solely on anatomy," says Hutchinson. But that doesn't necessarily tell you how fast an animal was. He and his team are instead using laser scans of fossils to build digital models of dinosaurs and pseudosuchians, which they put through gymnastics routines to test how the animals would have moved. The work won't be finished for another year or two, but the team has already cast fresh light on how dinosaurs got around. One species seems to have walked on four legs when young, but graduated to two legs as it grew.

There may never be a simple answer to the 200-million-year-old riddle of how the dinosaurs took the Jurassic throne. Our best guess is that they held a winning hand of adaptations: efficient lungs, high metabolism, fast growth and possibly other assets that we don't yet understand. Together, they won the pot. But if the environmental conditions they faced had been just slightly different, the rules of the game would have been changed, and the age of the dinosaurs may never have come to pass. As it worked out, however, those footprints on the edge of the lake were the start of an epic journey to greatness. ▮

Steve Brusatte is a palaeontologist at the University of Edinburgh. His most recent book is *The Rise and Fall of the Dinosaurs*

Triassic world

In the days of the Triassic, the world would have been scarcely recognisable to us. All land was joined together into a supercontinent. "Pangaea extended from pole to pole and straddled the equator, shaped like the video-game icon Pac-Man," says Jessica Whiteside at the University of Southampton, UK. Surrounding this was a vast ocean called Panthalassa.

You might think that animals would range freely across Pangaea, as there were no seas or major geographic barriers breaking up the land. But no. "Although an ambitious animal could walk across it in a single lifetime, there were climate zones that controlled where organisms lived," says Whiteside. Her research has shown that the equatorial region of Pangaea was obscenely hot and muggy, while its deserts would routinely be hotter than 50°C.

Dinosaurs had trouble colonising these extreme regions and lived mostly in mid-latitude areas. Pseudosuchians, the successful group of Triassic lizards (see main story), also lived in these latitudes, but managed to spread to the interior deserts too. As animals go, they must have been seriously tough customers.

About 220 million years ago, Earth's land mass looked starkly different

GARY HINCKS / SCIENCE PHOTO LIBRARY

"Essentially, this animal's lungs ran through its whole body. It is as weird as it sounds"

The stronger sex

To explain why women live longer than men, experts often point to different lifestyle choices. In fact, it's all thanks to superior genes, **Sharon Moalem** tells Clare Wilson

ROCIO MONTOYA

WOMEN generally outlive men and are less susceptible to certain illnesses – including covid-19, it now appears. Why health outcomes are so drastically different between the sexes is unclear. But Sharon Moalem, a doctor and genetic researcher based in New York, thinks he has the answer. It isn't because women tend to go to the doctor more or have healthier habits, he says. Instead, it's because they are typically better equipped, genetically speaking.

In humans, sex is largely determined by chromosomes, the bundles of tightly coiled DNA that carry our genes. The cells of most women possess two X chromosomes while most men have one X and one Y. So that women's cells don't have to carry two versions of each gene on the X chromosome, one from each X, one of the Xs is mainly switched off. It appears that which one stays active in which cells is chosen seemingly at random some time during the first few weeks of pregnancy. The result is that half a women's cells generally use the X chromosome she inherited from her mother, while the other half use the one from her father.

It has long been known that if one X has a harmful mutation, cells that use the other X can compensate. That's why, for instance, women are less likely to be colour-blind; a gene important for eye function resides on the X chromosome. Yet Moalem argues that the benefits are far more significant than this alone. He makes the case that even if there is no obviously harmful mutation, women tend to be at an advantage by having bodies made up of two populations of genetically different cells, and that this begins even before birth. He believes this is the reason why women are less vulnerable to certain congenital disorders and better at fighting off infections – including the coronavirus. As he sees it, women are simply genetically superior. Having two copies of an X chromosome has far more benefits than we realised, and serious implications for medicine.

Clare Wilson: How can women be the stronger sex, when we are generally smaller and physically weaker?
Sharon Moalem: All those things are true – on average, males have more muscle mass. But I am talking about genetic superiority, and the parameter is survival. We see the consequences in many areas of medicine. When you look at supercentenarians, those over the age of 110, they are 95 per cent female.

But it isn't just making it to old age – females have a survival advantage over the life course. When I was a physician at a neonatal intensive care unit, I saw that more girls make it to their first birthday than boys. And I was seeing lower rates of congenital malformations like tongue-tie and clubfoot. Anything that's biologically difficult to form, females do better.

How is this connected to the X chromosome?
Because there are about a thousand genes on the X. Mammalian females have two populations of cells that are active within them; they are really mosaics in this way. Males have just one copy of the X so they aren't mosaics. In females, those two populations build their bodies during fetal life. They cooperate and share not just genetic materials with one another, but proteins and enzymes, which give extra ability to handle disease. While the embryo is developing, you have an immense amount of cell multiplication where cells grow and divide into two, so the cells that have a growth advantage will be the ones that dominate in that tissue. Even in tissues that are initially ›

Lifelong effects: More females than males survive infancy, while women also tend to live longer than men and are less vulnerable to covid-19

SALVATORE LAPORTA/KONTROLAB/LIGHTROCKET VIA GETTY IMAGES

divided 50:50 between two Xs, that seems to change over the life course; they can skew. If there's injury in the skin, for example, and the skin is healing, you can have one population of healing cells taking over. It seems that when their function within the healing is complete, it eventually goes back down to 50:50. Men just have to cope with the genes on their one X.

How might this process affect other parts of the body?

Everywhere we have looked in the body, there can be skewing. In a woman's body, if the cells in the heart that carry her father's X can survive lack of oxygen during a heart attack, it will be that population that survives. We see that benefit in many parts of the body, including the liver and the kidneys. The toxic compounds that we can't withstand or get rid of will kill our cells. The cells with the X genes that can better withstand those toxins outcompete the others.

How does it affect resistance to infections?

Our first understanding of this was with the immune system because it's easy to tap – you just take out some blood. The X is rich in immune-related genes. If a population of a certain kind of immune cell does a better job using genes from the X from the father, that cell population will shift, so you might have 80 or 90 per cent of those cells using the X from the father.

And you believe that's why women tend to cope better with the coronavirus?

Yes. There's an important group of genes on the X that encode a receptor called toll-like receptor 7 (TLR7), which helps cells recognise single-stranded RNA viruses, such as the coronavirus. Women have two populations of immune cells, each one using a different version of TLR7 to recognise coronavirus. Another interesting layer is that the coronavirus uses a protein on our cells called ACE2 to enter our cells. The gene for ACE2 just happens to be on the X chromosome. Right from the get-go, females have an advantage.

What about behavioural reasons proposed for the female survival advantage in covid-19?

The first explanation I heard from some of my colleagues was that males don't wash their hands – which is nonsense when you see data that says more women are infected than men, and yet more men die. The other thing was that everyone rushed to say it's smoking. About 50 per cent of males in China smoke, and about 3 per cent of females smoke. But when you start looking at other countries – in the US, for example, the rate for male smoking is about 15 per cent, for females 13 per cent – you still see the same pattern of higher male deaths.

We rush to use behaviour as an explanation because we are told that the biggest differences between the sexes is behaviour. When I started my career, I was told that the reason we see so many more females at the end of life is because more men smoke and drink, and they take risks. All those things may be true, but it's ignoring the fact that more girls make it to their first birthday. Girls who have asphyxia at birth do better cognitively as well. It's hard to argue that the sexes' behaviours are different in the incubator.

But two X chromosomes don't always confer an advantage. Don't women have higher rates of autoimmune conditions, where the immune system mistakenly attacks healthy cells?

Yes, the female immune system is more aggressive than the male immune system. Part of that's because female hormones called oestrogens stimulate the immune system, while in males, testosterone inhibits it. But what's interesting is that even before puberty, autoimmunity is still higher in females. The explanation could be the X chromosome.

In both sexes, in the fetus, thyroid gland immune cells usually go through an "educational process", where if immune cells recognise other cells from the person's own body, the immune cells self-destruct. That's to make sure that once the baby is born, autoimmunity doesn't happen. The process works relatively well in males. But females, who have two genetically different cell populations, are more likely to fail at destroying all the self-recognising cells. Coming out of the thymus, female immune cells are more likely to recognise their own cells as "foreign". That sets up the perfect storm for autoimmunity.

"It's hard to argue that the sexes' behaviour is different in the incubator"

JILL LEHMANN PHOTOGRAPHY/GETTY IMAGES

That's a down side of having two X chromosomes?
Yes, but there's also an advantage of having a somewhat autoreactive immune system. Many microbes invade and escape detection in the body because they resemble human cells. Females have a better ability to be able to discern this kind of wolf in sheep's clothing because they keep cells that are more likely to attack things that resemble themselves. So women have higher rates of autoimmune diseases, like rheumatoid arthritis, lupus, multiple sclerosis. But if it helps you survive covid-19, that's the benefit.

Are there any other benefits to a stronger immune system?
More work is needed on this, but perhaps the propensity to autoimmunity is one of the explanations for females having a lower chance of certain cancers. Malignancies begin with our own healthy cells. The possible benefit of having an immune system that's more geared to attack your own cells is that you are clearing pre-malignant cells before they are detectable medically.

Couldn't that difference also be due to behavioural reasons, like men smoking and drinking more?
Yes, but I believe that that pattern holds true for certain cancers that start before puberty. The major differences in behaviour begin after puberty. But, there's no way to know for sure.

If these differences between the sexes are so widespread, why haven't we heard of them before?
When you see a six-foot-four man who is an Olympic weight-lifter and you try to say that they don't have a survival advantage over a five-foot-three woman, it's difficult to understand the difference between biological strength and physical strength. Plus, there's resistance to any new paradigm. The current paradigm is that most of the health differences that we are seeing between men and women are behavioural; it's very hard for people to let go of behaviour.

My lightbulb moment was in a neonatal intensive care unit. Although I was taught that the difference between the sexes was behaviourally based, I was seeing that it seemed to be driven by biology.

Why does it matter?
Because we need to understand the basis for the biological differences between men and women, in terms of disease susceptibility and sensitivity to medications. In general, drugs are metabolised slower in women, and their gut transit time is slower so women have to wait longer after eating to have an empty stomach. But if people go to their physicians, sex is never considered as a dosing variable and there is no requirement for drug approvals to recognise sex-based differences.

Melanoma kills twice as many young men as women. It's a classic example of where we blame men for behaviour: using less sun screen, not going to their doctor. Yet the differences in melanoma risk are actually biological. Women are more protected thanks to stronger immune response and benefits from female sex hormones. We should be investing in screening for men at a much earlier age. We need to stop treating men and women as if they are biologically the same. ▮

Clare Wilson is a biomedical reporter at *New Scientist* and author of Health Check: newscientist.com/healthcheck. Follow her @ClareWilsonMed

Why clever people make stupid decisions

Making the right decision is difficult, not least because our brains have many inbuilt biases that lead us to behave in ways that defy logic and good sense. In this extract from the *New Scientist* book, *The Brain: A user's guide*, we look at why that is and some of the most common cognitive biases to avoid.

HOW intelligent are you? When it comes to making good decisions, it doesn't matter, because even the brightest people can do ridiculous things. Clever people act foolishly because intelligence is not the same thing as our capacity for rational thinking – and that's what matters when it comes to making good decisions.

IQ tests, designed to measure general intelligence, are very good at measuring certain cognitive abilities, such as logic and abstract reasoning. But they fail when it comes to measuring those abilities crucial to making good judgements in real life. That's because they don't test things such as the ability to weigh up information, or whether a person can override the intuitive cognitive biases that lead us astray. Understanding the factors that lead intelligent people to make bad decisions is shedding light on society's biggest catastrophes. More intriguingly, it may suggest ways to evade the stupidity that plagues us all.

How to be less stupid

- **Clear your mind. Judgements are often based on information you recently had in mind, even if it's irrelevant. For example, people bid higher at auctions when they are primed to ponder the height of the tallest person in the room.**
- **Don't fall foul of spin. We have an inclination to be influenced by the way a problem is framed. For instance, people are more likely to spend a monetary award immediately if they are told it is a bonus, compared with a rebate.**
- **Don't let emotions get in the way. Emotions interfere with our assessment of risk. One example is our natural reluctance to cut our losses on a falling investment because it might start rising again.**
- **Use facts. Don't allow your opinion to cloud your analysis.**
- **Look beyond the obvious.**
- **Don't accept the first thing that pops into your head.**

Gut reaction

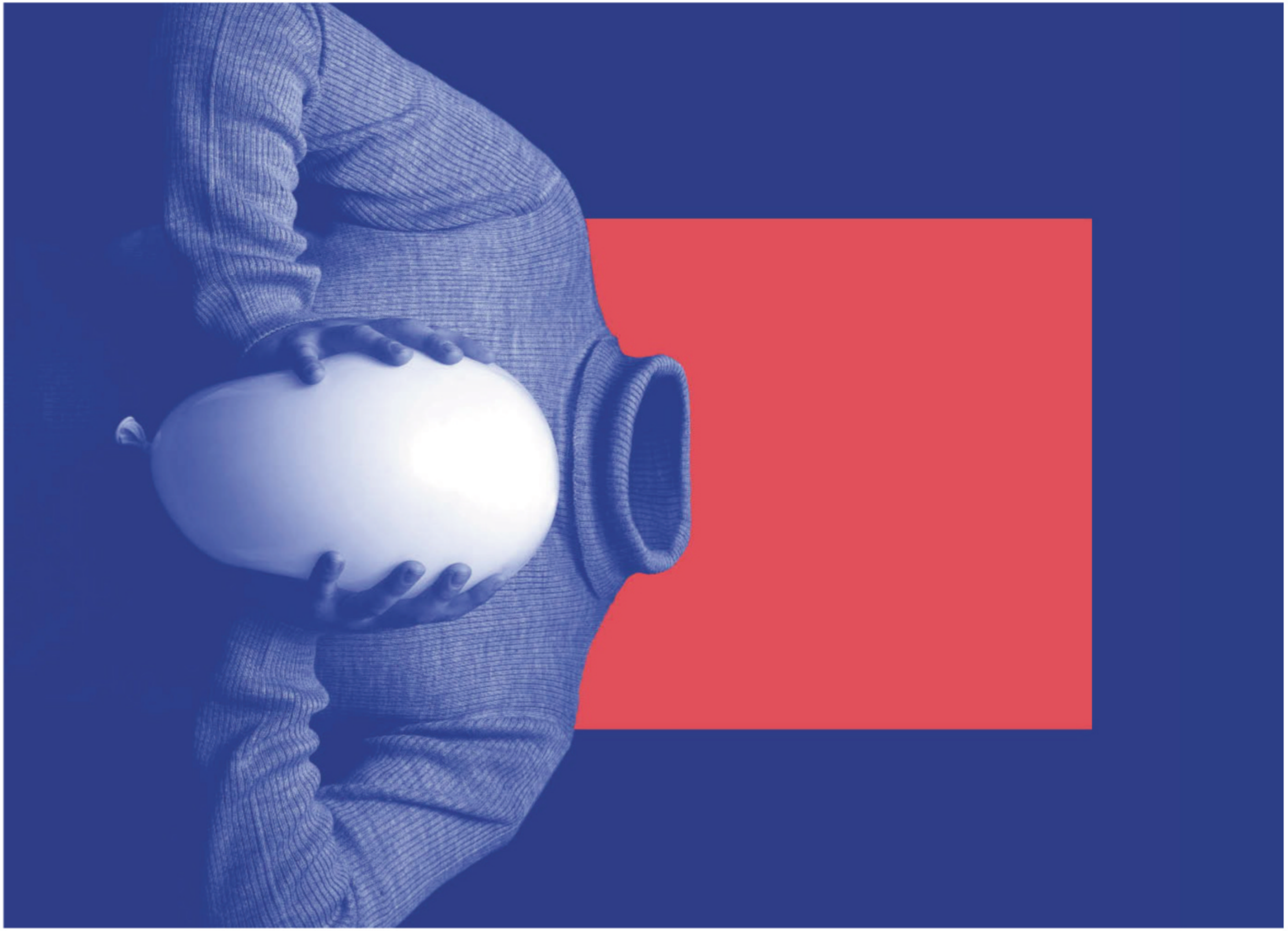
Consider this puzzle: if it takes five machines 5 minutes to make five widgets, how many minutes would it take a hundred machines to make a hundred widgets? Most people instinctively jump to the wrong answer that "feels" right – a hundred – even if they later amend it to the correct one, which is five.

When researchers put this and two similarly counter-intuitive questions to thousands of students at colleges and universities – Harvard and Princeton among them – only 17 per cent got all three right. A third of the students failed to give any correct answers.

Here's another one: Jack is looking at Anne but Anne is looking at George. Jack is married but George is not. Is a married person looking at an unmarried person? Possible answers are "yes", "no", or "cannot be determined". Most people will say it cannot be determined, simply because it is the first answer that comes to mind – but careful deduction shows the answer is "yes" (we don't know Anne's marital status, but either way a married person would be looking at an unmarried one).

We encounter problems like these in various guises every day. And regardless of our intelligence, we often get them wrong. Why? Probably because our brains use two different systems to process information. One is deliberative and reasoned, the other is intuitive and spontaneous. Our default mechanism is to use our intuition. This often serves us well – choosing a potential partner, for example, or in situations where you've had a lot of experience. But it can also trip us up, such as when our gut reactions are swayed by cognitive biases such as stereotyping or our tendency to rely too heavily on information that confirms our own ›

FRANCESCOCH/ISTOCK PHOTO



Avoid the flaws that lead you astray

Making the right decision is difficult and perilous, not least because your brain has many inbuilt biases that lead you to behave in ways that defy logic and good sense. Here's a guide to some of the choicest of these flaws. See how many you spot as you go about your day (though beware, having these biases may prevent you from being able to spot them).

DUNNING–KRUGER EFFECT

The bias of illusory superiority.

This is the tendency of people with low ability to mistakenly overestimate their competence.

The Dunning–Kruger effect is a close cousin of the better-than-average effect – the statistically impossible effect in which the majority of people rate themselves more favourably than average.

There's also the reverse Dunning–Kruger effect, know as Imposter Syndrome, where a competent person feels like a fraud who is about to be found out.

ENDOWMENT EFFECT

The tendency to value things more highly just because you own them.

"Let me pick up an ashtray from a dime-store counter, pay for it and put it in my pocket — and it becomes a special kind of ashtray, unlike any on earth, because it's mine", wrote Ayn Rand in her novel The Fountainhead.

This feeling is common, and leads us to make irrational decisions, like refusing to swap an item for something of higher value.

The endowment effect is one reason why the prospective purchaser of your old car won't pay the price you think it's worth.

HYPERBOLIC DISCOUNTING

A strong preference for getting something now over something of higher value in the future.

If you were offered £50 today or £100 tomorrow, the latter would be the obvious choice. It's less clear-cut when the delay grows. Would you still wait a year for the £100? As the time gap grows, so does your preference for the immediate reward.

Hyperbolic discounting is the reason why many people's retirement funds are empty. But as retirement looms, suddenly the "future"isn't so far away, and hyperbolic discounting comes back to bite.

STATUS-QUO BIAS

A preference for the current state of affairs, and the feeling that any change from this is a loss.

This bias is linked to our desire for familiarity, and the observation that we feel more regret for bad outcomes resulting from new actions than for bad consequences that arose from inaction. It's one reason why you still drink Coke, when in blind tests you actually preferred a rival brand.

BLIND-SPOT BIAS

The tendency to recognise the impact of bias in other people's judgements, but failing to see them in your own.

If you suffer from this (which you certainly do) you're not alone. Everyone thinks they are less biased than other people. This effect is related to the self-enhancement bias – the tendency to see yourself in a positive light. This blind spot means you won't be able to adapt your behaviour, even if your errors of judgement are glaringly obvious when carried out by other people.

GAMBLER'S FALLACY

The mistaken belief that if something has happened more frequently than normal, it will happen less frequently in the future.

Also known as the Monte Carlo fallacy, because of a famous incident at a casino roulette wheel there in 1913. The ball landed on black 26 times in a row and gamblers lost millions betting against black in the next spin. The chances were actually 50:50 but many people thought a red was due next time. The gambler's fallacy is the reason why, after having four boys, you think you're going to have a girl next.

opinion. While these biases may help our thinking in certain situations, they can derail our judgement if we rely on them uncritically. For this reason, the inability to recognise or resist them is at the root of stupidity.

Think rationally

To truly understand human stupidity you need a separate test that examines our susceptibility to bias. One candidate is a test called a rationality quotient, which assesses our ability to side-step cognitive bias and work out the likelihood that certain things will happen.

So what determines whether you have a naturally high rationality quotient? More than anything, it depends on something called metacognition, which is the ability to assess the validity of your own knowledge. People with a high rationality quotient have acquired strategies that boost this self-awareness.

But even the most rational among us can be tripped up by circumstances beyond our control. Emotional distractions are the biggest cause of error. Feelings like grief or anxiety clutter up your working memory, leaving fewer resources for assessing the world around you. To cope, you may find yourself falling back on your intuition.

Group stupidity

In the end, no one is immune to the biases that lead to stupid decisions. Yet our reverence for IQ and education means that it is easy to rest on the laurels of our qualifications and assume that we are, by definition, not stupid.

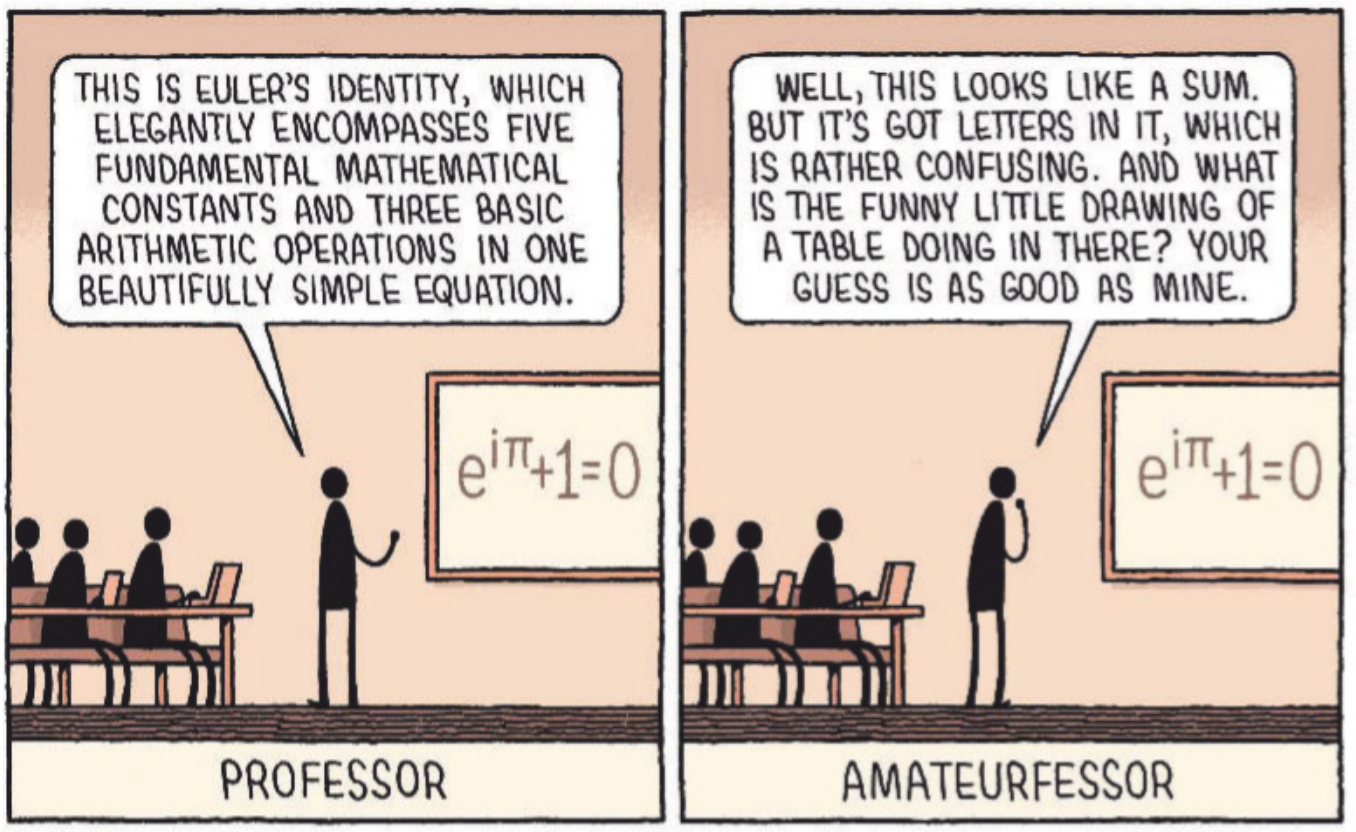
That can be damaging on a personal level: regardless of IQ, people who score badly on rationality tests are more likely, for instance, to fall into debt. Large-scale stupidity is even more damaging. Business cultures that inadvertently encourage it may have contributed to the 2008 economic crisis. The effects may have been so damaging precisely because banks assumed that intelligent people act logically while at the same time rewarding rash behaviour based on intuition rather than deliberation.

Most researchers agree that, overall, the correlation between intelligence and successful decision-making is weak. The exception is when people are warned that they might be vulnerable to bias, in which case those with high IQs tend to do better. This is because while clever people don't always reason more than others, when they do reason they reason better. Which just goes to say that we should all try to be a little more aware of how we make decisions – because you are probably more stupid than you think.

on't accept the first thing that pops into your head. ▮

The back pages

Tom Gauld
for New Scientist



Twisteddoodles
for New Scientist

Quick quiz #62
Answers

1 Testosterone

2 Continental drift, or what is now plate tectonics; Wegener first suggested that Earth's continents were moving relative to one another in 1912

3 Cabbage white butterfly; for those that distinguish, *P. rapae* is the small white, *P. brassicae* the large white

4 Vera Rubin. Her studies of rotating galaxies suggested unseen "dark" matter must far outweigh normal matter within them

5 Alveoli

Puzzle
set by Zoe Mensch

#70 Taking the biscuit

Alpha and Betty play a rather greedy game. There are eight digestive biscuits in one jar, and four rich tea biscuits in another. Each player can collect biscuits in one of two ways. They either:
• Take any number of biscuits from one jar, or
• Take an equal number of biscuits from both jars.

The player who takes the last biscuit wins the game and gets to keep all the biscuits. Alpha is set to go first. What biscuit or biscuits should she take?

Answer next week

#69 Cutting the flag

Solution

Three-fifths of the trapezium is blue, the same proportion as for the uncut flag.

One way to see this is to make a copy of the trapezium, rotate it by 180 degrees and place it next to the first. It will form a parallelogram made of five stripes, now all of equal length. Three-fifths of the parallelogram is blue, and because the two trapezia were identical, they will also have the same fraction of blue.

The Great Bare

With so much unpleasantness at ground level in recent months, it is hardly surprising that people around the world have sought solace in the heavens.

Particularly widespread hay was made of the recent arrival of Neowise, a comet that was first spotted in March and is now making its closest approach to the sun. C/2020 F3 (NEOWISE), as the giant iceball is properly known, has a 6800-year orbit, meaning that this approach may well be the last time any of us gets to see it. We aren't talking about any one person, obviously, but the human race as a whole.

Sigh. Of all the times to drop by, it had to pick the days of covid-19. Not really looking our best, are we? Feedback in particular hasn't had a haircut since late 2019. We have had to attach our fringe to the backs of our ears with bulldog clips so that we can still see the computer screen.

By some standards, though, that's practically overdressed for the occasion. According to a (since corrected) article in the Metro online, Neowise "has been spotted streaking across the night skies around the world and will be visible to the naked here in the UK".

Feedback correspondent Dominic Driver, who sent the clipping in, confesses to being "somewhat surprised by the requirement to strip off to view the comet and wondering why it is only a requirement in the UK. Perhaps something to do with social distancing?"

Good thought, Dominic. We would certainly advise keeping well away from any astronomers who are wandering the countryside in the altogether.

JOSIE FORD

Space names

On the subject of space, Feedback was over the moon to receive Alan Ashton's correspondence on the contrived acronyms used in much astronomical research. Not only does he agree with our fundamental point, he provides some very compelling receipts on the subject.

"One project," writes Alan, "is HoLiCOW. This stands for 'Ho Lenses in COSMOGRAIL's Wellspring' where COSMOGRAIL refers to 'COSmological MOnitoring of GRAvItational Lenses'. They are hoping to reconcile the results from HoLiCOW with SHoES, 'Supernova, Ho, for the Equation of State of dark energy'." All of which is wonderfully ARSE (AcRonym abuSE) about FACE (Frankly Absurd and self-indulgent aCronym crEation).

Alan goes on to tickle Feedback's fancy by suggesting the coinage of a neologism. "Astronomers seem to have cornered the market in bizarre acronyms. Maybe they should be called Astronyms." We love it.

Got a story for Feedback?

Send it to feedback@newscientist.com or
New Scientist, 25 Bedford Street, London WC2E 9ES
Consideration of items sent in the post will be delayed

Some certainty

In yet another entry in this week's "Previously on Feedback" sequence, reader Bob Mays wrote to us some time ago to object to our use of the expression "more than probable", and requested a reference table in which he could determine the exact probability referred to. We humbly prostrated ourselves before him and ceded his point.

But now, it seems that we may have ceded our ground too swiftly. Permit us, then, to quickly clamber back up onto the moral high ground and pretend we never left it in the first place. Sami Wannell has written in to direct us – and we quote – "to Sherman Kent's work with NATO around how people interpret different 'estimative probability' terms".

The study in question shows that people consider "unlikely" to be more likely then "little chance", but less likely than "improbable" – which, in turn, is seen as less likely than "likely" and even more unlikely than "probable".

What's more, the study reveals that "probable" is seen as less likely than "very good chance", "highly likely" and "almost certainly". Which means, Bob, that our posteriors are very amply covered. Profuse thanks to Sami, who – in classic Feedback fashion – points out that his surname is pronounced one-L but spelled with two.

Rhea sighting

At some point in the fairly recent past (the months, where do they go? Answers on a sterilised postcard), Feedback returned to the subject of unusual social-distancing yardsticks.

We focused in particular on an Australian airport that suggested staying one cassowary apart, a whimsical idea on which we riffed airily, pointing out that the cassowary's famously dangerous claws may warrant staying at least one cassowary apart from any cassowary.

Another flightless bird has made headlines since then, this time on the other side of the world. The scene is Brazil, and the protagonist is a noble rhea that took it upon itself to stroll around the grounds of the presidential palace.

The villain of the affair? Brazilian president Jair Bolsonaro, who foolishly violated social-distancing protocols by trying to feed the bird. The result? A pecking that – from a photographic point of view, at least – looks pretty painful indeed.

With Bolsonaro's popularity on the wane in Brazil, not everybody was immediately sympathetic. According to *The Guardian*, Margarida Salomão, a member of congress for the Workers' Party, was particularly scathing. "This rhea represents us," she tweeted. Duly noted.

Written by Gilead Amit

Sun down

UV radiation is strongest when the sun is highest. Is this down to the angle of the sun or UV attenuation? When does my face get the most UV?

Mike Follows
Sutton Coldfield, West Midlands, UK
When the sun is directly overhead, which only ever occurs in the tropics, sunlight has its shortest journey through the atmosphere. When the sun is lower in the sky, more ultraviolet light is attenuated because the sunlight has a longer journey through the air. That means your body will get most UV at midday, when the sun is highest in the sky. Of course, it depends where you are on the planet, as UV increases when you are closer to the equator.

Climbing a mountain will also reduce the distance sunlight has to travel through the atmosphere before hitting you: UV radiation levels increase by about 10 per cent for every 1000 metres of ascent. In addition, UV exposure rises when you are on a highly reflective surface, like water, snow or even dry sand.

About 20 years ago, I was taken by surprise when I discovered that my lower legs were sunburned after I had been wandering on the snow around Jungfraujoch in Switzerland, which is at an altitude of almost 3500 metres. I was there for only a couple of hours and didn't apply sunscreen to my legs because I was wearing trousers. However, sunlight had reflected off the snow and up inside my trousers, burning my unprotected skin.

Olivier Sorg
Geneva, Switzerland
The UV radiation spectrum is divided into three bands: UVA (320 to 400 nanometres), which is close to visible light, UVB (280-320 nm) and UVC (100-280 nm). The most energetic band, UVC, is absorbed by ozone in the atmosphere, and more UVB is absorbed by the atmosphere than UVA. Therefore, when the sun is low in the sky, the proportion of UVB falls compared with UVA. Because UVB can cause more biological damage than UVA, the effects of UV radiation on human skin are stronger when the sun is high in the sky.

When the sun is directly overhead, known as the zenith, its light doesn't hit the face of a person walking below. A walker's face is likely to get the most impactful UV radiation when the sun is between 40 degrees and 60 degrees above the horizon. Of course, if a person is lying on their back, their face will get the most UV when the sun is highest in the sky.

Chris Daniel
Colwyn Bay, Conwy, UK
The strength of ultraviolet radiation at ground level varies through the day due to attenuation that is largely dependant on the sun's angle in the sky. One recent study found that the greatest amount of UV radiation reaches the eye when the sun is at an elevation of 40 degrees. In the UK, the sun generally climbs higher than this only in the summer months.

This suggests that the face, much of it being a nearly vertical surface, receives the most radiation at this angle. The parts of the face that are angled slightly upwards, such as the nose, will be more susceptible to burning when the sun is higher in the sky, when irradiance will also be greater. But caution is needed even then as the eyes and face will still be subject to UV radiation reflected from the ground and backscattered from elsewhere in the sky.

Jonathan Wallace
Newcastle upon Tyne, UK
All light waves are scattered as they interact with molecules and particles in the atmosphere, a process known as Rayleigh scattering. Different wavelengths are affected to a different extent, with short wavelengths (blues and UV) affected the most.

This means that as sunlight passes through the atmosphere, blue light is filtered out more than other wavelengths. The more atmosphere the light passes through, the greater the effect. At sunset and sunrise, when sunlight strikes Earth at a low angle compared with the observer and therefore passes through a large amount of atmosphere on its route to the surface, the result tends to be red and yellow skies.

This effect is enhanced when there are more particles in the air, which is why volcanic explosions can lead to spectacular sunsets.

BRAD MITCHELL/ALAMY

Do animals that live at elevation get reverse altitude sickness?

This week's new questions

Ups and downs **When creatures accustomed to life at high altitude are brought to sea level, do they experience reverse altitude sickness?** ***Laura Montague****, Godalming, Surrey, UK*

Cold brew **People often say that to brew the best coffee you must start with cold water. Are they right?** ***Bor Carr****, Boulder, Colorado, US*

Cover-up

When you wash a duvet cover, why does other washing end up in it?

Mary Argent
Brentwood, Essex, UK
The problem with the duvet cover is caused by a lack of preparation before the wash. The removed cover should be kept inside out to allow it to be correctly replaced on the duvet when dry. All poppers or other closing mechanisms should also be closed before the cover is put in the washing machine. In this way, a large empty bag is converted into a large double thickness sheet. There is no way it can capture other washing, as there is now no entry point.

Tim Stevenson
Great Missenden, Buckinghamshire, UK
Finding itself naked and robbed of its proper innards in a threatening, dark, wet, frothy, swirly place brings out the protective parental instinct in a duvet cover. ▮

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