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The end of the universe

Will our universe collapse in on itself, rip itself apart or even succumb to an inescapable expanding bubble of doom, asks astrophysicist Katie Mack. Thursday 13 August at 6pm BST/1pm EDT.

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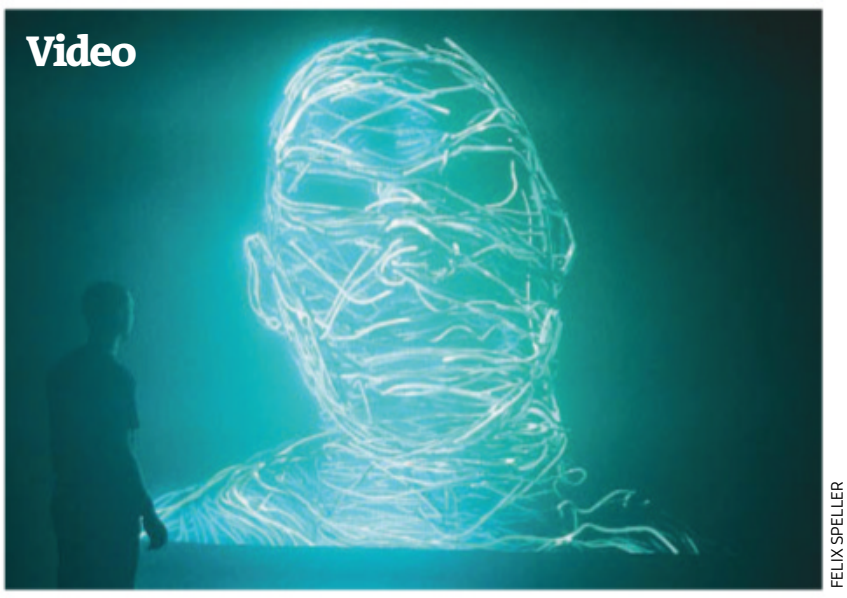

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Electronic music A tour of the London Design Museum's new show

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Electronic music

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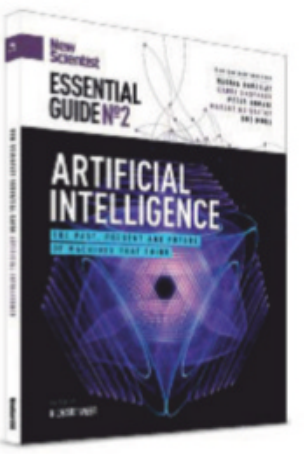

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Busting miscarriage myths

Blame is still falsely tied to pregnancy loss, but research shows its natural function

FOR more than a century, medical researchers have known that miscarriage is rarely preventable and is instead usually due to chromosomal abnormalities in an embryo. In recent decades, it has also become clear that miscarriage is very common: as many as one in five known pregnancies ends this way. That figure goes up as we get ever better at detecting pregnancy from its very first stages. It is now estimated that, among women in their early 20s, half of pregnancies end in miscarriage. This proportion rises with age.

No small effort has been made by medical organisations and advocacy groups to raise awareness and improve education around early pregnancy, but the notion that miscarriage is rare – or is somehow the woman's fault – still widely persists. Not only do surveys consistently show that many women blame themselves for a pregnancy loss, but some societies heap blame upon them as well. That only exacerbates the intense grief and trauma that women and their partners can feel after a pregnancy loss.

"Advances in fertility medicine reveal that miscarriage has actually served a fundamental role in our evolution"

However, conveying to women – let alone society more broadly – how misplaced this notion of blame truly is hasn't been easy, or straightforward. That is partly because, until recently, studying the very earliest stages of pregnancy, to better understand what is happening down at the molecular level, was physically complicated and ethically fraught.

Now, thanks to advances in fertility medicine, we are getting a more detailed understanding of how a developing embryo sends and responds to signals from the lining of the uterus, as well as learning more about the intensive vetting process that each embryo must go through (see page 40).

These insights reveal that miscarriage has actually served a fundamental role in our evolution – and even indicate that, surprisingly, women who experience multiple miscarriages may actually have optimal maternal fitness.

This revolution in our understanding of miscarriage has implications for the options available not only for those people trying to conceive, but also those coping with a loss. ▮

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Social distancing measures are in place at partially open schools, such as this one in London

Back to school?

With schools in many countries set to reopen in September, researchers are assessing their safety, reports **Adam Vaughan**

THE UK faces a second wave of coronavirus infections this winter if the country's testing and contact tracing system doesn't improve by the time schools fully reopen and people return to workplaces, researchers have warned.

Jasmina Panovska-Griffiths at University College London (UCL) and her colleagues found that there is a risk of a second peak in December that will be more than twice the size of the UK's first one. Her team modelled the amount of testing and tracing needed to stop the virus rebounding as society eases restrictions.

If all children in the UK return to school by early September, as is currently planned, and almost three-quarters of people return to workplaces, the UK would need to be testing 75 per cent of symptomatic covid-19 cases to stay on top of the spread of the virus. The current rate in England, which the team used as a basis for its UK modelling, is 50 per cent. The proportion of their contacts traced would have to jump from about 50 per cent in England now to 68 per cent for the whole of the UK (*The Lancet Child & Adolescent Health*, doi.org/d5qc).

"It needs to improve," said Russell Viner at UCL, who also worked on the study, during a press conference by the team.

"Plans have been put in place to ensure schools can reopen safely. Local health officials, using the latest data, will able to determine the best action to take to help curb the spread of the virus should there be a rise in cases," says a spokesperson for the UK's Department of Health and Social Care.

"We have stronger evidence that children play a very limited role in transmission"

The analysis comes amid wider questions about the role of children in transmitting the virus, as many countries across the world prepare to reopen schools. Initial research has been inconclusive but has indicated that the risk of children catching covid-19 at a school may be lower than first feared. A study published on Monday supports that, finding transmission rates were low at 15 schools and 10 pre-school childcare centres in the Australian state of New South Wales amid a first wave of infections. Only three of the schools and one of the centres saw secondary transmission of the virus. "Transmission in educational settings can be kept low and manageable," writes the team led by Kristine Macartney at the University of Sydney.

"We have stronger evidence that children play a very limited role in transmission," said Viner. "They do transmit this virus, there can be outbreaks in schools. [But] studies like this New South Wales paper show there's very little evidence they drive significant elements of this in schools." Most of the outbreaks at schools appear to have been triggered by staff rather than children, he said.

Debate over school reopenings returned to the fore after England's chief medical officer Chris Whitty said on 31 July that new data suggested the country has "probably reached near the limit or the limits of what we can do in terms of opening up society". Difficult trade-offs on restrictions would be needed, he said.

Graham Medley at the London School of Hygiene & Tropical Medicine (LSHTM), one of the government's scientific advisers, subsequently said that might mean closing pubs to allow schools to reopen.

The research shows what is needed to allow schools to reopen, said Chris Bonell at LSHTM, who also worked on the UK modelling study. "Schools absolutely have to go back in September, it's critical for the economy and for children's education and well-being. It's the most important of all the reopenings," he said. ▮

Infections

Huge surge in the US

The US is battling a massive second wave of coronavirus cases and has no cohesive national strategy to stop the spread, reports **Kayt Sukel**

WHEN Antoine Dupont started to feel under the weather in mid-July, he immediately wanted to be tested for the coronavirus. Unable to find a facility where he could get this done near his home in West Palm Beach, Florida, a friend told him about an urgent care clinic with a handful of appointments in Boca Raton, 30 minutes away. He secured a test for the next Friday.

"The nurse said I'd hear back by Tuesday because of the weekend, which seemed a little long to me," he says. "I didn't get my results until the next Friday – and only after I had been calling the clinic for a few days."

His test result came back negative. But the news didn't come as a relief. He was still feeling ill – and by then his ex-wife and son, who he sees on weekends, had tested positive for the coronavirus. Dupont says he doesn't believe his result was accurate. However, he sees no reason to get another test.

"The whole testing system is a dismal failure of epic proportions," he says. "With the labs backed up the way they are, I wouldn't get an answer in a reasonable amount of time anyway."

He isn't the only person in the US struggling to get a test. Individuals in other states that have been hit hard by the virus,

"In New York, they followed public health guidelines and didn't just flatten the curve – they crushed it"

like Texas, Louisiana and Georgia, are facing the same challenges – and it is damaging the ability of those places to effectively control the spread of covid-19.

As of 4 August, Florida had over 490,000 confirmed coronavirus cases and more than 7100 deaths related to covid-19. Even though cases have started to dip a bit, the number is still alarmingly high. "Florida is one state that is continuing to see massive spread, but it's not the only state that is showing those kinds of numbers," says Ali Nouri at the Federation of American Scientists.

"Unfortunately, it all goes to show, across the United States, by and large, we are not doing as much as we need to be doing in order to get this virus under control," he says.

On 23 July, the US passed an unwanted milestone: 4 million confirmed cases. This number makes up more than a quarter of the global total, despite the US accounting for just 4.4 per cent of the world's population.

That those last million cases were added over a mere 15 days makes the number even more distressing, says Leana Wen at the George Washington University in Washington DC. She says there is remarkable variation in infection rate – as well as in public health response – from state to state that cannot just be explained by the size and diversity of the US.

JEFFREY GREENBERG/EDUCATION IMAGES/UNIVERSAL IMAGES GROUP VIA GETTY IMAGES

A mobile covid-19 testing facility in Miami Beach, Florida

Inconsistent strategies

By 29 July, 28 states along with Washington DC were showing a rise in the seven-day averages of new coronavirus cases, with only five boasting the opposite trend (see map, right).

"While this is a new virus and we are learning new things about it every day, one thing we've known for a while is that wearing a mask, social distancing and handwashing can help limit spread," says Wen. "When you consider the New York region, they followed the public health guidance and, as a result, they didn't just flatten the curve in their state – they crushed it. Unfortunately, we aren't seeing the same approach in other states."

Even within some states, coronavirus mitigation regulations – such as mandatory face coverings in public or people returning from out-of-state travel having to self-quarantine – haven't been applied consistently from county to county or city to city. That can have dangerous results.

Rob Phillips at Houston Methodist Hospital in Texas says it is likely that the state's aggressive reopening plan is behind its current high positive test rate, which is 12.1 per cent of tests taken.

"As businesses opened back up, there was significant relaxation of social distancing and other measures, and people went

back to work, as well as back out to restaurants and bars," he says. "But we also have a lack of testing and contact tracing. It's exposed that we haven't invested enough in our public health infrastructure so we can identify cases, isolate them and stop little flare-ups of infection from turning into forest fires."

Testing failures

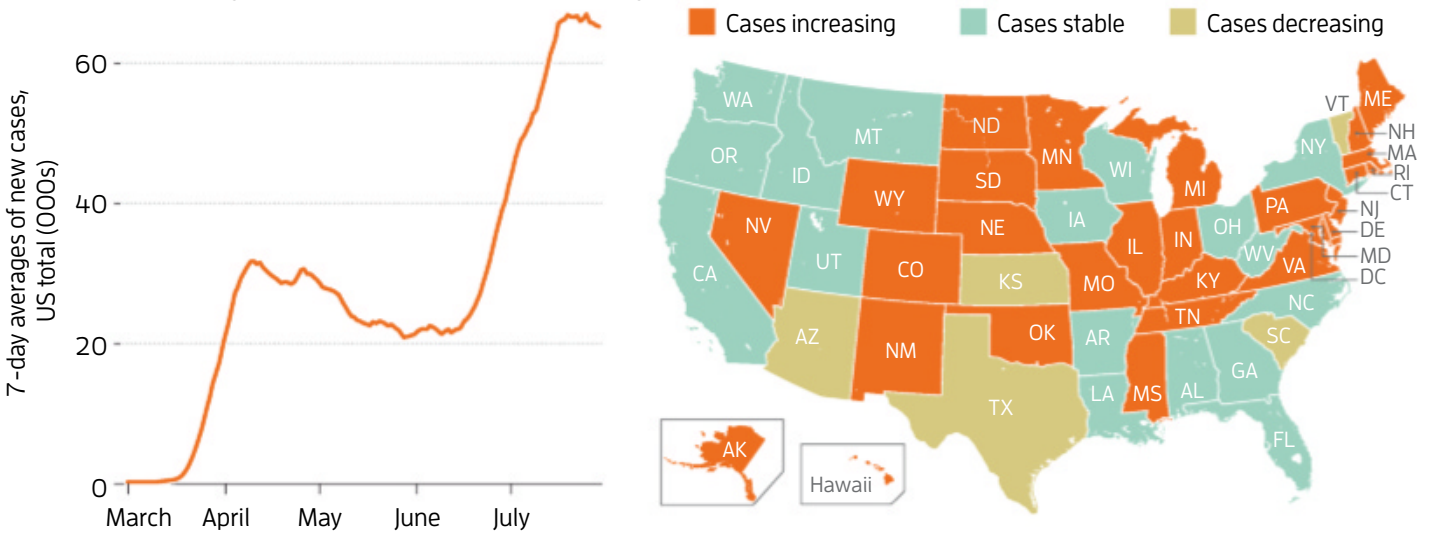
Eric Topol at the Scripps Research Translational Institute in California agrees that a strong testing and contact-tracing programme is required to help contain spread – and it is noticeably absent from the US's current pandemic strategy.

"The more testing you do, the better chance you have, regionally, of understanding where infections are," he says. "Contact tracing then lets you see where the virus may be going. The infrastructure for these things is just not in place in most localities, so sustained suppression remains out of reach."

And that is before you consider that some people in viral hotspots are waiting as long as two weeks for test results. North Carolina-based LabCorp, which runs one of the largest networks of diagnostic laboratories in the US, says that as demand for tests rises, so does the time it takes to process them. A spokesperson says the company has reduced the average time to deliver results to "three to five days from specimen pickup", and is continuing to actively decrease the turnaround time.

The longer it takes for patients and public health agencies to get test results, the harder it is to track and manage new outbreaks. "You are most contagious right before you develop symptoms," says Nouri. "So if I start feeling sick today, get a test tomorrow, but don't get my results for another 10 to 14 days, I have potentially infected a large number of people before I even get word that I'm, in fact, positive. That's a huge problem."

The seven-day averages of new coronavirus cases, which include the six days leading up to 29 July, show a concerning rise in most states and Washington DC



SOURCE: DATA FROM THE NEW YORK TIMES, BASED ON REPORTS FROM STATE AND LOCAL HEALTH AGENCIES.

Turning the tide

Despite the systemic failures that have led the US to this dire point, Topol says he is optimistic that things can still be turned around. The development and deployment of faster coronavirus tests, as well as advances in vaccine development, should help future efforts to contain the virus's spread, he says.

Yet the adoption of a cohesive, national mitigation strategy – as well as consistent messaging about public health initiatives – could help turn the tide now, says Topol. Nouri says, too often, the messages coming from both national and state leaders are contradictory at best – and outright misleading at worst.

In response to increasing coronavirus cases, US President Donald Trump announced on 23 July that the Republican party was cancelling the in-person portion of its convention due to be held in Florida in late August at which he was to have been formally nominated as the party's presidential candidate. He has also made recent comments about how wearing a face covering is patriotic.

But only a week later, Trump retweeted several accounts attempting to discredit Anthony Fauci at the National Institute of Allergy and Infectious Diseases, one of the most trusted public health officials in the US. Those tweets also promoted the use of hydroxychloroquine, a drug that numerous clinical trials have now shown isn't an effective treatment for the virus.

"It's hard for me and other doctors on the front lines to understand why mask wearing is so divisive"

Lack of clarity

"Misleading information has had enormous impact on where we are today," says Nouri. "The lack of clarity from the White House on simple measures like wearing a mask, as well as the spread of misinformation on social media, means that the public doesn't have accurate information on what this virus can do and what needs to happen to stop it."

Phillips agrees. He says that his hospital in Texas, as well as other medical centres across the state, have spent millions of dollars on public information campaigns to help people understand the value of face coverings and social distancing.

"It's hard for me, as well as other nurses and doctors on the front lines, to understand why something like mask wearing is such a divisive issue instead of a unifying one," he says. "But as more voices come together with consistent messaging, I'm hopeful that will change."

"This shouldn't be political," says Topol. "We just need to follow the science. Our strategy should be coordinated by public health experts that know what needs to happen and have the authority to get it done. They need to be building the right infrastructure for effective testing and contact tracing. They need to be the ones giving the briefings every day. They need to show us the way forward. That's going to be what gets us to where we need to be." ▮

The K number

How to stop superspreaders

An indicator of the likelihood of "superspreading" events that kick off outbreaks is key to containing the coronavirus, finds **Clare Wilson**

A SKIING trip, a wedding, a choir practice: what these events have in common is that they were all occasions of coronavirus "superspreading". This is when someone passes the virus on to a high number of people.

While there is no widely agreed definition of a superspreading event, it is sometimes taken to be an incident in which someone passes on the virus to six or more other people. Understanding why these clusters occur could be key to gaining control of the covid-19 pandemic and stopping a second wave of cases.

For months, we have heard that the R number, or reproduction number, is what is needed to gauge the spread of covid-19. This is the average number of people that each infected person passes the virus on to. Before lockdown in the UK, the R number for coronavirus was estimated at somewhere between 2 and 3.

It is now more appreciated that there is great variability in the number of new cases that each infected person generates. This can be described by the epidemic's "K number" – the dispersion parameter – with a lower value of K signifying more variability. You need to know both R and K for a good picture of how the virus is spreading through a community.

According to an analysis of how covid-19 had spread to other countries from China by the end of February, the K number was 0.1, an extremely low value. The researchers estimated that 80 per cent of cases were caused by about 10 per cent of infected people. Those 10 per cent could trigger a cluster of infections, while most others would pass on coronavirus to no one else and a few would give it to just one other person.

In other words, superspreading is integral to the pandemic, says Quentin Leclerc at the London School of Hygiene & Tropical Medicine.

20%

of infected people caused 80 per cent of 1037 cases in Hong Kong

In one well-studied example, at a choir practice with 61 attendees in March, in Skagit County, Washington State, one person infected an estimated 52 others. Doctors followed up with the close contacts of every secondary case, about three or four each, and could find only 10 further infections, says Lea Hamner, a public health official in Skagit County.

It is as if something qualitatively different was going on that night. Transmission clusters have been seen in other diseases, including HIV, TB and typhoid, with a famous superspreader being a New York cook in the early 20th century who came to be known as Typhoid Mary. In these cases, it seemed there was something biological that made the person more likely to pass on an infection, probably having a high number of the pathogens.

With coronavirus, virus burden may well play a role, but this hasn't been investigated and we have no easy way to do that, says Benjamin Cowling at the University of Hong Kong in China. "If we measure viral load in saliva, that's not the same as how much virus they're breathing out. You would have to do some kind of air sampling."

The circumstances of the spreading event also seem to be important, and some common themes have emerged. Cowling's group carried out contact tracing of the first 1037 coronavirus cases in Hong Kong. The team found a somewhat larger K value than the previous estimate, of 0.45, but that still means just 20 per cent of infected individuals caused 80 per cent of locally acquired cases (*Research Square*, doi.org/d5hw).

Mass transmissions

Superspreading events have tended to happen indoors, with people in close proximity. Social occasions led to more clusters than exposure in the workplace or home – mass transmissions occurred at weddings, temples, bars and karaoke parties, for

MARCO BOTTIGELLI/GETTY IMAGES

Superspreading is when someone infects a large number of people

instance. The risk seems to be higher if people are raising their voices in some way, such as singing or shouting. "It's the volume of air that comes out of your lungs," says Cowling.

Understanding superspreading is becoming even more important now that coronavirus cases are declining in many countries, says Adam Kleczkowski at the University of Strathclyde, UK. When case numbers are rising exponentially, superspreading is arguably less crucial, he says, as many clusters spread and merge.

But avoiding clusters is key early in an epidemic before sharp rises in case numbers, or when case numbers fall and a second wave must be avoided. "When you have very few cases, it's these [superspreading] events you need to watch out for," says Leclerc.

How can we reduce the chances of further superspreading events? "Our guiding principles right now are: outdoors is safer than inside, fewer people are safer than more people," says Hamner. She sees indoor bars as a particular risk. "A drunk person is well known for talking louder and louder the drunker they get."

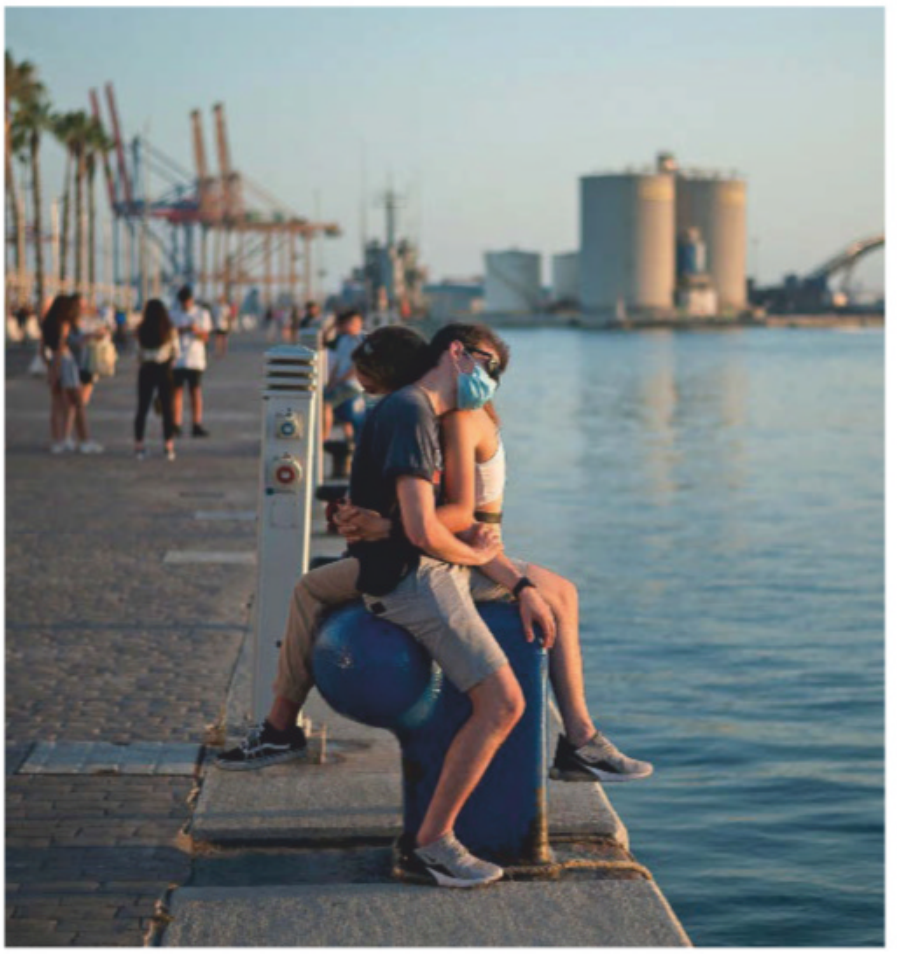
Making people aware of superspreading could reinforce the need to avoid risky situations. It could also help inform how to ease lockdown restrictions, says Leclerc, whose team has created a database of global superspreading events. Only eight of the 201 clusters the team identified took place in schools, which at the start of the pandemic were seen as a potential hotbed of infections.

Spotting clusters in real time is also key for contact tracing to work, he says. "If you manage to detect [superspreading events] and find the people infected, you can stop the spread before it goes on." ▮

Personal risk

Is it ever safe to hug someone?

Linda Geddes



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Hugs are less hazardous if they are brief and people wear face coverings

IF THE pandemic has left you craving a cuddle, you aren't alone. Some 60 per cent of people in the US reported feeling touch-deprived during the first month of lockdown, suggests a new study, even though only a fifth of those surveyed lived alone.

Tiffany Field at the University of Miami in Florida and her colleagues surveyed 260 adults and found that those reporting touch deprivation scored higher on scales measuring anxiety, depression, fatigue, sleep issues and post-traumatic stress.

Touch deprivation was more common in people living alone, but also affected those living with family or friends. "Only 33 per cent of people said they were touching their partner a lot, and as many as 37 per cent said they weren't touching them at all," says Field (*Medical Research Archives*, in press).

A separate study of more than 1000 US adults found that those who frequently hugged, kissed or met up with friends and family in lockdown were 26 per cent less likely to report symptoms of depression and 28 per cent less likely to report loneliness, regardless of whether they were married or cohabiting. Regular video chats didn't show the same benefits (medRxiv, doi.org/d5hf).

> "Most hugs are just a brief encounter, and there are ways to lower the risks"

"We saw stronger mental health benefits from types of contact that involved touch, which aligns well with the benefits we know come from close touching, like decreased heart rate, higher levels of oxytocin and lower levels of cortisol," says Molly Rosenberg at the Indiana School of Public Health in Bloomington, who led the work.

Given these benefits, is a quick hug out of the question? Rosenberg stresses the importance of limiting contact with non-household members to prevent the spread of the coronavirus, and most governments continue to advise people to maintain a distance of at least 1 metre from others.

But proximity isn't the only factor. "Because most hugs are just a brief encounter – and the short time is really key here – I think there are ways to lower the risks to what is, to me, an acceptable level, especially given the benefits of hugging," says Linsey Marr at Virginia Tech in Blacksburg.

Avoiding face-to-face contact is key. Marr recommends face coverings, pointing faces in opposite directions and not touching the other person's face or clothing with your face. "This is not a spontaneous act: you have to plan, and you should ask consent," she says.

"It would also be prudent to wash your hands before and after you hug, and maybe not exhale," says Margaret Hosie at the University of Glasgow, UK.

Experts emphasise hugging isn't risk free and shouldn't be routine. It should also be avoided by those in high risk groups or showing any symptoms of illness. Even so, "I believe we are at a stage of the pandemic in which we should all be able to make our own risk assessment, based on what is now known about the virus and its transmission patterns, and then act accordingly", says David Heymann at the London School of Hygiene & Tropical Medicine. ▮

Cosmology

Dark matter map hints at cracks in our understanding of the universe

Jonathan O'Callaghan

THE distribution of dark matter in the universe may be 10 per cent smoother than we thought, a finding that potentially upends our understanding of the evolution of the cosmos.

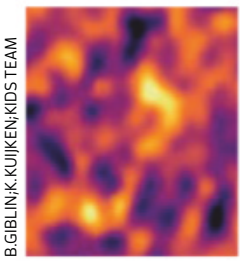
Last week, scientists announced the outcome of the seven-year Kilo-Degree Survey (KiDS). This used the Very Large Telescope at the European Southern Observatory in Chile to observe more than 30 million galaxies in the universe up to 10 billion light years from Earth. The results reaffirm previous indications about the spread of dark matter.

"The universe appears to be less clumpy than our best theory of the universe at the moment would suggest," says Catherine Heymans at the University of Edinburgh, UK, the study's lead author. "It [would] mean there's more to understand out there."

Following the big bang 13.7 billion years ago, our universe went through a period of inflation and expansion, leaving behind remnant heat in the process that we can observe today – the cosmic microwave background (CMB). This shows us the spread of matter throughout the universe.

But a number of dark matter studies over the past few years have begun to show a discrepancy between the CMB and the distribution of dark matter, which makes up about 85 per cent of the mass of the universe. The KiDS results find further evidence for that discrepancy.

The survey examined the light bent, or lensed, by the gravitational pull of dark matter in about 5 per cent of the universe as seen from Earth. This was combined with observations of the clustering of galaxies from a separate survey, called the Baryon Oscillation Spectroscopic Survey (BOSS), to provide an accurate measurement of the spread of dark matter (arxiv.org/abs/2007.01845).



B.GIBLIN;K.KUIJKEN;KiDS TEAM

In a new chart of dark matter, yellow marks the most dense regions

ESO/Y. BELETSKY

The Very Large Telescope in the Atacama desert, Chile

While other surveys have also conducted similar research, this latest study was noticeable for its level of accuracy, says Alan Heavens at Imperial College London. "They are the most precise [results] that have been published so far," he says.

If the findings are correct, they could have some broad implications. It could mean that gravity on large scales is different than we thought, with the rate at which matter falls into dense regions of the universe, as predicted by Albert Einstein's general theory of relativity, slower than predicted. Or it could be that our understanding of dark energy, thought to be the driver behind the accelerated expansion of the universe, is far from complete.

"This kind of discrepancy was not expected from our physical model of the universe," says Elisabeth Krause at the University of Arizona.

If results from other surveys suggest a similar smoothness to dark matter, it could be the start of some interesting new physics. "It's another crack in the model," says Heymans. ▮

Palaeontology

Did Da Vinci see a fossil and wonder about deep time?

A YOUNG Leonardo da Vinci may have seen a fossil whale embedded in an Italian hillside – centuries before what is currently regarded as the first description of such a fossil. The experience could have given the Renaissance-era polymath an intuitive appreciation of the vast age of Earth, long before geologists realised the planet's antiquity.

The claim that da Vinci, born in 1452 in what is now Italy, saw a fossil whale rests on passages in the Codex Arundel, a collection of scraps of his writings. On one page, he wrote of an animal that he imagined "tempestuously tearing open the briny waves", causing "terrified shoals of dolphins and big tuna fish" to "flee".

For many years, scholars thought this was metaphorical. But in 2014, Kay Etheridge at Gettysburg College in Pennsylvania argued that it might be a description of something da Vinci actually saw. Italy has many whale fossils, especially in the hills of Tuscany where he spent his early years.

A new paper by Alberto Collareta at the University of Pisa in Italy and his colleagues largely backs Etheridge, but they question one aspect of her interpretation.

"Etheridge put the location of this encounter between Leonardo and a fossil whale in a cave," says Collareta. This was because, on the neighbouring page of the Codex, da Vinci wrote: "I came to the entrance of a great cavern."

However, Collareta's team says Italian fossil whales aren't normally found in caves and the pages of the Codex aren't in any particular order, so the two passages are probably unrelated (*Historical Biology*, doi.org/d5g4).

The whale incident may have led da Vinci to think about the vast age of Earth long before geologists did. After mentioning the whale, which like his contemporaries he would have viewed as a fish, da Vinci added: "O time... how many kings, how many peoples have you undone... since the wondrous form of this fish died here?" ▮

Michael Marshall

Animal behaviour

Termites use cowardice to sidestep their hosts' anger

Jake Buehler

SOME termite species have figured out how to enjoy the shelter of the immense, complex nests that the insects build without contributing to their construction. They avoid the full wrath of their builder hosts by being extremely easy-going.

Animals that live in the dwellings of another species without affecting them are known as inquilines. Inquiline termites (*Inquilinitermes microcerus*) are unique among termites in being unable to make their own nests. Instead, they inhabit the labyrinthine hallways built by another termite, *Constrictotermes cyphergaster*. Until now, it has been unclear how the two parties kept peaceful in such tight quarters, because termites are typically very aggressive towards outsiders.

Helder Hugo at the University of Konstanz in Germany and his colleagues collected *C. cyphergaster* nests in the Brazilian Cerrado and brought them into the laboratory. They then placed host and tenant termites in either open or more constricted miniature arenas and used video to track and

"Aggression is not inherently any more successful or beneficial a strategy than 'cowardice'"

record the ways in which the two species reacted to each other.

Right from the start, the inquiline termites moved around less than their hosts and interacted little with them, even in the more confined arena.

"Many times," says Hugo, "when two unrelated colonies are put together in a single confined space – such as an experimental arena – the outcome is warfare with losses from both sides."

HELDER HUGO

***Constrictotermes cyphergaster* nests can be home to illicit lodgers**

But that didn't happen here. Despite attacks from host termites, the tenant termites were acquiescent. Hosts would bite or spray the inquilines with acrid chemicals, but their targets never responded in kind, opting to flee. Some ignored the hosts completely.

"We did not expect that they would never retaliate," says Hugo, noting that the inquilines are capable of protecting their own colony with snapping jaws.

At most, the lodger termites would squirt faeces towards a threatening host termite, surprising their assailant long enough to retreat (*Ecology and Evolution*, doi.org/d5hc). "By preventing conflict escalation, inquiline termites may considerably improve their chances of establishing a stable cohabitation with their host termites," says Hugo.

Emma Vitikainen at the University of Helsinki, Finland, says it is surprising that the tenant termite's de-escalation strategies are so effective at blunting their hosts' aggression. It means that "the cycle of revenge is not a necessary or unavoidable outcome", she says.

"Passiveness does not necessarily lead to defeat, but can be a very useful strategy, saving energy and resources," she adds. "Nature may not always be red in tooth and claw, and aggression is not inherently any more successful or beneficial a strategy than 'cowardice'." ▮

Medicine

Lyme disease vaccine performs well in clinical trials

Alice Klein

A VACCINE against Lyme disease has been shown to be safe and effective in a clinical trial and could be available by 2025.

Tens of thousands of people in the US and Europe are diagnosed each year with Lyme disease, which is transmitted by tick bites and can cause lifelong health problems like joint and nerve pain if it isn't treated early.

French company Valneva has developed a vaccine that works by stopping Lyme-causing bacteria in ticks from passing into people's

"Valneva, the company developing the drug, says it stimulates immune protection effectively"

bloodstreams when the ticks bite. It does this by targeting a protein on the bacteria called outer surface protein A.

The company has revealed the results of a clinical trial involving 572 adults in the US and Europe. It claims the vaccine was 82 to 96 per cent effective at stimulating immune protection against Lyme disease and caused no serious side effects. "The results are very promising," says Maria Gomes-Solecki at the University of Tennessee.

The next steps will be to test the vaccine in children and larger numbers of adults, and to determine whether booster shots will be necessary to provide long-lasting immunity, says Thomas Lingelbach, CEO of Valneva. "We hope the vaccine will be available within five years," he says.

In the late 1990s, a Lyme disease vaccine that also targeted outer surface protein A became available, but it was discontinued after unfounded claims of serious side effects spread by anti-vaccination campaigners made people too scared to get it. ▮

Space exploration

The Perseverance rover is on its way to Mars

Leah Crane

NASA has sent a life-hunter to Mars. The Perseverance rover, which will look for signs of life past or present on the Red Planet, blasted off on 30 July.

If all goes well, the rover will land on Mars in February 2021, where it will use a sophisticated suite of science instruments, including 23 cameras, to examine the planet's climate and geology.

"Perseverance will bring all human senses to Mars," said NASA's Thomas Zurbuchen during a press conference on 20 July. "It will sense the air around it, see and scan the horizon, hear the planet with microphones on the surface for the first time, feel it as it picks up samples to cache, perhaps even taste it, in a sense", as it performs chemical analyses of the dust, he said.

Once Perseverance lands on the surface of Mars, it will release a small helicopter called Ingenuity from its underside. "We as human beings have never flown a rotorcraft, a helicopter, anywhere outside of Earth's atmosphere, so it's really a Wright brothers moment on another planet," said MiMi Aung, Ingenuity's lead engineer, during the press conference.

Ingenuity is a technology demonstration and will fly for a total of 15 minutes at most, but, in the future, such helicopters could be used to scope out inaccessible areas or as scouts for rovers and astronauts, said Aung.

The rover will carry another technology demonstration, too, an instrument to extract oxygen from the carbon dioxide in Mars's thin atmosphere, which explorers may need to do to survive there. "Perseverance is also the bridge between science and human exploration that demonstrates how the two can support and reinforce each other," said Zurbuchen.

23

The number of cameras NASA's Perseverance rover took to Mars

The main science goal of the mission is to look for signs of life on Mars, whether that life is ancient and long dead or still around today. This is the first Mars mission to explicitly search for life since the Viking 1 and 2 missions in the late 1970s.

"It's exciting that NASA is moving past following the water and looking for signs of habitability to looking for signs of actual life," says Sarah Stewart Johnson at Georgetown University in Washington DC. "It was 'follow the water' for so long, and we just kept finding the water – we found swimming pools and swimming pools' worth of water."

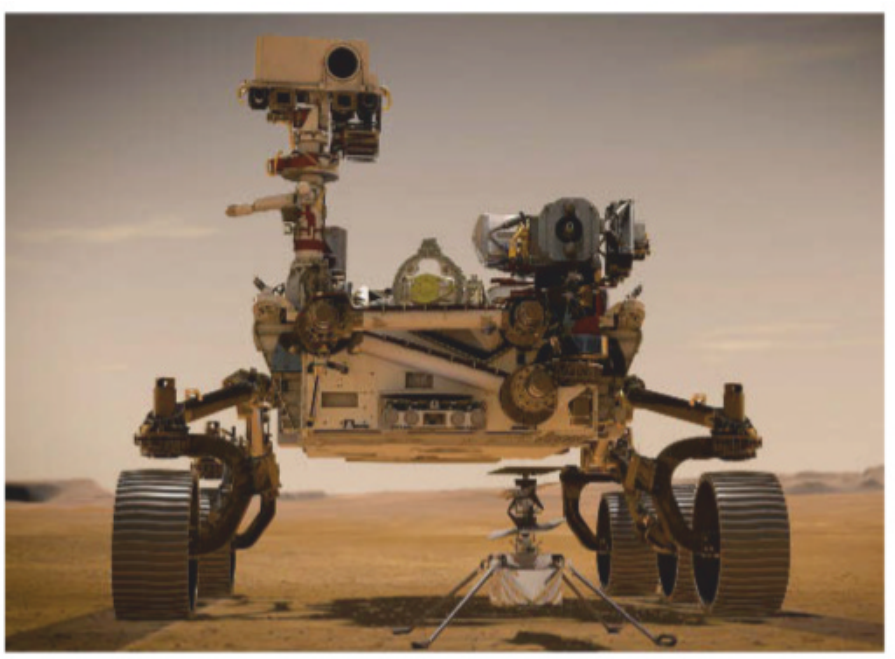
Now that we know that Mars has the ingredients for life – and that long ago it was probably far warmer and wetter than today – we are better equipped to look for signs of that life.

However, even if we find clues that there might have once been living organisms on Mars, we probably won't be sure until we can bring those clues back to Earth and examine them in the lab, says Johnson.

Fortunately, Perseverance is preparing for just that. It will take a series of samples as it trundles across the Martian surface, and although the rover doesn't have the capability to send those samples back to Earth, NASA has another mission planned for 2026 that will pick them up and bring them back for analysis.

"If we found any evidence of life, even if it was very small, that would be completely transformative," says Johnson.

"If we found a microbe that arose on the next planet over, if lightning struck twice in this one corner of the solar system, it would suggest that our whole universe could have life on lots and lots of planets and it's not just us alone in the dark night," she says. ▮



NASA/JPL-CALTECH

Ingenuity (under the rover) will be the first rotorcraft to fly on another planet

Palaeontology

Tiny mammals once scavenged huge dinosaur carcasses

Michael Marshall

THE first mammals were small and elusive, but that didn't stop them chowing down on dinosaur meat. A bone fragment from a giant dinosaur has bite marks that could only have been made by small mammals, which probably scavenged the carcass.

"This is the earliest direct evidence for mammalian feeding behaviour," says Felix Augustin at the University of Tübingen in Germany.

The bone fragment came from the neck of a sauropod dinosaur, which lived in what is now China in the late Jurassic around 160 million years ago. By this time, dinosaurs had dominated ecosystems for tens of millions of years. Mammals lived alongside them, but most were small and unobtrusive while the dinosaurs ruled.

"The teeth marks on the dinosaur bones were found in pairs, matching mammals' paired incisors"

Augustin and his colleagues had previously found bite marks on dinosaur bones from elsewhere, so they took a close look at the Chinese specimen. "I recognised small gnawing-like feeding traces," says Augustin.

To find out what made the traces, the team compared them to bite marks made by different kinds of animal and by other processes like trampling. Crucially, the marks were often found in pairs. That matches the paired incisors mammals have at the front of their mouths. Meat-eating dinosaurs and other dinosaur-era animals don't have paired incisors (*The Science of Nature*, doi.org/d5gg).

The mammals must have been scavenging, says Augustin, as it appears unlikely that such tiny mammals could have taken down a huge sauropod dinosaur. ▮

Archaeology

An offering to the gods

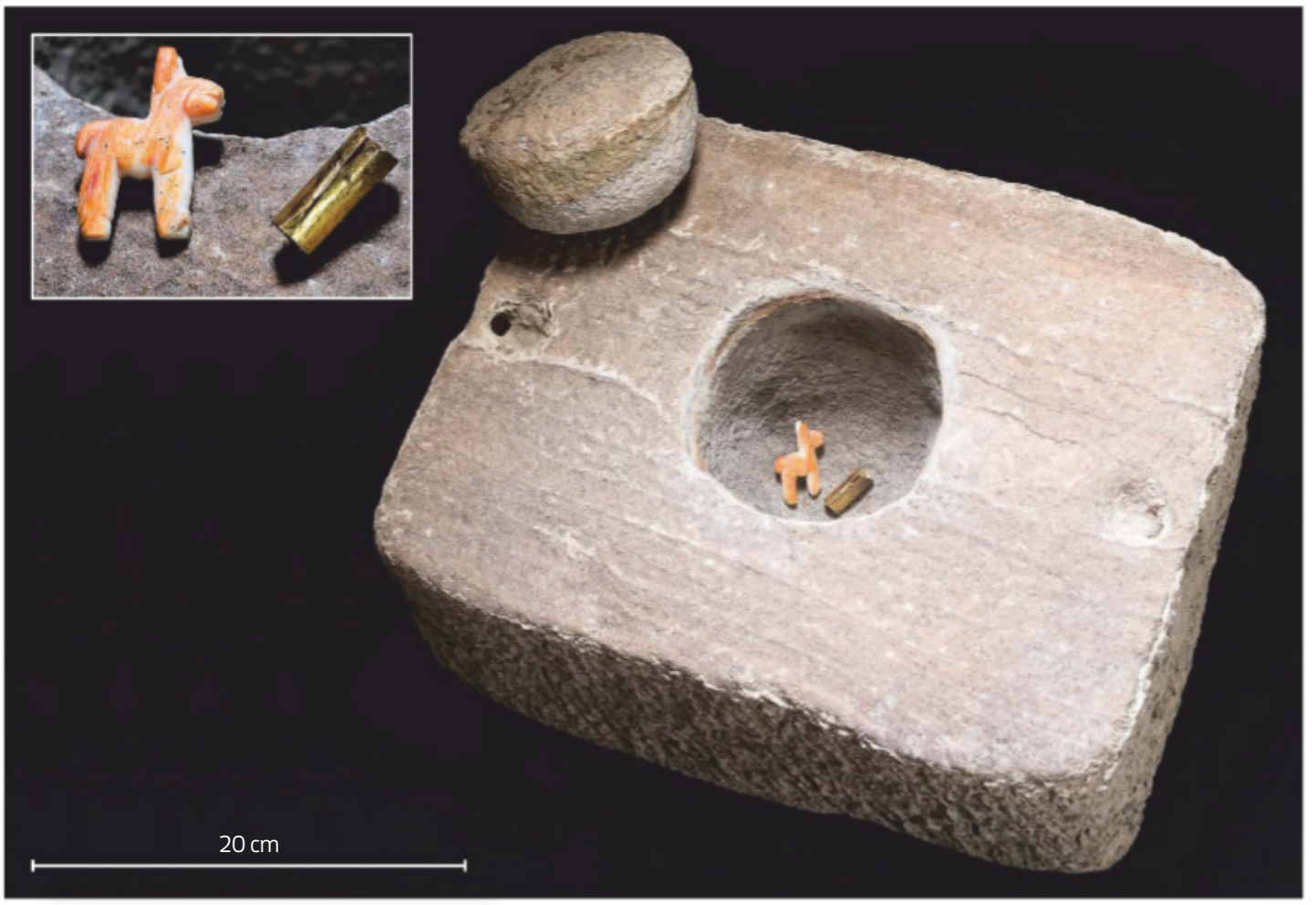
Stone box may have been used in human sacrifice ritual

Jason Arunn Murugesu

THIS 500-year-old stone box of Inca offerings was found by divers in the Bolivian half of Lake Titicaca. It contains a miniature llama made from mollusc shell and a cylindrical gold foil thought to be a tiny version of an Incan bracelet (*Antiquity*, DOI: 10.15184/aqy.2020.121).

Christophe Delaere at Free University of Brussels in Belgium and his colleagues think the box and its contents were part of a human sacrifice offering to the lake, as similar pairings of objects have been found in areas associated with Incan sacrifices. "This discovery extends the concept of 'sacrality' to the entire lake," says Delaere.

The Incas ruled large parts of South America from the early 13th century until the Spanish invaded in the late 1500s. Underwater offerings were mentioned in books by Spanish colonisers, but no intact artefacts have been found until now.



TEDDY SENGUIN, UNIVERSITÉ LIBRE DE BRUXELLES

Robotics

Uncrewed boats to patrol Australian coast

AUSTRALIA is deploying a fleet of uncrewed robot boats to patrol its waters and monitor weather and wildlife. They will also flag vessels potentially transporting asylum seekers, a plan that has concerned human rights groups.

The 5-metre-long boats, known as Bluebottles, look like miniature sailing yachts. They use a combination of wind, wave and solar power to maintain a steady 5-knot speed in all conditions.

Sydney-based Ocius Technology delivered the prototype in 2017 and Australia's Department of Defence has now awarded an AU$5.5 million (£3m) contract for further development. This includes four more Bluebottles to be delivered next year.

Ocius CEO Robert Dane says Bluebottles are ideal for extended maritime patrols. "They have no crew, no fuel, no stores. It's a robot that runs entirely on the power of the ocean," he says. Onboard sensors include cameras, radar and devices to detect transponder signals from ships and aircraft.

The prototype Bluebottle, known as Bob, recently carried out its first unassisted journey, sailing around 200 kilometres. "They are intelligent robots, so if they lose comms for a while they happily continue," says Dane.

The boats will patrol Australia's exclusive economic zone (EEZ), which extends 200 nautical miles from its shore, looking for boats transporting asylum seekers in the Indian Ocean.

Dane points out that Australia has 11 per cent of the world's coastline and only 0.3 per cent of its population. Crewed ships, typically costing tens of millions each, aren't a practical solution for monitoring this area, he says.

If a Bluebottle detects a vessel that may not have permission to be within the EEZ it will be sent in for a closer look by a human operator. If the operator deems the boat suspicious, a crewed Royal Australian Navy vessel will be dispatched to intercept it.

Australia has been previously criticised for forcibly turning back boats of asylum seekers and there are concerns new technology might exacerbate this.

"Using drone boats to deter or prevent women, men and children from seeking safety from persecution would be wholly wrong because the purpose is both illegitimate and harmful," says Steve Valdez-Symonds at Amnesty International UK.

"The Australian Defence Force acquires, deploys and operates all systems – now and into the future – in accordance with Australia's international and domestic legal obligations, including international humanitarian law," says an ADF spokesperson.

David Hambling

Health

Twelve ways to drastically cut your risk of dementia

Alice Klein

ALMOST half of all dementia cases could potentially be prevented or delayed, a major review has found.

The review identified the biggest known risk factors for dementia as smoking, excess alcohol consumption, high blood pressure, obesity, diabetes, head injury, depression, hearing loss and exposure to air pollution, as well as lack of exercise, education and social contact.

Minimising these 12 risks could potentially prevent or delay up to 40 per cent of dementia cases globally, according to the review of evidence, by 28 leading dementia experts from around the world.

"People who have family members with dementia often ask me, 'Is there anything I can do to prevent myself from getting it?'," says David Ames at the University of Melbourne in Australia, one of the authors of the review. "There are certainly some things you can do that might make a difference."

For example, the review finds that individuals can partially protect themselves by not smoking, drinking less than 21 units of alcohol a week, maintaining low blood pressure, avoiding activities that could lead to head injuries, using hearing aids if needed, eating a healthy diet and exercising regularly (*The Lancet*, doi.org/d5g5).

JEFF GILBERT/ALAMY

Exercise is one way to reduce your risk of developing dementia

"Even older people can delay or possibly prevent dementia by improving their lifestyles"

Even older people can delay or possibly prevent dementia by improving their lifestyles, says Ames. "It's never too early and it's never too late," he says.

In some higher-income countries, including the UK, US and France, dementia rates in older people have fallen in recent decades, possibly due to improvements in education, nutrition and health care. This suggests that preventative health measures can have an effect on dementia, in the same way they have helped to reduce rates of lung cancer and deaths from heart disease in many higher-income countries, says Ames.

Two-thirds of dementia cases currently occur in lower and middle-income countries, where education is often less accessible and rates of smoking, obesity and diabetes are relatively high.

That means state interventions like anti-smoking campaigns and increasing education could have an even bigger impact in such countries, says review co-author Adesola Ogunniyi at the University of Ibadan in Nigeria.

However, there is a limit to how much you can prevent dementia with lifestyle interventions, because the brain inevitably starts to shut down in very old age, especially in people who live past 100, says Ames. "We've become very good at keeping people from dying of things like childhood diarrhoea, and that means we now have a high life expectancy," he says. "If you hang around long enough, something eventually has to catch you, and dementia is one of those diseases." ▮

Animals

Lice can handle the pressure of life in the deep sea

SEAL lice – blood-sucking marine insects that live on seals, sea lions and walruses – can survive the crush of the deep ocean, including for several minutes at pressures found thousands of metres down.

These parasites (*Lepidophthirus macrorhini*) live out their entire life cycle on their marine hosts. Previous research has shown that the insects survive being submerged by entering an immobile, low-metabolism state to withstand the frigid cold, high salinity and lack of oxygen.

To find out how much pressure the lice could handle, Maria Leonardi at the Institute of Biology of Marine Organisms in Argentina and her colleagues captured 15 elephant seal pups and then collected lice from them using tweezers.

The team then submerged the lice in seawater and placed the water into a chamber where they were subjected to two rounds of varying hydrostatic pressures. These ranged from about 3 to 20 megapascals (MPa) for 10 minutes at a time – which is about the length of time that elephant seals spend on deep dives. Sometimes they will go around 2000 metres down.

All of the adult lice and 89 per cent of the nymphs survived pressures up to about 20 MPa, which you would find at that kind of depth in the sea (*Journal of Experimental Biology*, doi.org/d5ft).

During equipment calibration in the lab, one louse had the lousy luck of being accidentally subjected to just over 44 MPa for several minutes. That is the equivalent of being more than 4000 metres underwater. It survived. "Here we have an example of an insect with nothing particular or special, with the build of any other insect, that is able to adapt to this condition," says Claudio Lazzari at the University of Tours in France, who worked on the study.

"The host is its environment," says Katherine Moon at the University of California, Santa Cruz.

"Adaptation to the host or the way the host functions is exactly the way it's going to go. Otherwise it won't survive," she says. ▮

Richard Sima

Solar system

The sun's heat has baked a crust on Mercury's surface

Jonathan O'Callaghan

MERCURY may be covered in a very thin crust created by the extreme heat from the sun.

Like Earth's moon, Mercury's surface lacks a substantial atmosphere, meaning it suffers many impacts that should over time leave its surface coated in fine dust. However, Mikhail Kreslavsky at the University of California, Santa Cruz, and his colleagues have found a key difference between the two bodies.

The researchers looked through thousands of images of Mercury's surface taken by NASA's Messenger spacecraft, which orbited the planet from 2011 to 2015. They found features that resemble landslides on Earth, suggesting a hard surface on top of a softer interior.

"We believe there is a formation of a thin crust in the top centimetres of the soil because of the very high temperature," says Kreslavsky.

Mercury is the closest planet to the sun, at an average of 58 million kilometres away. During a day on its surface, which lasts 176 Earth days, temperatures can top 430°C, hardening the upper layer of the planet (*Icarus*, doi.org/d5d9).

"Moon astronauts walked and left dusty footprints. On Mercury, they would walk on a solid surface"

This process is known as sintering, where a material is hardened by extreme heat creating links within the material, says Kreslavsky. "Physically it means there are bridges between small dust and soil particles," he says. "They stick to each other."

This doesn't occur on the moon because temperatures there don't get high enough for long enough. Instead, the moon's surface remains powdery. "Moon astronauts walked and left footprints," says Kreslavsky. "On Mercury, astronauts would walk on a more solid surface." ▮

Artificial intelligence

Quantum game of Go could baffle even an AI

Leah Crane

A NEW version of the ancient Chinese board game Go that uses quantum entanglement to add an element of randomness could make it a tougher test for artificial intelligences than regular board games.

"Board games have long been good test beds for AI because these games provide closed worlds with specific and simple rules," says Xian-Min Jin at Shanghai Jiao Tong University in China. In Go, players take turns to place a stone on a board, trying to surround and capture the opponent's stones. There are 10^{171} possible states of the board, compared with around 10^{50} for chess, making Go a far more complex game.

AlphaZero, an AI created by DeepMind, has mastered this complexity to become the world's best Go player, but now Jin and his colleagues have developed a new version of Go that is even more complex (arxiv.org/abs/2007.12186).

Quantum Go can be played on an ordinary board, but also requires a computer to record the state of the game and equipment to generate pairs of quantum-entangled photons. Each player places two stones at once on their turn, representing a superposition of two possible locations of a single quantum stone. When a new stone is put next to either of those locations, the quantum state of a pair of entangled photons is measured to determine the original stone's location, collapsing the superposition. And then the other stone is removed.

This added randomness makes the game more complex. Players can also choose to adjust the probability of their quantum stone appearing in one location, meaning it doesn't have to be 50-50. This allows one player to have more information than their opponent about where a stone is likely to end up.

AIs can beat humans at other such "hidden information" games, like certain variants of poker, but the complexity of Go brings a new challenge.

"Quantum Go adds a lot more complexity to regular Go by expanding the possible ways the board can change on a player's turn and that adds a lot more mental load to planning," says Mike Cook at Queen Mary University of London. "You end up planning for many different possible futures", which takes more computing power.

10^{171}

The number of possible states of the board in ordinary Go

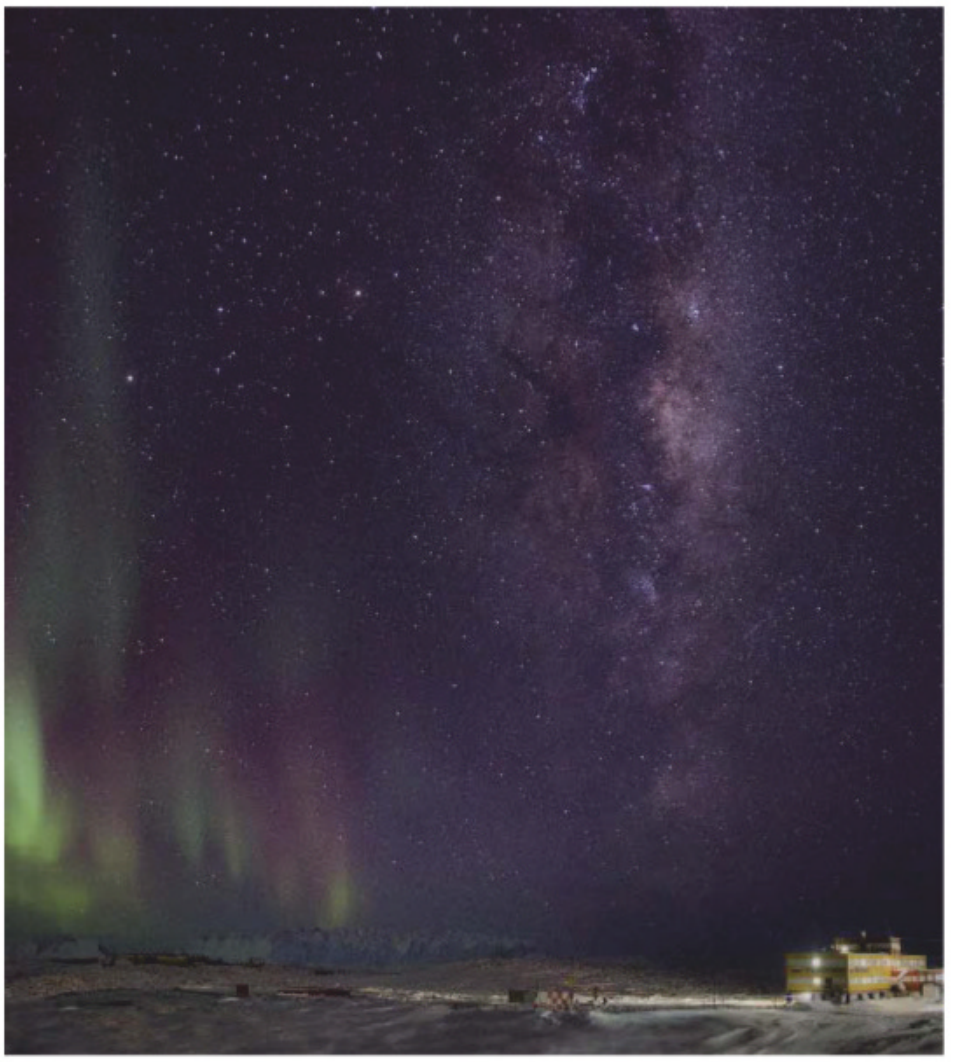
"As artificial intelligences surpass humans in various fields, the quantum regime may be the only space where human consciousness and intuition may beat the huge computing power of artificial intelligence," says Jin. The team has yet to train an AI to play quantum Go, so we don't know if it would beat human players.

Cook says harder board games may not be the way forward. "AI research isn't just about finding the most complex, tangled problem possible, it's also about finding problems that are deceptively simple and figuring out why AIs are so bad at them," he says. "Quantum Go sounds like a very fun game, but I don't think we'd learn a lot about AI by beating it – although I'd still very much enjoy seeing it happen." ▮

SHUTTERSTOCK

AI players are able to beat all humans at ordinary Go

Astronomy



ANTARCTICA/ALAMY

World's finest view of the stars is from an Antarctic hill

THE best place on Earth from which to look at the night sky is the top of a hill of ice in Antarctica called Dome A.

The atmosphere can be turbulent, often blurring the images taken by telescopes on the planet's surface, making it difficult to see faint objects clearly. We refer to that blurring as astronomical "seeing".

"Bad seeing smears your images," says Zhaohui Shang at the Chinese Academy of Sciences in Beijing. "At a site with good seeing, a telescope can outperform a similar telescope at a site with worse seeing."

Dome A, one of the coldest locations on Earth, was known to have great seeing because of the cold, dry air and the height of the hill. But now Shang's team has used a specialised telescope to measure the seeing there for the first time.

One of the most important factors for astronomical seeing is the thickness of the boundary layer of the atmosphere, which is where most of the air turbulence caused by weather takes place. Above the boundary layer is the free atmosphere, which is more stable, so it doesn't blur images as badly.

"At a temperate site, the boundary layer is usually hundreds of metres high or higher, preventing one from reaching the free atmosphere," says Shang. "However, the median thickness of the boundary layer at Dome A is only 13.9 metres, making it much easier to build telescopes above it."

A large telescope built on Dome A could take clearer images of fainter objects than a telescope anywhere else on Earth (*Nature*, doi.org/d5fk).

Leah Crane

Health

Gut microbes protect mice from dementia

A SUPPLEMENT that nourishes "good" bacteria in the gut seems to protect against an Alzheimer's-like disease in mice and will soon be tested in a human clinical trial.

Growing evidence points to a link between Alzheimer's disease and gut health. For example, studies have found that people with the condition tend to have more pro-inflammatory, or "bad", bacteria and less anti-inflammatory, or "good", bacteria in their guts. They also tend to have a less diverse mix of gut microbes overall.

Chun Chen at Emory University in Atlanta, Georgia, and her colleagues have added to this evidence by showing that mice engineered to have an Alzheimer's-like disease also have more pro-inflammatory bacteria and less anti-inflammatory bacteria in their guts.

They have also demonstrated that healthy mice housed with mice with the Alzheimer's-like disease were more likely to develop the condition themselves, possibly through exposure to their cagemates' unhealthy gut microbes (*Science Advances*, doi.org/d5gt).

Chen and her colleagues gave mice a prebiotic supplement called R13 that is designed to promote a healthy mix of gut microbes. Mice treated with R13 were less likely to accumulate a protein called beta-amyloid in their guts. Beta-amyloid builds up in the brains of people with Alzheimer's disease – forming sticky clumps that damage brain networks. Recent research in mice hints that this protein can travel from the gut to the brain and cause Alzheimer's symptoms.

R13 has recently been granted approval to be tested in a small clinical trial to see if it helps to slow or prevent Alzheimer's disease in people. **Alice Klein**

Research inequality

Half of science Nobels go to just five fields

JUST five research fields scooped more than half of the Nobel prizes for science awarded in recent decades, according to an analysis exposing an "honours inequality" that may skew research funding.

John Ioannidis at Stanford University in California and his colleagues combed through the Nobel winners from between 1995 and 2017 and found that work on particle physics, cell biology, atomic physics, neuroscience and molecular chemistry accounted for 52.4 per cent of the Nobel prizes for chemistry, medicine and physics over the period. Only 36 of 114 scientific fields were honoured, leaving fields including planetary science and respiratory disease excluded (*PLoS One*, doi.org/d5gr).

KAY NIETFELD/ALAMY

"It would be absurd to expect that all fields in science are having an equal chance of making groundbreaking discoveries and major advances," says Ioannidis. But he says it is also likely that the situation creates a self-reinforcing mechanism that drives money to a limited number of fields and skews what the most influential science journals choose to publish, exacerbating the problem.

Ioannidis also says that some disciplines may not be very relevant for the three science awards. One fix he suggests is to create new awards, but he says the Nobel committee should brainstorm solutions.

Adam Vaughan

Really brief

ANDRE PATTENDEN (ENGLISH HERITAGE)

A Stonehenge mystery solved

Most of the giant boulders in the stone circle at Stonehenge came from a site 25 kilometres away. Archaeologists analysed the chemical composition of 50 of the boulders, and found a match with rocks at a nearby site called West Woods (*Science Advances*, doi.org/d5d7).

Sperm swim in a bizarre way

It was assumed that sperm swim by beating their tails symmetrically. Now an analysis using a high-speed camera reveals that they rotate like a corkscrew while beating their tails asymmetrically – a finding that might aid research into male infertility (*Science Advances*, DOI: 10.1126/sciadv.aba5168).

Risk of extreme rising seas by 2100

The area of land at risk from coastal flooding could increase by almost half by 2100 as sea level rises put more homes, roads and other infrastructure in the firing line. Asia and north-west Europe would be hit hardest if the world fails to prevent the worst-case climate change scenario (*Scientific Reports*, doi.org/d5g3).

Space

How to predict solar flares before they hit

A NEW way to predict when solar flares are about to strike could help us to prepare for potential disasters caused by these huge eruptions on the sun.

Predicting solar flares is difficult because we don't know exactly how they are triggered. While telescopes can see a flare when it occurs, providing some warning, energetic particles can reach Earth in as little as 8 minutes, potentially putting astronauts' health at risk and damaging satellites before we can react.

Kanya Kusano at the Institute for Space-Earth Environmental Research in Japan and his colleagues used magnetic and imaging data from NASA's Solar Dynamics Observatory (SDO) from between 2008 and 2019, and were able to predict seven of the nine largest flares, known as X-class flares, up to 24 hours ahead of time (*Science*, doi.org/d5gx).

Previous prediction methods have at most a 50 per cent success rate, says Kusano, and rely on observations of sunspots in active regions of the sun. Kusano's "kappa-scheme" instead uses the strong magnetic fields associated with solar flares.

Before a flare begins, electric currents flow along the sun's magnetic field lines. When two of these lines overlap, they snap together in a reconnection event and release a vast amount of energy as a solar flare. The two flares that couldn't be predicted had reconnection events outside the viewing field of the SDO.

Kusano's team is now trying to use the work to create a solar flare forecast. **Jonathan O'Callaghan**

Life

EDITH A. WIDDER

Anglerfish immune system lets them fuse with their mate

SOME species of anglerfish – a deep-sea predator that uses a luminous lure to attract prey – fuse with their mates to reproduce. We now know they can do it because they have a weird immune system.

There are 168 known species of anglerfish, which are found at depths beneath 300 metres. Some species mate using a process called sexual parasitism. Males, often less than 10 millimetres long, attach to the larger female, as shown above.

For some species, the attachment is temporary. In others, the two fish fuse together, their circulatory systems connect and the male is dependent on its mate for nutrients.

In other vertebrates, such fusion of tissues would trigger a big immune response because immune systems attack foreign cells.

Now Thomas Boehm at the Max Planck Institute of Immunobiology and Epigenetics in Freiburg, Germany, and his colleagues have found that fusing anglerfish species lack key immune system genes that are needed to let antibodies mature and assemble receptors for immune cells called T-cells (*Science*, doi.org/d5gw).

How anglerfish can defend themselves from infection given these immune system changes is a mystery, says Boehm. Donna Lu

Renewable energy

Solar panels that could cut carbon emissions

CHANGING the way we make solar panels could reduce their carbon footprint, providing a boost to green energy.

Solar panels are a source of renewable energy, but making them has an environmental impact. Fengqi You at Cornell University in New York and his colleagues have compared the impact of solar panels made from two layers of a mineral called perovskite against that of panels made with crystalline silicon wafers, the current industry standard.

The perovskite-perovskite tandem solar panels contain two layers of the material on top of each other, each optimised to absorb a section of the electromagnetic spectrum.

Silicon panels took 1.52 years to generate the amount of energy required to produce them, but perovskite-perovskite tandem panels took only 0.35 years.

Over its lifespan, the perovskite tandem cell also has an associated emission of about 10.69 grams of carbon dioxide equivalent per kilowatt-hour of electricity it generates, which is 43.4 per cent of the emissions for silicon solar panels (*Science Advances*, DOI: 10.1126/sciadv.abb0055). **DL**

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Be wary of food data shared online, warns **James Wong** p25

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Comment essay

Hiroshima's lesson

The dropping of the first nuclear bomb 75 years ago taught us that the greatest threat to humanity's survival is humanity itself, say **Anders Sandberg** and **Thomas Moynihan**

ON 6 AUGUST 1945, a nuclear bomb was dropped on the Japanese port city of Hiroshima. Three days later, Nagasaki suffered the same fate. Three-quarters of a century on, the full human toll is still unclear. In Hiroshima alone, some 75,000 souls were obliterated instantly, with many more deaths in the following months and years.

These are the only times nuclear weapons have been used in war; debates about the rights and wrongs continue. As we remember those who died, we might also usefully cast a wider view: on what the bombings meant for humanity, for our relationship with technology and for our perception of what we now call existential risks, those that threaten to irrecoverably damage our potential or extinguish us as a species.

Doing so can inform our response to dangers we are confronted with today. Whether it is the covid-19 pandemic, climate change or the emergence of new technologies such as artificial general intelligence, we are faced with threats that are, in their own way, just as great as the nuclear bomb – but also subtly different. Hiroshima was the start of a long, continuing learning process of understanding them.

Humans have probably talked about the end of the world for as long as we have talked. It is a common part of mythology, giving a sense of structure to history: there was a beginning, we live in the middle and there will be an end. But existential risks were, by and large, not practical matters, except to a few millenarian cults.

KEYSTONE-FRANCE/GAMMA-KEYSTONE VIA GETTY IMAGES

Nagasaki was hit by an atomic bomb three days after Hiroshima

With the development of science came various realisations. The past was far, far vaster than we knew. There had been a time before humanity. Humanity was a species among others – and species could go extinct. Cosmic disasters, from asteroid impacts to supernovae, were real. Eventually, the universe's energy might run out, dooming it to heat death.

These insights made for good popular science, and inspired plenty of science fiction. But such thinking as there was on human extinction focused on natural threats, and these were seen as remote and unlikely. Lecturing at the Royal Institution in London in 1902, the writer H. G. Wells declared that "worlds may freeze and suns may perish", but we need not worry about such distant calamities. In 1933, the biologist J. B. S. Haldane echoed Wells's point, suggesting that the only real threat would be if our species developed weapons and technologies too far. Luckily, he concluded, it was "wildly unlikely" we would ever unlock the power of the atom.

The next year, physicist Leo Szilard conceived of the nuclear chain reaction. He patented a reactor the following year. By 1942, the first nuclear reactor had been constructed in Chicago as part of the Manhattan Project to build an atomic bomb. Soon after, a second sun rose over Hiroshima.

Hiroshima was the moment we first became fully aware that humanity could cause devastation possibly even on a global scale. As the hydrogen bomb was developed over the following decade, this destruction became not just a possibility, but also a part of geopolitical strategy. We realised that our survival as a species now rested in our own foolish hands.

In the years since, growing environmental concerns have reinforced this perspective: there could be an end of nature and habitability driven by human actions. Today, we recognise that the covid-19 pandemic was enabled and exacerbated by our impact on the environment.

In 1945, the end of the world shifted from being a myth or mere scientific possibility to something very real, even banal, that could be caused by bad policy-making, meaningless stupidity or plain mistake. The end of humanity need not be an end that made ›

sense, but just the end of sense: a total nihilistic threat.

This transformed how we related to our own ingenuity as an intelligent species. Previously rosy views of the march of progress took a battering. It highlighted another chilling possibility, too. One reason it took so long for people to take existential risk seriously in the scientific age was the assumption that humanoid civilisation is omniprevalent throughout our galaxy. If we wiped ourselves out on Earth, another intelligent species would simply pick up where we left off.

But in 1950, Enrico Fermi, chief architect of the atomic age, asked the question "Where is everyone else?", referring to those other civilisations throughout our galaxy. The search for extraterrestrial intelligence was revving up, yet despite early optimism, it was returning just deep, ominous silence.

This seemed like an omen for humanity's own troubled cold war trajectory. Perhaps we hadn't seen evidence of other civilisations because, before they can make themselves visible, they wipe themselves out in thermonuclear holocaust. Technology itself might put a time limit on technological civilisations.

Scientists were soon listing other plausible technological threats, and how best to anticipate and mitigate them. This has lately led to existential risk emerging as a research field in its own right. It attempts to understand different kinds of catastrophic and existential risks, and then find their commonalities and effective ways to reduce them. We are just two of many people exploring these questions.

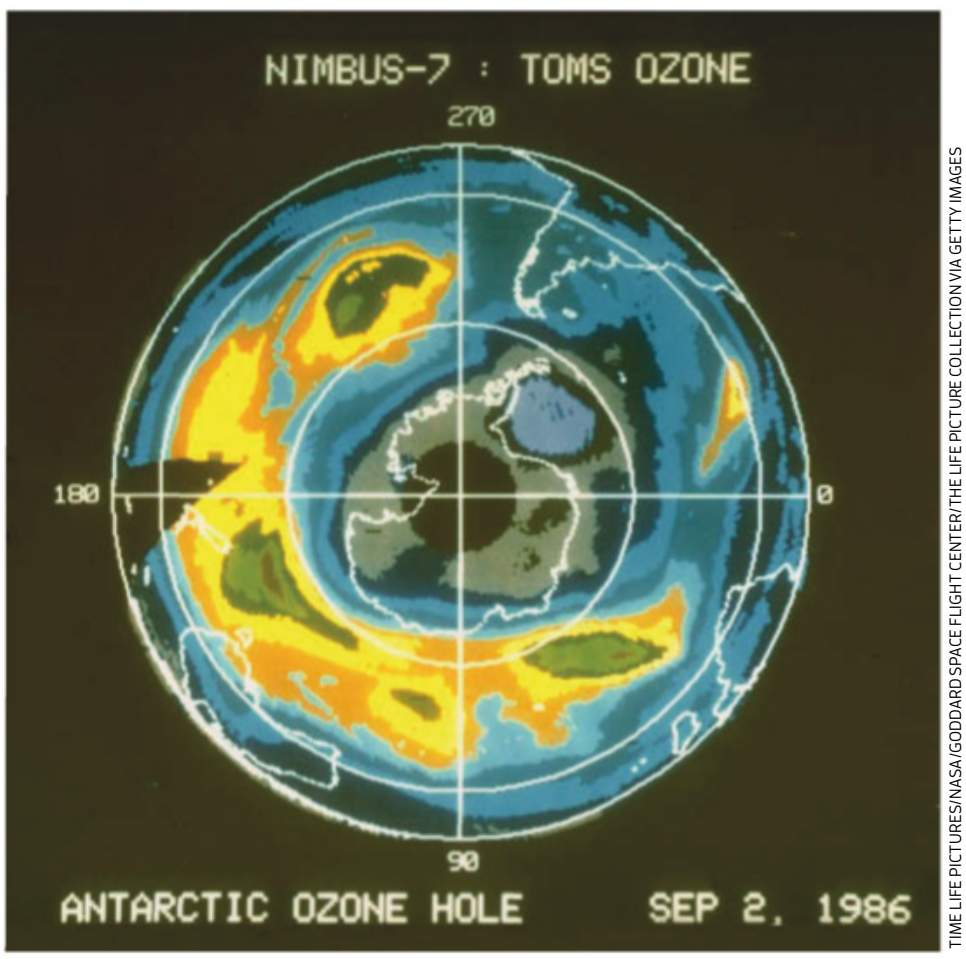
There is much still to learn. In the past, there was an unfortunate tendency to ignore or forget that which had been learned. An early instance occurred during the Manhattan Project. The physicist Edward Teller, a driving force behind the later creation of the hydrogen bomb, had warned that nuclear explosions could trigger fusion in the atmosphere, igniting it. Other researchers were sceptical, but serious debate and calculation convinced them the bomb was "safe" in that regard.

"Technology itself might put a time limit on technological civilisations"

After the second world war, a report was published on the risk of atmospheric ignition, the first time a possible anthropogenic disaster was scientifically analysed, using several independent arguments to minimise the risk of the overall conclusion being flawed. It stated that "the complexity of the argument and the absence of satisfactory experimental foundations makes further work on the subject highly desirable". The world was too busy with other things to take note: the hydrogen bomb's development continued.

What have we learned over the intervening decades? One central insight is that existential risks come in different forms, each posing different challenges. Nuclear weapons fall under the category of actual technological innovations. Other examples today are bioweapons or AI with human-like, or greater, capability. Here, the goal is to predict what future technology may be able to do and steer away from dangerous possibilities. As the cold war showed, something being dangerous for everyone doesn't make it easy to coordinate against.

Other risks start out as disturbing scientific possibilities, like Teller's concern about igniting the atmosphere. The fear that CERN's Large Hadron Collider could make planet-eating black holes is a recent example. Whether there actually is a risk requires careful further analysis. This has been carried out for catastrophic asteroid impacts, where we now know the risk over the next century is manageably small, thanks to astronomical surveys. With that has come a recognition that it may be good to have some readiness for when a surprise impactor is discovered.



TIME LIFE PICTURES/NASA/GODDARD SPACE FLIGHT CENTER/THE LIFE PICTURE COLLECTION VIA GETTY IMAGES

The mid-1980s Antarctic ozone hole is now healing thanks to decisive action

Still other risks are discovered – and their disaster potential recognised – only later. Examples include supervolcanoes, ozone depletion or dramatic climate change. Anthropogenic climate change was first predicted by Svante Arrhenius in 1896. Being a Swede, he mostly saw it as a good protection against a future glacial period. It wasn't until the 1970s that we realised the actual danger.

Finally, there is a messy category of systemic risks. A huge solar flare might not kill anybody on Earth directly, but it could wreck electricity supplies for months. Much of the world is dependent on intricate online services. Food security requires perfect logistics, low fuel prices and a predictable climate. Things could go existentially wrong via a chain reaction of mishaps, disasters and conflicts. This is the hardest category to study and do something about.

And what of covid-19? Where does it fit into this taxonomy of risk? On its own, a naturally emerging pathogen such as the new coronavirus seems unlikely to cause the outright extinction of humanity; evolution provides a trade-off between lethality and transmissibility with natural diseases, if not with engineered ones. We have relatively few examples of infectious diseases wiping out or threatening to wipe out entire animal species. The current ravages of chytrid fungi among amphibian populations are an exception, but we know of almost no examples in mammals.

Instead, a pandemic's true risk may be that it weakens society and compounds the likelihood of other threats being fatal. Certainly, our response to covid-19 proves how unprepared we still are for genuine large-scale perils.

It can take surprisingly long to recognise problems. Researchers have proclaimed artificial general intelligence to be around the corner since the 1950s, but almost nobody seems to have taken the risks seriously until the late 1990s. Before then, the only risks raised

REUTERS/MATTHIAS RIETSCHEL

Covid-19 shows how blasé we are about many large-scale risks

were some safety concerns with industrial robots. This is peculiar, since even human-level AI could be used for nefarious purposes, and there is no reason to think human intelligence is a ceiling. Perhaps researchers were privately more realistic about AI's progress than their public pronouncements, but it is equally likely that they didn't want to sound too outrageous or science fiction-like. We may be downplaying many other serious risks because we don't want to rock the boat or because they sound too silly.

At other times, problems may be missed by accident. Ozone depletion from CFCs was predicted in the 1970s. However, because software screened out the extremely low measurements of ozone over Antarctica as errors, the hole in the ozone layer wasn't spotted until 1985. The shocking new data helped spur political action. In 1987, the Montreal protocol phasing out CFCs was signed, a case where a global risk has been somewhat successfully handled. It can happen.

Some mid-20th century existential concerns have also receded, such as a systemic risk associated with widespread overpopulation and starvation. In 1968, the biologist Paul Ehrlich stated that, in the 1970s, "hundreds of millions of people will starve to death in spite of any crash programs embarked upon now". It didn't happen: the spread

"We may be downplaying serious problems because we don't want to rock the boat or sound silly"

of contraception, education, better crop yields, trade globalisation and other factors rendered the prediction mostly wrong, although undernutrition and deprivation remain with us.

Indeed, concerns about underpopulation and population ageing are increasing. To some extent, the predictions about mass starvation were self-defeating because they motivated people to work out solutions, but these were largely just reasonable solutions that we would have wanted to pursue anyway.

Even the threat of nuclear war receded a few times, through safety-increasing mechanisms such as non-proliferation treaties, the "red phone" between the Kremlin and the White House, disarmament and periods of detente. Sadly, it can also advance due to bad governance and inept diplomacy. We have been far more successful in feeding the world than getting rid of nuclear arms.

So how can we use all these insights? Decision-making has to be done under conditions of uncertainty, yet most of our institutions hate uncertainty and use it as an excuse for not reacting. The tough lessons of the covid-19 pandemic show the price of being paralysed by uncertainty. Yet planning for every conceivable disaster or blocking everything new as a precaution is also foolish.

Top-down solutions are needed for rapid, decisive responses, like a crash programme to deflect an asteroid, avert nuclear conflict or ensure alternative food sources to cope with an impending, decade-long "winter" caused by a nuclear firestorm or supervolcano eruption. They are also needed for strong unanimity, as with climate deals.

One lesson of covid-19 is that these solutions are best prepared long beforehand, rather than improvised on the spot. Creating and implementing emergency playbooks and building the capacity to coordinate responses internationally takes time. Often what is needed is top-down decision-making to promote solutions, rather than prescribing them from the start. This can include sponsoring research into technologies that defuse predicted risks from other technologies, such as bioweapons or AI, before they become powerful enough to be dangerous. Other examples are creating markets or international standards for solutions.

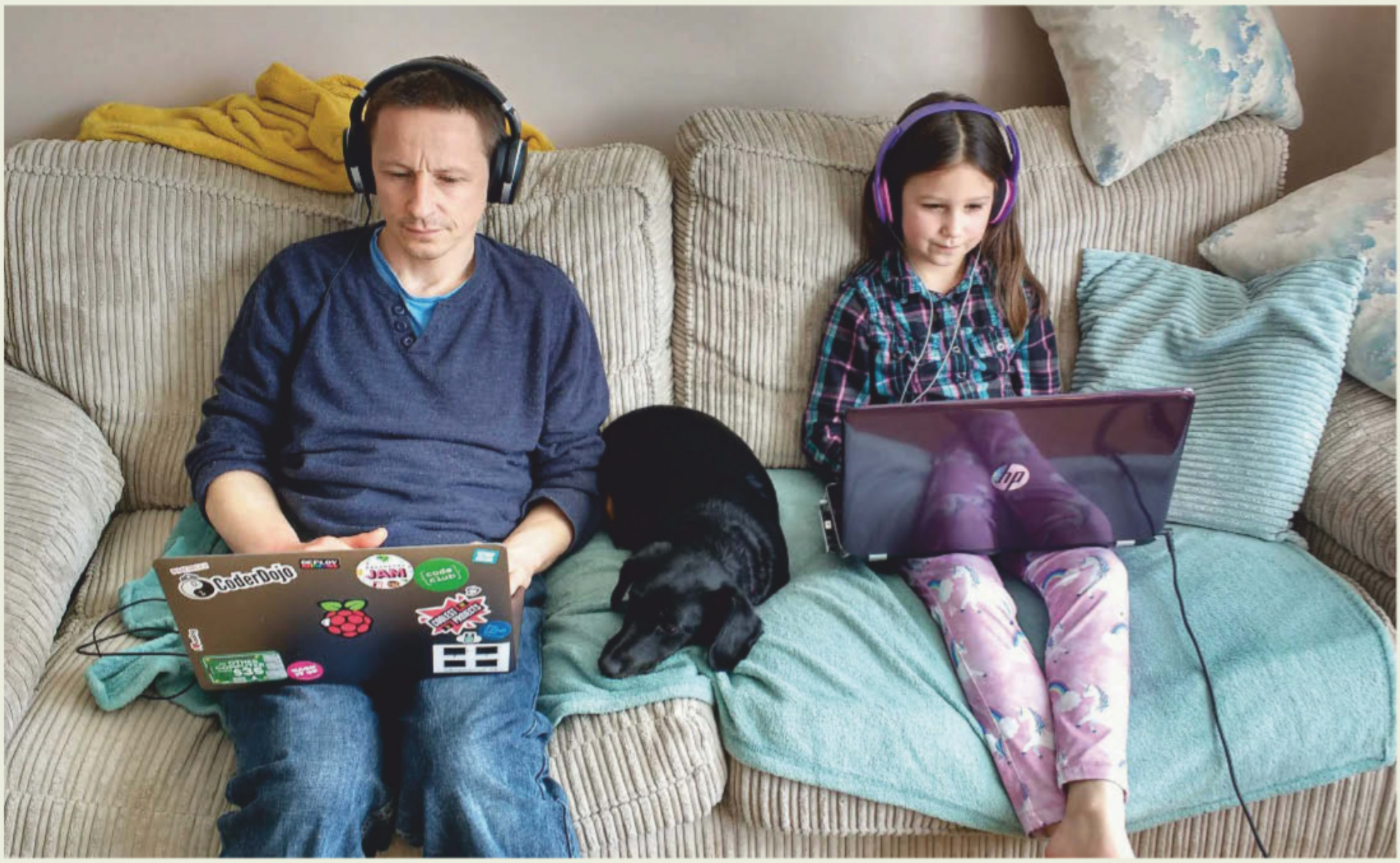
But solutions consist more of smaller building blocks than of heroic decisions, Hollywood movies notwithstanding. Finding and implementing useful solutions can also be bottom-up. The changes that helped the world avoid the 1970s overpopulation scenario are an example, as is the current solar power revolution, and the search for ways to shift the global economy to a low-carbon mode. These innovations don't need a UN security council resolution supported by all. There might be other solutions that help us defuse the nuclear arsenals. The only way to know is to investigate.

None of this is a given: we must have the will to work on solutions to the existential threats we face. In that sense, perhaps the greatest cause for hope as we remember Hiroshima is that humanity still exists 75 years on. ▮

Anders Sandberg and Thomas Moynihan are researchers at the University of Oxford's Future of Humanity Institute. Moynihan's book *X-Risk: How humanity discovered its own extinction* is out later this year

Signal Boost

Welcome to our Signal Boost project – a weekly page for charitable organisations to get their message out to a global audience, free of charge. Today, a message from the **Raspberry Pi Foundation**



The Raspberry Pi Foundation have launched a new, free Learn at Home initiative to support parents, young people and families with coding activities at home. You don't need any coding experience to join in, and all of our resources and activities are free forever.

We have over 200 online step-by-step projects for children age 6 and above, support tutorials for parents who want to understand the computing tools used in schools such as Scratch and Python, and a series of fun and engaging instructor-led videos and live code-along sessions for young people at home.

TOP TIPS FOR HELPING YOUR CHILD WITH CODING AT HOME

If possible, sit with your child and have them explain to you what they are doing. You don't have to understand the code, but you can listen and ask questions. If they talk through their thought process, they're more likely to be successful.

- Maintain a hands-off approach: offer them suggestions rather than instructions, and keep your hands off their keyboard and mouse.
- Getting things wrong is one of the best ways to learn. When they encounter bugs in their programs (which they will!), ask questions before giving answers. Try "Why do you think that didn't work? or "Have you tried changing this bit of code?"
- Pick tools that are accessible or familiar to the young person. If they like Scratch, then stick with it until they're trying to do things so complicated that they need more advanced software.
- If a young person is going to share their project online, you should remind them not to include personal information in it. Tip: Your child has probably learned about e-safety at school, so why not ask them about the rules they've learned in class?
- Always ask the young person to show you what they have made, and show enthusiasm for their work. You may not have a clue what it is, or you might think it's super simple, but they'll be proud of it and encouraged if you are too.

Want to learn to code?

All of our resources are accessible online at any time at **rpf.io/learn-at-home**

James Wong is a botanist and science writer, with a particular interest in food crops, conservation and the environment. Trained at the Royal Botanic Gardens, Kew, he shares his tiny London flat with more than 500 houseplants. You can follow him on Twitter and Instagram @botanygeek

James's week

What I'm reading
An online dictionary of Singlish, a Singaporean patois that blends English with Malay, Tamil and a bunch of Chinese dialects, plus some Arabic, Dutch and Portuguese words.

What I'm watching
Mrs. America *(binged in a single evening).*

What I'm working on
A plant science podcast for the Royal Botanic Gardens, Kew. Out on 5 August.

This column appears monthly. Up next week: Chanda Prescod-Weinstein

#FactsMatter

Number crunching

Shareable online graphics give easy-to-understand breakdowns of food's nutritional content, but they may be misleading, says **James Wong**

LET'S face it, nutritional data isn't the most fascinating, so it can be really helpful when food writers delve through the dry tables of stats to translate them into easy-to-understand messages. One of the most popular formats are eye-catching memes based on simple two food comparisons. These appear on my social media timelines at least half a dozen times a week. Are they accurate?

"Do you really need meat to get protein?" asks one image that recently crossed my social media feed. It shows two forks, one holding a piece of lean steak and the other an equal-sized piece of broccoli.

In accompanying text, beef was listed as containing a meagre 6.4 grams of protein per 100 calories, compared with broccoli's whopping 11.1 grams.

Food data tables usually measure nutrient levels per serving or per 100 grams, not per calorie. This matters because broccoli is far lower in calories than steak. By using this metric, the meme is actually comparing the nutritional content of more than three servings of broccoli (285 grams) with less than a third of the typical serving of steak (55 grams). Not exactly the fork-by-fork comparison it suggests.

According to the US Department of Agriculture, even per 100 calories, steak has more than twice the protein of broccoli, containing more than 15 grams of protein versus just less than 7 grams.

So does the stat in the meme stand up? It is hard to tell on social media alone as it references an online article that is no longer functioning. However, there may be a simple explanation. While the image shows a steak vs broccoli comparison, the text refers to beef in general. Different cuts of beef have different fat-to-protein ratios and therefore different protein values. Also, as fat has about twice the calories of protein, picking fattier cuts distorts the "per 100 calorie" metric to give you even lower protein values. Bottom line?

"Humans aren't pandas. We don't survive by just eating one type of food, but a diverse range of them"

DEEPOL BY PLAINPICTURE/EDWIN GIESBERS

The meme is at best misleading, at worst based on questionable stats.

Now let's look at another meme that tells a very different story. This one compares the nutritional content of apples and liver. According to the graphic, liver is higher in a range of nutrients from protein to selected vitamins and minerals like iron, so is by far the healthier choice.

But who is eating apples thinking they are a rich source of protein? I mean, frankly, it isn't a like-for-like comparison. It is comparing apples with, well, liver. That is before we even consider the stats. I had thought this may be because the image in the meme is of pork liver, yet the meme links to poultry data as a source. When I compared the figures in the meme with tables for beef, pork, chicken, lamb, goose and duck liver, I couldn't find any exact matches. Curious.

Why compare apples and liver anyway? It may be because when it comes to animal foods, liver is a particularly rich source of vitamins and minerals, including things like vitamin C, which isn't found in more commonly eaten cuts of meat.

Comparing this with apples, which aren't the most nutritionally dense of plant foods, is a neat way of supporting a pro-meat stance. However, if you were to pick a more commonly eaten cut like steak and compare it with a more nutrient dense plant like kale, then the opposite is true: kale comes out on top in the majority of nutrients.

All this number crunching skirts around the most important issue here. Humans aren't pandas. We don't survive by just eating one type of food, but a diverse range of them. Because of this simple fact, there is scientifically really no such thing as healthy or unhealthy foods, just healthy or unhealthy diets. The idea of a balanced diet may be a bit old school for 2020, but unlike social media memes it is based on scientific reality. ▮

Editor's pick

Leaders should be judged on their actions not style

4 July, p30

From Andrew Glassner, Seattle, Washington, US

Your article contrasting two types of leadership – prestige and dominance – emphasised style over substance. Someone's past and promised actions and agenda are important criteria when people consider that person for leadership. I would hope many would reject a leader who denied science, vilified immigrants and placed children in cages, be they dominant or prestige. In the end, actions should have a more broad and enduring impact than the style a leader adopts.

From Toby Pereira, Rayne, Essex, UK

One major difference between leaders of countries and leaders of more traditional, small-scale societies is that the latter have to interact with their followers in person and command their respect or they won't remain leader for very long.

National political leaders don't necessarily require the same qualities. With a good team behind them to help cultivate their public image and the ability to respond in some manner to questions without stuttering to a halt, the job is half done. Even then, it can be enough just to be hated slightly less than the main opposition.

Hadza diet also holds lessons for healthier life

18 July, p28

From Craig Sams, Hastings, East Sussex, UK

In "How to sit", the authors suggest that squatting might maintain enough muscle activity to prevent triglyceride build up and lessen risk of cardiovascular disease. They cite the Hadza of Tanzania as an example.

The Hadza diet is very fibre-rich. The microbiomes of individuals have been studied and they have an extensive population of microbes that varies with the seasonality of their food, almost all gathered from the wild. This seems to be a likely additional factor in lower triglyceride levels.

From Hillary Shaw, Newport, Shropshire, UK

The problem with how many of us sit may be a desk or table problem. If we are to squat on the floor to improve health, we would need desks that are much lower.

Let's make a pandemic wearable for everyone

Letters, 4 July

From Chris Morley, Bradford, West Yorkshire, UK

The solution to the problems of developing a coronavirus contact tracing app in the UK for multiple devices could be to develop a single wearable packaged as a watch, brooch or key fob. It would have to be backed up by a central database, but that would be under NHS control. The device would hold no personal details just, say, three weeks of contact info.

There is still time to do this. Such a device could be developed and tested by Christmas and manufacturing ramped up in the new year. There is, of course, the question of cost. Devices with similar hardware are available for £30, so equipping everyone in the UK for this pandemic, and future ones, wouldn't be prohibitively expensive.

How long can you shut borders to control a virus?

25 July, p10

From Linda Phillips, Narrogin, Western Australia

You list places where the virus has almost been eliminated, including Iceland, Taiwan and New Zealand. In Western Australia, the virus has been eliminated too – the few cases are inbound travellers who are in quarantine. As a result, life has returned to near normal. The hard lockdown of the state border is often credited for this.

But this raises a conundrum: just how long will we have to ban ingress? As the virus spreads around the world, are we going to keep borders locked down for years or, at some point, do we open them, accepting the spread of the virus as inevitable?

If the UK were, by some miracle, to eliminate the virus, it would face the same dilemma.

Blanket testing might beat covid-19 within weeks

18 July, p7

From Graham Jones, Bridgham, Norfolk, UK

To avoid a coronavirus resurgence, the UK should follow the guidance of the World Health Organization and test more widely. How about testing everyone every week and quarantine under supervision anybody who tests positive?

I estimate this could be done for about 2 per cent of the cost of furloughing 7 million people. This way, the UK could be free of covid-19 in a matter of weeks.

Cosmology's fudge factors hint at a systematic error

6 June, p30

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

You have lately had some great articles by giants in the cosmology field, including Jim Peebles admitting that there are huge gaps in our understanding.

As a biologist, if I had to review results that required fudge factors in the way cosmology does (dark matter and dark energy, both lacking experimental evidence), to explain the data, I would suggest looking for a systematic error.

New take on gravity raises many other questions

11 July, p30

From Bryn Glover, Kirkby Malzeard, North Yorkshire, UK

I was a little surprised that Claudia de Rham's article on new ideas about gravity made no mention of dark energy. It seemed to be the logical next step to wonder, if gravitons have mass, and thus have finite range, whether there is any need, in considering the expansion of the universe, to invoke dark energy at all.

From Robert East, London, UK

If gravity does have mass, as de Rham suggests, how does it escape a black hole?

Space rings may have an innocent explanation

11 July, p14

From David Feldman, London, UK

Further to your story "Circles in space are like nothing we've ever seen" about inexplicable radio signals spotted by astronomers. Could they result from gravitational lensing of other objects?

Use lightning rods to save the rainforests

27 June, p40

From Christopher Eve, Lynton, Devon, UK

You say that "half of the deaths of large tropical trees are down to lightning". One way to reduce this toll could be to fit such trees with cheap lightning conductors.

For the record

Andrew Wight was the author of the article on links between drug cartels and deforestation in Guatemala (11 July, p17).

Teijin is Elitac's partner company in developing a vibrating belt for navigation use (25 July, p15).

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Blackmagic Design is a leader in video for the medical industry, and now you can create your own streaming videos with ATEM Mini. Simply connect up to 4 HDMI cameras, computers or even technical equipment. Then push the buttons on the panel to switch video sources just like a professional broadcaster! You can even add titles, picture in picture overlays and mix audio! Then live stream to Zoom, Skype or YouTube!

Create Training and Educational Videos

ATEM Mini's includes everything you need. All the buttons are positioned on the front panel so it's very easy to learn. There are 4 HDMI video inputs for connecting cameras and computers, plus a USB output that looks like a webcam so you can connect to Zoom or Skype. ATEM Software Control for Mac and PC is also included, which allows access to more advanced "broadcast" features!

Use Professional Video Effects

ATEM Mini is really a professional broadcast switcher used by television stations. This means it has professional effects such as a DVE for picture in picture effects commonly used for commentating over a computer slide show. There are titles for presenter names, wipe effects for transitioning between sources and a green screen keyer for replacing backgrounds with graphics!

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Monitor all Video Inputs!

With so many cameras, computers and effects, things can get busy fast! The ATEM Mini Pro model features a "multiview" that lets you see all cameras, titles and program, plus streaming and recording status all on a single TV or monitor. There are even tally indicators to show when a camera is on air! Only ATEM Mini is a true professional television studio in a small compact design!

ATEM Mini.....**US$295***
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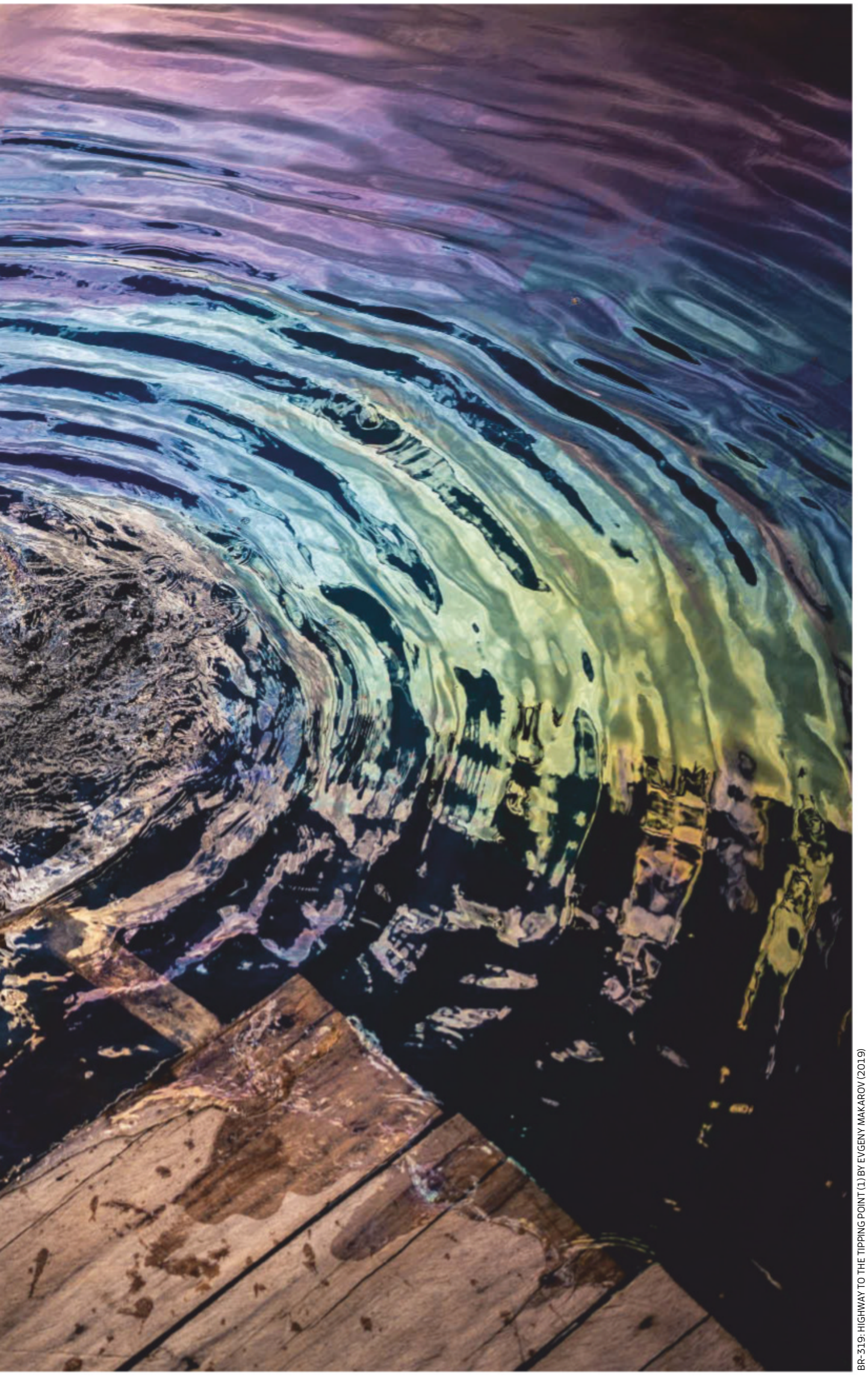


BR-319: HIGHWAY TO THE TIPPING POINT (1) BY EVGENY MAKAROV (2019)

Amazon peril

Photographer Evgeny Makarov

THIS local keeps an eye out for river dolphins in the Amazon river in Brazil as an oil spill from a nearby boat adds a chromatic sheen to the water.

The photo is called *BR-319: Highway to the Tipping Point* and was taken by Evgeny Makarov. It is shortlisted for the Royal Geographical Society's Earth Photo 2020 competition in the category A Climate of Change.

To get the shot, Makarov made a 10-day journey down the BR-319 highway, which was conceived to connect the rest of Brazil to the city of Manaus at the heart of the Amazon rainforest.

The 870-kilometre-long road was built in the 1960s and 70s to open up the area's economic potential. However, poor construction and long rainy seasons meant the route was soon abandoned and it has been impassable to vehicles for more than 30 years.

Thanks to good conditions, Makarov was able to make it past the potholes and rainforest debris to capture the livelihoods of those living along the BR-319. His journey coincided with an announcement by Brazilian president Jair Bolsonaro last year to repave the road, which would trigger further deforestation of the Amazon rainforest.

The winners of the competition will be announced later this year, with shortlisted photos being exhibited at the Royal Geographical Society in London from 7 December.

Gege Li

Alternative timelines

Two recent books imagine a different history of science, but one handles the prejudices of the time much better than the other, says **Jacob Aron**

NUCLEAR weapons haven't been used in armed conflict since 1945, when the US dropped two bombs on Japan, killing hundreds of thousands of people. This is, in part, due to the man behind the bomb, J. Robert Oppenheimer, who later advocated for international nuclear arms control.

As head of the scientists within the Manhattan Project, the secret war effort to develop the bomb, Oppenheimer supported the race to beat Nazi Germany to unleashing the power of the atom, but clearly felt unease with his creation. At the detonation of the first test bomb on 16 July 1945, he is said to have quoted from Hindu scripture: "Now I am become death, the destroyer of worlds."

In *The Oppenheimer Alternative*, sci-fi author Robert J. Sawyer gives the physicist a chance of redemption in an alt-history tale that sees him team up with Albert Einstein and John von Neumann to save the world. Shortly after the nuclear bombings, Oppenheimer and his colleagues realise that the sun appears to be slightly too hot – and, as a result, is set to blow up in 2028, taking Earth with it.

The scientists split into three teams: one to study the sun, one to explore options for space travel and evacuating humanity and one to look into unconventional ideas. And they are unconventional – the solution to the disaster, though grounded in theoretical physics, is so left field that I had to go over the final chapter to be sure of what I had just read.

Apart from the ending, Sawyer tries to deviate from real history as little as possible, making the book more like a fictionalised biography than a sci-fi novel. Every character is a real person and most of the events in the book did happen, which doesn't leave much room for the end-of-the-world plot to develop.

It also means the book is stuffed full of the attitudes of the time, particularly towards women. I almost gave up when the first chapter opened with Oppenheimer and a friend discussing a "busty young woman" and the benefits of being able to pick up female students.

There are almost no women in the book, a failing that Sawyer seems to lampshade with an epigraph quoting rocket builder Wernher von Braun complaining that no publisher wants to pick up his novel about Mars because it "lacks a girl".

STOCKTREK IMAGES, INC/ALAMY

In The Lady Astronaut series, a meteorite wipes out much of the US

You can argue that Sawyer is merely portraying the early 20th century as it was, but that seems a feeble excuse in an alternate history book.

The Lady Astronaut series by Mary Robinette Kowal shows a better approach. She imagines a world in which Thomas Dewey beat Harry Truman to become president of the US in 1948, accelerating the space race to see the first satellite launched by the US in 1952, rather than the real-life launch of Sputnik by the USSR in 1957. Shortly after, a meteorite hits the east coast of the US, obliterating much of the nation.

"Kowal doesn't rewrite the prejudices of the 1950s, but the book centres on the people fighting against them"

There is worse to come. The meteorite sets off catastrophic climate change that will make Earth uninhabitable in 50 years. Nations band together to form the International Aerospace Coalition (IAC) in an effort to get humanity off-world before it is too late.

The first book, *The Calculating Stars*, owes obvious inspiration to *Hidden Figures*, the book and later film about the black female mathematicians who calculated flight trajectories for NASA's early missions.

Elma York performs the same task for the IAC. She wants to put her wartime pilot training to good use as an astronaut, but only men – and white men at that – are allowed to go to space. York, who is also white, forces the IAC to accept astronauts of any gender or race.

Kowal doesn't wave a magic wand and rewrite the prejudices of the 1950s. They still exist, but the book centres on the experiences of the people fighting against them.

A sequel, *The Fated Sky*, sees York take part in the first crewed mission to Mars, where even in deep space, black astronauts cannot escape racism. The recently released third book, *The Relentless Moon*, follows York's friend Nicole Wargin, who must weed out saboteurs in a lunar colony who disagree with the plan to evacuate Earth while also contending with an outbreak of polio.

Kowal's characters are smart, funny and, most importantly, flawed, making them seem more realistic than the real-life cast of Sawyer's novel. The Lady Astronaut is a must-read series.

For more on the legacy of Hiroshima see page 21

A spaceship-studded epic

The Expanse is an old-fashioned, multidimensional space opera. Sci-fi fans should give it a go, says **Emily Wilson**

TV

The Expanse
Mark Fergus and Hawk Ostby
Available on Amazon Prime Video

This review contains as few spoilers as is humanly possible.

AMAZON PRIME VIDEO

Shohreh Aghdashloo plays a high-powered politician in *The Expanse*

WHEN the Syfy channel pulled the plug on *The Expanse* three seasons in, that looked to be it for the sprawling TV show. But then Amazon picked it up for a fourth season, the show went on and a fifth season could come out at any time. What we have now is a really ambitious programme with legs – one that all sci-fi fans should at least consider.

If you haven't tried it yet, *The Expanse* deliberately starts rather mid-sentence, but then makes perhaps too few concessions to people who haven't read the source books by James S. A. Corey.

Your heart slumps a bit at how much exposition you have to swallow, at the tendency of some of the characters to talk in a grating fake patois, and at yet another scene of people you don't recognise in dark spaces (on ships, in asteroids etc.) cutting away to a scene of other people you don't recognise in other dark spaces. But press on, brave TV soldier! All will be starlight-clear soon enough.

***The Expanse* is 100 per cent old-fashioned proper sci-fi of the sprawling, spaceship-studded, multistranded, multidimensional epic variety.**

It is a future vision of the solar system in which a horribly polluted Earth has become horribly divided between the vastly rich and the occupation-less poor. Then there is colonised Mars, its citizens extremely militarised and dressed in absolutely killer space armour when out-ship and otter-sleek uniforms when on ship. And then there is the rough asteroid mining belt, reminiscent of *Blade Runner* in its aesthetics, that is home to the annoying patois.

We join the action as a rich young woman goes missing somewhere out in the belt. A belter detective is tasked with finding her and so begins a story that will take us to the edges of the solar system and beyond. There is also a strange, glowing plant-thing… but of that I should say no more.

The ideas are wonderful, the effects and action fantastic and the writing – while nothing can be perfect – good enough. But the reason I stuck with *The Expanse*, and will continue to do so, is, predictably, because the characters work, whether stuck on different planets or, if we are lucky, thrown together on ships hurtling this way or that.

On paper, the show's chief hero is Earther-turned-belter ship's officer James Holden, played by Steven Strait, and he actually holds his end up fine given that everyone around him is given a lot more room to have fun with their parts.

Of those given more room, my favourite is the furiously patriotic Martian marine Bobbie Draper, played by Frankie Adams. Whether sweetly agonising over her loyalty to Mars or abruptly bursting into ultraviolence, she is totally convincing. Need anyone to take back a hijacked spaceship or similar? Definitely call for Bobbie!

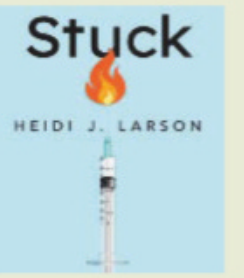
My second favourite is the politician Chrisjen Avasarala, played by Shohreh Aghdashloo. Early on, her arch-manipulator-of-worlds character seems rather implausible, but the amazing Aghdashloo soon has you eating out of her jewel-encrusted hand.

It's not yet clear where season five will take us in terms of new ideas or even new galaxies. And we still don't know when it will be released given the pandemic. But that makes this an excellent time to sit back and get bang up to date with the *Expanse*-verse, ready for whatever our heroes face next. ▮

Don't miss

Visit

And Say the Animal Responded? at FACT in Liverpool, UK, from 12 August looks at the world from a non-human perspective. The exhibition will immerse visitors in animal communication through film, art and technology.



Read

Stuck: How vaccine rumors start – and why they don't go away sees anthropologist Heidi Larson share her radical ideas on how we restore public confidence in vaccines. It is a globe-spanning account of how people perceive risk.

Watch

Project Power is a Netflix blockbuster starring Jamie Foxx and Joseph Gordon-Levitt, available from 14 August. A new pill gives the user a superpower for 5 minutes. All they have to do is work out what it is – and avoid dying.

DEMELZA KOOIJ; NETFLIX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Life's big bang

Simple explanations of how life got started don't add up, which leaves a surprising alternative, finds **Michael Marshall**

WHEN Earth formed 4.5 billion years ago, it was a sterile ball of rock, slammed by meteorites and carpeted with erupting volcanoes. Within a billion years, it had become inhabited by microorganisms. Today, life covers every centimetre of the planet, from the highest mountains to the deepest sea. Yet, every other planet in the solar system seems lifeless. What happened on our young planet? How did its barren rocks, sands and chemicals give rise to life?

Many ideas have been proposed to explain how it began. Most are based on the assumption that cells are too complex to have formed all at once, so life must have started with just one component that survived and somehow created the others around it. When put into practice in the lab, however, these ideas don't produce anything particularly lifelike. It is, some researchers are starting to realise, like trying to build a car by making a chassis and hoping wheels and an engine will spontaneously appear.

The alternative – that life emerged fully formed – seems even more unlikely. Yet perhaps astoundingly, two lines of evidence are converging to suggest that this is exactly what happened. It turns out that all the key molecules of life can form from the same simple carbon-based chemistry. What's more, they easily combine to make startlingly lifelike "protocells". As well as explaining how life began, this "everything-first" idea of life's origins also has implications for where it got started – and the most likely locations for extraterrestrial life, too.

The problem with understanding the origin of life is that we don't know what the first life was like. The oldest accepted fossils are 3.5 billion years old, but they don't help much. They are found in ancient rock formations in Western Australia known as stromatolites and are single-celled microorganisms like modern bacteria. These are relatively complex: even the simplest modern bacteria have more than 100 genes. The first organisms must have been simpler. Viruses have fewer genes, but can reproduce only by infecting cells and taking them over, so can't have come first.

The bare necessities

With physical evidence lacking, origin-of-life researchers begin by asking two questions. What are the fundamental processes underpinning life? And what chemicals do these processes use? Here, there are answers.

Life can be boiled down to three core systems. First, it has structural integrity: that means each cell has an outer membrane holding it together. Second, life has metabolism, a set of chemical reactions that obtain energy from its surroundings. Finally, life can reproduce using genes, which contain instructions for building cells and are passed on to offspring.

Biochemists know the chemicals underpinning these processes too. Cell membranes are made of lipids, molecules containing long chains of carbon atoms. Metabolism is run by proteins – chains of amino acids, twisted into pretzel shapes – especially enzymes, which help catalyse chemical reactions, speeding them up. And genes are encoded in molecules called nucleic acids, such as deoxyribonucleic acid, better known as DNA.

Beyond this, things start to become more complicated. Life's three core processes are intertwined. Genes carry instructions for making proteins, which means proteins only exist because of genes. But proteins are also essential for maintaining and copying genes, so genes only exist because of proteins. And proteins – made by genes – are crucial for constructing the lipids for membranes. Any hypothesis explaining life's origin must take account of this. Yet, if we suppose that genes, metabolism and membranes were unlikely to have arisen simultaneously, that means one of them must have come first and "invented" the others.

An early idea put proteins in the driving seat. In the 1950s, biochemist Sidney Fox discovered that heating amino acids made them link up into chains. In other words, they formed proteins, albeit with a random sequence of amino acids rather than one determined by a genetic code. Fox called them "proteinoids" and found that they could form spheres, which resembled cells, and catalyse chemical reactions. However, the proteinoids never got much further. Some researchers still hunt for lifelike behaviour in simple proteins, but the idea that proteins started life on their own has now been largely rejected.

More recently, much research has focused on an idea called the RNA world. Like DNA, ›

OLLIE HIRST

Death to panspermia

A handful of scientists argue that life didn't begin on Earth, but elsewhere in the universe, and that it was carried here on meteoroids and other space bodies. The origin could be somewhere nearby, like Mars, or light years away. The idea is called "panspermia".

Aside from the fact that this simply relocates the problem of how life got going, we also haven't found evidence of life elsewhere. If panspermia were true, bacteria would be raining down on Earth from space, and neighbouring worlds like the moon would be scattered with their remains. But there is no evidence of incoming bacteria, and moon rocks are sterile.

Furthermore, space is hostile to life. In experiments where bacteria were placed outside the International Space Station, even exposures of a year took a heavy toll. This leaves a window for life to travel within the solar system, but it is a narrow one: the trip from Mars to Earth would take many months at least. Travel from other stars would take millennia, so looks impossible.

Panspermia advocates may also be disappointed to learn that scientists are finally cracking the mystery of how life began on Earth (see main story). Like the planet itself, its raw materials came from space – but it seems more than likely it was Earth that brought them to life.

NASA

A billion years after Earth formed, life emerged. Did it happen elsewhere too?

RNA (ribonucleic acid) carries genes. The discovery that some kinds of RNA can also catalyse chemical reactions hinted that the first RNA molecules could have been enzymes that made copies of themselves and so got life started. However, biochemists have spent decades struggling to get RNA to self-assemble or copy itself in the lab, and now concede that it needs a lot of help to do either.

Perhaps, then, membranes came first. David Deamer at the University of California, Santa Cruz, has championed this option. In the 1970s, his team discovered that lipids found in cell membranes could be made when two simple chemicals, cyanamide and glycerol, were mixed with water and heated to 65°C. If these lipids were subsequently added to salt water and shaken, they formed spherical blobs with two outer layers of lipids, just like cells. "The simplest function is the self-assembly of membranes. It's spontaneous," says Deamer. Nevertheless, he now accepts that this isn't enough, because lipids can't carry genes or form enzymes.

The shortcomings of these simple models of life's origin have led Deamer and others to explore the seemingly less plausible alternative that all three systems emerged together in a highly simplified form.

This isn't a new idea. In 1971, Hungarian biochemist Tibor Gánti wrote a book in which he imagined the simplest object that biologists would consider alive. His "chemoton" consisted of a crude metabolism, based on enzymes, which made genes and a membrane. When the genes copied themselves, they released by-products that ended up in the membrane, causing the chemoton to grow and ultimately divide. Gánti's ideas failed to get recognition until the early 2000s, however, by which time others had independently hit on something

similar. Now, the everything-first hypothesis is gaining momentum.

The first line of support for it comes from the biochemistry of life's three key systems. Nucleic acids such as RNA are chemically very different from proteins, which differ again from lipids. So, until recently, biochemists had assumed that these three components of life were unlikely to form in the same place from the same starter chemicals. That assumption seems to be wrong.

An early clue came from meteorites, many of which are as old as Earth, and therefore tell us what the planet was like when it was new. One of the most studied is the Murchison meteorite, which hit Australia in 1969. In 1985, Deamer found lipid-like molecules in it, which could form membranes. Others have found amino acids and, in 2008, Zita Martins, then at Imperial College London, identified a component of RNA in the Murchison meteorite. None of these chemicals was plentiful, but their presence indicated they could form together.

"Life's key molecules can form together thanks to 'Goldilocks' chemistry"

Simple ingredients

Meanwhile, Ernesto Di Mauro at Sapienza University of Rome in Italy has spent two decades exploring how this might happen on Earth. He focuses on formamide, a chemical related to cyanide, with just six atoms in each molecule. It is found throughout the universe and was probably common on the newly formed planet. In 2001, his team found that formamide could give rise to several components of RNA if it was heated to 160°C in the presence of minerals like limestone. The researchers later discovered that a common type of clay called montmorillonite helps. Formamide can also generate amino acids, the building blocks of proteins. "It produces complex mixtures," says Di Mauro.

And formamide isn't the only chemical capable of such feats. By combining a similar organic compound called cyanamide with other simple chemicals, John Sutherland at the MRC Laboratory of Molecular Biology in Cambridge, UK, has created nucleotides, the building blocks of RNA. The reaction requires ultraviolet light, heating and drying, and wetting with water. Sutherland's team found that the same starting chemicals can also make the precursors of amino acids and lipids. "All the cellular subsystems could have arisen simultaneously through common chemistry," he concluded. The key is what Sutherland calls "Goldilocks chemistry": a mixture with enough variety for complex reactions to occur, but not so much that it becomes a jumbled mess.

So there are ways in which the key molecules of life might all have been created together. But how did they then combine into a crude cell? Deamer still argues that the first lipids spontaneously formed membrane-based protocells, but he now thinks the three groups of molecules work together closely. Lipid containers help RNA and proteins to form and RNA to replicate, and RNA stabilises the lipid membranes. If all are present, the system works better, he says.

Jack Szostak at Harvard Medical School has taken remarkable strides toward revealing how this might have happened. Beginning in 2003, his team built model cells with outer layers of fatty acids surrounding an internal space that could host RNA. These protocells formed particularly quickly in the presence of tiny particles of montmorillonite, which often became trapped inside them, carrying RNA inside too. The more RNA a protocell obtained, the more it grew: they were competing. What's more, they could divide to form daughter cells, much like modern cells do. "Growth and division can result from simple physico-chemical forces, without any complex biochemical machinery," the team wrote. Szostak's group has even persuaded RNA to copy itself within protocells.

The one system still missing from these protocells is metabolism. This is particularly challenging because it means creating entire sequences of chemical reactions. In modern organisms, these are controlled by battalions of protein enzymes, which can't have existed when life began. However, other researchers have begun finding ways to get metabolic chemical reactions going without proteins. It turns out that many of the key reactions ›

PHILIPPE PLAILLY/SCIENCE PHOTO LIBRARY

Stromatolite fossils are the oldest evidence of life here

New research suggests life didn't emerge in deep sea vents after all

RALPH WHITE/GETTY IMAGES

can be driven by metals like iron, often paired with sulphur, which have always been abundant on Earth. Szostak and others have recently shown that clusters of iron and sulphur atoms can form within protocells, driven by ultraviolet light. It remains to be seen whether metabolic reactions can work in the protocells.

A crude prototype

Nevertheless, Szostak's protocells are our best model yet for what the first living organisms might have looked like. Despite containing just a handful of chemicals, they grow and reproduce and carry RNA "genes" that can copy themselves. It is too early to say whether they arose from the sorts of chemistry advocated by Di Mauro or whether Sutherland is closer to the mark. That depends on the setting in which life emerged, which we can never know for certain. Intriguingly, though, the chemistry itself helps us narrow down the options.

If the everything-first idea of life's origins is correct, then genesis occurred under specific conditions. Most of Sutherland's and Di Mauro's chemical reactions depend on ultraviolet light and some key steps require drying. This implies that, to get started, life needed a solid mineral surface ideally including a clay such as montmorillonite, sunlight with a fair bit of ultraviolet radiation, and enough warmth to periodically evaporate water. That seems to rule out the popular idea that it originated on chemical-rich hydrothermal vents in the deep sea. Instead, the everything-first researchers believe life began in chemical-rich pools on land. Sutherland has developed a scenario involving streams of water running down a meteorite impact crater. Deamer favours geothermal ponds in volcanic settings and is focusing research on these. For instance, he has shown that lipids can form protocells in the water of these ponds, but not in seawater.

As well as helping to locate where on Earth life originated, the everything-first idea also suggests where to look for it elsewhere in the solar system. The biochemical requirements rule out two current front runners: Jupiter's moon Europa and Saturn's moon Enceladus. Both are thought to have deep oceans beneath a layer of ice. Those oceans might sustain life if it were introduced, but aren't a promising site for it to form. Instead, the most likely place to find life – or at least fossil evidence of it – is Mars. Today, it is cold and lacks liquid water on the surface, but billions of years ago it probably had rivers running over its rocks. It was also volcanically active, so may have had geothermal ponds like those Deamer is exploring.

"The most likely place to find other life, or at least fossil evidence of it, is Mars"

Of course, all this depends on the everything-first idea proving correct. Szostak's protocells and the new biochemical insights have won over many researchers, but some pieces of the puzzle are still missing. Perhaps the most persuasive argument is that the simpler ideas don't work. As is the case with many things in life, the beginning was probably more complicated than we had thought. ▮

Michael Marshall is a writer based in Devon, UK. His book *The Genesis Quest* is out in the UK on 20 August and in the US on 22 October

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Coronavirus effects on children, and on other diseases, changing the way you sit could add years to your life and supercrops for a climate-changed world

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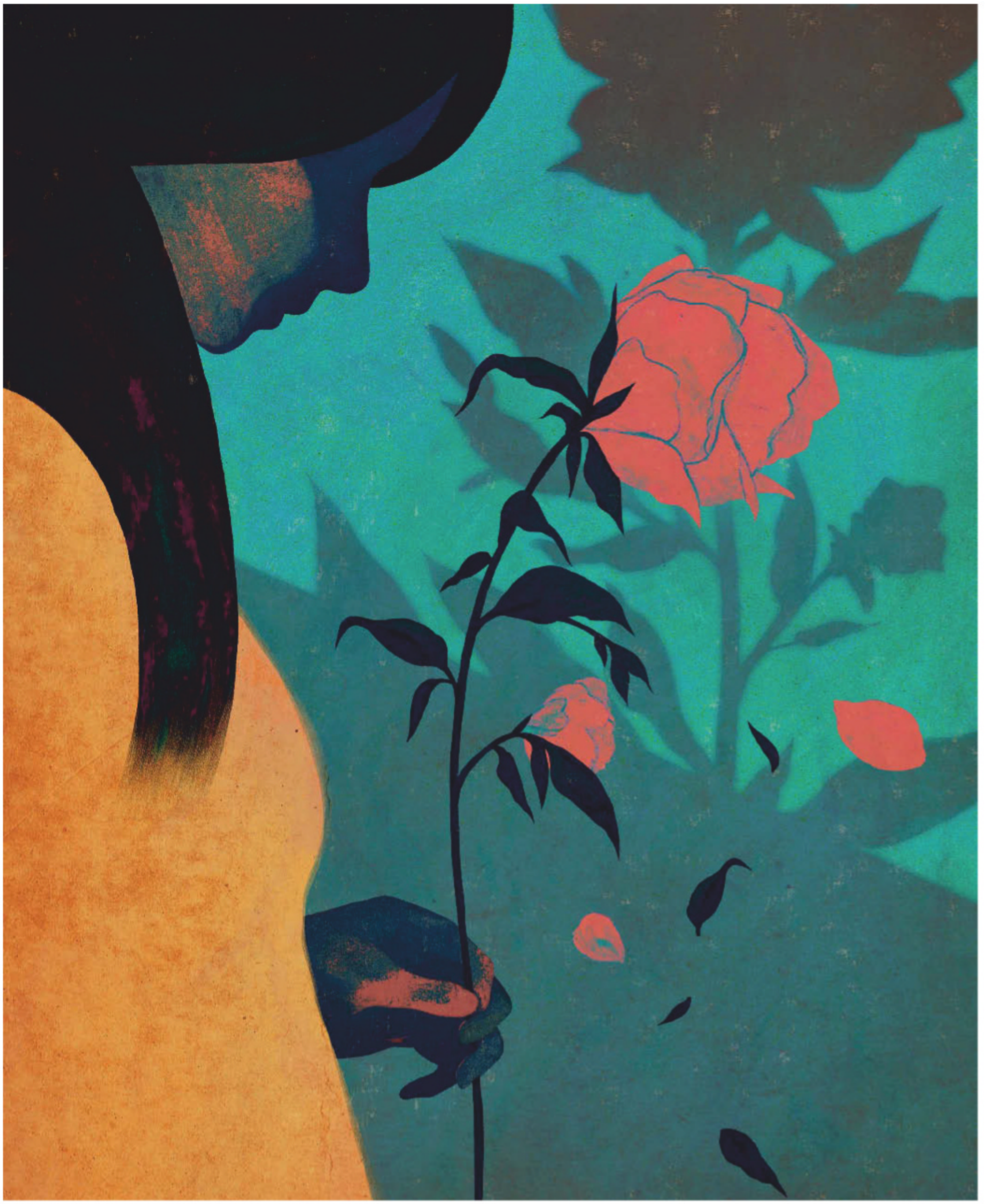


OWEN GENT

Rethinking miscarriage

Lost pregnancies are far more common than successful ones. Finding out why may change how we think about fertility, finds **Alice Klein**

WHEN I saw the positive result on my at-home pregnancy test, my mind raced ahead. I imagined how it would feel to hold my child for the first time, what we would call them. I thought of the bedtime stories we would read, pictured family camping holidays at the beach.

I never imagined that, just weeks later, while dancing at a friend's wedding, a sharp twisting pain would signal that the pregnancy was over.

Like many women who have a miscarriage, I worried I had done something to trigger the loss. Had I exercised too hard? Slept too little? Around the world, studies show that many women experience shame and guilt after losing a pregnancy. One US survey found that 40 per cent of women who had a miscarriage believed it was because of something they did wrong. Though there is no evidence covid-19 increases miscarriage risk, the pandemic only exacerbates these worries. Society can add to the problem. In some countries, the culture of blame is so widespread that losing a pregnancy can land a woman in jail.

When I looked into the latest research, what I discovered not only challenged ideas that women are somehow responsible for their miscarriages, or experience them because something is wrong, but suggested that, surprisingly, they are usually associated with optimal maternal health. With advances in fertility medicine, we are finally starting to understand what happens in a miscarriage. This progress may offer solace when pregnancies don't work out and help women struggling to become pregnant. It could even shed light on the role of miscarriage in our evolution.

Until a few decades ago, even medical professionals had little understanding of how often miscarriages occur. The first hint came in 1975, when *The Lancet* ran a paper titled, "Where have all the conceptions gone?" The authors calculated how many babies you would expect to be born annually to married women in their 20s in England and Wales, and found the true figure was a staggering 78 per cent lower. They proposed the radical idea that most pregnancies are naturally terminated before women know they are pregnant, and that miscarriage is our "principal method of quality control", but had no way of proving it.

Since then, the invention of early pregnancy detection tests – like the pee-on-a-stick test that I did – have confirmed that we do indeed have an exceptionally high rate of pregnancy loss. The pamphlets that come with these tests advise that one in four pregnancies don't make it past the early stages, but the real figure may be far higher. The latest estimate is that for women in their early 30s, 60 per cent of pregnancies end in miscarriage, mostly in the early stages. This is six times higher than the rate in mice and rabbits and twice that for pigs, sheep and goats. For women in their early 20s, 50 per cent of pregnancies end in miscarriage; in their early 40s, it is 80 per cent.

"For women in their early 30s, 60 per cent of pregnancies end in miscarriage"

Silence and stigma

Most people have no idea that miscarriages are so common. A survey of 1000 men and women in the US, for example, found that the majority thought they occurred in fewer than 5 per cent of pregnancies. "There is this whole silence and stigma around miscarriage," says Jade Bilardi at Monash University in Australia. Often, we are oblivious even when our close friends go through them because they typically occur before the 12-week mark when it is considered socially acceptable to announce a pregnancy, she says. "It means that couples often feel very alone and isolated when it happens to them."

Then there are those haunting feelings that so many women experience in this situation that we did something wrong. This is because stress, diet, exercise, prior birth control use and lifting heavy objects are often incorrectly blamed for miscarriages, says Bilardi. "There tends to be a lot of questioning afterwards, like, 'Have I been too stressed at work? Did I eat something wrong?'," she says. "It is common for women to feel shame or guilt or like their body has betrayed them."

There is evidence that some lifestyle factors like stress, smoking and heavy alcohol consumption do slightly increase the risk of pregnancy loss, as do conditions including endometriosis and thyroid disorders, as well as infectious diseases like the flu. ›

Dealing with loss

Miscarriages can take a toll on mental health. Research from earlier this year found that one in six women who experience a miscarriage or ectopic pregnancy have symptoms of post-traumatic stress disorder nine months later. One UK study found that 28 per cent of women and 12 per cent of men experience anxiety after losing a pregnancy, which may be due to uncertainty about whether they will eventually be able to have children.

Yet support is lacking. A survey of 300 French women who lost pregnancies found that 78 per cent weren't given adequate information about the causes of miscarriage and 82 per cent subsequently worried about future pregnancies.

In a study of 22 women in the UK who had miscarriages, one who was sent home without any plans for follow-up care said: "They wouldn't dream of taking somebody's appendix out and saying, 'Bye, we won't see you again'." Similarly, a man surveyed in an Australian study about miscarriage said: "The whole process was really clinical... It was just... 'Yep that's it, there's no heartbeat. Off you go to the next room'." No countries offer routine check-ups for couples who have experienced pregnancy loss.

Research suggests that men in particular have a hard time finding a sympathetic ear after a miscarriage. They often feel like they are expected to be the strong, stoic ones and that their grief is less valid than their partner's.

LOST FOR WORDS

It can be hard to know what to say to a friend or relative who has a miscarriage, but Jade Bilardi at Monash University in Australia says a simple "sorry about your miscarriage" is better than staying silent for fear of saying something wrong.

She also recommends listening, letting them grieve for as long as they need to, encouraging them to talk to other people who have had miscarriages and offering practical help like dropping off meals.

However, she cautions against offering unhelpful clichés like "It wasn't meant to be" and unsolicited advice like "it's because you've been working so hard".

However, most miscarriages are unavoidable because they are caused by chromosomal errors in the embryo, says Shawn Chavez at Oregon Health and Science University. The reason maternal age increases miscarriage risk is due to the rate of chromosomal abnormalities in embryos rising as women get older. Advanced paternal age also slightly increases the rate of chromosomal abnormalities in embryos.

The gatekeeper

Human embryos contain far more chromosomal errors than those of most other mammals. Up to 80 per cent of embryos made through in-vitro fertilisation (IVF) contain at least one chromosomally abnormal cell, and this figure is probably similar for naturally conceived embryos, says Chavez. In comparison, this is true for fewer than 10 per cent of mouse embryos.

Our chromosomes contain all the genes needed to build a functioning human, so embryos with significant abnormalities usually don't survive. Humans have to be extra fussy because we usually only have one child at a time, says Chavez. "In the case of animals that have litters, maybe they make 10 embryos a month and only eight make it to live birth, but that's still eight," she says. "Whereas we typically can only make one embryo per month, so if it isn't a good one, maybe it's better to try again next month."

Until recently, we didn't know how this vetting system might work, because the ethical and technical challenges of studying early pregnancy made it a "black box", says Nick Macklon at the London Women's Clinic in the UK. In the past decade, his research group has started to piece together some of the evidence.

The researchers began by studying what happens when an embryo burrows into the lining of the uterus, called the endometrium, which normally occurs about five days after conception. They couldn't study this implantation process in pregnant women for risk of harming their pregnancies. So

instead, they placed embryos donated by previous IVF patients in a dish on a layer of cells that had been collected from a woman's endometrium.

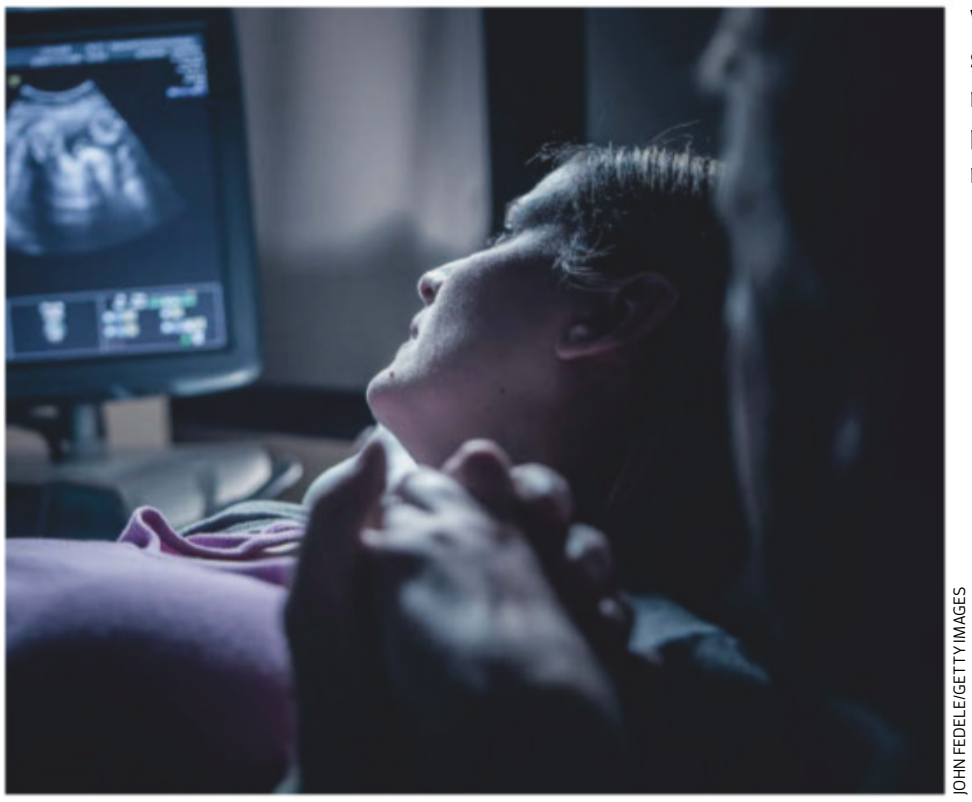
When embryos were added, the endometrial cells usually flocked to them and released chemicals designed to promote implantation and growth. But when the embryos had chromosomal abnormalities, the endometrial cells avoided them and stopped secreting pro-implantation chemicals. By depriving them of essential nutrients, the endometrium appears to prevent embryos that are unlikely to survive from attaching to the uterus, says Macklon.

To find out more about this process, Macklon's team used the liquid that human embryos had been grown in during IVF and flushed it through the uteruses of live mice. Liquid that had sustained embryos that produced successful pregnancies activated 90 genes involved in fostering embryo implantation and growth. In contrast, liquid used with embryos considered unlikely to survive, and so not transferred to a uterus, triggered an extraordinarily strong stress response, activating 544 genes that are thought to work together to drive embryo rejection.

Taken together, these findings hint that the endometrium acts as a gatekeeper that waves through the embryos that are most likely to survive while doing everything it can to shut out others, says Macklon. The challenge now is to conduct human studies to confirm this.

One option may be to use an IVF technology called shared motherhood that has recently become available to lesbian couples. It involves one partner incubating an embryo made from her egg and donor sperm in a removable porous capsule inside her uterus for the first 18 hours. The embryo is then transferred into her partner's uterus to implant and grow into a baby. Researchers could study how different embryos affect gene expression of the endometrium by taking biopsies from women who provided the initial incubating, after the embryos have been safely moved to their partners' uteruses, says Macklon.

"There's this idea that human reproduction is inefficient – that's not true"



JOHN FEDELE/GETTY IMAGES

Women who have several miscarriages may actually get pregnant more rapidly than others

Studies like these could yield critical insights: it is now estimated that about three-quarters of miscarriages occur at the implantation stage. In the past, these early losses probably would have gone unnoticed because they would have looked like a period that was perhaps just slightly heavier or a few days later than normal, says Macklon. Now, early pregnancy tests and the close monitoring of IVF have made us more aware of them.

Even if they occur at an early stage, miscarriages are no less distressing, says Bilardi (see "Dealing with loss", left). "A lot of people start planning right from the minute they know they're pregnant: they know their due date, they start planning around that, and start dreaming of becoming a parent," she says. "When that is taken away, it doesn't matter how far along you are, it can be a huge source of grief."

Understanding how the endometrium works as a gatekeeper may also provide an explanation for the small proportion of couples who struggle to have children, says Macklon, either because they can't get pregnant or they have recurrent miscarriages. He thinks both conditions result from the endometrium sensor being programmed on a slightly wrong setting.

If, for example, the sensor is overly selective, it will block the implantation of all embryos, leading to infertility. In contrast, if it is overly receptive, it will let through embryos with chromosomal abnormalities, potentially resulting in later miscarriage or stillbirth.

If Macklon is correct, this may explain why women who experience recurrent ›

Pregnancy, day by day

A pregnancy lost before 24 weeks is considered a miscarriage by the National Health Service in the UK

DAYS 1-5
MENSTRUATION
The uterus lining (endometrium) is shed because pregnancy didn't occur in the last menstrual cycle

DAY 6
The endometrium starts regrowing to support pregnancy

DAY 14
OVULATION
The ovary releases an egg into the fallopian tube

CONCEPTION
The egg is fertilised by sperm in the fallopian tube. The resulting embryo begins its journey towards the uterus

DAY 19
IMPLANTATION
The embryo enters the uterus and burrows into the endometrium

DAY 21
Pregnancy detected by blood test

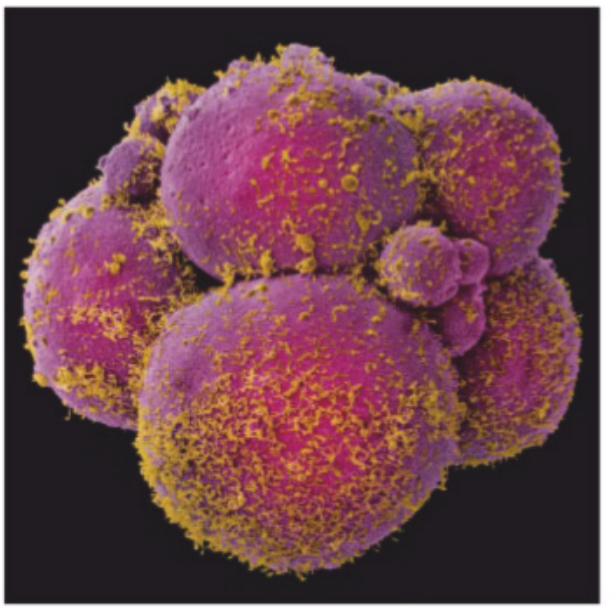
DAY 25
Pregnancy detected by urine test

DAY 29
FIRST MISSED PERIOD
First symptoms like nausea, frequent urination and sore breasts may begin

WEEK 13
Second trimester starts

WEEK 27
Third trimester starts

WEEK 40
Baby delivered



DR YORGOS NIKAS/SCIENCE PHOTO LIBRARY

A developing embryo may send signals that make the uterus more or less receptive

miscarriages paradoxically tend to become pregnant faster than other women. "Recurrent miscarriage is a cruel thing because it makes women feel like serial rejectors of babies," he says. "When I tell these patients that actually it might be the opposite problem – they're in fact serial acceptors of babies that nature never intended to make it – they look at themselves differently and often feel an awful lot better." He says that figuring out why the endometrium sensor is on the wrong setting for these women could lead to new treatments.

Beyond control

Many other factors, including external events beyond a woman's control, may also influence whether a pregnancy results in a live birth, says Tim Bruckner at the University of California, Irvine. Normally, slightly more male babies are born than female babies. But in the three to five months after traumatic events like the September 11 attacks in New York or the Fukushima Daiichi nuclear disaster in Japan, birth records show that there were fewer male births than usual in affected areas.

Exposure to extremely stressful events in pregnancy may promote the loss of male fetuses because male babies are generally more vulnerable in infancy than female babies. In times of trouble, when this effect is magnified, it may trigger a long-evolved process in a woman's body to reduce the risk of investing in a male who may not survive, says Bruckner.

There is still a lot we don't know about the biological mechanisms of the various types of pregnancy loss. But we can surmise that our high miscarriage rate has probably evolved as a way to give us the best chance of having healthy children, says Bruckner. "According to the theory of natural selection, we want to have children that survive infancy and grow up and have children of their own so they can pass on our genes," he says. "There's this idea that human reproduction is inefficient because so many pregnancies are lost, but overall it may have led to the preservation of our species."

As traumatic as my own miscarriage was, it is comforting to learn that it probably wasn't because of anything I did or anything that was wrong with me. On the contrary, it was most likely due to a random genetic error that I had no control over. Instead of my body failing me, it may have protected me from investing further in a pregnancy that probably wasn't going to produce a healthy baby.

Bilardi thinks we need more education and public conversation about the true rate and causes of miscarriage so couples aren't blindsided if it happens to them. "At school, sex education is all about how not to get pregnant. There is nothing to prepare you for what happens if you do want to get pregnant one day," she says. "It means that when you get to the stage of wanting a family, you often don't understand how difficult it can be."

The second time I became pregnant, I felt more prepared for the possibility of something going wrong. I was also very nervous, with every slight abdominal twinge sending me into a panic. But one by one, the nine months ticked by, and I finally delivered my son into the world. Knowing the elaborate vetting process he went through to get here makes me even more appreciative of the fact that, like every other baby, he is truly a miracle. ▮

Alice Klein is a *New Scientist* reporter based in Australia. Follow her @alicevklein

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Knot too difficult

Mathematician **Lisa Piccirillo** untangled a problem that had tied up fellow mathematicians for decades. She tells Chelsea Whyte how she did it

ROCIO MONTOYA

OVER the course of one week in 2018, Lisa Piccirillo cracked a mathematical problem that had gone unsolved for half a century. Posed by legendary mathematician John Conway in 1970, it concerns a complex geometrical object known as the Conway knot. While an ordinary overhand knot – the kind you would tie at the end of a thread – sees the string cross over itself three times, the Conway knot has 11 crossings. What Conway wanted to know is whether his knot can be formed by cutting a slice out of a more complex four-dimensional knot – or, as mathematicians put it, is it "slice"?

Piccirillo discovered that it isn't. Her breakthrough came after finding a back door into the problem that could help mathematicians understand other four-dimensional objects. Currently a post-doctoral mathematician at Brandeis University in Waltham, Massachusetts, solving the Conway knot – along with her other research – has seen her offered a tenure-track position at the Massachusetts Institute of Technology. *New Scientist* spoke to her about the week she spent on the problem, her approach to mathematics and why it is time we stopped talking about geniuses.

Chelsea Whyte: How did you first become interested in mathematics?

Lisa Piccirillo: As a kid, I always liked maths and I was good at it in school. I'm from quite a rural area in Maine, and people said "if you like maths, you can become an engineer". So I thought that's what you do with maths, become an engineer. I went to a lot of day camps for engineering and made a lot of bridges out of popsicle sticks, and found out that I didn't want to be an engineer. After that, I thought I didn't want to do maths.

But then I took calculus in college because I had to, and I had a professor that encouraged me to take the next class. By then, I had started getting hooked.

What was it that lit the spark?

Part of what got me hooked was learning that a field called topology, the study of shapes, existed. It's somehow a little more free-flowing, and I really liked the imaginative aspect of asking: "What can these shapes do?" It turns out that these complicated shapes can do some weird stuff, and understanding the realm of possibilities was a big draw.

How did you end up making maths your career?

The decision to go to graduate school was a difficult one. I still had this idea that I think a lot of people have, which is that the only way to be a successful mathematician is to be a genius, and I'm certainly not anything like that. So I thought: "Why bother? I'm never going to be that good."

There's a strong stereotype of what people who do maths are like – introverted, nerdy, probably male, probably dead – and I was none of those things. I was very worried that I would have to give up other aspects of myself to be a maths robot and I didn't want to do that. I felt that tension very acutely in my undergraduate programme, but in graduate school, I learned that this tension isn't real. Mathematicians are interesting humans and none of them are geniuses.

Before I ask you about the Conway knot problem, can you tell me about knots more generally?

Let me back up and make a couple of definitions. I like to think about taking an extension cord out of the basement where it's been for a while. It's probably a hot mess, and if we just plug the ends together, it will still be a hot mess. We say a knot is "trivial" if it isn't a hot mess – that is to say, if it's possible to untangle it without unplugging the ›

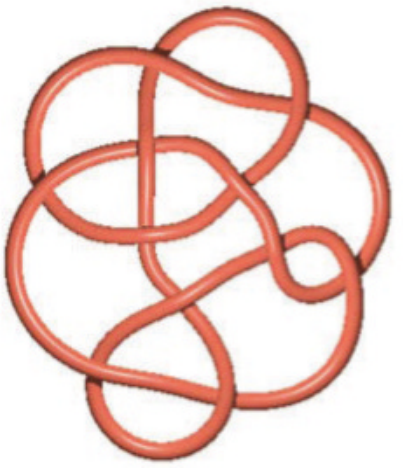
ends. In classical knot theory, trivial means you could move it around to look like the rim of a dinner plate. Mathematicians like to say "it bounds a disc". What makes things confusing is that while the knot has to live in three dimensions, the disc it bounds doesn't have to; it could live in four dimensions, for example.

When you say four dimensions, I think of the three dimensions of space, plus time. Is that too literal?
Yes, that's too literal. We just have four independent directions to work with. It doesn't really matter to us what they correspond to in the real world.

When you are solving these problems, do you picture four dimensions in your head?
I'm only ever thinking about 3D spaces because that's all I can visualise, just like everybody else. Let me give you an example. Imagine that you and I existed in a 2D universe – so a flat plane like a sheet of paper – and a hollow beach ball came through our world. If only the very bottom of the ball made contact with our world, from our perspective, it would look like a point.

But if more of the ball entered our 2D universe, it would look like a circle. As it kept passing through, we would see larger and larger circles, and then smaller circles, and then a point at the top of the ball and then nothing. You have point, circles, point again. Of course, in 3D space, it is far easier to just picture an entire beach ball instead of cutting it up into 2D slices. But when I want to think about an object in 4D space, I can't just picture it, so we use this trick of cutting it up into 3D slices.

Do you slice things up in the same way when you think about knots?
Yes. If a knot in 3D space bounds a disc in 4D space, we say it is "slice". The knot lives where we do, in three dimensions, but the disc is allowed to use another space. So the Conway knot problem is just: does this particular knot with 11 crossings bound a disc in four dimensions? Is it "slice"? It's yes or no.



It took 50 years for a fundamental property of the Conway knot, above, to be determined

"You do maths because you love it on the days when you don't prove anything"

How did you first hear about Conway's knot?
It was in a talk at a conference at the end of July 2018. The speaker mentioned that it was still an open problem. I thought that was ridiculous: it's 2018, we know a lot about sliceness, whether this 11-crossing knot is slice shouldn't be an open question. The ridiculousness of the problem is what made me think about it.

But I really didn't know very much about it. I thought it was just quite esoteric. It's an open problem, but I thought, "probably the reason it's open is mostly because nobody's tried very hard".

Now that you have solved it, do you still think that?
No, apparently that's not true. It took a specific tool that I happened to have been developing.

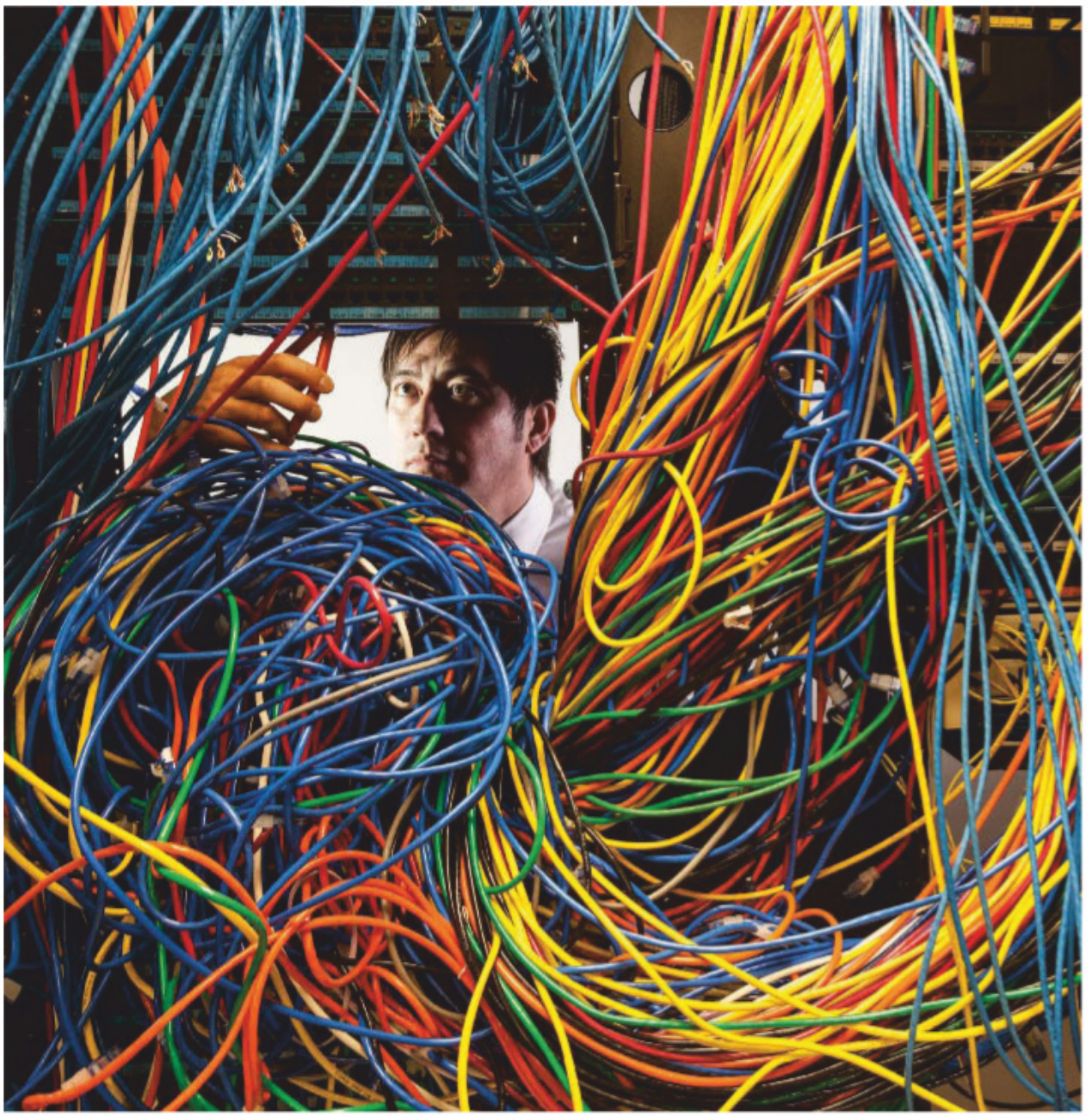
One way that mathematicians describe four-dimensional shapes – what we call 4-manifolds – is by making knots in 3D space and using the knots as sort of instructions for how to build them.

All knots have something called a trace, which is the manifold you can build from that knot. I knew that if you have two knots with the same trace, they're either both slice or both not slice. That has been known by mathematicians for a long time. This fact was very present in my mind, because I use it for my study of knot traces.

I knew that if I could build a second knot that shared a trace with the Conway knot and that happened to be slice, then I'd have solved the problem. While that's a technical thing to do, it just takes a bit of calculation.

How long did it take you?
I learned about the problem on a Saturday and I certainly knew the answer by the next Saturday. And I thought: "Nobody's going to care about this." I was only working in the evenings. I wasn't tearing my hair out and burning the midnight oil.

My idea worked right away. I guess it was overlooked because people weren't really studying traces and this calculation isn't completely trivial – it uses tools that I'd



MINT IMAGES/GETTY IMAGES

Knots are an everyday phenomenon with deep mathematical meaning

developed in other work. But I think anyone who had my technical knowledge could have solved it quickly too.

Did you know how big a deal this was when you had solved it?
No, I thought it would go in a very low-tier journal, or perhaps I wouldn't try to publish it at all.

Did you go into the field of maths to solve big problems like this?
In maths, 100 per cent of the days, basically you won't solve anything. So you have to learn to be okay with that and still enjoy what you're doing, even though today you won't answer anything, and tomorrow you also won't answer anything and the same thing will be true for the rest of your life except for a few good days. You have to be doing maths because you love it on the days when you didn't prove anything. The good days are so far apart. It doesn't matter how good they are. If that were the reason I was in it, I know I wouldn't make it.

That reminds me of the conceptual artist John Baldessari, whose advice to young artists was: "You have to be possessed, which you can't will."
Yes. It's more fun when you're possessed too.

Forgive me for asking this, but why does any of this matter?
The reason a lot of mathematicians – myself included – care about sliceness is because it helps us understand 4D spaces. One of the major challenges in 4D topology is distinguishing between simple 4D spaces. Generally, this is pretty hard because there aren't many tools available. Traces provide a tool.

If you have two different 4D spaces, and both of them have some 3D space on the boundary, it's very possible that a knot in 3D space can bound to a disc in one 4D space but not the other. That can help us understand differences between two 4D spaces in a way that would otherwise be very complicated.

What will you be working on next?
I'm still very interested in 4-manifolds and in using sliceness to understand them better. It's also true that this trick I used for the Conway knot doesn't work on some other, more complicated knots. The reason is because it isn't always possible to build a trace – sometimes it's provably impossible or we just don't know how to do it.

I'm trying to understand how to apply this type of argument more broadly to sliceness problems. More concretely, it turns out that sometimes, for some special knots, I can go home and build you another knot that shows a trace, but a computer can't. Why not? It's because we don't know the rules of how we do it ourselves. If the maths gods hand me a knot and ask me to build a trace, I may get lucky, but I don't know if I could tell you how I got there. And I'd like to understand why. ▮

Chelsea Whyte is a news editor at *New Scientist* based in Portland, Oregon

HOW TO MAKE PLASTIC OUT OF MILK AND VINEGAR

You would imagine that you'd need some pretty noxious, smelly chemicals to make plastic, but you can actually find the things you need to make malleable, doughy pieces of material in your own home.

Instead of putting vinegar on your fish and chips and wasting your milk in your tea, use the two liquids to become a polymer chemist . . .

WHAT DO I NEED?

- a pint of milk
- a saucepan
- a sieve
- a spoon for stirring
- 20 ml of white vinegar
- rubber gloves
- water
- a grown-up helper

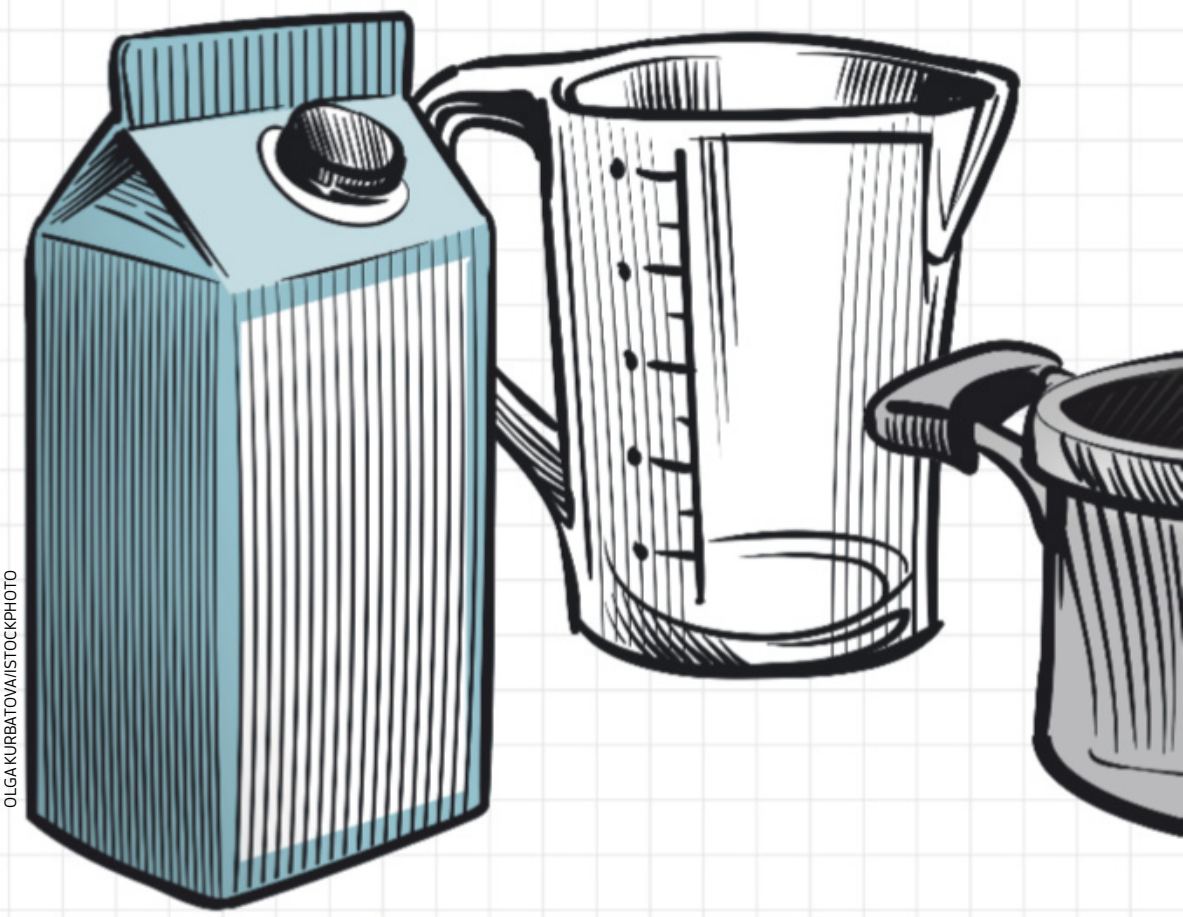
WHAT DO I DO?

Pour the milk into the pan and gently warm it. When the milk is simmering (don't let it boil) stir in the white vinegar until you notice whitish-yellow rubbery lumps beginning to curdle in the mixture at the same time as the liquid clears. Turn off the heat and let the pan cool.

WHAT WILL I SEE?

First of all, you'll smell the vinegary reaction, which is the key to this process at work. As the vinegar is added and stirred, the liquid gets clearer and the yellowy rubbery lumps form.

When the pan has cooled, you can sieve the lumps from the liquid, tipping the liquid down the sink. Put on the rubber gloves and wash the lumps in water. You can then press them together into one big blob – they will be squishy and will feel as if they are going to fall apart, but they will stick together after some firm kneading.



OLGA KURBATOVA/ISTOCKPHOTO

You can now use your artistic skills to fashion the material into the shapes of your choice – *New Scientist* staff came up with balls, stars, a heart-shape for a pendant and even dinosaur footprints. Leave the material to dry for a day or two and it will be hard and plastic enough to paint and varnish.

WHAT'S GOING ON?

You have used the combination of an acid – in this case vinegar, which contains acetic acid – and heat to precipitate casein (a protein) from the milk.

Casein is not soluble in an acid environment and so, when the vinegar is added, it appears in the form of globular plastic-like lumps. Casein behaves like the plastics that we see in so many objects around us, such as computer keyboards or phones, because it has a similar molecular form. The plastics in everyday objects are based on long-chain molecules called polymers. These are of high molecular weight and get their strength from the way their billions of interwoven criss-crossing molecules tangle together.

PS: Some forms of cheese-making rely on a similar technique – the name casein comes from caseus, the Latin for cheese. The Indian cheese known as paneer is made in a very similar way to the plastic you have just made, although in this case lemon juice is the acid used rather than vinegar. Afterwards, unlike our plastic milk, it is not dried out and allowed to harden to tooth-breaking consistency, and so remains soft and edible.

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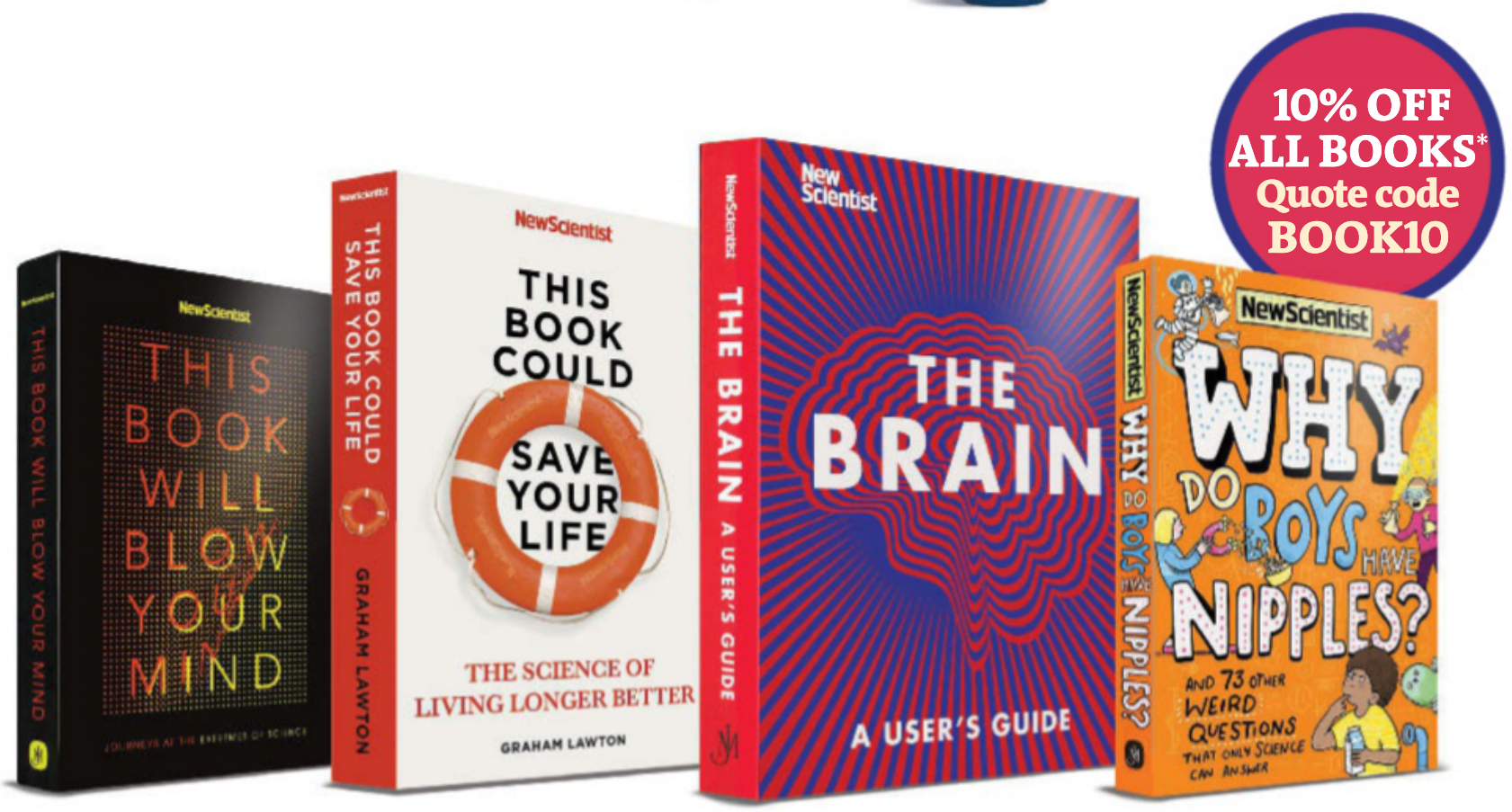

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The back pages Puzzles

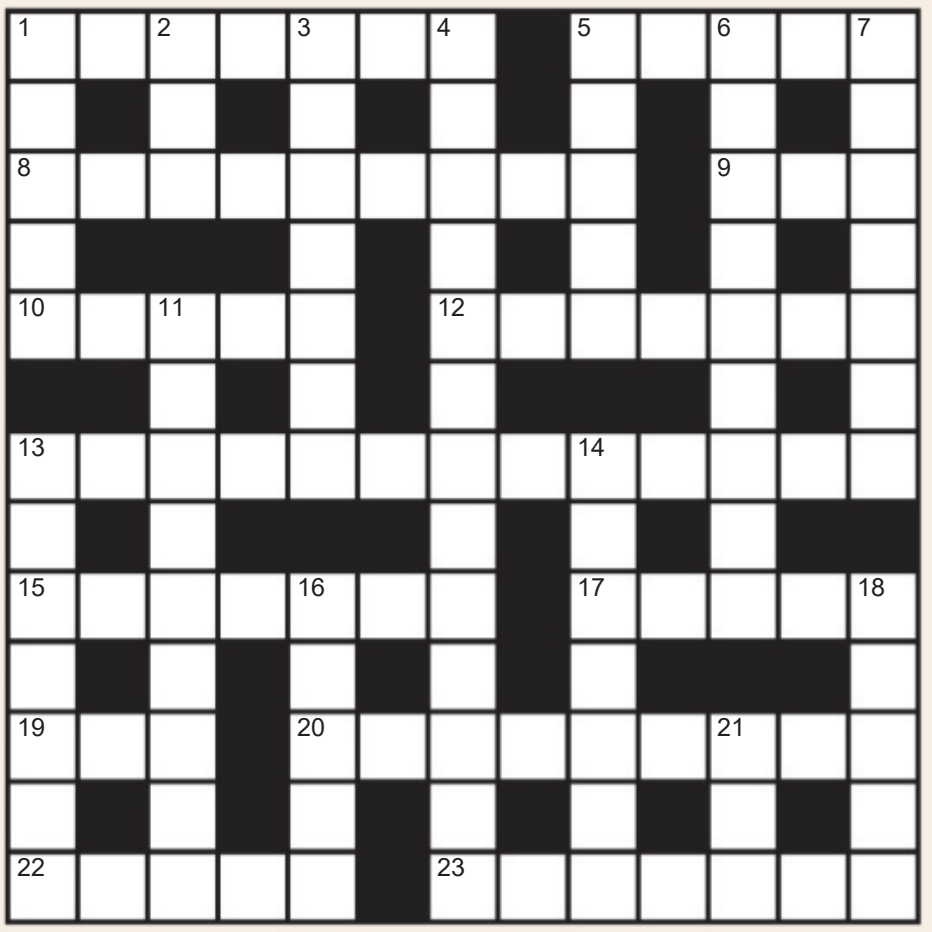
Puzzle
Can you draw a line through all the white squares? p54

Cartoons
Life through the lens of Tom Gauld and Twisteddoodles p54

Feedback
Hexing the moon and strange limericks: the week in weird p55

The last word
Are our tastes in food down to genetics? Readers respond p56

Cryptic crossword #37 *Set by Sparticle*



Scribble zone

Answers and the next quick crossword next week

ACROSS

1 Full of rural good humour, even about abdominal pain (7)
5 Decorates plumbing (5)
8 Messes with 151 superb countries (9)
9 No longer interested in hearing where babies come from (3)
10 Lowest point on a Dirac segment (5)
12 Chemical twin with one less proton in opposite reaction (7)
13 Type of radiation produced by the first Greek god, say (5,8)
15 Belgian town established by a fool (7)
17 Rinse off sticky tree secretion (5)
19 Historic Japanese town brings back poetic form of address (3)
20 Cunning line heard from engineer's one-time assistant (5,4)
22 Uri Geller has the makings of a star (5)
23 Disease ravages UN state (7)

DOWN

1 It's the fifth element that Robert reversed on! (5)
2 Trump in the vicinity of little people (3)
3 Country librarian ran out to bind first edition (7)
4 Important use of the index to establish when phases merge (8,5)
5 Pasta sauce made from Pope's tomatoes (5)
6 Snout raised, with classic sob or plea extracted (9)
7 Triangle gets a small leitmotif in section of opera (7)
11 Complex vowel sound PhD got in her first broadcast (9)
13 A mature doctor is incompetent (7)
14 Make life difficult for blokes engaged in crime (7)
16 Relax London's source of support for painting (5)
18 Wants directions given to Edward to add salt (5)
21 Run around ornamental vase (3)

Quick quiz #63

1. What nugatory addition did Indian mathematician Brahmagupta apparently make to the number system in AD 628, enabling modern arithmetic?

2. In solid-state physics, what name is given to the absence of an electron?

3. Two mirrors placed opposite each other in a vacuum will move towards one another. What is this effect called?

4. Nitrogen 78 per cent, oxygen 21 per cent... what comes next on this list?

5. What procedure did William Morton first demonstrate on Gilbert Abbott in front of a large audience in Boston in 1846?

Answers on page 54

Quick Crossword #63 *Answers*

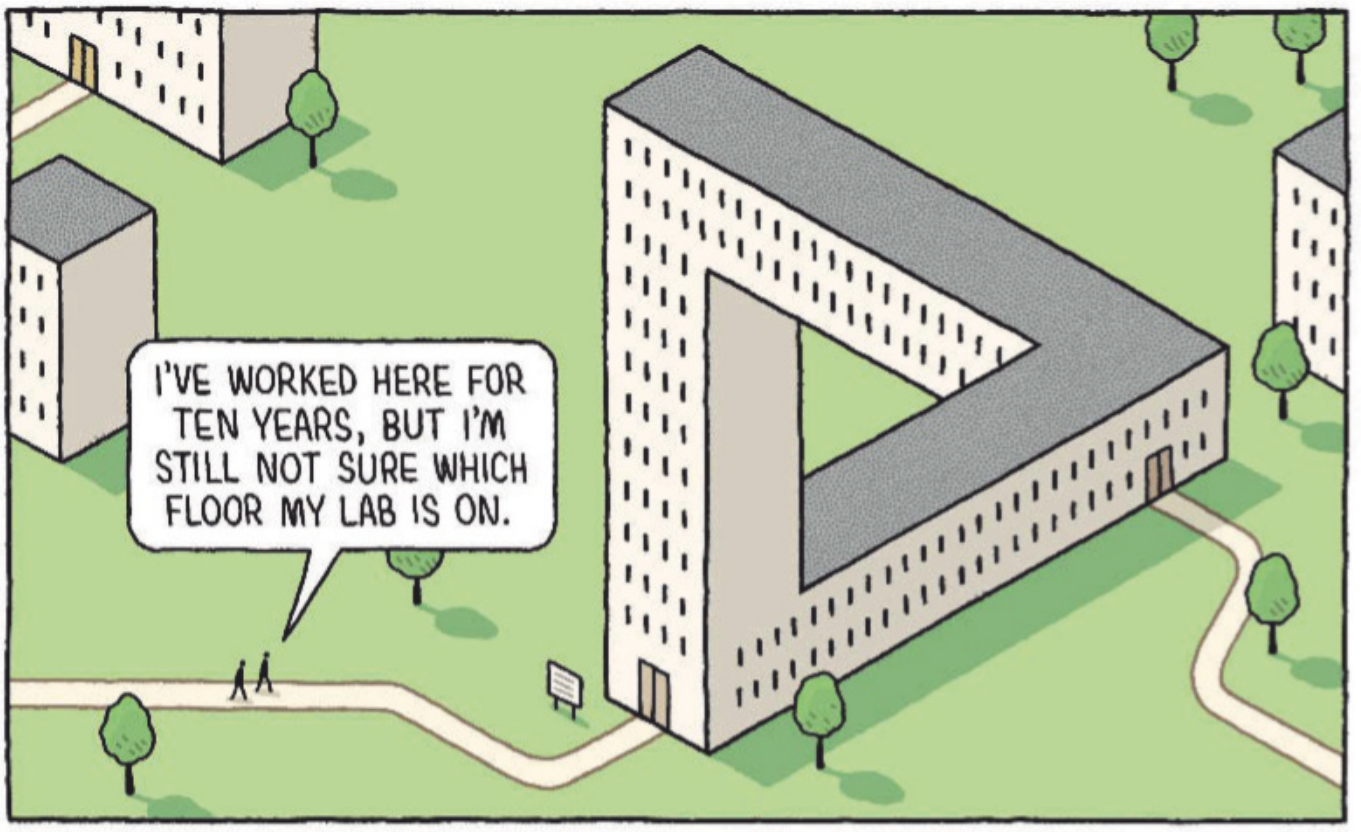
ACROSS 9/3 Down Patient zero, **10** Caltech, **11** Lugworm, **12** Doppler, **13** Resonance, **15** Track, **16** Robocop, **19** Trekkie, **20** Cache, **21** Prismatic, **25** Chaotic, **26** La Jetee, **28** Echidna, **29** Nodular

DOWN 1 Apolar, **2** Stages, **4** Stamen, **5** Acid test, **6** Slipstream, **7** Keelback, **8** Cherokee, **14** Nucleotide, **16** Ricochet, **17** Backache, **18** Pipeclay, **22** Island, **23** Totals, **24** Cherry, **27** Jedi

Our crosswords are now solvable online
newscientist.com/crosswords

The back pages

Tom Gauld
for New Scientist



Twisteddoodles
for New Scientist

Quick quiz #63
Answers

1 The number zero, and rules for its manipulation

2 A hole. It is a convenient mathematical fiction sometimes to regard electric current as made of moving holes

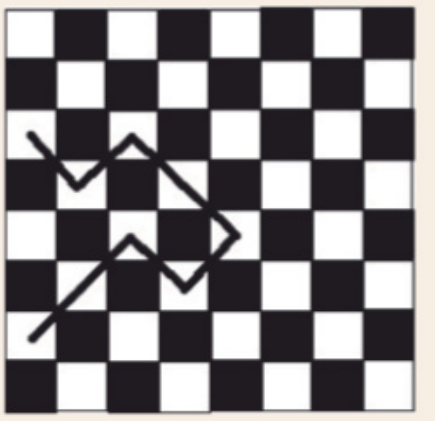
3 The Casimir effect. It is due to a vacuum not being empty, but full of quantum fields

4 Argon 0.9 per cent, in the list of abundances of gases in Earth's atmosphere

5 Anaesthesia by inhaling ether

Puzzle
set by Hugh Hunt

#71 White lines



There are 32 white squares on a chessboard. Your task is to draw a line that passes through all of the white squares only once, moving via the corners where they touch without lifting your pen off the board. The diagram shows the kind of line that is required. Start from any square you like. Can you get through all the squares with a single line? If not, then what is the smallest number of separate lines that you need?

Answer next week

#70 Taking the biscuit

Solution

Alpha should grab one digestive biscuit, leaving seven and four in the two jars. The key to the game is ultimately to leave your opponent with two biscuits in one jar and one in the other. Whatever move they make, you can follow with a winning move. From seven and four, Betty's next move can't be three digestives because Alpha would win straight away.

Whatever other move Betty makes, Alpha will be able to follow it either by getting to five and three (and thereafter to two and one or zero), or to two and one. Whatever happens, she has a guaranteed path to win. This is formally known as Wythoff's Game.

Cursed crescent

One time, on a particularly cloudy holiday with friends, Feedback glanced up at the sky and noticed a dim ball of light floating not far above the horizon.

"Look at that," we said, for want of anything more interesting to say. "It's the day-moon."

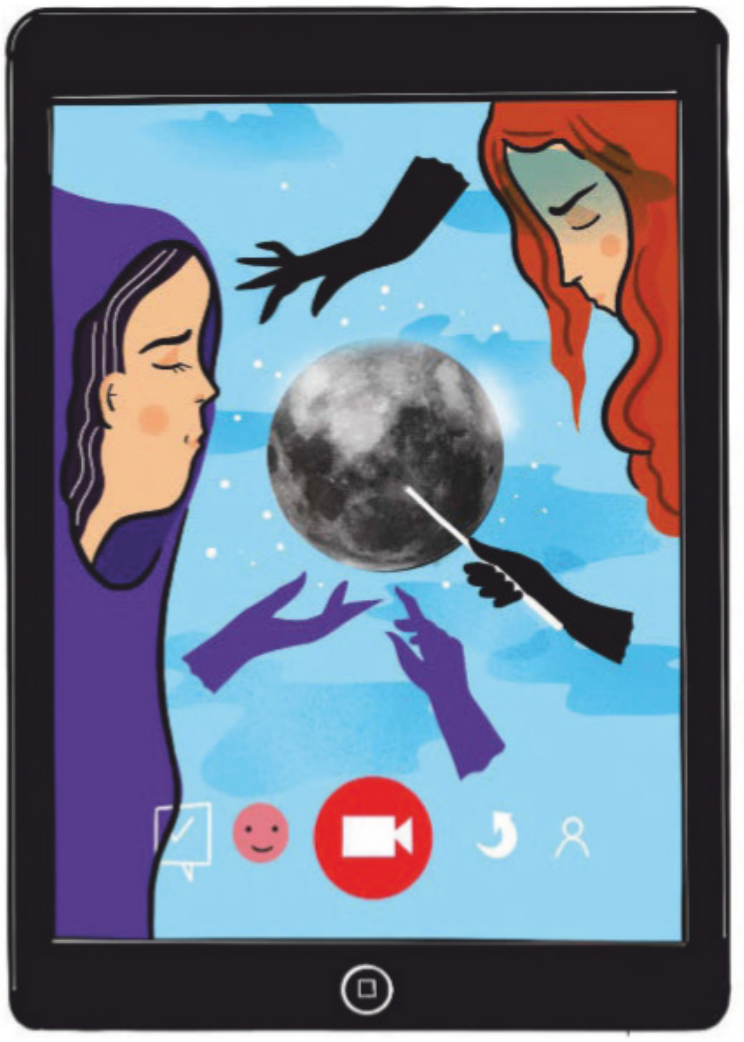
Readers, it was not the day-moon. It was, in fact, the sun.

What this anecdote serves to illustrate is that if something has been askew in the heavens of late, Feedback would be among the last to notice.

So you can imagine our surprise at discovering that a coven of "baby witches" has hexed the moon. Or, at least, so says the internet.

It appears that in an occult corner of the social networking app TikTok – known as WitchTok to its friends – a group of young witches decided to cast a curse on the moon. This appears to have caused all sorts of turmoil within the witchcraft community, and no little amusement outside it.

For, after all, we people of science know that the moon cannot be hexed. The moon isn't some primordial reservoir of arcane energy to be used in witchcraft. It is a symbol for mutually antagonistic countries to race towards in an attempt to prove the relative superiority of their way of life. Much more sensible.



New chip on the block

While we are on the subject of chocology (chocolatey topology), Feedback was intrigued by a story this week about the quest to redesign the chocolate chip.

It turns out that the conventional tear-drop shaped chocolate chip, while effective in a brute force sort of way, lacks the geometrical finesse that chocolate chip cookie bakers wish it would have.

Namely, according to *The Times*, "it lacks a broad surface area to maximise taste and texture". That is why Remy Labesque at Tesla – yes, electric car maker Tesla – has spent three years attempting a chocolatey redesign.

The new shape is a squashed diamond that tapers in three directions to maximise the textures it can achieve when melted. It is aesthetic, allegedly scientific and above all tasty. Feedback will be awaiting future updates with heavy and bated breath.

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

Lean times

A worrying trend in the Feedback inbox of late is the amount of attention that nominative determinism spotters are devoting to *New Scientist* itself.

We pass no judgement on this, but point ominously at a drawing of a snake eating its own tail while muttering about infinite recursion under our breath.

This week, for example, James Haigh writes in to comment on the name of an expert quoted in an article on public health policy regarding obesity.

"Michael Lean interviewed for the 'Public health's hard problem' article??" asks James, making excellent use of the lesser-spotted (well, double-spotted, really) double question mark. "You couldn't make this stuff up."

Rumbling on

Some weeks ago, Feedback invited readers to send in the opening lines of limericks that we would do our humble best to complete.

Thank you to Ted Webber for throwing down the first gauntlet, based – in his words – on a *New Scientist* cover story. The opening line he wanted us to riff off was "If consciousness lies in our gut". Well, Ted, here you go. Don't say you didn't ask for it.

If consciousness lies in our gut,
Then what is the role of the butt?
Neither Kant nor Foucault
Have pretended to know,
But to us it seems: open and shut.

Don't be a square

Big news for geometry fans this week, as a German court has ruled that the Ritter Sport brand of chocolate can keep its trademark on square-shaped bars.

In its report, the BBC referred to the case as reinforcing Ritter's "three-dimensional monopoly", which – while being a charming phrase – perplexed Feedback. It goes without saying that the chocolates are three-dimensional: to our knowledge, no one has yet derived any pleasure from licking an atom-thick layer of chocolate spread off a graphene substrate.

But the trademark specifically covers square chocolate, not cubic chocolate. This, we are afraid, is a two-dimensional monopoly. And the reason we are afraid to say it is because the last time we checked, Hasbro had the trademark on that.

Good knights

There have been times of late, what with all this plague business going around, that the world has seemed to take on a distinctly medieval hue.

If you find this state of affairs discomfiting, then Feedback's suggestion is that you stay well away from the Swedish island of Gotland. According to a report in *The Times*, the powers that be on Gotland have commissioned a troupe of knights on horseback to patrol the area around the ferry terminal, reminding people to socially distance.

The article is sadly lacking in detail about how exactly these reminders are to be enforced. At the point of a lance, perhaps? Or through several layers of PPE chainmail? Either way, the convergence of Sweden, medieval knights and global pandemic has a certain *The Seventh Seal*-iness about it that is making Feedback shiver. ▮

Written by Gilead Amit

JOSIE FORD

Innate taste

My girlfriend's sister doesn't like coriander and says she has heard this could be related to genetics. Is this true? Are there certain genes associated with a dislike of certain tastes?

Paul Clark
Battle, East Sussex, UK
Yes, there seems to be a genetic component to taste. I had my DNA analysed by 23andMe last year and the company provided me with a list of probable traits I would have as a result of my genetic make-up.

One was that I was likely to dislike the taste of cilantro, another name for coriander. This was apparently due to two genetic variants that are associated with a dislike of soapy aromas, markers rs2741762 and rs3930459.

The markers are located near genes that help determine one's sense of smell through olfactory receptors that detect aldehydes. These aldehydes are compounds found in soap and thought to be a major component of coriander aroma.

It is indeed the case that I dislike the taste of coriander, whereas my wife likes it. Some other traits were correctly predicted, including eye colour and, most surprisingly, a wake-up time of 6.58 am.

The tests also said that I am likely to suffer from misophonia, the hating of chewing sounds, which is the case.

Julian Money-Kyrle
Calne, Wiltshire, UK
It is true that specific genes are associated with the perception of certain tastes, or to be more precise smells, because nearly all of what we think of as taste is really volatile chemicals being detected in our nose.

There are hundreds of different chemical receptors in the olfactory epithelium at the top of the nose, and each is coded for by a specific gene. No two people have exactly the same mix, and therefore each individual's sense of smell is unique.

There are some smells that are undetectable to a lot of people. About one in four of us aren't able to smell the delicate fragrance of freesias, for example.

Similarly, some people can't smell the sulphur-containing metabolic products excreted in the urine after eating asparagus. For the rest of us, this is a strong and unpleasant sulphurous-metallic smell that is obvious even if only a tiny bit of asparagus is ingested.

So does coriander contain something unpleasant that only some people can smell, or something delicious that only a few people miss? From my own experience, I would venture to suggest the latter.

Nearly three years ago, I completely lost my sense of smell following a parainfluenza virus infection, which was confirmed by DNA testing.

I was completely anosmic for three months, and since then I have had a slow partial recovery. I would say that I am now 5 or 10 per cent recovered.

Before the infection, I had an unusually good sense of smell, and I was able to discriminate a lot of smells that other people seemed to be unaware of. Each of the roses in the garden had its own scent, for instance.

Now there are whole classes of things that I can't smell at all, including all body-related and animal smells, most spices and all fruit except for rhubarb and cooked limes.

While there are some things that smell the same as I remember them, such as cloves and chilli, most of what I can smell is greatly simplified, such as tomatoes, cheese, cooked meats and onions.

I imagine what is going on is that I can detect the main substances that characterise these foods, but not the vast number of additional chemicals that provide the subtlety and variety to their flavours.

Sadly, I am no longer able to enjoy fine wine, which can be an intense pleasure like nothing else, although one that not everybody gets. These days, I find it difficult distinguishing a decent claret from black coffee; both have become equally repulsive.

Curiously, there are some smells or tastes that are completely different from how they should be. Cucumber, for instance, now has a strong and unpleasant smell that is unlike any food at all: something like gloss paint with an undertone of slightly off mackerel.

So I would say that what people like about coriander, and what I used to like about it, is a specific smell or taste that not everybody is able to perceive, and what lies beneath it is a different and mildly unpleasant odour.

JGI/JAMIE GRILL/GETTY IMAGES

Why might water make the tips of fingernails translucent?

This week's new questions

Contagious cures **Why don't we make disease cures that are themselves infectious?** ***Holly Brockwell****, London, UK*

White water **After my hands have been in water for a long time, the tips of my fingernails become translucent. What causes this?** ***Christine Duncan****, Surrey Hills, Australia*

Cyclic logic

A triplet bike is lighter and has less resistance per person, so is more efficient than a tandem, which is more efficient than a regular bike. Does this trend hold however long the bike? (continued)

James N. Cawse
Pittsfield, Massachusetts, US
The improvement trend seen from singlet to tandem to triplet bikes certainly holds up to five-person machines.

In the 1890s, the great African-American cyclist Marshall Walter "Major" Taylor set indoor track speed records riding solo with people on a five-man bicycle acting as pacers.

In one legendary case, the white pacers decided that they wouldn't let a black man get the record, so they decided to slow down on the last lap. Taylor, however, was tipped off, so when they slowed down he shot out of their slipstream, pulled ahead of them, and broke the record. ▮

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