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SPECIAL ISSUE

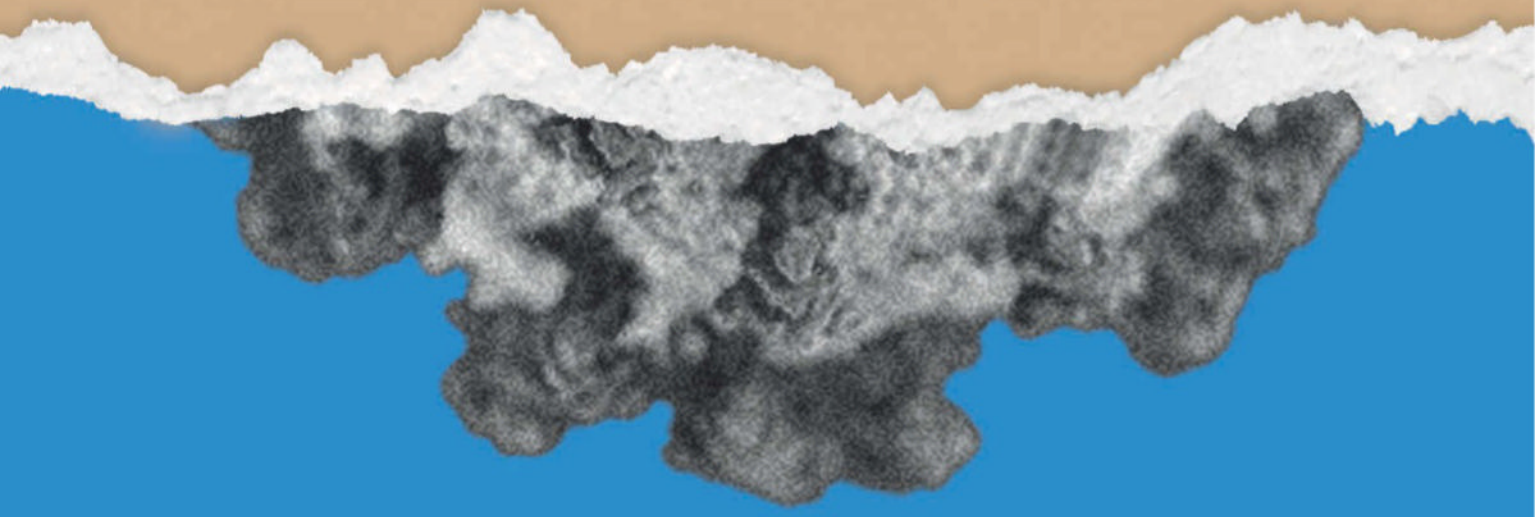
# FIVE YEARS OF COVID-19

AS WE LOOK BACK, WE ASK:

**WHAT DID WE LEARN?**
And what we still don't know

**HOW DO WE TACKLE LONG COVID?**
The latest science, from causes to treatment

**WHAT WILL THE NEXT PANDEMIC BE?**
And how to best prepare for it



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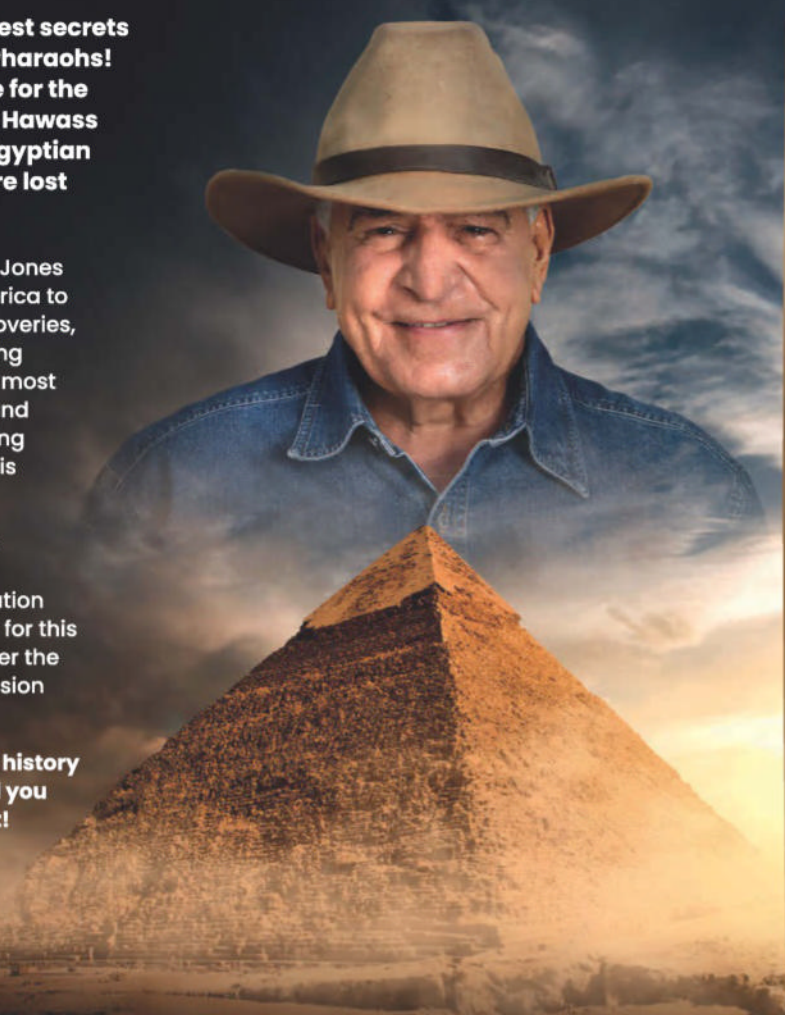

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# This week's issue

## On the cover





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**8 News**

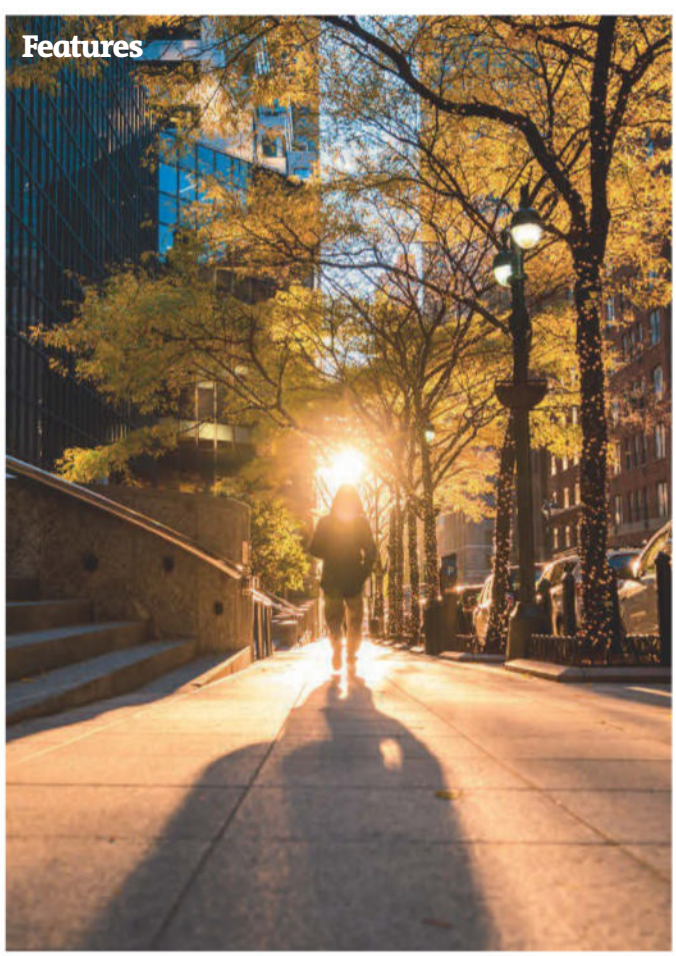
**"On the scale of pandemics, covid-19 was moderate. There will be others"**

## News



## Views






MARCO BOTTIGELLI/GETTY IMAGES



## Features



## The back pages

# Elsewhere on New Scientist

## Instant Expert

### Mysteries of matter

Ever since the model of the atom was devised a century ago, scientists have carried out ever-grander experiments with gigantic, atom-smashing particle accelerators to probe deeper into what these particles are made of. But our best theory, the standard model, isn't quite complete. Join six leading experts to find out everything we know about particles – and what puzzles remain – on 18 January at London's Congress Centre.

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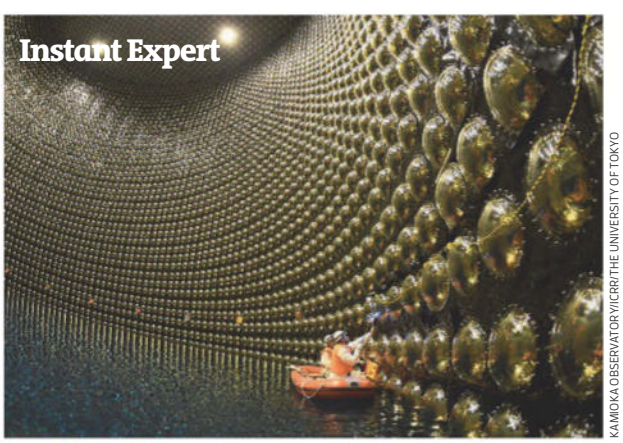
### Weekly

Our special end-of-year show was recorded live at the Science Museum in London. Join hosts Timothy Revell and Rowan Hooper alongside editor Catherine de Lange and the *New Scientist* team as they discuss their favourite stories of the year, pick their cultural science highlights – and take questions from the audience.

**newscientist.com/nspod**


SHUTTERSTOCK/BJOERN FISCHER

**Monstrous snowflake** Can we create the biggest snowflake ever?




KAMIOKA OBSERVATORY/ICRR/THE UNIVERSITY OF TOKYO

**Elusive neutrinos** Immense detectors grapple with material reality

## Video

### Supersized snowflakes

The Guinness world record for the largest snowflake stands at 38 centimetres across. This whopper was recorded in Montana in 1887. Now, *New Scientist* environment reporter Madeleine Cuff uses state-of-the-art facilities for studying snow and its climatic effects to try to break that record. Join her on a journey into the complex world of snow physics.

**youtube.com/newscientist**

## Newsletter

### Lost in space-time

*New Scientist*'s Karmela Padavic-Callaghan shares how the stories they covered this year about the multiverse, quantum mechanics and time itself are forcing scientists to rethink reality. Get the inside scoop on what it is like to be a reporter having your assumptions about nature constantly reconfigured.

**newscientist.com/lost-in-space-time**

Podcast

**"When a civilisation becomes advanced, it will find ways to control the output of its local star"**


## Essential guide

Achieving a state of well-being can feel like a constant struggle. Let science be your guide to better mental and physical health, including recent research on possible ways to slow ageing and the best methods to get fit. Find out more in this 25th *Essential Guide*, available now.

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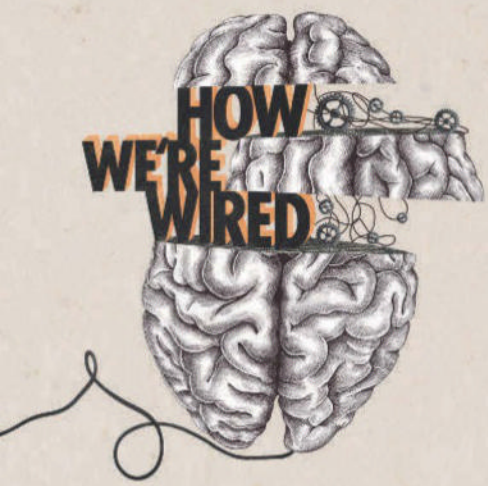


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# Why look back?

Revisiting the coronavirus outbreak five years on can help us in many ways

YES, it really has been five years. On 7 January 2020, we published an article with the headline "Doctors scramble to identify mysterious illness emerging in China". By then, at least 59 people had been infected with what we now know to be SARS-CoV-2, the virus behind covid-19. The rest is – well, has now become – history.

Of course, you know all of that: you lived through it. So why are we publishing a special report on covid-19 now? For many, the height of the pandemic was an incredibly painful and difficult time (see page 21). We lost loved ones. Many of us developed life-changing illnesses. We were scared and uncertain and desperate for a return to normality. Perhaps it is better to keep those memories sealed up in a distant mental box somewhere and move on?

Yet there are good reasons to take this opportunity, half a decade on, to look back and open that box. While it is impossible to predict the future, we can say with near certainty that another pandemic will eventually arrive, and we need to be prepared (see page 8). We can also, with the benefit of hindsight, examine what we should have done differently and learn from that for next time (see page 13).

**"People with long covid still aren't receiving the support that they need"**

Putting the next pandemic aside, there are also still questions to address with regards to covid-19. People with long covid still aren't receiving the support that they need (see page 11), while there is more scientists would like to know about SARS-CoV-2 (see page 16). We should also take time to celebrate the vaccines, the fastest ever developed thanks to an extraordinary technology that may bring more benefits in treating other conditions (page 19).

Even with all of that in mind, it is understandable if you face this special report with some trepidation. We at *New Scientist* have certainly experienced mixed emotions in putting it together, taken back to a time when we were suddenly forced to report on events from kitchen tables and spare bedrooms (see page 24). Like you, we each hope to never live through another pandemic. But we need to look back to help us prepare for when the next one arrives. ▮


PUBLISHING & COMMERCIAL

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**Tel** +44 (0)203 615 6456
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**Sales director** Claudia Nicoletti
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CONTACT US

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**General & media enquiries**
**US** 600 Fifth Avenue, 7th Floor, NY 10020
**UK** 9 Derry Street, London, W8 5HY
**Australia** 58 Gipps Street, Collingwood, Victoria 3066

**US Newsstand** **Tel** +1 973 909 5819
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# FIVE YEARS OF COVID-19

A special report on the coronavirus pandemic, from what we learned and the outstanding scientific questions to whether we are prepared for another global outbreak

Future outbreaks

# WHAT COULD CAUSE THE NEXT PANDEMIC?

Covid-19 won't be the last global outbreak, so we need to be prepared, says **Michael Le Page**

THE coronavirus behind covid-19 has infected most people in the world, killing around 15 million people and leaving about 400 million individuals with long-term health problems. It also caused the biggest economic downturn since the Great Depression of the 1930s. Despite all this, it could have been much more devastating.

"On the scale of pandemics, covid-19 was moderate," says Mark Woolhouse at the University of Edinburgh, UK. "There will be others, and they very easily could be an awful lot worse than the one we had. This is an eventuality we should be prepared for."

So, what infection could cause the next pandemic? Can we stop it before it does? And are we better prepared for another pandemic if we fail to stop it?

The term "pandemic" can mean a widespread outbreak of a mild infection. But what we are really worried about is an infectious condition – sometimes referred to as disease X – that spreads rapidly around the world, infects a huge number of people and kills a significant proportion of them, as occurred in the 1918 flu pandemic.

Fast-spreading global outbreaks are most likely to be caused by a virus that spreads via the air, and respiratory viruses that can be sneezed, coughed, spoken or sung out are most likely to get airborne. When the covid-19 pandemic began, there was debate about its airborne spread, but not any more. "The debate is settled," says Lidia Morawska at the Queensland University of Technology in Brisbane, Australia, who led calls for more to be done to prevent airborne spread.

The big worry is H5N1 bird flu. A form of it has been spreading around the world in wild birds, spilling over into domestic poultry and mammals, including people. Of the nearly 1000 reported human cases since 2003, around half have been fatal. It is likely that many mild cases have been missed, meaning that the true infection-fatality rate is lower, but it is still a major threat. "At the moment, it is what keeps me up at night," says Aris Katzourakis at the University of Oxford.

Coronaviruses remain a threat too. It is also possible that the next pandemic will be caused by an unknown virus or one that significantly differs from its known relatives. In 2021, for instance, it was revealed that a type of virus previously thought to cause gut infections had been found in people in Colombia hospitalised with respiratory illnesses.

To cause a pandemic, however, animal viruses such as H5N1 don't just need to be capable of infecting humans, but also to spread from person to person. In theory, every time a virus such as H5N1 infects someone, it could mutate and gain this ability – but the odds of this happening are tiny.

> "On the scale of pandemics, covid-19 was moderate. There will be others"

Such mutations can also happen in an intermediate species that is more similar to humans in certain ways than the original viral host is. For example, the covid-19 virus may have jumped from bats to raccoon dogs and evolved in them for some time before infecting people. This is why H5N1's spread among dairy cows in the US and the resulting cases in some people, bringing an increased risk of mutations, is so concerning. "It's not inevitable, but the likelihood is sufficiently different to zero to worry me," says Katzourakis.

Besides evolution via random mutations, plenty of viruses are also able to swap genes with related viruses in a process called recombination. The H1N1 virus behind the 2009 swine flu pandemic was a mix of bird, human and pig flu viruses.

The worst-case scenario is a recombinant virus that is as good at spreading as the human flu but as lethal as the bird flu, which may have happened with the 1918 flu virus.

Many researchers think the risk of pandemics is growing rather than diminishing. For one, the increasing human population continues to expand into new areas, meaning greater risk of exposure to new viruses.

Global warming is forcing many animals to migrate, raising the risk of viruses jumping between species. It is also causing more extreme weather events, which often lead to infectious outbreaks and could provide a window of opportunity for a new virus.

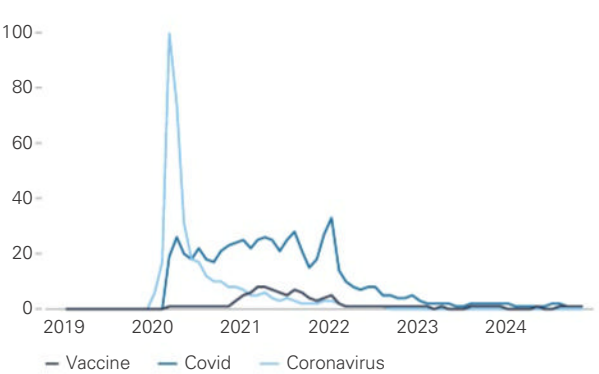
Then there's the growing population of domestic animals, which can incubate new viruses. In fact, the particularly

## When the world changed, in data

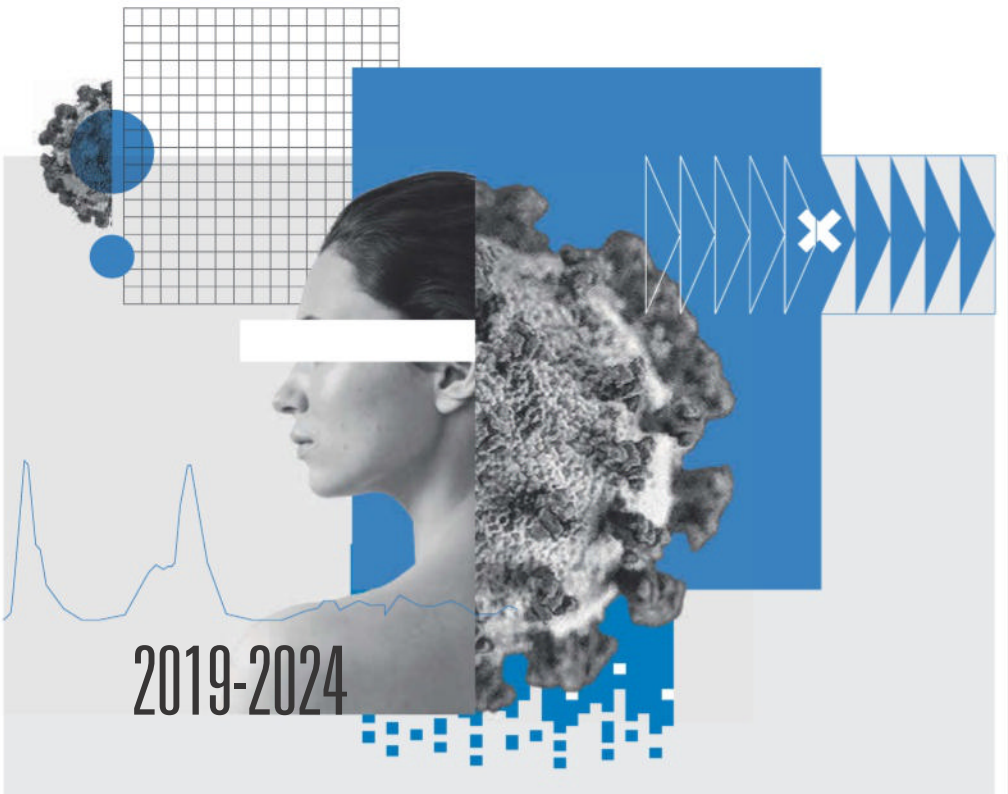
**As the covid-19 pandemic took hold, the world was transfixed and transformed while we came to terms with just how vulnerable society is to a deadly virus. Across this special report, you will find graphs highlighting these changes and whether things have returned to "normal".**

### Global search interest, percentage relative to peak

The desire for information on the novel coronavirus was intense, subsiding as we developed vaccines




SOURCE: GOOGLE TRENDS




RYAN WILLS/ADBODE STOCK

nasty form of H5N1 spreading around the world at present appears to have evolved in duck farms in China.

Last but not least, people are travelling ever more, meaning outbreaks can spread further faster.

There are two schools of thought when it comes to preventing another pandemic. One is that efforts should focus on finding as-yet-unknown viruses that are already infecting people, as those that can jump to people are most likely to have pandemic potential.

The other is that we should try to spot potentially dangerous viruses before they jump to people. Thousands of viruses circulate in wild animals, but it is hard to figure out which ones might be dangerous to humans, says Sergei Pond at Temple University in Philadelphia. "It turns out that's a really difficult question that we don't know how to answer," he says.

Trying to answer it means doing experiments with live viruses, says Pond, which has an element of risk. While there is no evidence that the covid-19 virus escaped from a lab (see "Where did the virus come from?", page 17), such incidents may have happened. For instance, the flu pandemic that began in the Soviet Union in 1977 could have been caused by a strain frozen since 1950 getting into people.

While the risks are vanishingly small, the outcomes are potentially catastrophic, says Pond. "Say you run a million experiments and they go fine, but one of them does not go fine, and then you kill 10 million people," he says. "That is unacceptable."

Others see the risk-benefit balance differently. "There are always risks in any research, but I think what we learn about viruses from that research far outweighs those risks," says Katzourakis.

Earlier this year, the US tightened rules on some research, but a lab escape could occur in any country.

"More regulations should be put in place and high-ranking scientific journals should stop publishing risky research," says Virginie Courtier at Paris City University, France.

Rather than hunting for viruses in animals, Pond thinks resources are better focused on looking for viruses that are already infecting people. This could not only help identify viruses that might be capable of causing a pandemic, but could even help us nip one in the bud – as was achieved with the SARS outbreak that started in China in 2003.

## GETTING AHEAD

But as recent human H5N1 cases in places like California and Missouri show, the next pandemic could emerge anywhere. What's more, if a new kind of respiratory virus does start passing between people, there might be a short window of opportunity for stopping it before it spreads more widely – perhaps just weeks, say Woolhouse.

"That means you have to have surveillance systems in place that pick these things up unbelievably fast," he says. "And, at the moment, we don't have a system that could do that."

There are some promising technologies, such as monitoring sewage for new viruses, but doing this more systematically on a global scale would be expensive.

The focus is instead on quickly developing tests, treatments and vaccines once another pandemic begins. This is the "100 day mission" of the International Pandemic Preparedness Secretariat that has been set up by the G7 nations.

"Maybe that's the right decision," says Woolhouse. But he thinks the idea of snuffing out pandemics before they grow should be kept on the table.

If we fail to avert another pandemic, our health systems may at least deal with it better. A survey of researchers by the Abbott Pandemic Defense Coalition found that 60 per cent think we are now better prepared. ›

**612 DAYS**

The longest known covid-19 infection


People waiting to go to a covid-19 hospital in Wuhan, China, in 2020

STR/AFP VIA GETTY IMAGES

Woolhouse thinks so too, but says much more needs to be done. "We certainly haven't reached where we think we ought to be in terms of the public health response," he says. For instance, the response to mpox has been lacking, he says.

Technologies also need improving. For example, while the mRNA covid-19 vaccines (see "A new era of vaccines", page 19) have saved millions of lives, they have failed to halt the pandemic altogether. Ideally, we need vaccines capable of stopping the transmission of respiratory viruses, as well as reducing their severity.

There is another major issue that is even harder to tackle. According to the Abbott survey – which was done long before the recent US election – researchers' single biggest worry about the next pandemic isn't surveillance or developing a vaccine, but public trust and misinformation. The fear is that if there is another pandemic, far more people will ignore health advice, such as to wear a mask, or will refuse vaccines.

"The way people behave in terms of taking precautions, managing their own risk, that's crucial," says Woolhouse.

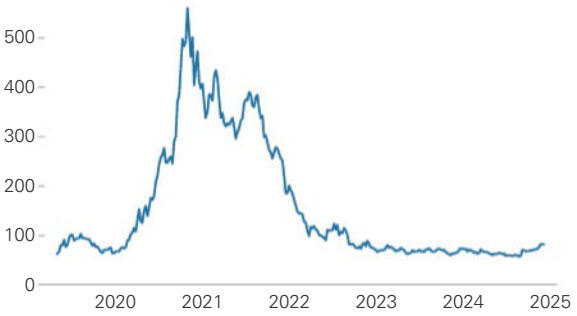
"I am really worried about the misinformation," says Katzourakis. "I'm not hugely optimistic about the incoming US administration's likelihood of managing a pandemic effectively." ▮

**13.72 BILLION**

The number of covid-19 vaccines administered worldwide

## Zoom share price, US dollars

The switch to homeworking saw videoconferencing taken up by many and sent the value of firms like Zoom skyrocketing




SOURCE: NASDAQ

## Timeline

These are the key events of the covid-19 pandemic, from first infections to the end of the emergency

**12.12.19:** Reports of an unusual pneumonia emerge from Wuhan, China

**31.12.19:** The World Health Organization (WHO) is informed of cases of this pneumonia

**07.01.20:** Public health officials in China identify a novel coronavirus as the cause

**11.01.20:** China reports its first death

**13.01.20:** Thailand reports the first confirmed case outside China

**20.01.20:** The US reports its first case, in Washington state

**23.01.20:** Wuhan goes into lockdown

**31.01.20:** The WHO declares the outbreak a public health emergency of international concern

**11.02.20:** The WHO names the illness covid-19

**19.03.20:** California becomes the first US state to issue a stay-at-home order

**23.03.20:** The UK goes into lockdown

**24.08.20:** Hong Kong reports the first known case of reinfection


CHRISTOPHER FURLONG/GETTY IMAGES; JACOB KING/POOL/EPA-EFE/SHUTTERSTOCK

**28.09.20:** The reported global death toll exceeds 1 million

**07.10.20:** New Zealand lifts restrictions

**16.11.20:** Moderna's covid-19 vaccine is 95.4 per cent effective in its trial

**17.11.20:** US medical leader Anthony Fauci talks about "long covid"

**18.11.20:** Pfizer/BioNTech's vaccine is 95 per cent effective in its trial

**08.12.20:** Margaret Keenan (pictured below) of Coventry, UK, gets the first vaccine outside a trial

**30.12.20:** The UK authorises the Oxford/AstraZeneca vaccine for emergency use

**27.02.21:** The US approves the Johnson & Johnson vaccine for emergency use

**14.03.21:** Countries start suspending distribution of the Oxford/AstraZeneca vaccine amid reports of blood clots

**07.04.21:** The UK restricts the Oxford/AstraZeneca vaccine to people aged 30 and over

**13.04.21:** The US pauses the Johnson & Johnson vaccine while blood clot reports are investigated

**23.08.21:** The US fully approves the Pfizer/BioNTech vaccine for adults

**06.10.21:** The WHO defines long covid

**31.01.22:** The US fully approves the Moderna vaccine for adults

**14.03.22:** China goes for "covid zero"

**05.05.23:** The WHO says covid-19 is no longer a global health emergency

**06.05.23:** The Johnson & Johnson vaccine stops being available in the US

**08.05.24:** AstraZeneca withdraws its vaccine

# WHAT WE KNOW ABOUT LONG COVID

Even mild covid-19 can have complications, which we are still trying to understand, writes **Michael Marshall**

FOR many people, the covid-19 pandemic feels like a thing of the past. But for those with long covid, it is far from over. Five years on from when covid-19 turned up, those with lingering symptoms still can't live their lives as they did before.

The emergence of long covid in the first few months of the pandemic sparked an explosion of research into why some people develop persistent symptoms after being infected with the SARS-CoV-2 virus. Half a decade later, there is growing clarity about how common long covid is and its underlying mechanisms. What is less clear is how many people recover and how best to treat it.

The World Health Organization defines long covid as symptoms that persist three months after the initial infection, or that develop after that point with no alternative explanation. The symptoms of long covid are diverse, the most common being fatigue, headaches, brain fog and post-exertional malaise – meaning even small amounts of physical activity can cause severe exhaustion.

Initially, there was a lot of debate about how common long covid is, but now a rough consensus has formed. Around 5 to 6 per cent of people who are infected with SARS-CoV-2 develop long covid, says Ziyad Al-Aly at the VA St Louis Health Care System in Missouri. While this is lower than some early estimates, "it's not an insignificant number", he says. Some people are also more vulnerable, notably women and people who are middle-aged.

The risk doesn't disappear after the first infection, says Nisreen Alwan at the University of Southampton, UK. The first time you catch covid-19 poses the biggest risk, but it still mounts up with subsequent infections, as Alwan and her colleagues found in a 2023 study of more than 100,000 UK cases.

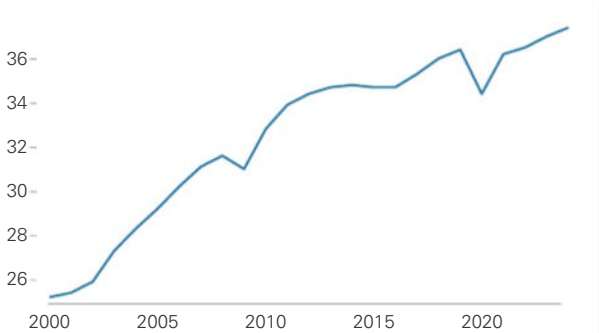
On the plus side, newer variants of SARS-CoV-2 are less likely to trigger long covid than the ones that circulated earlier in the pandemic. "It's not the same virus that it was three, four years ago," says Al-Aly. In a study published in July last year, he and his colleagues found that the risk of long covid decreased in unvaccinated people from when the early alpha variant was circulating to when it was replaced by delta and omicron. "There's a clear decline in the risk and burden of long covid as a function of the changes in SARS-CoV-2 itself," says Al-Aly.

It is also clear that covid-19 vaccines lower the risk. There is some debate about the scale of this reduction, says Al-Aly. But, "I haven't seen a credible study that suggests that the vaccines don't reduce the risk of long covid", he says.

> "I haven't seen a credible study that suggests vaccines don't reduce the risk"

Annual global carbon emissions, gigatonnes

Lockdowns led to the biggest fall in annual carbon emissions in modern times, though this decrease wasn't sustained




SOURCE: GLOBAL CARBON BUDGET

What is less clear is how many people recover from long covid or how long it takes. "I don't really think we have a proper definition [of recovery]," says Alwan. Does it mean having no symptoms at all, and if so for how long, or does it mean being able to return to your previous lifestyle even if you still have mild symptoms? Some researchers have attempted to tackle these questions, but used conflicting definitions of recovery. "It's a mess," says Al-Aly.

Crucially, many people with long covid report that their symptoms ease, sometimes for weeks or months, then return. This must be factored in, says Alwan. "We could possibly talk about it more in terms of remission."

To learn more about recovery, we need much more clarity about the underlying causes of long covid.

## PATHWAYS TO ILLNESS

"There are multiple mechanisms at play," says Al-Aly, which helps explain why long covid's symptoms are so variable.

In at least some cases, SARS-CoV-2 persists in the body. Early in the pandemic, this was widely believed to be unlikely. However, David Putrino at the Icahn School of Medicine at Mount Sinai in New York says there have now been many well-conducted studies showing that entire viruses, or parts of them, can remain in various body parts.

In a study published in October last year, Putrino and his colleagues found that molecules called antigens from the virus could be detected in people's blood up to 14 months after infection, and this was more common in those with long covid. The question now is why this leads to symptoms – and why some people are unaffected.

Additional infections may also contribute to the risk. Viruses like herpes and Epstein-Barr linger in the body for years, "not really causing much trouble", says Putrino, but covid-19 somehow triggers them into action. "All of a sudden, you've got symptoms," he says. "Previously latent pathogens are reactivating."

Other mechanisms see the body turning against itself. One much- ›

discussed finding is that people with long covid appear to be prone to blood clotting, often having tiny microclots in their bloodstream that could block smaller blood vessels, causing inflammation or damaging vessel walls. This could be due to the immune system misfiring in some way or it may be a consequence of the virus persisting in the body. If the latter, treating clotting may ease some symptoms, but won't eradicate the virus or cure long covid.

Long covid is also strongly associated with disruptions of the immune system. Evidence has accumulated around the importance of autoantibodies, which cause the immune system to attack the body. Last year, in a study that wasn't peer-reviewed, Putrino and his colleagues found that people with long covid had higher levels of autoantibodies, and those with neurological symptoms had autoantibodies that targeted nervous system proteins. When the team transferred immune proteins from these people into mice, the animals became less able to balance or coordinate their movements, mirroring the dizziness experienced by the participants. A group that included Rob Wüst at VU Amsterdam in the Netherlands reported similar findings in a preliminary study in May. "Most likely, one of the pathological drivers there is a functional autoantibody," says Putrino.

## THE ROAD TO RECOVERY

Some of the fatigue that marks long covid may be due to a literal energy shortage. Our cells contain mitochondria, which supply energy. "There is some form of mitochondrial dysfunction happening in people with long covid," says Al-Aly. Last year, Wüst's team reported muscle abnormalities in people with long covid-related post-exertional fatigue, which indicated that their mitochondria weren't working properly.

Like with many conditions, the gut microbiome could also play a role. The idea is that when we get sick with covid-19, so do the microorganisms in our gut, says Al-Aly. "Maybe they don't fully recover, and then when they don't recover, we don't really recover." He calls it "a less-accepted hypothesis", but points out that a 2023 randomised controlled trial found that a daily cocktail of probiotics reduced long covid symptoms. "So there may be something to it," he says.

What does all this mean for people who have long covid? If they have access to healthcare, they should be offered treatments that tackle their symptoms. For instance, people with heart palpitations may be given beta blockers. They could also be recommended lifestyle interventions. "Pacing is widely recommended for long covid – doing what you can within your energy level," says Alwan.

However, there is no treatment that tackles the root cause or causes. Not a single medication has been approved in either the US or the European Union, which Al-Aly calls "a major collective failure".

Part of the problem is that the US National Institutes of Health allocated most of its long covid funding to observational studies, holding little back for randomised-controlled trials, says Al-Aly. "Now they're trying to play catch-up."

Many treatments are being tested, with Al-Aly, Putrino and Alwan all being involved in such trials. However, Al-Aly and Putrino both say that long covid requires a different approach to testing.

Traditional trials that focus inflexibly on one treatment will take too long, because there are so many potential therapies to sort through and long covid is so diverse. If researchers stick to the traditional paradigm, we will be in the same position on the 10th anniversary of covid-19, says Al-Aly.

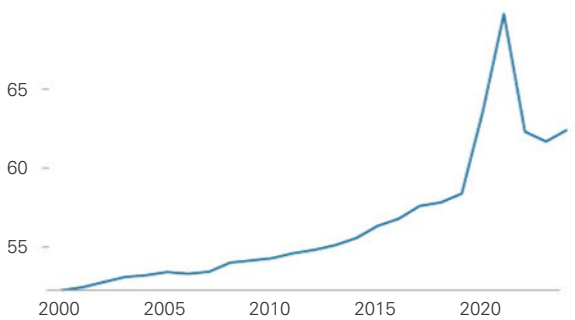
Instead, he and Putrino want to do adaptive trials, in which multiple treatments are offered and people can change therapies during the study, which has been done in cancer and cardiology research. "The concept is not new," says Al-Aly.

Healthcare and public health systems also need to be rejigged to better handle conditions like long covid. "We need to have proper frameworks for these infection-induced non-communicable diseases," says Alwan. This could include rules around ventilation to reduce transmission and introducing care teams that provide a range of treatments and support.

"There's going to be another pandemic," says Al-Aly. "We just don't know when and what." Like with covid-19, that infection could also cause lingering symptoms. To understand the causes of post-infection complications, and avoid widespread ill health, Al-Aly wants to see more focus on long covid, not just SARS-CoV-2 itself: "How do we best optimise our response to 'long virus 2030'?" ▮

### Annual global deaths, millions

The number of deaths each year broadly rises in proportion to population increases, but the pandemic saw a huge spike



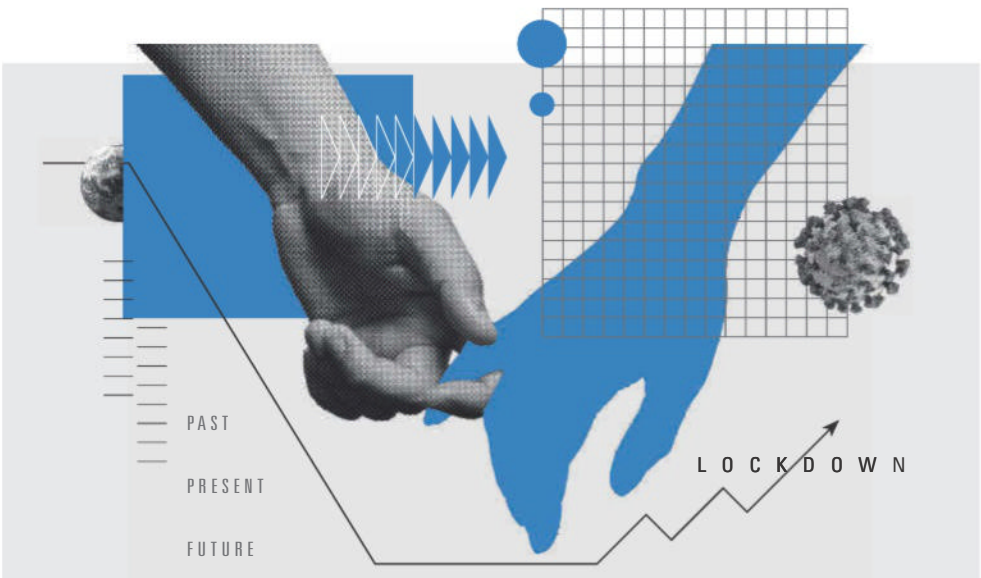

SOURCE: UN, OUR WORLD IN DATA

**300 MILLION**

the number of people using Zoom a day in April 2020

A socially distanced yoga class in Toronto, Canada, in June 2020

REUTERS/CARLOS OSORIO




# HAVE WE LEARNED THE LESSONS OF COVID-19?

Science initially struggled in the face of the pandemic, but now we know much more, reports **Penny Sarchet**

NOT touching your face. Panic-buying toilet roll. Disinfecting groceries. Some of the advice and behaviour of the early days of the covid-19 pandemic can, in retrospect, seem utterly bizarre. But when an unknown virus swept rapidly around the world, we were engulfed by questions – how does it spread, who is most at risk, how can I avoid catching it and just how bad is this going to get – that the instruments of medical science couldn't immediately answer.

"None of us could comprehend the scale and broad societal impact of this, the speed at which it developed," says Jeremy Farrar, who participated in the UK government's Scientific Advisory Group for Emergencies (SAGE) for much of the early years of the pandemic, and is now chief scientist at the World Health Organization.

But even from the very beginning of the crisis, researchers were examining every aspect of covid-19 – its biology, how to prevent and treat it, how to stop it spreading and how to manage a deadly outbreak amid the complexities of modern society. The twists and turns of the past five years have yielded many insights – and should leave us better prepared for future pandemics, if governments choose to listen.

## FLATTENING THE CURVE

Initially, much of the focus was on epidemiology and statistical modelling in an effort to forecast the spread and impact of the virus. Officials in many countries started speaking of the need to "flatten the curve". Anthony Fauci, then director of the US National Institute of Allergy and Infectious Diseases, told journalists in March 2020 that "if you look at the curves of outbreaks, they go big peaks, and then come down. What we need to do is flatten that down." That, he said, "would have less people infected. That would ultimately have less deaths. You do that by trying to interfere with the natural flow of the outbreak."

> "None of us could comprehend the speed at which it developed"

Social distancing and then lockdowns became necessary to prevent countries experiencing those big peaks of infection and death. But as graphs depicting hypothetical outbreak dynamics became commonplace on TV and social media, messages to the public became confusing and unclear.

"I think a lot of people got anchored to the idea of: we can have hospitals not overwhelmed, and we can have a single wave, and it will all be over," says Adam Kucharski at the London School of Hygiene & Tropical Medicine, who was a member of the UK government's pandemic modelling science advisory group. But without containing the virus, this would never have been possible, as a large majority of the population hadn't yet been infected.

"We had all this silly discussion about whether a second wave was going to happen, and you just had to look at the amount of susceptibility," says Kucharski. "There was never a reason that we weren't going to have a second wave, if we still had transmission."

In the US and UK, the infection waves of late 2020 to early 2021, after some restrictions had been lifted, had a heavy death toll. But while this should have been predictable, it wasn't inevitable. Other countries that had made more concerted efforts to contain their outbreaks earlier on in 2020 tended to continue taking action to keep infection rates and death counts down.

Devi Sridhar, a public health researcher at the University of Edinburgh, UK, and author of *Preventable*, points to the strategies of Japan, South Korea, Denmark, Norway and New Zealand: "contain until you get a scientific breakthrough, and then you mass vaccinate and open up. If you look at the death rates, that really paid off."

But how could we know there would soon be a vaccine? When the pandemic began, vaccine development was considered "fast" if it only took four or five years. Countries that remained heavily locked down were betting that either this could be done quicker ›

or other game-changing medical interventions would soon be developed – a bet worth taking, says Sridhar, though this view wasn't universal at the time.

"Faith in science was probably one of the biggest disagreements at the start," she says. "I'm quite an optimist, but also, if you look at most human afflictions over time, we have developed ways to defang them." This hasn't always involved vaccines – for AIDS, we now have antiretroviral drugs, for example, even if it has taken some time. "The idea that we'd have a disease and have absolutely no scientific response to it was just astonishing to me," says Sridhar.

As the months went by, science did indeed deliver. Trials determined which drugs were best for treating covid-19 – the steroid dexamethasone, for example, was found to cut the risk of death in severe cases by up to a third, while IL-6 inhibitors were discovered to reduce the odds of people with severe cases requiring a ventilator by 28 per cent.

And we soon had the fastest vaccines ever developed, many of them based on mRNA technology that hadn't been used in this way before (see "A new era of vaccines", page 19). "You'd be lying if you said you weren't surprised," says Farrar, although he notes that "this didn't come out of total left field" – the 2023 Nobel prize in physiology or medicine, seen as the covid-19 vaccine Nobel, was given for foundational work on mRNA conducted decades ago.

Another surprise was that, as well as reducing a person's risk of getting infected, the vaccines also lowered their risk of transmitting the virus to others if they did still get infected. This wasn't a given. "I think the early vaccine results were just better than anyone could have hoped for," says Kucharski. Because they were so good against the alpha variant, they made it possible for countries like the UK to reopen after the heavy waves of late 2020 and early 2021, he says.

## COVID-19 WAS AIRBORNE

While treatments and vaccines were a triumph, there were failures. One of the most notable is how long it took the WHO to acknowledge that covid-19 was airborne. In March 2020, the agency emphatically tweeted "FACT: #COVID19 is NOT airborne", stating that the coronavirus is mainly transmitted through droplets when someone coughs, sneezes or speaks. The agency's advice at that time was to keep a 1-metre distance from others, disinfect surfaces frequently, avoid touching your eyes, nose and mouth and practise good hand hygiene.

"It really wasn't any great surprise that this virus was airborne," says Trish Greenhalgh at the University of Oxford. "SARS-1 was airborne. MERS was airborne. Flu is airborne. TB is airborne. Any respiratory disease is airborne."

Greenhalgh had been arguing from the early months of the pandemic that wearing face masks should be advised on the basis of the precautionary principle. But she says handwashing won out as the most evidence-backed way of preventing the spread of disease because doctors need to wash their hands to prevent spreading infections between their patients, and as a result have conducted "loads of randomised controlled trials of handwashing". That contrasted with the state of evidence on the efficacy of mask-wearing before the pandemic, which was less extensive or accepted.

Testing for coronavirus beneath a mural in Shah Alam, Malaysia

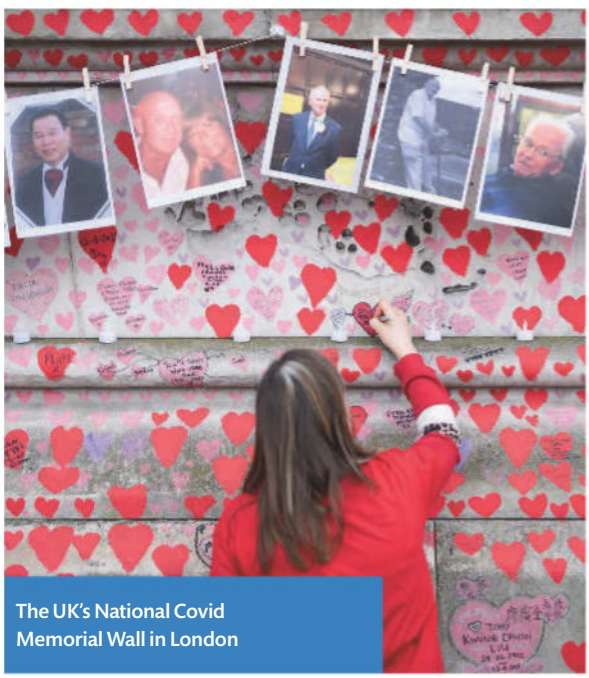
REUTERS/LIM HUEY TENG

> "It really wasn't any great surprise that this virus was airborne"

"The medical profession is a powerful profession and tends to think towards therapeutics and vaccines, and less towards social and behavioural factors," says Farrar. "I think one of the key lessons that we must all learn is the critical importance of behavioural, social and non-pharmacological interventions, including masks and social distancing, ventilation and opening windows."

As the pandemic progressed, the WHO began recommending mask wearing and ventilation alongside its original advice, but it wasn't until late 2021, when the omicron variant was spreading rapidly, that the agency introduced the phrase "airborne spread" to its public communications.

"Throughout the pandemic and in all its work, WHO has reviewed evidence, consulted a broad range of experts and adapted its guidance with the evolving science," says a WHO spokesperson, noting that one issue had been differences in terminology used by different fields. In April 2024, the agency



The UK's National Covid Memorial Wall in London

LEON NEAL/GETTY IMAGES

Queen Elizabeth II at the funeral of Prince Philip, her husband

JONATHAN BRADY - WPA POOL/GETTY IMAGES

introduced updated definitions of phrases such as "through the air" and "airborne transmission".

## WOULD WE LOCK DOWN AGAIN?

Hopefully, better agreement about scientific terminology will help when the next pandemic hits, but what about one of the most contentious interventions in the virus-fighting arsenal – lockdowns?

Media reports now commonly suggest that people would never lock down because of an illness again, but Christina Pagel at University College London disagrees. "We probably would if people were dying in the streets," she says, or if children were badly affected or the symptoms were as nasty as Ebola, for example.

This pessimism about people's willingness to make sacrifices echoes speculation in the early days of the pandemic that people wouldn't tolerate too many restrictions for too long – the UK government talked of "behavioural fatigue", despite behavioural scientists at the time pushing back on the concept.

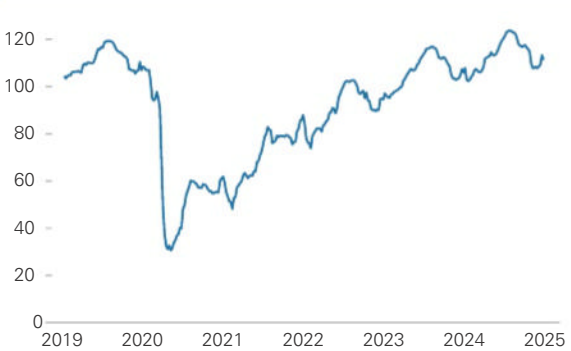
"I think it's really important that the lesson is learned that you don't start off with an assumption that people don't understand and they don't sacrifice themselves, and they don't look after each other or do really difficult things, because they do," says Susan Michie, a health psychologist who chairs the WHO's behavioural science advisory group and has also served on UK government advisory groups.

**525%**

the rise in internet searches for banana bread by the end of April 2020

### Global airline passenger capacity, millions

Lockdowns and other travel restrictions saw a sharp fall in flight numbers, which have only just returned to pre-pandemic levels




SOURCE: OAG

"Whatever the crisis, you see people really pulling together and looking after each other. A collective solidarity builds in. This is seen in so many different types of disasters, in so many different places."

Michie argues "if there's trusted leadership, if there's clear communication as to what the benefits are for yourself, your loved ones, your communities and services, and the negative consequences of not doing it, people will rally." But she notes that people need to be helped to do so – different countries provided differing levels of state support for people who had covid-19 and needed to self-isolate, for example, which may have led to people continuing to work while infected as they had no other choice.

But it may be possible to avoid lockdowns in a future pandemic, says Sridhar. "Countries that were reluctant to implement measures ended up in harsher cycles," she says, veering from not reacting to the virus to putting in place strict lockdowns and going back and forth again. Conversely, governments that better controlled the virus – like those of Japan and New Zealand – were more consistent in their messaging around trying not to catch the virus and having faith that scientific solutions would follow.

Farrar says there is no doubt we are better prepared for the next pandemic. "We've understood the importance of genomic surveillance much better than we've ever understood it before. The diagnostics and surveillance around the world needs to be sustained, but is in a much better place than it was in 2019." But he is concerned that there are gaps in our preparedness, especially when it comes to effective interventions like drugs and vaccines for threats such as a possible flu pandemic.

"I think we have a real vulnerability around therapeutics and indeed vaccines for things we know about, let alone for things we don't know about," says Farrar. "And as interest in the pandemic wanes, then my concern is the interest in making sure we close that gap will also wane." ▮

Coronavirus science

# THE UNANSWERED QUESTIONS

When the first signs of an unknown virus began showing up in Wuhan, China, in December 2019, scientists raced to understand what was happening. In the five years since, they haven't stopped running, with over 1 million papers published about SARS-CoV-2 and covid-19. Yet despite this outpouring, some big scientific questions about the virus remain, finds **Graham Lawton**

An emergency hospital was built in just over a week in Wuhan, China

## IS THE VIRUS LURKING WITHIN WILDLIFE?

EARLY in the pandemic, it became clear that the coronavirus could jump from humans into other animals and back again. This was initially seen with domesticated species, including pets, zoo animals and farmed mink, and was quickly identified as potentially troublesome. In November 2020, 17 million mink in Denmark were culled after it was discovered that the virus was circulating among them and had infected a farm worker.

Wild animals, too, were soon found to be susceptible. In November 2021, researchers at Pennsylvania State University revealed that SARS-CoV-2 was circulating in white-tailed deer, a common species in the Americas. The virus was also detected in a Eurasian river otter and feral mink. This raised the spectre of "wildlife reservoirs" that could brew up new and dangerous variants capable of jumping back into humans – or re-expose us to older lineages to which our immunity has largely waned.

A 2023 analysis confirmed that this "reverse zoonosis" can and does occur. A team led by researchers at the US Department of Agriculture's Animal and Plant Health Inspection Service: Wildlife Services in Fort Collins, Colorado, analysed nearly 9000 samples from white-tailed deer across 26 states and Washington DC and found evidence of at least 109 SARS-CoV-2 spillover events from humans into deer, creating 39 wildlife reservoirs – and three potential reverse spillovers back into humans.

Until recently, however, the full extent of wildlife reservoirs beyond white-tailed deer has largely been overlooked, according to Carla Finkielstein at the Fralin Biomedical Research Institute at VTC in Roanoke, Virginia. But the problem has only become more pressing, she says. As the virus shifts towards endemicity in humans (see "Could we go back to square one?", page 18), one of the main threats to our progress in controlling covid-19 is the emergence of more virulent and/or transmissible strains, possibly from wildlife reservoirs.

"We've made great strides, but we can't ignore the risk that wildlife can still be a problem," says Finkielstein. "First, they can pass the virus back to humans. And second, they can be a source of new mutations that make the virus more contagious or harder to control."

Between May 2022 and September 2023, she and her colleagues collected samples from 24 species of wild mammal in Virginia and Washington DC. As expected, they detected the virus in white-tailed deer, but also in six other species: the deer mouse, Virginia opossum, raccoon, groundhog, Eastern cottontail and Eastern red bat.

> "A future mutation could confer adaptations that allow the virus to spread more efficiently"

They have since expanded their search to other geographical areas and additional wild species and discovered more of the same. Their initial findings are "absolutely" the tip of an iceberg, she says.

One sample from an opossum contained a previously unknown mutation, which Finkielstein says demonstrates that the virus can evolve outside humans. "The key takeaway here isn't necessarily this specific mutation, but the fact that the virus is mutating within a wildlife host," she says. "This raises the possibility that a future mutation could confer adaptations that allow the virus to spread more efficiently."

The discovery, she says, emphasises the fact that "wildlife reservoirs do pose a potential threat to the progress we've made in controlling SARS-CoV-2. If we look at the history of previous pandemics, we can see how animal reservoirs played a key role in re-emerging infections, for instance, the plague. To stay ahead of this, we really need to keep monitoring wildlife closely."

STR/AFP VIA GETTY IMAGES

Priests used water pistols to dispense holy water while social distancing

JIM WEST/ZUMA WIRE/SHUTTERSTOCK

## HOW MANY PEOPLE HAVE PERSISTENT INFECTIONS?

IN JANUARY 2022, a team of researchers led by Marc Johnson at the University of Missouri in Columbia detected a previously unknown mutant of SARS-CoV-2 in waste water in Wisconsin. That was no great surprise: infected people often shed the virus in faeces and urine, and waste water is surveilled to monitor its presence, spread and evolution.

The Wisconsin mutant, however, was a watershed discovery. Before then, we had occasionally seen "cryptic" lineages with no clear origin and a genetic sequence that didn't match any found in clinical samples from infected people. The first was detected in New York City's waste water in January 2021 and they have since turned up all over the world.

This time, Johnson and his team painstakingly traced the source of the Wisconsin cryptic by following it up the waste-water stream, eventually pinpointing it to a single sewer pipe draining the toilets in a commercial building. The only explanation, says Johnson, is that someone in the building had a persistent infection and was shedding – literally – shitloads of virus.

This scenario, he says, is almost certainly the source of cryptic lineages. "For the longest time, I thought they were coming from animals, specifically rats," he says. "But it was a total red herring. Our suspicion, based on various factors, is that it's probably cases of the virus adapting to infect the gastrointestinal tract. People have gotten infected and are unable to clear the virus."

Although there is no direct evidence of a cryptic lineage going on to infect humans, Johnson believes they can and have. "Omicron and [its subvariant] BA.2.86 – both of which went on to sweep the world – we're all but certain that those were also from persistent infections," he says. The thinking is that an extended stay in the gastrointestinal tract allows the virus to evolve new and useful mutations, enabling it to evade the immune response, sometimes giving rise to a new source of infections.

Indeed, many of the adaptive mutations seen in new variants were first spotted in cryptics. "When omicron first came out, I looked at the sequence for about 10 minutes before I could convince myself it wasn't one of our cryptic lineages because every one of its mutations we had seen before, just not in the same combination," says Johnson.

What causes some people to develop persistent infections, and the health effect of this, isn't known, but it is clear that these are a potential source of new, dangerous variants. They are a major public health problem that should be prioritised for further investigation, says Thomas Friedrich at the University of Wisconsin-Madison. "We don't know how many are out there," says Johnson. "We would like to know."

**53 MILLION**

The number of masks thrown away in the UK each day at the height of the pandemic

## WHERE DID THE VIRUS COME FROM?

NATURAL origin or lab leak? After five years and numerous investigations, we still don't definitively know the answer and probably never will. But one has a lot more going for it than the other.

First, consider the basic facts. The earliest recorded infections occurred in Wuhan, China, in December 2019, clustered around the Huanan Seafood Wholesale Market (which also traded in wild mammals). Of those 155 cases, 35 had had direct contact with the market.

When researchers sequenced the virus's genome, they found it belonged to the coronavirus family, with its closest-known relative being a virus found in horseshoe bats in China. The only other wild species known to naturally harbour a SARS-CoV-2-like virus is the Sunda pangolin, which is native to South-East Asia and is one of the world's most trafficked mammals. These facts quickly led to the idea that the virus jumped from bats to pangolins (or another terrestrial mammal), which were subsequently trafficked to the market and infected humans.

But Wuhan also happened to be home to two research bodies known to work on bat coronaviruses, the Wuhan Institute of Virology (WIV) and the Wuhan Center for Disease Control (WCDC). This led to the alternative hypothesis that the virus came from a laboratory.

The lab leak hypothesis is actually an umbrella term for multiple, often mutually exclusive, claims, says Edward Holmes at the University of Sydney in Australia. These include an infection during fieldwork, a lab accident and the deliberate release of a bioweapon and are superficially appealing, he says, but the evidence is circumstantial at best.

Among other things, WIV is located more than 30 kilometres from Huanan market and had no connection to any of the earliest cases. WCDC is a few hundred metres from the market, but, ›

until November 2019, it was in a different part of the city, and its virus-related work was focused on collecting and sequencing samples from wild animals, not on culturing or genetically manipulating viruses.

There are many reasons to discount a lab leak, says Holmes, and many more pointing to a natural origin. "SARS-CoV-2-like viruses have natural transmission cycles in a region spanning Yunnan province [in China] and southwards into South-East Asia and were most likely imported into Wuhan via the wildlife trade," he says. "All the scientific evidence points to this. There is no scientific evidence for any other hypothesis."

"The lab leak theory remains completely unsupported and, worse, incoherent and inconsistent, frequently requiring complex conspiracies to be a viable hypothesis," says David Robertson at the University of Glasgow, UK. "Indeed, it seems clear that there's a political agenda behind much of the proponents of the lab leak theory."

We probably won't ever know for sure. "I honestly can't see any other new evidence coming to light," says Holmes. "Research on this matter in China is at a standstill as the official narrative is that the virus is not from China. Besides, it is now far too late to find any intermediate animal species that still has the virus or antibodies to it."

Does it even matter at this point? Yes, says Robertson. "The lab leak theory has become part of a wider, anti-science disinformation landscape. This is all very unfortunate, as preparedness to virus threats requires strong international cooperation and evidence-based response."

Socially distanced musicians performing for plants in June 2020

JORDI VIDAL/GETTY IMAGES

**17 MILLION**

mink were culled in Denmark in 2020 after signs of the virus spreading

Nurses greet each other during coronavirus testing in Paraguay

AGUILAR/EPA-EFE/SHUTTERSTOCK

## COULD WE GO BACK TO SQUARE ONE?

THE covid-19 pandemic is over... right? "Covid-19 has become endemic," says Sarah Otto at the University of British Columbia in Vancouver, Canada. "Scientifically, that means it's persistent within a population and does not disappear." Yet the virus isn't harmless, and could still spark a fresh pandemic.

Exactly when the virus made the shift from pandemic – characterised by huge global surges of infections as it burns through susceptible populations – to endemic is a grey area, says Otto, but it probably happened after the omicron variant became dominant in late 2021.

"It's certainly endemic," says Peter Markov at the London School of Hygiene & Tropical Medicine. "Formally, that means low levels of spread and relatively constant over time, perhaps with fluctuation."

That may sound like cause for celebration, but isn't. "Endemic" is often misinterpreted as meaning "harmless", says Otto. "Scientifically, that is not a part of the definition at all. A lot of people think that when you say the word endemic, you're dismissing it as a disease. When I use the word endemic, it's exactly the opposite. It's like, it's here to stay and we better deal with it." There is no prospect of eradicating it, she says.

Endemic diseases such as malaria and polio are far from harmless. So is covid-19. "It is a dangerous virus," says Otto. "For sure, there's susceptibility – older individuals are much more likely to die or land in hospital. But I also know many cases of 30-year-olds who landed in hospital and have died."

The number of cases fluctuates over the course of the year, with peaks in the winter and troughs in the summer when people spend more time outdoors, says Otto. "That is happening because immunity is waning and the virus is evolving fast enough that it continues to be able to find new, susceptible hosts at any time of year."

That, however, could change. The virus arguably became endemic before, in 2021, but then omicron appeared. "It was really a different disease type," says Otto. "It gets into our cells differently. It wasn't a lower lung infection, it was an upper lung infection. There wasn't much immunity to it, so we saw this massive spike in cases, and so you could say that that was a shift from an endemic virus to a pandemic virus because everybody was susceptible to it."

That could happen again, sparked by a radically different variant from an animal reservoir or a persistently infected, immunocompromised person, which was the probable source of omicron and the beta and delta variants that preceded it, according to Markov. Another potential black swan is recombination, where two different variants of the virus co-infect a single host and create a mash-up of their genomes. "Then there is a risk of production of a new virus which has bits of the two genomes combined, and perhaps maybe in one bit we have a gene that is giving it high transmission rates and the other part is perhaps giving it ability to evade immunity," says Markov.

These are unlikely, but can't be ruled out, says Markov. "If that happens, then we may have a very fast wave because it will be almost like a new virus."

And we may be less lucky next time. Omicron was less lethal than previous dominant variants, says Otto, but that was just a coincidence. There is nothing in evolution pushing viruses to become less dangerous over time, says Markov. So, while the pandemic is over, it isn't gone for good. ▮

# A NEW ERA OF VACCINES

mRNA technology altered the course of the pandemic – and has potential for much more, says **Grace Wade**

THE covid-19 pandemic saw the advent of a revolutionary technology: the first vaccines to be approved that contain messenger RNA (mRNA). The approach helped scientists create vaccines based on this genetic material in less than a year, turning the tide of the pandemic and shattering the previous four-year record set by the mumps vaccine.

Not only have these new vaccines saved millions of lives, they have also confirmed the potential of mRNA to transform treatments. Today, hundreds of trials for mRNA-based therapies are under way. "This is a technology that's just starting to hit the market," says Mirella Salvatore at Weill Cornell Medicine in New York City.

mRNA vaccines might seem entirely new, but they were actually more than half a century in the making. In 1961, this genetic material was discovered and found to carry instructions for producing proteins in cells.

This raised an exciting possibility: we could use mRNA to get our cells to pump out proteins, so long as we know their genetic sequences. The trouble was that our immune system flags foreign mRNA as an intruder, rapidly destroying it before it can be translated into proteins.

But in 2005, Katalin Karikó and Drew Weissman, both at the University of Pennsylvania, found a way to modify mRNA so it could slip past our defences, laying the groundwork for vaccines.

Most antiviral vaccines work by introducing a dead version of the pathogen or a protein from it into the body. This trains our immune system to recognise the virus as an invader so it can quickly identify and attack it in the future. Proteins for these vaccines must be made in living cells, though, which is expensive and time-intensive.

But mRNA vaccines provide cells with the genetic instructions to produce the protein themselves. "mRNA allows us to turn you into a little manufacturing powerhouse facility," says Hamilton Bennett at pharmaceutical company Moderna in Massachusetts. This rapidly accelerates the process of making vaccines. For instance, Moderna started testing its mRNA covid-19 vaccine in people just 66 days after the SARS-CoV-2 virus was sequenced.

Another reason why mRNA vaccines rose to the occasion with covid-19 is that drug companies already had systems in place for producing them. Before the pandemic, they were being tested for infections such as Zika, says Karikó. "So we were able to move with a lot of speed and confidence in the manufacturing platform," says Bennett.

> "mRNA vaccines could tackle influenza, norovirus, malaria, HIV and more"


Another benefit is that they are adaptable. "Once you have the [protein] sequence, you can produce a vaccine," says Salvatore. So if a virus mutates, manufacturers can tweak their vaccines.

The ones made by Moderna and Pfizer/BioNTech have already paved the way for an mRNA vaccine against respiratory syncytial virus, which is approved in the US, Canada, the European Union and Qatar. Many more mRNA-based interventions could be on the horizon. "There are around 300 mRNA clinical trials going on," says Weissman. "Many are for vaccines, including [against] HIV, influenza, norovirus, *C. difficile*, malaria, tuberculosis and other pathogens."

In June 2024, Moderna announced promising results from a final-stage trial of a combined mRNA vaccine for influenza and covid-19. This elicited higher immune responses against the viruses responsible than the licensed flu and covid-19 vaccines in people aged 50 and up. The firm aims to submit the data to the US Food and Drug Administration by the end of the year, says Bennett, noting that a dual vaccine should improve immunisation compliance.

Other conditions may also be treated with mRNA technology. For instance, a trial of a personalised vaccine against melanoma skin cancer is scheduled to conclude in 2029. In an earlier trial, combining it with a standard cancer drug reduced the risk of the cancer spreading or the person dying by 65 per cent during the roughly one-year study period, compared with the drug alone.

Weissman and his colleagues are also investigating mRNA as a treatment for genetic conditions, such as sickle cell disease. The idea is to deliver gene-editing therapy by encoding it in mRNA, but the challenge is developing ways to deliver mRNA therapies to the part of the body we want to target, says Karikó.

While mRNA may take years to reach its full potential, Weissman believes it is halfway there. This is largely due to the covid-19 vaccines sparking interest and investment that have brought the tech closer to revamping medicine. ▮

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# Views



Comment

# The covid-19 time warp

Many of us experienced time differently in the pandemic. Learning why can help us, say **Ruth Ogden** and **Patricia Kingori**

FIVE years ago, in January 2020, a new year had begun, one that would be like no other in living memory. Three months later, much of the world was in lockdown. Most people were unable to leave home for work or social activities, and with schools shut, many of us were juggling homeschooling while feeling anxious about the future.

Covid-19 had countless impacts on health and well-being, but one surprising effect was a widespread distortion of people's experience of the passage of time. How were those lockdown days for you? Did they fly by or drag on? As academics with young children, our lives became seas of unfillable hours that seemed to stretch out far beyond their actual duration. To say that lockdown dragged would be an understatement.

SIMONE ROTELLA

We weren't alone in our covid-19 time warp. Our research shows that UK adults experienced time differently during lockdowns. For about 40 per cent of people, it passed more quickly than normal, but for another 40 per cent, it passed slowly, meaning lockdown days felt longer and slower. How this time passed was determined by how well individuals coped. People who were socially satisfied and had less depression and stress tended to experience lockdown as passing faster than those who were socially dissatisfied or had greater stress and depression. Even after the crisis was no longer a global health emergency, for many of us time remained distorted, with those who fared worst remembering the period as lasting longer than those who coped well.

These changes appear to have fundamentally altered how we value time. Prior to covid-19, it was often taken for granted. The sudden lack of autonomy during lockdown left many feeling that time had been lost forever. Unable to control "when", people missed out on time-critical events like IVF and other medical appointments or final visits to loved ones. These lost opportunities had impacts long into the future.

Anecdotally, covid-19 appears to have focused our attention on the finite nature of time, increasing our desire to avoid wasting it and instead slow down and use it well. However, intense online working and blurred boundaries between work and home have increased the pace of life compared with before the pandemic. In a world where everything is available at the touch of a button, we are more time-poor than ever before. Five years on, these shifting time values have far-reaching health, economic and employment consequences.

This is why we are working to develop a deeper understanding of how experiences of time affect health and decision-making. Covid-19 showed that perceptions of time are a barometer for well-being, and how its passing feels can reshape our emotions, values and priorities. Harnessing this subjectivity and enhancing our autonomy over time may therefore improve how we respond to major life events.

By viewing our experience of time as active and malleable, we may be better placed to improve our quality of life. While it is often considered a "great healer", the slowing and elongating of time during stress highlights the possibility that changes in our sense of time contribute to the development of trauma. Preventing the elongation of highly stressful events, for example by using strategies that reduce emotional and physiological arousal, may thus be an effective, and currently overlooked, way to aid recovery.

While the loss of time to covid-19 remains unbearable for some, our experiences show how attending to time changes how we feel. By appreciating its finite nature, we may be better able to spend what remains of it well. ▮


Ruth Ogden (left) is professor of the psychology of time at Liverpool John Moores University, UK. Patricia Kingori is professor in global health ethics at the University of Oxford

No planet B

# Defossilise your life

Everyday household products are made almost entirely from newly extracted fossilised carbon. But there is an exciting alternative, finds **Graham Lawton**

Graham Lawton is a staff writer at *New Scientist* and author of *Mustn't Grumble: The surprising science of everyday ailments*. You can follow him @grahamlawton

## Graham's week

**What I'm reading**
*Not much; I have started work on a new book of my own.*

**What I'm watching**
*I enjoyed* Hunt for the Oldest DNA *on BBC iPlayer.*

**What I'm working on**
*A story somewhat related to the hunt for ancient DNA.*

This column appears monthly. Up next week: Annalee Newitz

AT HOME, I am surrounded by fossils. They are in my clothes, carpets and soft furnishings, the packaging wrapped around the food I buy and the myriad cleaning products I use every day. Even the contact lenses in my eyes are full of fossils.

I'm not talking about ancient life forms preserved in rock (though I do have quite a lot of those too), but fossilised carbon atoms, laid down millions of years ago and brought back to the surface by the petroleum industry.

Compounds extracted from oil are the backbone of modern life. The vast majority of household products are created, in part, from them. That is around 70,000 classes of product, from shampoo to toothpaste, 15 gigatonnes of which are produced every year, said Jenny Yang at the University of California, Irvine, at a recent US National Academy of Sciences (NAS) panel discussion on making household goods greener.

For someone like me who tries to keep their carbon footprint as small as possible, these products feel like a fossil of a bygone age. Some of the carbon in them will inevitably end up in the atmosphere, making them a significant contributor to greenhouse gas emissions. I can't choose products that are fossil free, however, as they barely exist. Not yet, anyway. But researchers like Yang are trying to change that.

Carbon is undoubtedly extremely useful. Its ability to form stable chains and link up with other elements make it the basis of chemical compounds with all sorts of desirable properties. Pick up any household product and check the ingredients and you will see a long list of carbon-based compounds that are vital to its function. "When it comes to household products, we cannot decarbonise them. They're still going to contain carbon," said Yang at the NAS panel discussion.

The problem isn't carbon per se, but where we get it from. For decades, the go-to source has been oil. This is a quintessential example of the linear economy, where we extract resources, turn them into products and discard them. But there is a circular alternative, where we instead use abundant sources of waste carbon – such as discarded plastic and carbon dioxide from heavy industry – and so don't need to extract new hydrocarbons from underground.

There is a name for this process:

> **"Defossilisation deserves to be more widely known, perhaps splashed as a selling point on products"**

carbon capture and use, or CCU. This is similar to carbon capture and storage except the captured carbon is used to make new products rather than sequestered in long-term repositories. It isn't easy to do, however, as converting oxidised carbon – which isn't chemically useful as it is very unreactive – into useful reactive compounds like ethanol is energy intensive. Advances in microbial fermentation are starting to crack this problem on a large scale, however.

CCU hardly gets the pulse racing, but I recently heard a new term that I think could catch on: defossilisation. This is to household products what decarbonisation is to energy, transport and industry. Those sectors can remove carbon by using electricity produced from renewables. The household product sector doesn't have that option, but it can at least stop using fossil carbon.

The seeds of a defossilised household products sector are starting to grow. One of the leading companies in this area is LanzaTech, based in Skokie, Illinois. It uses bacterial fermentation to convert waste $CO_2$ into industrial chemicals such as ethylene, which can then be fed into existing industrial processes. One of its products is polyester made from $CO_2$ emitted from blast furnaces. This CarbonSmart polyester has already been used in clothing from leading brands including Zara, H&M and Adidas.

Defossilisation has the potential to go further than household products. Another area ripe for this approach is plastics used in medicine, such as polypropylene, which tend to be made from virgin materials – i.e. oil. That is because of doubts over the safety of recycled polypropylene, said Craig Bettenhausen at *Chemical & Engineering News* when moderating the NAS panel.

Ultimately, bacterial fermentation of waste carbon could produce vast amounts of the chemicals widely used by the chemicals industry, such as carbon monoxide, alcohols, ethylene and olefins, according to Yang.

As yet, however, the term defossilisation doesn't have much currency, said Bettenhausen. But it is beginning to trickle down into the wider world. It deserves to be more widely known, perhaps splashed as a selling point on products made in this way. They might be slightly more expensive than their traditional counterparts but conscientious consumers are willing to pay a premium for greener alternatives. I would certainly shell out a bit more to defossilise my life – if only I knew which products to buy. ▮

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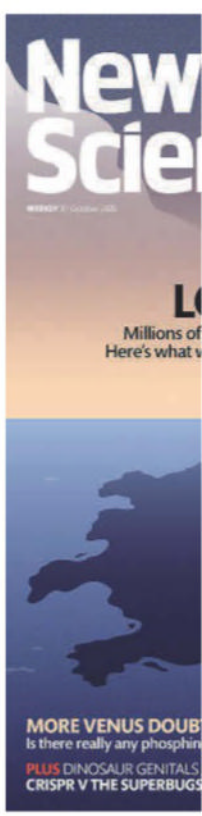
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# Covering covid

IN THE first two years of the covid-19 pandemic, *New Scientist* published almost two dozen editions with reports about the virus and related matters on the cover – an unprecedented run in our nearly 70-year history. They tell a story about our evolving understanding of the SARS-CoV-2 virus, beginning with our 8 February 2020 magazine, when it was still known only as "the novel coronavirus".

Just a month later, we went with a bold declaration: this was now a global pandemic. It wasn't an easy decision, given the World Health Organization wasn't yet ready to use the word, but the strength of our reporting and the need to inform readers meant we felt we had to. A week later, the WHO finally took the same line.

Even so, it was still unthinkable then that the virus would claim a million lives, a brutal toll that was flagged up on the front of our 19 September 2020 edition. The design of this was a deliberate reference to our earlier pandemic issue, a testament to the scale of the loss in such a short time span.

Likenesses of the virus, with its infamous surface spike proteins that put the word "corona" (Latin for crown) in "coronavirus", became emblematic. We examined its lingering impact with our special on long covid on 31 October 2020 and our "Generation covid" cover on 18 September 2021.

For me, looking back at these dredges up a strange mix of emotions, from fear to pain to disbelief at what we all lived through. But I am also proud that the team at *New Scientist* was able to bring readers the information they needed, and hopefully some light in dark times.

**Jacob Aron**

## Editor's pick

### Liver is seat of emotions for modern Iraqis, too

**14/21 December 2024, p 11**

*From Sadiq Hussain, Bolton, Greater Manchester, UK*

**You report that Mesopotamians felt happiness in their livers. For Iraqis like myself, the liver is indeed a seat for emotions. All in all, it seems that people's feelings in Iraq nowadays are harmonious with how those in Mesopotamia felt, as a recent hit pop song in Iraq shows. The lyrics go something like: "The doctor was assessing my pulse rate. Leave my hand alone, sir, I say. The pain of love is in my liver, so let go of my hand, master!"**

### Time to start mass bird flu vaccination programme

**7 December 2024, p 11**

*From Geoff Harding, Sydney, Australia*

You report that H5N1 bird flu may be adapting to become more infectious to humans. Considering the high death rate in people infected so far and the projections that even minor mutations could cause a virulent pandemic, mass production of an H5N1 vaccine and the inoculation of most of the population should be considered.

Unfortunately, only wealthier countries could probably consider this pre-emptive strategy, but the best option for future pandemics may be to take some preventative action to avoid economically destructive lockdowns and save as many people as possible.

### On climate, self-interest is still winning the day

**30 November, p 9**

*From Bruce Denness, Niton, Isle of Wight, UK*

The COP 29 climate summit was held in Baku, the capital of Azerbaijan, whose economy is massively dependent on exploiting its huge fossil fuel resources. The nearby Caspian Sea is rapidly drying out as a result of hydrocarbon-propelled global warming. Yet this connection seems to have eluded stingy higher-income nations as they failed to cough up enough money to address the climate change repercussions faced by lower-income countries. I guess immediate self-interest trumps irony every time.

### We can't ignore root cause of the food crisis

**16 November 2024, p 36**

*From Graham Cooper, Hollacombe, Devon, UK*

The climate-related food crisis is a consequence of overpopulation, causing the destruction of huge areas of natural environment by animal farming in particular and intensive chemical agriculture, both highly polluting.

The constant quest to defeat nature with chemicals, intensive farming, genetic engineering etc. only offers stop-gap measures. Eventually, the house of cards will collapse. The maxim "for every action, there is an equal and opposite reaction" is a reality being ignored.

### Calories on menus may actually be of little help

**30 November 2024, p 14**

*From Dyane Silvester, Arnside, Cumbria, UK*

Your article on calorie counts on menus says the UK guidelines require them to sit within a 20 per cent margin of error, yet the gap between your opening example of a chicken burger and fries (1597 kcal) and their plant-based alternative (1746 kcal) is within this margin. Presumably even those who want to make "healthy" choices might not be picking the lower-calorie option. Maybe the bigger problem is that it is so cheap and easy to buy a meal with 70 per cent of an adult's daily recommended calorific intake.

### Earlier lessons for the myopia epidemic?

**Letters, 7 December 2024**

*From Sam Edge, Ringwood, Hampshire, UK*

Further to the discussion of early-onset myopia, it occurs to me that some of the themes were explored in Aldous Huxley's 1942 book *The Art of Seeing* and W. H. Bates's 1920 book *Perfect Sight Without Glasses*, from which the former draws.

These were both condemned by eye health professionals, although neither seem to have been written with avarice or an agenda other than to suggest methods to exercise the eyes to minimise degenerative effects. Most notably, the books promote the idea of regularly spending more time outdoors without wearing optical aids to take advantage of brighter light and longer distances.

### Guinea pig trumps a robot pet any day

**12 October 2024, p 22**

*From Penny Jackson, Barrow-in-Furness, Cumbria, UK*

The idea that robot pets would solve our carbon footprint issue seems a bit blinkered. The pet options aren't just cat, dog or robot. Small herbivores have a far smaller carbon footprint, one that may be less than that of a dog-sized robot.

What's more, the suggestion that animal intelligence consists solely of the ability to follow our "simple commands" completely misses the point of a pet. Yes, some level of obedience is important for dogs, but this is a safety net, not their primary purpose. My guinea pigs fascinate me not because they ever do what I say, but because they never cease to surprise me with their varied personalities, and are a constant source of entertainment by learning and doing things completely unlike what would ever occur to a human. This, by definition, would be very difficult to put into an AI.

### We've paved over paradise and made it hot as hell

**23 November 2024, p 36**

*From Merlin Reader, London, UK*

Pertaining to the problem of urban heat, many suburban roads in the UK have effectively more than doubled in width, as front gardens have been largely or completely paved over. As well as a loss of wildlife habitat, this has significantly increased the heat island effect. In my street, less than 5 per cent of front gardens are at least half lawn or shrubs, while more than 90 per cent are completely paved.

### For the real story on what a dog wants, read on

**14/21 December 2024, p 66**

*From Peter Slessenger, Reading, Berkshire, UK*

It seems novelist Patrick Ness may have been correct when it comes to communing with dogs. His *Chaos Walking* trilogy starts with: "The first thing you find out when yer dog learns to talk is dogs don't got nothing much to say... 'Need a poo, Todd.'" ▮

### For the record

- **When we ran our story on bird flu (14/21 December 2024, p 20), not everyone affected was known to have recovered.**
- **A temperature difference of 770°C is equivalent to 1386°F (7 December 2024, p 38).**
- **Cameron Browne led the Digital Ludeme Project (14/21 December 2024, p 48).**

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# Tune into 2025's top TV

From *Doctor Who* to *Apple Cider Vinegar*, there are plenty of great sci-fi and science-inflected shows coming up this year, says **Bethan Ackerley**

IF YOU live in a part of the world where January is a hardscrabble month of inclement weather, you might well be tempted to lock yourself away for the rest of the year, fearing the sun will never return. Should you succumb to this awful temptation, there would, at least, be a wealth of brilliant television to fill your days, as some hotly anticipated science fiction and science-focused TV series are arriving in 2025.

We don't have to wait too long for sci-fi gold: three years after it first aired on Apple TV+, *Severance* returns for its second season on 17 January.

This psychological thriller follows employees of the shadowy megacorp Lumon Industries whose memories of work are surgically "severed" from their home lives, effectively creating two people in a single body, one of whom only exists at the office. Unable to communicate with their "Outies" – and subject to the abasements of corporate culture – the "Innies" begin to chafe at their confinement. It is the perfect show to watch if you are returning to office life after the holidays.

Another long-awaited show, the gritty *Star Wars* series *Andor* (Disney+; see right), will arrive in April for its second and final season. Back in 2022, we saw how self-interested thief Cassian Andor (Diego Luna) was radicalised by the banal evil of the Empire and joined the Rebel Alliance. In season two, he is set to lead the resistance to victory at any cost.

*Andor* isn't the only sci-fi series bowing out this year. Survival thriller *Squid Game* (Netflix) returns for its final season in 2025, and it is your last chance to visit the monstrous worlds of Gilead and the Upside Down in *The Handmaid's Tale* (Disney+/Hulu) and *Stranger Things* (Netflix)

JAMES PARDON/BAD WOLF/BBC STUDIOS

**Ncuti Gatwa returns for more adventures as the Fifteenth Doctor**

respectively, at least until their spin-off series arrive.

Sticking with horror, anthology show *Black Mirror* (Netflix) airs its seventh season of technological dystopia this year. Creator Charlie Brooker has promised a return

**"*Severance* is the perfect show if you are returning to office life after the holidays"**

to "OG *Black Mirror*" – which seems to signify especially bleak stories – as well as the series' first sequel, following on from season four's *Star Trek*-inspired episode "USS Callister".

Meanwhile, the first TV show of the *Alien* franchise is slated for mid-2025. *Alien: Earth* (Disney+/Hulu) takes place in 2120, just two years before the events of the original, and sees a mysterious vessel crash-land – you guessed it – on our planet. With early trailers revealing that "Mother Earth is expecting", you can bet there will be plenty of psychosexual torment in this series.

In a more family-friendly region of time and space, the adventures of the Fifteenth Doctor (Ncuti Gatwa) and Ruby Sunday (Millie Gibson) are expected to continue on BBC iPlayer and Disney+ in May. The *Doctor Who* duo will be joined by new companion Belinda Chandra (Varada Sethu) this time round. Intriguingly, Sethu appeared in the previous season as a different character, Mundy Flynn – something timey-wimey is clearly going on.

If that's not enough *Doctor Who* for you, a five-part spin-off series, *The War Between the Land and the Sea*, should also arrive later this year. It sees UNIT face off against a classic Doctor Who enemy, the Sea Devils.

If you would prefer something a little closer to reality, try *Playing Nice* (ITVX), which airs this month. When two couples learn that their babies were switched at birth after a mix-up at the hospital, they are forced into each other's orbit.

Their uneasy friendship soon gives way to suspicion, as they accuse each other of poor parenting and trying to take back their biological child. This four-part thriller is sure to dig into difficult questions about the parent-child bond, and just how much comes hardwired.

There is also *Apple Cider Vinegar* (Netflix), billed as a "true-ish story based on a lie". It stars Kaitlyn Dever as wellness guru Belle Gibson, who falsely claimed that she had cancer and that she was managing her condition using diet, exercise and alternative medicine.

We live in a time of rampant misinformation and distrust of vaccines, so the story of Gibson's wellness empire should be a cautionary tale.

Dever also appears in the next instalment of post-apocalyptic drama *The Last of Us* (NOW/Sky/Max), playing a soldier seeking vengeance for her loved one's death. Set five years after the previous season, the world remains ravaged by a *Cordyceps* fungus that turns the infected into zombie-like monsters.

In season one, Joel (Pedro Pascal) became a father figure to Ellie (Bella Ramsey), but their relationship has grown strained with time. Expect yet more

heartbreak and jump-scares in season two, which should arrive in the first half of the year.

With filming over for season three of *Foundation*, an Apple TV+ adaptation of Isaac Asimov's stories, we can reasonably expect the show to return some time in 2025. Inspired by its concept of psychohistory, a mathematical and sociological means of forecasting future events, we can attempt to predict which series will arrive later on in the year.

*For All Mankind* (Apple TV+) looks like a safe bet. In this alternate history, the space race never ended and humans landed on Mars in 1995. Season five takes place in the 2010s, when a fully fledged colony has been built on the Red Planet.

Elsewhere (specifically on Paramount+), *Star Trek: Starfleet Academy* may reach our screens before 2025 is done. The new series is set in the 32nd century after a cataclysm, as it follows the first new class of Starfleet cadets in over 100 years.

Cyberpunk fans may rejoice at the arrival of *Neuromancer* (Apple TV+), which sees washed-up hacker Case (Callum Turner) and the cybernetically enhanced Molly Millions (Briana Middleton) team up for the heist of a lifetime. And there is also *Blade Runner 2099*, of which little is known except that it is set – as you might expect – 50 years after *Blade Runner 2049*.

Other additions to the Apple TV+ sci-fi stable this year may include *Murderbot*, starring Alexander Skarsgård as the titular security android who has gained free will, and a series from *Breaking Bad* creator Vince Gilligan so hush-hush that not even its name has been officially announced.

Now that's what I call speculative fiction. ▮

# The best of the best

*New Scientist* staff share their favourite sci-fi TV series of all time, from *Quantum Leap* to *Black Mirror*

### Battlestar Galactica (2004)

**Rebooted from an ill-fated 1978 series, *Battlestar Galactica* begins with a nuclear holocaust and humanity's remnants crowding aboard battered spaceships to flee from sentient machines. But its most compelling moments involve the survivors struggling to balance societal and ethical norms against the cold calculus of survival.** Jeremy Hsu

### Quantum Leap (1989)

**My family weren't into *Doctor Who*, so this show was, I think, my introduction to sci-fi (if you count time travel as sci-fi, which I most definitely do). It follows physicist Sam Beckett, who has invented a way to travel through time, although it's not quite what he expected. Sam has vanished from his own reality, but his consciousness leaps into the bodies of other people, whose lives he must sort out before he can move on – and hopefully return home. The series was revived in 2022, and when I get a minute to myself that isn't filled with children or books or the need to sleep, I shall be watching it.** Alison Flood

### Andor

**The *Star Wars* franchise started as an uncomplicated space opera: the Empire is evil because its agents look like fascists; the rebels are good because they aren't that. But recent instalments have gone a long way in complicating that narrative. *Andor* explores what an "ordered" space empire would look like – colonialist, banal, dehumanising – and why those conditions make heroes out of thieves.** Linda Rodriguez-McRobbie

### The X-Files (1993)

**I began watching *The X-Files* at around 9 years old – far too young! I thought Mulder was the epitome of cool, I wanted to believe and I was fascinated and terrified by the monsters he and Scully encountered each week. Revisiting the series as an adult, I identified more with the sceptical Scully and was drawn to the long-running narrative of an alien conspiracy. It is this structure of weaving standalone plots with ongoing stories that makes *The X-Files* so good. Let's just pretend the 2010s revival never happened.** Jacob Aron

### The Expanse

**Two parts sci-fi, one part noir, the richly detailed universe of *The Expanse* has drawn me in like no other. Set in a future where humanity has colonised the solar system and the governments of Earth and Mars are on the brink of war, it follows the crew of a deep-space ice hauler and a hard-boiled detective investigating the disappearance of a wealthy heiress. Before long, they are embroiled in conspiracies and a rebellion by the exploited, asteroid-dwelling Belters. Long live the Outer Planets Alliance!** Bethan Ackerley

### Futurama

**Set in New New York at the turn of the 31st century, this animated series is, in essence, your classic workplace sitcom. It follows the employees of interplanetary delivery company Planet Express, including Philip Fry, who was cryogenically frozen in 1999 and wakes up 1000 years later. It has an absurdly high gags-per-minute ratio, but there are also very poignant moments – the mere thought of Fry's dog makes me sob – and satisfying sci-fi homages.** Tim Boddy

### The Leftovers

***The Leftovers* isn't just the best sci-fi series I have seen, it is perhaps the greatest TV show ever made. The premise is weird: what if one day, out of nowhere, 2 per cent of the population disappeared? Don't expect answers to why this happened – the series doesn't offer any. Instead, it explores the gritty fallout of so much inexplicable grief and loss.** Chelsea Whyte

### Black Mirror

**Each episode of *Black Mirror* dives into the way technology is warping human experience, hopping genres from rom com to slasher horror. The earliest series are the most arresting – the first episode, featuring the UK Prime Minister and a pig, will be burned into your brain – but, throughout, *Black Mirror* is thought-provoking, disturbing and often darkly funny.** Madeleine Cuff

For more top sci-fi TV picks from *New Scientist* staff, head online

# Sci-fi movies to enjoy in 2025

From *M3gan 2* to *28 Years Later*, this year is all about inventive sequels, series and remakes – plus some dazzling adaptations like *Mickey 17*, says **Simon Ings**

WHEN your goofy, low-budget, horror sci-fi about an AI doll that runs amok grosses $180 million, you would be foolish not to make another. Three years after *M3gan* cleaned up at the box office, *M3gan 2* sets the tone for 2025. Yes, it is going to be a year of sequels, remakes and series continuations.

Economically, this makes sense, as studios recover from covid-19, the writers' strike and bloated budgets. Artistically, the news is better than it might appear: there is enough creativity going into these projects to make me hope that the industry is returning to more inventive filmmaking.

A few traces of this can be seen in the third *Tron* movie, *Tron: Ares* (directed by Joachim Rønning, best known for *Pirates of the Caribbean: Dead men tell no tales*), which at the very least promises us Jared Leto as an AI out to offer humanity a deal it cannot refuse.

Gareth Edwards, known for *Rogue One* (a rare hit for the Disney *Star Wars* franchise) and *The Creator* (an ambitious original that should have been better than it was), has been handed the reins of the *Jurassic World* franchise. *Jurassic World: Rebirth* has a script by screenwriter David Koepp, who wrote the original *Jurassic Park*, so let's dare to be optimistic about it.

We can also hope for good things from James Cameron, who promises that *Avatar: Fire and Ash*, the third instalment of his five-film project, will immeasurably enrich the story. It may have to, frankly, but the "ash people" – fiery and unsympathetic versions of the Na'vi – do sound fun.

No special pleading will be needed to bring cinema-goers flocking to *28 Years Later*. The film has been stuck in various circles of development hell for well over a decade (and, yes, it was once called *28 Months Later*). Now, like buses, three arrive nearly at once. The next, *28 Years Later Part II: The Bone Temple*, was shot back-to back with 2025's release; an unnamed third is in the wings.

*28 Years Later* looks to be a rather gimmicky, lightweight production – it was shot using the new iPhone, plus many dinky attachments. It is bound to have great moments, though, since it is a reunion of original director Danny Boyle, original screenwriter Alex Garland and an older, wiser Cillian Murphy reprising his lead role from the original movie.

Moving on from sequels, there is much guilty pleasure to be had in anticipating 2025's roster of remakes. In 2022, Guillermo del Toro needlessly complicated Carlo Collodi's *Pinocchio* in an act of literary sacrilege for which I have yet to forgive him. Redemption may be in the offing with his *Frankenstein*, starring Oscar Isaac as the agonised doctor. If not, then Maggie Gyllenhaal's *The Bride!* promises an iconoclastic take on Mary Shelley's undead creation. Christian Bale in a sci-fi, comedy musical – it sounds like a blast.

We also have the latest from director Edgar Wright (*Shaun of the Dead* and *Baby Driver*), whose version of Stephen King's *The Running Man*, about a dystopian game show, promises a more faithful adaptation of the original material than the 1987 version with Arnold Schwarzenegger (which was, to be fair, a lot of fun).

Elsewhere, *Bugonia* is an English-language retread of South Korean director Jang Joon-hwan's *Save the Green Planet!* It is about a couple of conspiracy theorists trying to save Earth from a high-powered (and possibly alien) CEO. Yorgos Lanthimos directs; Emma Stone and Jessie Plemons star.

It has become a slightly tiresome habit among makers of original films that they let nothing slip about their stories. In that spirit, we have *Flowervale Street* by writer-director David Robert Mitchell, which stars Anne Hathaway and Ewan McGregor in an alternate 1980s for reasons that are firmly under wraps – although you may have to wait till 2026 if the rumours of a reschedule are true. Chris Pratt's cop-on-the-run adventure *Mercy* swears it is sci-fi without telling us why.

**"Maggie Gyllenhaal's latest promises an iconoclastic take on Mary Shelley's undead creation"**

In more expansive mode, there are a couple of promising "originals" – basically new adaptations. In 2017, Anthony and Joe Russo got hold of Simon Stålenhag's graphic novel *Electric State*. They said that the story wasn't strong enough and instead came up with their own, rather generic-sounding, screen adaptation (the AIs are fighting for their rights, again) using Stålenhag's 1990s-inflected visuals. It does look wonderful.

For sheer wit and mischief, I am willing to bet the most memorable film of the year will be *Mickey 17*, *Parasite* director Bong Joon-ho's adaptation of Edward Ashton's sci-fi novel *Mickey7*. Robert Pattinson plays an "expendable": a disposable, easily regenerated blue-collar employee in a terraforming company. Watch the trailer and tell me you don't agree.

DISNEY

**In the latest *Tron* movie, Jared Leto's AI has an offer for humanity**

# How to be an optimist

Optimism can be extremely beneficial – if it's used in the right way. **Sumit Paul-Choudhury** wrestles with how to become a positive thinker

IT IS hard to tell if a chicken is an optimist. After all, you can't ask it if a glass of water is half full or half empty. But you can repeatedly show it a white card in front of a bowl of tasty mealworms and a black card in front of an empty bowl. Once a chick has learned to reliably choose the white card, you show it a grey card. Chicks that head immediately for this card apparently surmise that it is more white than black, and thus probably contains food – the equivalent of deeming a glass half full. On this basis, most chickens do indeed turn out to be "optimistic".

You can test optimism-like behaviour in many animals – and even fine-tune it. European starlings become more "optimistic" if they can take a bath whenever they want. Bottlenose dolphins show more optimistic behaviour if they have been swimming in synchrony with each other. Bumblebees make more optimistic choices after being given an unexpected sweet treat.

These findings might seem eccentric, but the fact that optimism, of a sort, appears in such a wide range of animals suggests that a positive outlook might be important in our own lives – and that it is deeply connected to our well-being. In recent years, these and other insights into how a glass-half-full way of thinking can affect our health have begun to help us distinguish different types of optimism. This, in turn, has allowed us to identify types that are good for us, and even understand how to train ourselves to become the right kind of positive thinker.

For many, this might seem dubious, for reasons that go back centuries. As I explore in my book, *The Bright Side*, optimism didn't start out as a psychological concept, but as a philosophical one. Its origins lie in an attempt by the 18th-century polymath Gottfried Leibniz to explain why an all-knowing, all-powerful and all-loving God allows evil to exist. His suggestion was that if you dispelled evil in one particular instance, you might end up doing more harm in the greater scheme of things. Drawing on insights provided by his invention of calculus, he proposed that the cosmos was arranged "optimally" – that we live not in a perfect world, but the "best of all possible worlds", meaning the one that was most harmonious and logically consistent.

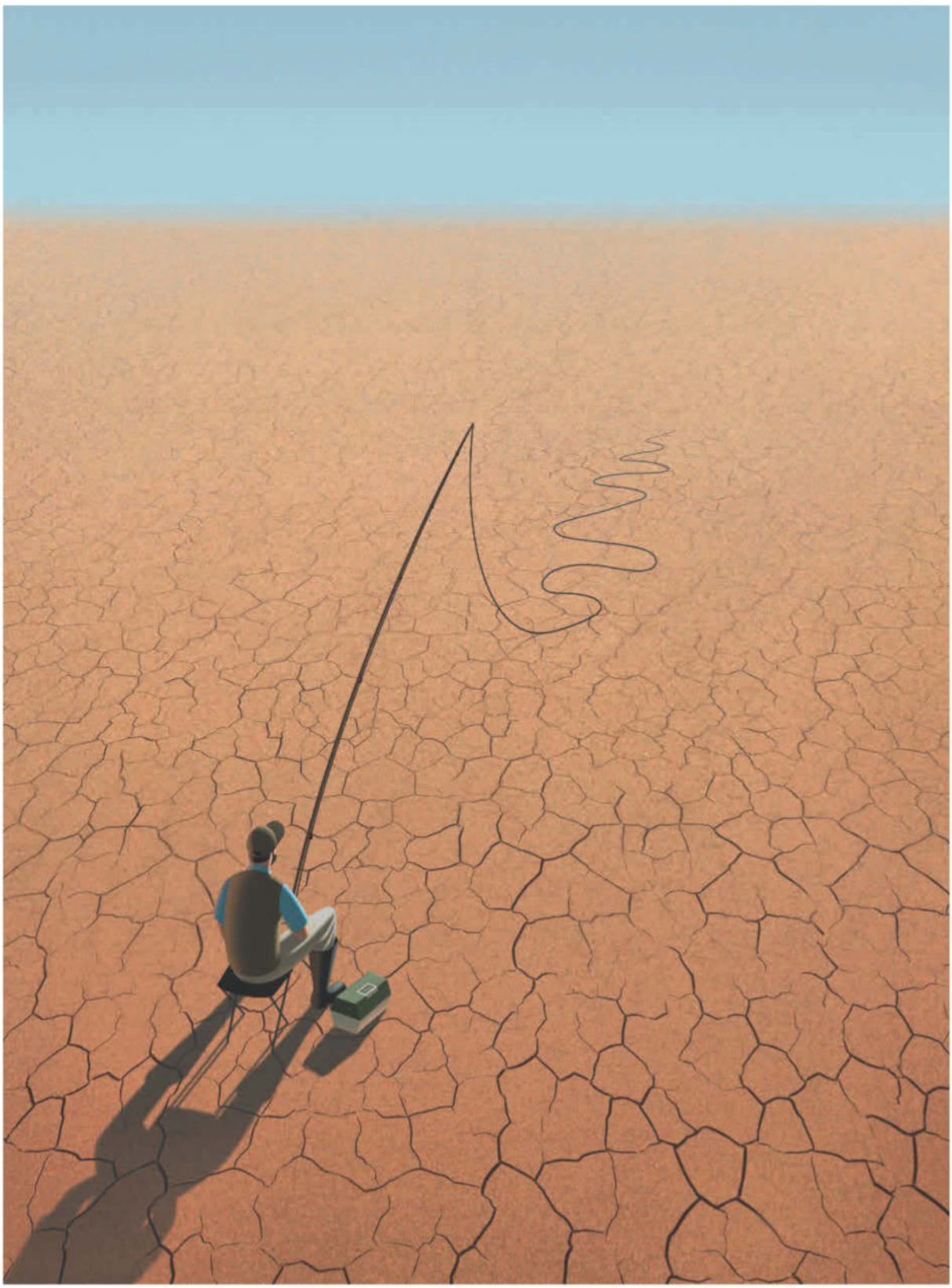
## Are we delusional?

This bold explanation was an early attempt at what we would now consider a scientific theory of cosmology, and one whose suggestion of multiple universes prefigures the concept of the multiverse. But not everyone was impressed. The French satirist Voltaire wrote a vicious parody of Leibniz into his 1759 novel *Candide, or Optimism*. His Doctor Pangloss insists that "all is for the best, in this best of all possible worlds" throughout many dire trials and tribulations. By the end, Pangloss looks like a fool and his philosophy is rejected as nonsense. It was hardly a fair critique of Leibniz's thesis, but it stuck, and optimism has carried connotations of naivety and delusion ever since.

That was one reason it took a long time for psychologists to examine optimism properly. But when they did, the results supported the idea that we are fairly delusional about our futures. In a pioneering 1980 study, Neil Weinstein at Rutgers University in New Jersey asked more than 200 people to estimate their chances of experiencing 42 different life scenarios. Some were positive, like owning their own home or receiving an award for their work; others were negative, like getting divorced or having a heart attack. Most people turned out to significantly overestimate their likelihood of experiencing happiness, health and success, and rated their chances of experiencing negative events as below average.

While it is striking that people tend to consistently err on the bright side, these unrealistically positive expectations may not come from conscious estimation but from sheer ineptitude with probabilities. It takes a lot of data and modelling to make accurate estimates of the chances of a car crash or cancer diagnosis, for example. But studies also show that this bias is persistent: even when we are given accurate information about our chances, we tend to pay more attention if it supports our optimism than if it contradicts it.

It is hard to see how making poor estimates could be good for us, though, and indeed there are indications that people whose estimates are the least accurate – who are strongly optimistic about specific situations, in other words – may be less inclined to take preventative measures or listen to health advice. "It never did my grandad any harm" or "I can give up whenever I like" pretty much sum it up. Researchers have also found links between optimism and risky financial behaviour, including problem gambling. Then there's the "planning fallacy", the tendency of optimists to assume everything will go smoothly. This ›



JON KRAUSE

might mean they are never on time or their work projects run wildly over budget.

So why haven't we evolved to make more realistic judgements of our futures? In 2009, the late Daniel Dennett and psychologist Ryan McKay at Royal Holloway, University of London, set out to test the assumption that realism is best. To do this, they considered whether there might be an evolutionary advantage in holding various kinds of "misbelief" – objectively unsupportable beliefs, such as the existence of supernatural entities. It turned out that one kind did fit the bill, a family of misbeliefs called "positive illusions": our tendency to overestimate our own abilities, control over situations and expectations of the future. In short, optimism.

Dennett and McKay suggested that positive illusions help us strive for goals that might otherwise seem out of reach; ensure that we perceive our children and partners as exceptional and worthy of our love and care; and enable us to moderate the stress we experience when we encounter difficulties.

There is no consensus as to whether this really is the basis for optimism – the evolutionary rationale for psychological traits and their resulting behaviours is notoriously hard to pin down. But perhaps we can take a leaf out of Leibniz's book and ask whether our inability to assess risk and reward in a particular situation might prove beneficial over the many varied opportunities and challenges we face through the course of a lifetime. Perhaps optimism helps us lead optimal lives, not perfect ones. After all, evolution doesn't care about what you die of as long as you've done the work of having and raising offspring before you do. And that involves making a great many decisions about a great many situations. Erring on the positive with each of those might cumulatively deliver significant benefit.

A few years after Weinstein's study, the psychologists Michael Scheier and Charles Carver devised a short questionnaire that explores this possibility. The Life Orientation Test asks people not about specific events, but about how they generally look at life. The test's simplicity has made it enormously popular with researchers for decades, and it has now been used in thousands of studies investigating everything from the coping strategies of people with cancer to the success of stage magicians. Many of those studies have found that this kind of general, dispositional optimism seems to be beneficial – physically, professionally and personally.

This goes some way to explaining the studies showing that optimists fare better when it comes to heart problems, diabetes and infertility, and cope better with stress and pain, as well as with the consequences of extreme events like natural disasters and terrorist attacks. There is evidence of similar patterns in the professional sphere: optimists tend to be high achievers at school and work, enjoy more job satisfaction and cope more effectively with drastic setbacks like the covid-19 pandemic. They do better socially, too: people like being around optimists and optimists have more enduring and satisfying romantic relationships.

**"Our default optimism levels are probably set during adolescence"**

LAOSHI/GETTY IMAGES

**Children's boundless optimism helps them learn**

When looked at in this way, the consensus is that optimists tend to enjoy longer, happier and healthier lives – despite making the odd risky decision and being prone to ignore health advice. The reverse is true for people who score low on optimism and high on pessimism in psychological assessments, which, at the extreme, is strongly associated with mental health conditions, notably depression.

Putting all this together, it seems that while taking an overly optimistic view of a specific event or experience might not work to our advantage, holding generally positive expectations seems to be associated with good outcomes.

But where does our innate optimism come from? And if we are low on it, can we retune it, as it appears we can in dolphins, starlings and bumblebees? Like most psychological traits, our levels of optimism are determined both by our genes and our environment, but what we learn from our experiences seems to be the more important factor.

Children start out boundlessly optimistic: if you think about the magnitude of the challenges they face, they have to be. But over time, that optimism gradually wanes. Exactly how optimism changes through our adolescence and early adulthood is unclear, although it appears to retain its association with physical and mental health throughout our youth and it seems likely that our "default" levels of optimism are set during this time.

What if we want to be more optimistic? Just asking people to think about the future can immediately make them feel more positive about it, as can techniques as simple as giving them cues such as optimistic words hidden in a jumble of others. There are also drugs that achieve the same effect. L-dopa, a chemical that increases dopamine activity in the brain, can boost positive expectations of the future, for instance.

Unfortunately, increases in optimism

THOMAS HOEPKER/MAGNUM PHOTOS

**Envisioning a brighter future can help boost optimism**

that last longer than a week or so have proven more elusive, with researchers trialling a wide variety of techniques, including mindfulness and meditation as well as more esoteric approaches such as sensory deprivation.

A more plausible contender is the Best Possible Self exercise, invented by Laura King at the University of Missouri. The idea is to spend 15 minutes a day writing about the version of yourself in a future where everything has gone right: all your efforts have paid off and you have accomplished everything you ever wanted to. Then you spend 5 minutes imagining that future. Studies so far have examined the effects of doing this for a week or two, and found that the positive impact is modest and melts away within another week or so. Psychologists are now trying to figure out if practising this technique more routinely can make the gains more permanent.

For longer-lasting increases in optimism, the answer may lie within – and that brings us to yet another way of looking at optimism. University of Pennsylvania researcher Martin Seligman, the so-called father of positive psychology, thinks that we learn to explain events, particularly negative ones, in characteristic ways. An optimist, by Seligman's reckoning, tends to think that such events are the result of transient factors, typically external to themselves, and specific to a particular situation. So, for instance, if an optimist fails a job interview, they might chalk it up to an off day: they were feeling tired or the interviewer was biased. A pessimist, on the other hand, would consider it to be just one more example of their general lack of charisma and inability to perform under pressure.

If you are in the latter camp, the solution, according to Seligman, is to practise something he calls the ABCDE approach, in which you challenge your own pessimistic thoughts when they arise. In his book *Learned Optimism*, Seligman gives the example of a person who has lost an expensive earring borrowed from a friend – that's A, for Adversity. B is for their Belief that their friend will be justifiably furious with them for this characteristic irresponsibility. C is for Consequences: feeling sick and stupid. Next is the critical Disputation stage, in which they aim to re-evaluate their thought process by acknowledging that the friend will be disappointed, but also that they will most likely realise it was just one of those unfortunate accidents. E is for Energisation: they dust themselves off and move on.

## Believing in the future

The disputation stage of Seligman's approach is really just a variation on cognitive behavioural therapy (CBT), which teaches people to recognise and change patterns of negative thought and behaviour. CBT is widely used and can be effective for depression, so it makes sense for the ABCDE approach to increase optimism. There are few studies looking at this, but to work, the ABCDE method would probably need to be practised routinely and regularly until it becomes second nature.

Boosting our optimism for the long term is one challenge. Yet we also need to make it broader. We tend to be optimistic about our own lives. We are also optimistic, although less so, about our family and friends. We are even willing to extend our positive expectations to people who aren't close to us, but who we regard as likeable and competent. Widen it further, however, and our optimism shifts to negativity. Although we are inclined to believe that we and those around us are doing fine, we tend not to believe that society on a broader level is doing well. And when asked about our expectations of the world, we are inclined to say that things are going from bad to worse.

This "optimism gap" has been widening in recent years – most strikingly among younger people – and expanding to cover not just economics but also crime, the environment and health, all areas in which we seem unable to extend positivity about our personal experience to the world at large. That matters, because what goes for us as individuals might also apply to our societies: optimism could give us the strength to seek out and devise solutions to our collective problems. So, maybe we need to believe in optimism's power not only to change our own lives, but to do so for all our lives. Or to put it another way: we need to be optimistic about the power of optimism. ▮

Sumit Paul-Choudhury is a former editor-in-chief of *New Scientist*. His book *The Bright Side* is out now in the UK and on 7 January in the US

# Dust to dust

The discovery of ancient human DNA in dirt opens a new window on prehistoric worlds, finds **Laura Spinney**

IT WAS an otherwise ordinary day in 2015 when Viviane Slon had her eureka moment. As she worked at her computer, the results revealed the sample she was examining contained human DNA. There was nothing so unusual about that in itself: at the time, the ancient DNA (aDNA) revolution was in full swing, and surprising new insights about our ancestors were being gradually unveiled. But Slon's sample wasn't from human remains – it was just dirt from a cave floor. That immediately told her she was onto something big.

Many archaeological sites yield tools and artefacts that tell us about human occupation, but few have provided the bones or teeth that could still harbour human aDNA. Even when such remains are present, the chances that genetic material survives within them is slim because DNA is damaged by heat, moisture and acidity. So finding another source of aDNA – the soil itself – was a game changer. "That opens up hundreds of prehistoric sites that we couldn't work on before," says Slon.

Besides, humble dirt can reveal a lot about our distant past. Whereas fossils provide snapshots of prehistory, sediment gives a DNA source that can, in theory, generate an unbroken narrative. Researchers can study hominins predating the practice of burial. They can work out which groups created particular tools and other artefacts, learning more about their cognitive and artistic capacities. And, because the hominin DNA comes with that of ancient plants, animals and microbes, analysis of sedimentary aDNA can reconstruct what life was like for prehistoric humans. "It's a huge advance," says Chris Stringer at the Natural History Museum in London.

As with some of the best discoveries in science, Slon's was an accident. Now at Tel Aviv University in Israel, in 2015 she was one of the young researchers in Matthias Meyer's lab at the Max Planck Institute for Evolutionary Anthropology in Leipzig, Germany, who were attempting to refine the methods for extracting and analysing aDNA. Fossilised remains of hominins are rare and probing for genetic material damages them. So, she thought, before tampering with a precious relic in an attempt to extract a nugget of DNA, it would be useful to have an indication of whether any had survived.

## Accidental discovery

Slon got her inspiration from a group led by geneticist Eske Willerslev at the University of Copenhagen, Denmark, which in 2003 had shown that DNA can survive in sediment for hundreds of thousands of years. Her initial idea was that if aDNA from other mammals had survived to be detected in the soil around hominin remains, perhaps those remains would be more likely to contain aDNA too. Tests showed she was right.

But the surprise came when she used the method on soil from a Spanish cave called El Sidrón where 13 Neanderthals were buried 49,000 years ago. In 2017, Slon and her team reported finding DNA from Neanderthals in the cave floor. This was a first for aDNA in sediment (sedaDNA), but it was just the beginning. The team had identified mitochondrial DNA (mtDNA), a type of genetic material that passes from mother to child. Cells contain many mitochondria, so, in theory, mtDNA is more plentiful than DNA from cells' nuclei and hence dirt samples will be richer in it. But the latter is more informative, because the nuclear genome is larger and contains contributions from both parents. Finding nuclear DNA in

SHUTTERSTOCK/MICROGEN

**Ancient human remains are rare and don't necessarily contain DNA**

sediment would be the next challenge. In 2021, Benjamin Vernot, then in Meyer's lab but now with his own group at the Max Planck Institute for Evolutionary Anthropology, did just that. This time, the results weren't just proof of principle, they also told a story.

Vernot analysed soil from three caves – two in Siberia and a third in Spain called Galería de las Estatuas – and found ancient human nuclear DNA in all three. Since the two Siberian caves had previously yielded hominin bones, he could show that the sedaDNA in the dirt samples confirmed what was already known. But the Spanish cave is where the new method came into its own. Although it was already established that this site had been occupied by Neanderthals for 40,000 years, it had only given up one tiny Neanderthal bone. The sediment analysis revealed much more: it showed that two distinct populations of Neanderthals had occupied Estatuas, with one replacing the other around 100,000 years ago.

That's not all. By comparing the sedaDNA with aDNA from other Neanderthal populations across Eurasia, Vernot was able to

> **"The ancient DNA field is often seen as cutthroat due to the scarcity of bones"**

link these two populations to two Neanderthal range expansions. These occurred on either side of the date that one group replaced the other in Estatuas – perhaps during warmer periods. "It's a change in the populations in that area of the Neanderthal world that we didn't have any inkling of before," says Slon. Suddenly, the great arc of human history was visible, ebbing and flowing across Eurasia.

Given its potential for such revelations, it is hardly surprising that many palaeoanthropologists and geneticists are ›

EDDIE GERALD/ALAMY

SHUTTERSTOCK/IGOR BOSHIN

**DNA from dirt has revealed when different groups of humans lived in Denisova cave, Siberia**

embracing sedaDNA analysis. The cherry on the cake is that there is a near-unlimited supply of source material. That is a relief to some in the aDNA field, which has a reputation for being cutthroat due to the scarcity of bones. "There's enough dirt in the world to go around," says Diyendo Massilani at Yale University, who was also previously in Meyer's lab. The challenge is finding the DNA in all that dirt – and distinguishing hominin aDNA from that of the other species lurking there. If you are lucky, hominin aDNA constitutes 0.001 per cent of sedaDNA, says Massilani. This makes sense, because in the deep past humans were massively outnumbered by other animals – even megafauna such as mammoths, bison and horses – as well as plants and microbes. But it also complicates matters. "It's like looking for a needle in a haystack," he says.

So far, the best sites for yielding sedaDNA have been dry caves. In these cases, geneticists work closely with archaeologists, taking sediment cores during active excavations where possible and correlating their findings with the stratigraphy – the geologically distinguishable layers. More recent disturbance of these layers, for example by burrowing animals or leaching water, can complicate matters, but archaeologists are able to recognise and account for this when working out the chronological sequence. They can also date the layers using artefacts within them that are amenable to radiocarbon dating, along with clues from pollen and bone fragments from extinct species. The assumption is that any sedaDNA will be the same age as the layer it is found in. However, if enough is present, it can even date itself, by virtue of the mutations the DNA has clocked up over evolutionary time compared with known older or younger samples of the same species.

In a clean room, the geneticists extract the DNA from their sediment cores and "enrich" it for hominin DNA. This entails adding probes or bait comprising fragments of DNA found only in the archaic human group of interest that bind to their counterparts in the mix, so that these can be fished out. The hominin aDNA is then sequenced, which gives much finer-grained information about the group concerned, and also allows researchers to verify that it is ancient. They do this by discerning the chemical changes that have accrued in it over time, and that set it apart from potentially contaminating modern DNA.

"It's the combination of the genetic work and the really detailed archaeological work that makes the technique powerful," says Vernot. And, as Massilani told a recent conference at the European Molecular Biology Laboratory in Heidelberg, Germany, it has already earned its stripes.

**"If you are lucky, hominin DNA constitutes 0.001 per cent of the ancient DNA in sediment"**

Take research done in Denisova cave, Siberia, which was occupied by a variety of human groups for more than 200,000 years. A team led by Elena Zavala at the University of Copenhagen, who is yet another Meyer lab alumna, used sedaDNA to reconstruct the timeline of human presence there. In another first, the researchers were also able to work out which groups created which of the thousands of artefacts that have been discovered in various layers of the cave floor.

Their analysis of mtDNA from 175 sediment

MPI FOR EVOLUTIONARY ANTHROPOLOGY

samples revealed that the first hominins to occupy Denisova, starting around 250,000 years ago, were the eponymous Denisovans. They probably fashioned the oldest stone tools found there. At least two different populations of Denisovans and another of Neanderthals then alternated intermittently until about 45,000 years ago, when modern humans appeared in its cavernous chambers. "In the upper layers, people have found these beautiful artefacts, bracelets and pendants that are usually associated with *Homo sapiens*," says Zavala, "but there was no evidence that *sapiens* had been in the cave." Archaeologists had wondered if Denisovans or Neanderthals made the objects, which would have been remarkable if true. Zavala's discovery of genetic material from *H. sapiens* in the cave increases the odds that they were responsible for creating them.

The researchers also found animal DNA preserved in hundreds of other sediment samples, leading them to suggest that archaic humans had probably followed the mammals they preyed on into the Altai mountains where Denisova cave is located. Yaks and horses, for example, are known to have migrated there from South-East Asia via the foothills of the Himalayas, when the climate permitted.

We know that Denisovans and Neanderthals interbred at times, and that at least one individual found in Denisova cave had mixed Neanderthal-Denisovan parentage. Unfortunately, it is hard to tell from the sedaDNA whether the different lineages of Denisovans, Neanderthals and humans met in the cave: one of its limitations is that DNA traces found in the same layer can't be differentiated in time. Nevertheless, with sedaDNA we can start to test predictions about the ranges and possible interactions of these hominins.

For years, Denisovans could only be definitively tied to Denisova cave. One or two other remains had come to light elsewhere, but they were so sparse that together they would fit inside a large envelope. Then, in 2020, a team led by Dongju Zhang at Lanzhou University, China, found DNA in cave sediments on the Tibetan plateau, which showed that Denisovans were there 100,000, 60,000 and possibly 45,000 years ago. This fits with a recent prediction, based on evidence from climate science and palaeobiology, that these human ancestors inhabited a huge and chilly swathe of northern Eurasia and that, at times, their territories would have overlapped with that of Neanderthals, who preferred more temperate climes.

## Prehistoric interactions

"With cave sediment DNA, we can really start to get a fix on the ranges of Neanderthals and Denisovans," says Stringer. We might also learn more about how the areas they occupied overlapped with early modern humans. For example, Massilani has teamed up with archaeologists from Mongolia and the US to try to identify the hominin group that left artefacts in Mongolia 45,000 years ago. "We suspect that these are the cultural remains of the first *Homo sapiens* living in the region, who would have met with Denisovans while expanding eastward," says Nicolas Zwyns at the University of California, Davis.

Undoubtedly, sedaDNA has the potential to reveal a lot more about human evolution. But there are still some big unanswered questions, including where exactly any hominin DNA in sediment comes from. Corpses are obvious candidates, but such remains could have wound up there naturally or through burial, or may even been excreted by a predator. Fossilised hominin faeces and blood are other potential sources. Nor can geneticists know, at first glance, if they are dealing with one or more individuals. However, an ingenious experiment by Vernot is helping to narrow the possibilities. He asked his students to search for dog DNA throughout the Max Planck Institute of Evolutionary Anthropology building. Dogs, which are allowed inside, must pass through lifts and corridors to get to their owners' offices. However, the students only detected canine DNA in the offices themselves. In other words, it requires a prolonged presence or concentrated deposition to produce DNA in detectable quantities – even when not accounting for a time lag of thousands of years.

Over millennia, DNA is gradually lost, and extracting informative quantities of the hominin variety is another problem. Massilani, for one, has been working on ways to optimise the return, using soil archives that have been hoarded by some archaeologists over the decades. Sampling blocks of sediment from 13 prehistoric sites across five continents, he found that seda DNA from any species tended to cluster. The clusters were often associated with bone fragments or fossilised faeces, giving a clue to the source of the DNA in soil. Then, by analysing the blocks containing concentrated amounts of hominin aDNA at much finer resolution, he was able to obtain far more information about the individuals who shed the DNA, down to their sex.

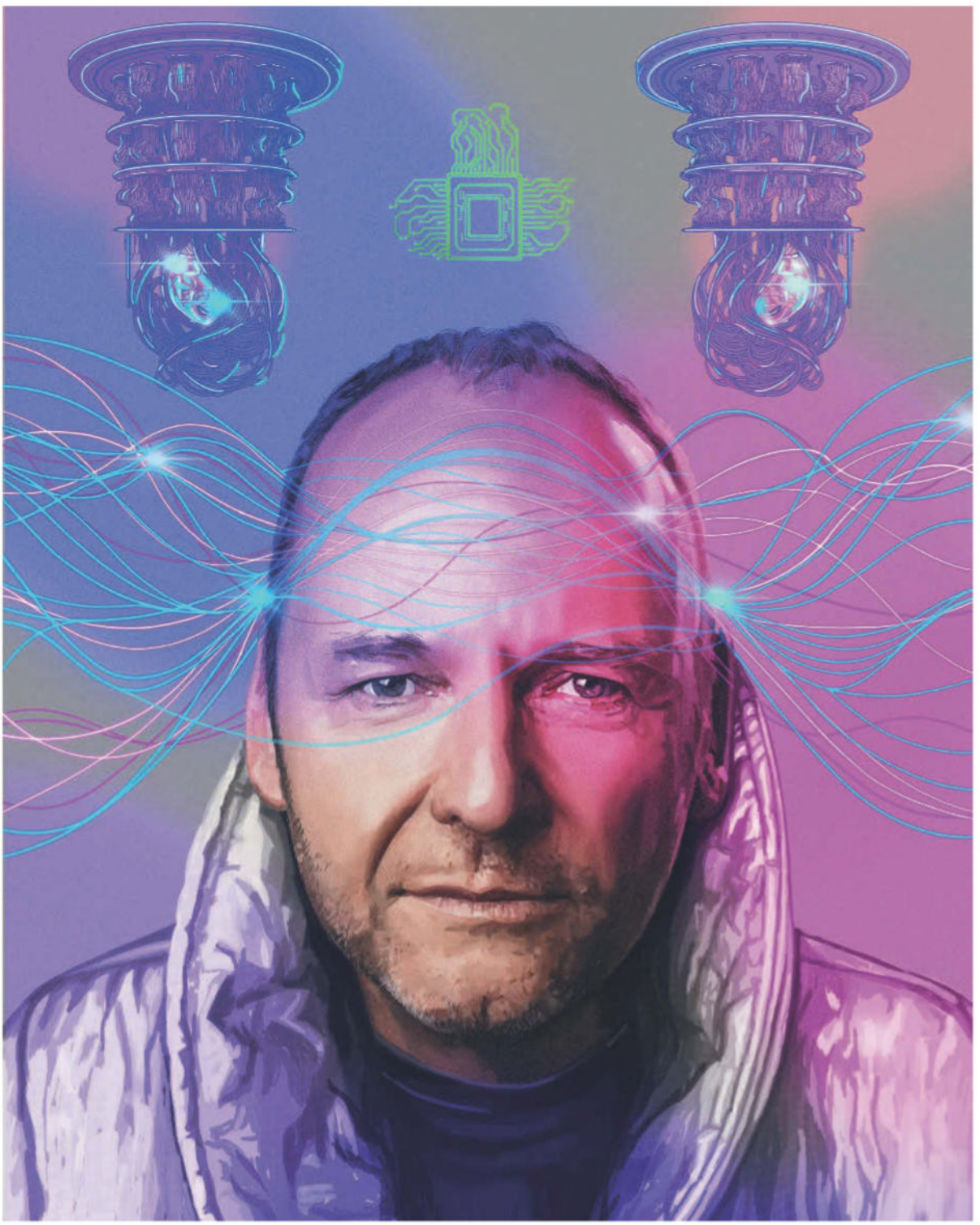
As the pioneers of this field improve their method, one of its most exciting applications could be in parts of the world that have yielded little or no aDNA to date, notably places where heat and high humidity are common. Massilani is currently testing his approach at cave sites in his native Gabon, and Slon has already reported finding mammalian aDNA up to 70,000 years old in an Israeli cave.

Other opportunities abound. Lake sediments could tell us about the world when sea levels were lower. Sites like the Tibetan cave that produced Denisovan sedaDNA could reveal how humans adapted to life at high altitude. From the assemblies of species that occur with archaic humans, researchers hope to track the domestication of plants and animals, as well as changes in human diet and health and the associated genetic adaptations. Within prehistoric settlements, they might be able to discern the segregation of people of different sexes or ancestry. Massilani can even envisage a future where it is possible to detect the presence of ancient people where no human sedaDNA has been found, just from changes in the associated microbial community.

The potential, if not as limitless as the supply of dirt, is huge – and still mostly unexplored. As Slon says: "We're far from having exploited the possibility to its maximum." ▮

**The ancient DNA lab in Leipzig, Germany, where the revolution began**

Laura Spinney is a writer based in Paris, France



MARTA ZAFRA

# "Entangling your brain with a quantum computer could unlock higher levels of consciousness"

**Hartmut Neven** leads the Google lab that builds some of the world's most powerful quantum computers. He tells Thomas Lewton how we might use them to test the idea that consciousness involves quantum phenomena

THE suggestion that consciousness has its origins in quantum weirdness has long been viewed as a bit, well, weird. Critics argue that ideas of quantum consciousness, the most famous of which posits that moments of experience arise as quantum superpositions in the brain collapse, do little more than merge one mystery with another. Besides, where is the evidence? And yet there is a vocal minority who insist we should take the idea seriously.

Hartmut Neven, who leads Google's Quantum Artificial Intelligence Lab, is among them. He originally trained as a physicist and computational neuroscientist before pioneering computer vision – a type of AI that replicates the human ability to understand visual data. Later, Neven founded Google Quantum AI, which in 2019 became the first lab to claim its quantum computers solved calculations that are impossible on a classical computer, a milestone known as quantum supremacy. In December 2024, his team announced another step forward with its new quantum processor, Willow, which it claims is more powerful and reliable than previous chips.

But Neven is also interested in the relationship between mind and matter. And now, in a use case for quantum computers that no one saw coming, he reckons they could be deployed to put the idea of quantum consciousness to the test. Neven spoke to *New Scientist* about his belief that we live in a multiverse; why Roger Penrose's theory of quantum consciousness is worth pursuing, albeit possibly with a new twist; and how we can test such ideas by entangling quantum computers with human brains.

**Thomas Lewton: How has working at the forefront of quantum computing altered your view of what reality is?**

Hartmut Neven: We recently ran a computation on our new quantum processor, named Willow, that would take the best classical supercomputer an astounding amount of time to complete: $10^{25}$ years. This mind-boggling number exceeds known timescales in physics and vastly exceeds the age of the universe. To me, this result suggests that quantum processors are tapping into something larger than just our universe, lending credence to the notion that their computation occurs in many parallel universes.

Over the years, I've come to appreciate that the most straightforward reading of the equations of quantum mechanics is that, indeed, we live in a multiverse: that every object, including myself or the cosmos at large, exists in many configurations simultaneously. This view of reality has profoundly shaped my everyday outlook on life.

**In what way?**

My general stance when describing the world is physicalism, which states that every phenomenon we witness can be explained as a manifestation of matter. But the only phenomenon that we are certain exists is conscious experience. Everything starts from experience; without mind, nothing matters.

So then the task you have as a physicalist is to identify the locus of consciousness. Here, I think, quantum mechanics has a unique advantage over classical mechanics – and it is directly related to the multiverse picture.

If the multiverse picture is correct, then there are a vast number of parallel worlds. But right now, you and I coexist in a definite, classical branch of the multiverse. So why do we witness this configuration and not the other ones? This is an opportunity to place consciousness in your physicalist theory. An attractive conjecture is that consciousness is how we experience the emergence of a unique classical reality out of the many that quantum physics tells us there are.

**Consciousness seems like a very different kettle of fish to quantum physics. How can one be accommodated into the other?**

I'm a disciple of Roger Penrose, who, in his 1989 book *The Emperor's New Mind*, put forth the idea that consciousness involves a state of matter in quantum superposition, where a ›

quantum object exists in multiple configurations at the same time. When the superposition collapses during a "measurement" process, one classical branch gets selected out of many possible branches and this implements a conscious moment. I always thought this was beautiful because then qualia – specific subjective experiences such as the redness of a rose or the feelings that music evokes – can naturally be encoded into the state that [the superposition] collapses into.

**Is there any way to test the idea that consciousness is quantum in origin?**
There are already some insights coming from experiments with anaesthesia. Anaesthetics reversibly knock out your consciousness. You are still breathing, your heart is still pumping, but you can't report conscious experiences anymore. However, even though anaesthetics are a medical godsend and in use for almost 180 years, we still have no clue how they work. Nobody understands it.

Interestingly, the simplest anaesthetics are inert gases like xenon. Even more peculiarly, there are reports that different isotopes of xenon, each of which has slight differences in mass and a quantum property called spin, have different anaesthetic potency. If that can be confirmed, then you can't possibly explain this without considering quantum mechanics. I feel this is a smoking gun experiment.

**And you have proposed another kind of experiment in a recent paper. Can you tell us a bit more about that?**
Let's first picture our brain as containing qubits, which are the basic units of information in quantum computing. I think that's rather uncontroversial. Some researchers – like our colleague Stuart Hameroff, [the director of the Center for Consciousness Studies at the University of Arizona] – suggest that large protein structures in neurons called microtubules act as qubits. But any biophysicist or biochemist would say that, at the very least, on the level of molecules with electron clouds, there are quantum states in our brain – so we can be said to have qubits in our brains.

Then let's say we have "N" qubits in our brain and "M" qubits in an external quantum computer, with the letters referring to a certain number of qubits. If a person could entangle their brain with this quantum computer, they could create an expanded quantum superposition involving "N+M" qubits. If we now tickle this expanded superposition to make it collapse, then this should be reported by the person participating in this experiment as a richer experience. That's because in their normal conscious experience, they typically need "N" bits to describe the experience, but now they need "N+M" bits to describe it.

I call this the "expansion protocol", as it would allow us to expand consciousness in space, time and complexity. In fact, if we can find a way to set up this experiment, and someone reports these richer experiences, then this would support our explanation that quantum processes generate consciousness.

**What do you imagine it would be like to experience this expanded consciousness?**
The number of bits per second that we are consciously aware of is not very large. Many things that you could potentially be consciously aware of you're not. Let's say the James Webb Space Telescope shoots a beautiful picture, we make a screensaver out of it and we admire it. We are not able to consciously behold all the information that's in the myriads of photons streaming into the James Webb telescope. That's an experience we are not able to have.

So, in principle, we could generate way richer experiences than we normally have using our default biological brain. Some extraordinary states of consciousness, such as those experienced under psychedelics, for example, may be sort of a preview of what you could expect here. Entangling one's brain with a quantum computer could potentially unlock higher levels of consciousness, creativity and understanding.

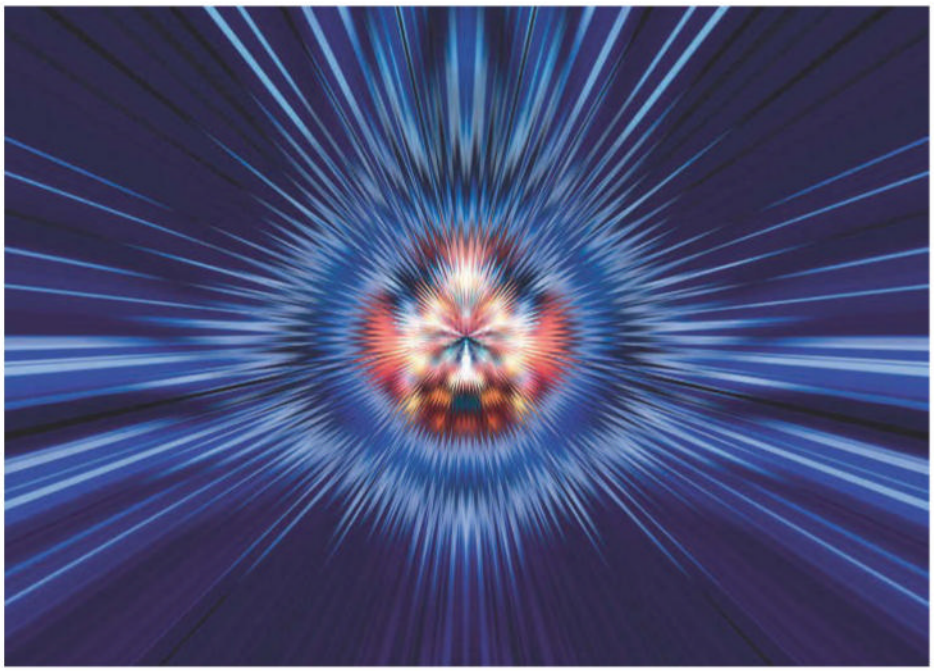
> "In principle, we could generate way richer experiences than we normally have"

**How would this help you to understand the relationship between mind and matter?**
We could use this experimental set-up to identify which quantum states of matter correlate to different qualia. We can do this by asking a person whose brain is entangled with a quantum computer about the specific characteristics of their feelings and measuring the qubits associated with those feelings.

**How has considering this experimental concept changed how you think about the origin of conscious moments?**
When I started to think about this experimental programme, I realised,

SZILAGYI/EPA-EFE/SHUTTERSTOCK

**Quantum computers, like the one shown here, encode information in qubits**



PAOLO CARNASSALE/GETTY IMAGES

**It may yet be possible to test the idea that quantum states give rise to consciousness**

oh, wait a minute, there's actually an issue with Roger's ideas. If I measure a qubit in the quantum computer, the superposition collapses into a state that instantly goes hand in hand with an experience in the person who is entangled with the computer. If this were to happen, then I could use this entanglement – a unique phenomenon in quantum mechanics where two or more particles become intrinsically linked – as a channel to transmit information faster than light.

So, when Roger associated conscious moments with the collapse of superpositions, this opened the possibility of faster-than-light communication, which goes against fundamental rules of physics. I don't like this – I'm the more orthodox physicist on this point. But if, instead, we say that a conscious moment is experienced when a superposition forms, not when a superposition collapses, then this challenge with faster-than-light communication goes away.

In our experimental set-up, we could test which of these ideas is correct. In Penrose's version, the richer experience would be felt when the superposition collapses. However, if conscious moments occur when superpositions form, then the richer experience would be felt as soon as the qubits in someone's brain become entangled with the qubits of the quantum computer.

**What other problems does flipping Penrose's idea on its head help to solve?**

The role of entanglement in the formation of conscious moments naturally explains our unified experience of reality. This is a well-known issue in neuroscience called the binding problem.

When we see an object, such as a face, neurons in the brain's primary visual cortex fire in response to certain features being present, such as edges in certain orientations, creating the rough outline of a face. Then, this brain activity propagates to the higher visual cortices where richer facial features are represented. Our experience is distributed through the brain, rather than single neurons existing that fire to, say, represent your grandmother. We perceive holistically. So there is a disjoint between what we experience and the structure of our material brains. This is called the binding problem.

We can solve this by proposing that entanglement between qubits creates a unified conscious experience. Entanglement is the only true binding agent we have in physics, as it allows for the creation of holistic states where individual components are fundamentally interconnected. Thus, entanglement offers an elegant solution to the binding problem.

**Will it ever be practically possible to entangle a human mind with a quantum computer?**

At this point, the expansion protocol is technically still very challenging. But we can do a simpler warm-up experiment.

In recent years, researchers have become adept at growing little balls of human brain cells called brain organoids. We could use two qubits coupled via a brain organoid and carry out a Bell test – a quantum experiment that checks whether or not two systems are entangled. If we were to find that entanglement is needed to explain the results of this Bell test, then we can conclude that the brain organoid, at least in part, deserves a quantum mechanical description.

Maybe all the ideas I've been talking about turn out to be incorrect. But if it works, then you could ask, how is the quantum coupling best realised? Do you want to use photons? Do you want to use spin – a quantum property that atomic nuclei or electrons have? Or perhaps you want to use collective modes in microtubules.

**What other practical obstacles are there?**

One key requirement for a coherent link between brain tissue and a quantum processor is that it ought to be non-invasive to ensure safety and ease of use. This likely involves using quantum sensing techniques to indirectly probe and interact with the brain's quantum states, potentially through methods like nuclear magnetic resonance [which underpins MRI]. But at this point, we are still too early in our research to attempt to specify this in any further detail.

**How are these ideas about the quantum nature of consciousness received in your circles?**

It's an acquired taste. I'm often surprised how, among scientists, the nature of consciousness is considered a question one shouldn't ask or be involved with. Whereas I think, look, when I have a toothache, this experience is very real, much more real than, say, the big bang or other constructs of science.

The philosopher of science Thomas Kuhn, in his book *The Structure of Scientific Revolutions*, said that before "normal science" can begin, there's a "pre-paradigmatic" phase where we are still searching for the right framework to understand a phenomenon. I believe consciousness research has reached this inflection point. Our conjecture on what creates consciousness and our proposal on how to test it show that the nature of consciousness might be addressed with the methods of experimental science. ▮

Thomas Lewton is a features editor at *New Scientist*

## Mathematics of life

# What day is it anyway?

A mathematical magic trick lets you work out the weekday of any date – with a little help from Lewis Carroll, says **Peter Rowlett**


Peter Rowlett is a mathematics lecturer, podcaster and author based at Sheffield Hallam University in the UK. Follow him @peterrowlett


### What you need

| | |
|---|---|
| January | 0 |
| February | 3 |
| March | 3 |
| April | 6 |
| May | 1 |
| June | 4 |
| July | 6 |
| August | 2 |
| September | 5 |
| October | 0 |
| November | 3 |
| December | 5 |

*Mathematics of life reveals the mathematical ideas and shortcuts behind everyday situations*

### Next week

Debunking gardening myths

TIME comes in cycles, and we deal with it using a cyclic number system. What time is 5 hours after 10pm? Hopefully you would say 3am, not 15pm. You know 10 + 5 isn't 3, but you also know to reset to zero when you hit 12. In mathematical terms, this is called modular arithmetic: we divide 15 by 12 and keep the remainder. We write this as 10 + 5 = 3 modulo 12.

Modular arithmetic has many applications, from cryptography to magic tricks. There is a trick you can learn where you ask someone to name a date this year and respond with the weekday. Imagine they say 4 January 2025. To the number 4 we will add 2, because this month started on a Wednesday, so we missed two weekdays at the start of the year. 4 + 2 = 6, so this date is the sixth day of the week, Saturday.

Later dates in January need a little more work. For example, the 16th gives 16 + 2 = 18. There isn't an 18th day of the week, so we calculate this modulo 7, which means we divide by 7 and use the remainder. 16 + 2 = 4 modulo 7, so 16 January is a Thursday.

We can calculate the weekday of a date in 2025 by adding the day + 2 to the month number from the table on the left. Let's pick a date at random: 19 May. The month number for May is 1, so we work out 19 + 2 + 1 = 1 modulo 7, so 19 May 2025 is a Monday.

The trick is remembering the table of month numbers, or working them out quickly. On 31 March 1887 (a Thursday), Lewis Carroll published a neat

H. ARMSTRONG ROBERTS/CLASSICSTOCK/ALAMY

shortcut for these: if a month starts or ends with a vowel, use 10 minus the calendar number of the month. For example, for April, the fourth month, we use 10 – 4 = 6, so the month number for April is 6. It is a fun coincidence that this works for April, June, August and October.

We can get the number for the month after each of these by adding 2 if it is following a 30-day month or adding 3 if it is 31 days. So we only need to remember January is 0, February and March are 3 and December is 5.

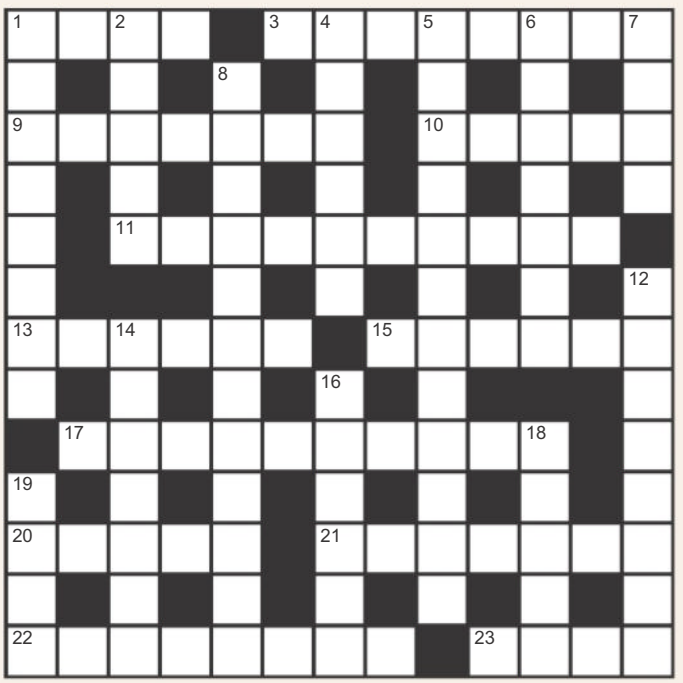
For dates in 2025, we added 2 to the day. In 2026, we will add 3, because 2026 starts on a Thursday. This pattern shifts by 1 a year, or 2 if it is a leap year. This makes the number we add for the year tricky to calculate. Carroll's solution was to work with the last two digits of the year: add to 6 the number of times this number divides by 12, the remainder and the number of times the remainder divides by 4.

For 2030, for instance, we find that 30 can be divided by 12 twice, with a remainder of 6, which can be divided by 4 once. 6 + 2 + 6 + 1 = 15, or 1 modulo 7, so we add 1 to dates that year. In a leap year, we deduct 1 for dates before March. Dates in the 1900s happened one weekday later than in the 2000s, so add 1 for years starting 19.

Carroll said he could do this trick in 20 seconds. Try it on your friends and family and see if you can beat him! ▮

**These articles are posted each week at newscientist.com/maker**

## Cryptic crossword #152 *Set by Trurl*



Scribble zone

Answers and the next quick crossword next week

**ACROSS**

**1** Six-footer lived with parents, to begin with (4)
**3** It's used to keep characters apart in galactic watering hole (5,3)
**9** Tour crew getting Isadore drunk (7)
**10** After relocation, earns some breathing spaces (5)
**11** Gland containing ejaculant evacuated – in Kuwait? (10)
**13** Workplace no longer chilled! (6)
**15** Arguing with @13579, etc. (2,4)
**17** It might be pulled by workaholic learner taken in by "real thing", unfortunately (3-7)
**20** Dread being beheaded by mistake (5)
**21** Stark test of endurance (4,3)
**22** Deep slumber being disturbed repels me (3,5)
**23** Board member retained by Forex economists (4)

**DOWN**

**1** Chop and change grub to obtain absinthe ingredient (8)
**2** Adjusted clasp, where hair grows (5)
**4** Part of engine unit of weight mostly under 3.14 (approx) (6)
**5** Physical qualities, collectively, that may be subject to amendments (12)
**6** Delayed, after change of direction, and ticked off (7)
**7** Red half of country supported by Trumpist premier (4)
**8** Labour regulation? (5,7)
**12** Regressive type exists on nothing, having not raised one cent (8)
**14** Loaded fragment, we're told, is point where leverage might be applied (7)
**16** Concealed by design, it emits light (6)
**18** Adjusted number – about 1009 (5)
**19** Strange, incomplete obstruction in runner's path (4)

**Our crosswords are now solvable online**
newscientist.com/crosswords

## Quick quiz #283
*set by Corryn Wetzel*

**1** What species is Pando, the world's largest tree?

**2** Shark skin is covered in tiny, tooth-like scales called what?

**3** What is the densest planet in our solar system?

**4** What does the acronym CAPTCHA stand for?

**5** What was the first human organ to be successfully transplanted, in 1954?

*Answers on page 49*

## BrainTwister
*set by Katie Steckles*
### #54 New year, new numbers

**Using the numbers 2, 0, 2 and 5 exactly once each, and the operations of addition, subtraction, multiplication and division (and as many brackets as you need), find a way to make each of the totals 1-10.**

**If you are also allowed to raise one number to the power of another, join digits into two-digit numbers before calculation and use the factorial operator (n! is the product of all the numbers from 1 to n, and 0! is defined as 1), can you make all the numbers up to 30?**

**For an additional constraint, can you find a way to write each calculation while keeping the numbers in the order 2, 0, 2, 5?**

*Solution next week*

# ‘Bel Can-do’

**In November 2022 we introduced the Bel Canto.** Instantly making haute horology accessible. This subtly chiming timepiece caused a cacophony. And enormous demand. (The first 600 sold out in 8 hours.) Asked could we produce 5,000 annually, our Swiss CEO Jorg Bader Snr replied: “No. But we’ll find a way.” Because that is our way. Today, our supply chain is as fit for purpose as the gear chain of the new Bel Canto Classic. Which features a dressed-up dial. A dialled-down handset. And a gorgeous guilloché finish, with a precision only achievable (and affordable) using a femto laser. Outward displays, we like to think, of inward grace.

**(Bel Can-)Do your research**

Christopher Ward

christopherward.com

## Building blocks

**All life on Earth is based on DNA. If we ever find life on other worlds, are there viable alternatives for coding for life that it may be based on?**

***Mike Follows***
*Sutton Coldfield, West Midlands, UK*
Life on our planet relies on carbon-based DNA. The panspermia hypothesis suggests that life could have originated in a different part of the universe and then been transported to Earth. In that case, the coding we see on Earth might be universal. However, while molecules like amino acids have been discovered in space, the extraterrestrial formation of complex molecules like DNA and their survival in transit is entirely speculative.

Although carbon-based DNA could have formed independently in different parts of the universe, it is also possible that any alien life could be based on different building blocks, like silicon, or could rely on a different biochemistry. Extraterrestrial life could even use quantum mechanics to process information, transfer energy and communicate.

In his 1944 book *What is Life?*, Erwin Schrödinger introduced the possible role of quantum mechanics in biological processes. Since then, it has been suggested that quantum phenomena – such as superposition (where particles exist in multiple states) and entanglement (where particles affect each other across distances) – could enable life to function more efficiently, with faster energy transfer and information exchange, which could allow alien life to survive in extreme environments.

**"Quantum phenomena might enable alien life forms to function more efficiently and so survive in extreme environments"**

It is possible that many of the plausible life forms imagined in science fiction, as well as any artificial intelligence or artificial life that we might develop or initiate in the future, already exist somewhere else in the universe.

***Garry Marley***
*Stillwater, Oklahoma, US*
First, let's assume that this question is aimed towards life as we know it in the "Goldilocks zone" of planetary temperature, where water is mostly in liquid form. Also, let's assume that matter there consists of the atomic elements we know. Those criteria favour a biochemistry heavily dominated by carbon, which has exceptional affinity for itself. That is why the discipline of organic chemistry – the chemistry of carbon compounds – is so vast.

In the 1952 Miller-Urey experiment, the presumed gases (ammonia, methane and hydrogen) of Earth's primordial atmosphere were mixed with water vapour and exposed to electrical sparks (simulating lightning). The reaction products were a biochemical feast that included amino acids and nitrogenous bases, the organic building blocks of proteins and nucleic acids, respectively.

When made non-biologically, amino acids are produced in a random mixture of "left-handed" and "right-handed" forms. All amino acids in terrestrial life are "left-handed". Some meteorites have yielded fascinating data on amino acids, starting with the Murchison meteorite that hit Australia in 1969. Samples from its fragments revealed a mixture of amino acids that were skewed towards "left-handed" forms.

DNA is a unique, self-replicating, polymeric molecule that carries genetic information encoded as three-letter sequences. In contrast, crystals, for example, can replicate with precision, but don't convey any coded information.

However, many molecular biologists hypothesise that DNA had chemical precursors at the dawn of terrestrial life. In our time, some RNA sequences, known as ribozymes, can catalyse processes such as the formation of short chains of amino acids called peptides.

DNA is only subtly different from RNA, with one of its nitrogenous bases being different and having a deoxyribose sugar instead of ribose. Yet these changes impart a greater chemical stability to DNA and thus to the life it encodes.

The incredible variety of enzymes present in life also facilitates complex biochemical pathways far beyond the catalytic properties of RNA. Therefore, given our current environment, DNA seems to be at the spearhead of a long and complex chemical evolution that highly fit extraterrestrial life would be likely to emulate.

SHUTTERSTOCK/ALONES

Would it make sense to genetically modify any people we send to live on Mars?

## This week's new questions

**Life on Mars** **Should we be thinking about genetic modifications for the humans that we send to colonise Mars?** ***Fred Zemke****, Grover Beach, California, US*

**Feeling contagious** **There are good and bad bacteria, but are there any good viruses? And what would happen if all viruses disappeared?** ***Beth Morrell****, Raleigh, North Carolina, US*

## Being nosy

**Why do our nostrils point down while those of most mammals point straight out from their face?**

***Richard Mohr***
*Wombarra, New South Wales, Australia*
As an ocean swimmer, I find this facial peculiarity the most convincing bit of evidence for the "waterside ape" hypothesis.

When I dive through a wave or

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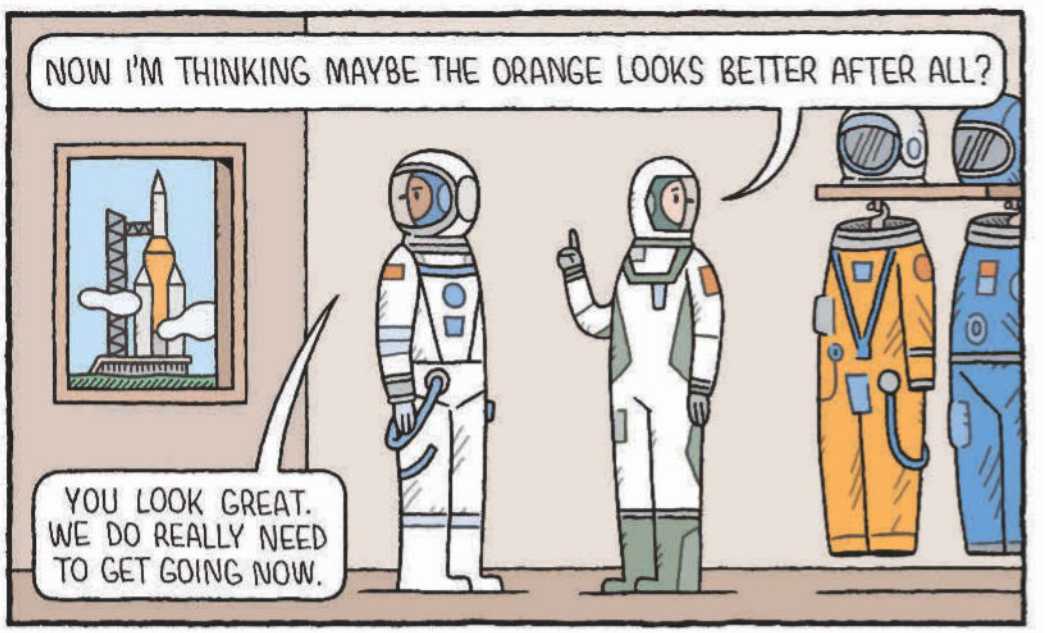
**Tom Gauld**
*for New Scientist*




dive down to look at rocks at the bottom of the sea, I am so glad my nostrils don't point forward, which would force water up them. This orientation would have given a serious evolutionary advantage to primates living near the nutritious riches of the sea and estuaries.

A marvellous 2016 podcast by David Attenborough, crediting Elaine Morgan's work on the aquatic ape idea, also highlighted the value of seafood in explaining why humans developed such large brains.

***David Pitcher***
*Auckland, New Zealand*
The correspondent who posed the question has too small a sample size.

Dogs' nostrils allow them to breathe out sideways (so as not to disturb a scent trail), birds' nostrils are streamlined along their beak, and the nostrils of humans, Japanese macaques and proboscis monkeys all face down (all three of these species commonly swim). Elephants can point their trunks up to form a snorkel, while whales and dolphins have blowholes on top of their heads.

**"Having nostrils that point down would have given a serious evolutionary advantage to primates living near the sea"**

## Wind speed

**If an athlete consumed flatulence-inducing food, could the resulting emissions provide enough jet propulsion to enable victory rather than coming second, given the tiny margins in sprint races?**

***Bethany Snyder (runner)***
*Illinois, US*
If an athlete ate flatulence-inducing foods before a race, they might have an advantage not due to propulsion, but by clearing away the competition.

However, eating such foods probably wouldn't make for a stellar race performance.

***Garry Trethewey***
*Arkaroola, South Australia*
If I fart while running, I always have to concentrate a bit to ensure it is just a fart. I am sure that slows me down a microsecond or two.

## Scaling it up

**Why do we only use 12 notes in Western music? (continued)**

***Tony Durham***
*Brighton, East Sussex, UK*
Music theorist William Sethares had the insight that pitch systems used in different cultures depend on the physics of the instruments being played. The strings and pipes in Western music generate frequencies known as overtones at integer multiples of the lowest distinct frequency, the fundamental one. Having 12 notes per octave happens to deliver a set of pitches that approximate the overtones of Western instruments. Today, the pitches are equally spaced, but early keyboard players experimented with different 12-note tunings. ▮

# Answers

## Quick quiz #283 *Answers*

**1** Quaking aspen (*Populus tremuloides*)
**2** Dermal denticles
**3** Earth
**4** Completely Automated Public Turing test to tell Computers and Humans Apart
**5** Kidney

## Quick crossword #173 *Answers*

**ACROSS 8** Muscle, **9** Universe, **10** Suborder, **11** Ginkgo, **12** Washer, **13** Shinbone, **15** Rabbits, **20** Astatine, **22** Alkali, **23** Eighty, **25** Tapeworm, **26** Rawlplug, **27** Ring up

**DOWN 1** *Futurama*, **2** Acrophobia, **3** Deodar, **4** Sucrose, **5** Kingbird, **6** Mean, **7** Isogon, **14** Black swans, **16** Tricycle, **18** Delirium, **19** Vertigo, **21** Spiral, **22** Ampere, **24/17** Hall-Edwards

## #53 Dividing digits *Solution*

We can add a 6 to get 1236, which is divisible by 4.

We can add a 5 to the end to get 12365, which is divisible by 5, then a 4 to get 123654, which is divisible by 6. But then we are stuck, as none of the remaining digits, 7, 8, 9, 0, gives a multiple of 7 when added to the end.

Using the digits 0-9 once each in the order 3816547290 gives a number that is divisible by 10, 381654729 is divisible by 9, 38165472 is divisible by 8, and so on.

## New year, new you

Welcome to 2025, everyone. No doubt many of the people you know have announced their New Year's resolutions – you may have done so yourself.

Feedback is inherently wary of the New Year resolution phenomenon, for a number of reasons. First, we live in England, so January is a time of grey skies and near-constant rain. It seems utterly counterproductive to launch a life-changing endeavour that usually involves a degree of further suffering at such a miserable time.

Feedback also remembers some dispiriting statistics on the proportion of people who manage to stick to their resolution until the end of January, let alone until the end of the year.

In a bid to refresh our port-fogged memory, we trawled the internet and uncovered a raft of articles claiming that only 10 per cent of resolutions made in January will survive until December.

So we were going to talk about how the social pressure for endless self-improvement is probably driving unhealthy levels of perfectionism, and just generally encourage readers to relax a bit. But first we tried to verify that 10 per cent figure, just to be on the safe side, and we fell down an internet rabbit hole. Several dozen browser tabs later, we have re-emerged with our findings.

The 10 per cent figure seems to be an approximation. The "true" figure (for a given value of true) is 8 per cent and apparently comes from a paper out of the University of Scranton in Pennsylvania, published in December 2012 in the *Journal of Clinical Psychology*. However, we looked in that issue and there is no such paper.

At this point, we were starting to get a little twitch in our right eye, but resolved to plough on. Deep in the Google results, we found a discussion on the Stack Exchange Q&A network about the 8 per cent figure, posing the question: "Is this statistic made up?" In the comments therein, we finally found a source, a paper entitled "Auld lang Syne: Success predictors, change processes, and self-reported outcomes of New Year's resolvers and nonresolvers". It was indeed written by authors at the University of Scranton and published in the *Journal of Clinical Psychology*, but in March 2002.

Eager to finally reach the end of our journey, Feedback read the abstract – and found no sign of the 8 per cent figure. The paper's main claim is that people who made resolutions were more likely to claim success six months later than people who didn't. At this point we screamed internally, read one more paper, didn't find a satisfactory answer, and gave up.

At any rate, Feedback has made a New Year's resolution: we are going to fact-check every unsourced statistic that we see before we restate it.

## Twisteddoodles *for New Scientist*


### Got a story for Feedback?

Send it to feedback@newscientist.com
or New Scientist, 9 Derry Street, London, W8 5HY
Consideration of items sent in the post will be delayed

## Watching the skies

Like many others, Feedback has been mildly bemused by reports of mystery drones whizzing around over the eastern US. We aren't quite sure what to make of it.

However, we are extremely sure what to make of an X post by Larry Hogan, who was governor of Maryland from 2015 to 2023. On his @govlarryhogan account, he posted a video of the night sky "above my residence in Davidsonville, Maryland". At first glance, the clip seems to show lights whizzing around in the sky. However, after a few seconds it is apparent that this is because he is filming it handheld and is moving the camera around. All the video actually shows is some stars, notably the constellation Orion.

Feedback has a long-standing interest in the UFO phenomenon and the ways anomalous lights in the sky can be misinterpreted as alien spacecraft. Plenty of skilled pilots have struggled to determine what's what, which inclines us to cut Hogan a little slack. However, on the other hand, how can you not know what Orion looks like?

Feedback is wary of claims that society is decadent and in decay – it always seems to be a prelude to someone suggesting using violence to fix the problem. But how on Earth did we get from hunter-gatherers who could read the stars in incredible detail – to the point that ancient Aboriginal Australians may have had some ability to predict lunar eclipses, to say nothing of early Polynesian navigators using the stars to find their way across the vast expanses of the Pacific – to someone in a position of authority confidently posting a video of one of the most well-known constellations in the northern hemisphere and claiming it is something malign?

## What's in a name?

Feedback was surprised to learn that virologists are trying to change the naming conventions for viruses. According to a story in *Science* magazine, the US National Center for Biotechnology Information is adding "about 3000 new, Latinized names to its databases in spring 2025". The new names have been chosen using a system devised by the International Committee on Taxonomy of Viruses.

The idea is apparently to systematise an inconsistent mess. But in the process, virologists are trying to change the names of some rather well-known viruses. Human immunodeficiency virus (HIV) is now to be called *Lentivirus humimdef1* and covid-19's SARS-CoV-2 is to be *Betacoronavirus pandemicum*. Researchers quoted in the story said the new system "makes my job harder, not easier" and that reading the new names provided "a much-needed laugh".

Never let it be said that scientists can't squabble over tiny things.

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## MARINE BIOLOGY AND CRUISES

### Whale watching and marine ecosystems in the Azores Islands: Portugal

**13 May 2025 | 7 days**

Participate in whale research, witness their social behaviours and dive into marine life and conservation efforts in this unique Atlantic paradise and spend time exploring the stunning Azores, from volcanic craters to lush landscapes.

### Arctic expedition cruise with Richard Dawkins, Svalbard, Norway

**22 June 2025 | 12 days**

Join Richard Dawkins on an unforgettable Arctic expedition aboard the Greg Mortimer. Explore the polar bear's domain, enjoy Zodiac safaris and discover glaciers, wildlife and the science behind this remote, stunning region.

### Marine conservation cruise exploring Darwin's Galapagos: Ecuador

**14 July 2025 | 8 days**
**28 July 2025 | 8 days**

Set sail on the Solaris yacht to the wild wonders of the Galapagos with marine biologist Jo Ruxton. Encounter sea lions, sharks and vibrant marine life, while exploring stunning islands and learning from expert guides on this unforgettable journey.

### Alfred Russel Wallace's expedition: Cruise Indonesia exploring nature and evolution

**23 January 2026 | 13 days**

Sail the Spice Islands and Raja Ampat like Alfred Russel Wallace, exploring rainforests, marine life and stunning biodiversity aboard the luxury Ombak Putih. Enjoy expert talks, kayaking, snorkelling and encounters with exotic wildlife.

### Cruise wild, historical and archaeological Scotland

**26 May 2026 | 12 days**

Explore Scotland's wild isles aboard the Sylvia Earle, uncovering ancient civilisations, Viking history and wildlife. Visit iconic sites like St Kilda, spot whales and seals and enjoy expert talks on this unforgettable, intimate expedition.

### Total solar eclipse 2026: Iceland to Greenland polar cruise

**7 August 2026 | 13 days**

Embark on a once-in-a-lifetime adventure to witness a total solar eclipse in Greenland's Scoresby Sund. Cruise the Arctic aboard the Sylvia Earle, enjoy expert talks and wildlife sightings, and explore stunning glaciers and fjords.

**Find out more**

**newscientist.com/tours2025**

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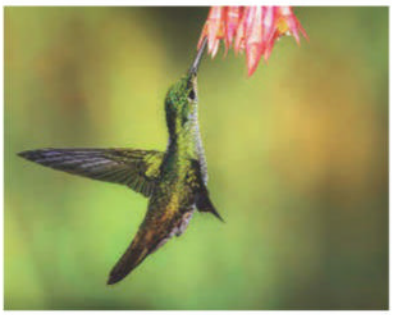
NATURAL WORLD

## Tasmania's flora, fauna and geology: Australia

**1 April 2025 | 12 days**

Explore Tasmania's pristine wilderness, from misty mountains to stunning beaches. Encounter unique wildlife like Tasmanian devils and platypuses while discovering ancient geology, Aboriginal culture and vibrant ecosystems in an immersive, eco-friendly adventure.



## In the footsteps of Alexander von Humboldt: Ecuador

**21 July 2025 | 8 days**

Trace Alexander von Humboldt's 1802 Ecuador expedition through the Avenue of the Volcanoes and cloud forest, exploring stunning landscapes that inspired his "unity of nature" theory, with snow-capped peaks, lagoons and lush valleys.

## The science of primary rainforests and wetlands: Malaysian Borneo

**10 August 2025 | 10 days**

Venture through Malaysia's lush rainforests and wetlands, from Kinabatangan to Danum Valley, spotting orangutans, sun bears, proboscis monkeys, and more – just as Alfred Russel Wallace did when exploring this biodiversity hotspot in 1869.

## Conservation and rewilding in the Central Apennines: Italy

**29 September 2025 | 6 days**

Explore Italy's Central Apennines, tracking wildlife with a nature guide while learning about the Rewilding Italy project. Discover the region's rich culture and warm people, and indulge in delicious local cuisine on this immersive journey.

## Churchill polar bear expedition: Canada

**21 October 2025 | 6 days**

Journey to Churchill, Canada, to witness the world's largest concentrations of polar bears. Explore their evolutionary history and discover how ecotourism supports polar bear conservation and Arctic biodiversity.

## The science of biodiversity: Costa Rica

**5 November 2025 | 13 days**

Embark on an unforgettable journey through Costa Rica's diverse ecosystems – cloud forests, rainforests, volcanic zones and marine reserves – while uncovering the science behind its incredible biodiversity in national parks and wetlands.

**Experience the world's most precious places**

## GEOLOGY AND EARTH SCIENCE

### Astronomy and volcanoes in the Canary Islands: Spain

**27 November 2025 | 7 days**

Embark on an exciting journey to La Palma, Europe's top astronomy site. Explore telescopes, enjoy expert-led stargazing across Tenerife and La Palma, and discover rare rainforests, volcanoes and ancient cave petroglyphs.

### Retracing Charles Darwin's travels across North Wales

**5 May 2025 | 6 days**
**1 September 2025 | 6 days**

Explore Wales' stunning Eryri National Park, uncovering volcanic and glacial geology. Retrace Charles Darwin's 1831 and 1842 journeys from Shrewsbury to Snowdonia, discovering the landscapes that inspired his groundbreaking theories.

### The Rockies and the Badlands: Geology and dinosaurs in Canada

**16 June 2025 | 7 days**

Journey through the stunning Rocky mountains and Alberta Badlands with palaeontologist Jon Noad, exploring World Heritage Sites, dinosaur fossils and the geological story from the Cambrian period to the present.

### Total solar eclipse 2027: Nile cruise, Egypt

**27 July 2027 | 10 days**

Join us in 2027 to witness the longest total solar eclipse this century, from a luxury Nile cruise. Sail from Aswan to Luxor, exploring Egypt's ancient landmarks, including the Valley of the Kings, Karnak, Luxor and Abu Simbel.

### Land of fire and ice: Iceland

**9 June 2025 | 8 days**
**18 October 2025 | 8 days**

Embark on an unforgettable Iceland adventure, exploring volcanic landscapes by day and chasing the aurora borealis by night. Experience erupting geysers, hot springs and fumaroles in a land where nature's power is on full display.

### The geology of the Pyrenees: Spain

**14 September 2025 | 7 days**

Discover the stunning Pyrenees in Aragón, Spain, where unique geology, rich culture and delicious food and wine await. Explore the dramatic landscapes shaped by the collision of the Iberian and European tectonic plates.

**Find out more**

**newscientist.com/tours2025**

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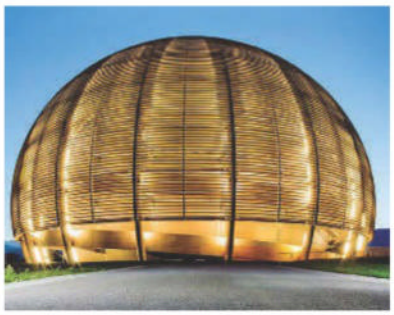
## ASTRONOMY AND PHYSICS



### CERN and Mont Blanc, Dark and Frozen Matter: Switzerland and France

**5 May 2025 | 6 days**
**7 October 2025 | 6 days**

Discover the wonders of CERN, Europe's particle physics hub, with a private tour of the Large Hadron Collider, guided by physicist Darren Price. Explore Geneva's rich history and visit Mont Blanc and a nearby glacier.

### Astronomy and culture through Silk Road cities: Uzbekistan

**23 August 2025 | 14 days**

Discover Uzbekistan's astronomical legacy, rich scientific history and stunning landscapes. Explore ancient observatories, learn about Silk Road cultural exchanges and stargaze under the breathtaking skies of the Central Asian steppes on this captivating journey.

### Renaissance astronomy in Kepler's Prague: Czech Republic

**14 September 2025 | 6 Days**

Explore Prague's Renaissance legacy with astronomer Martin Griffiths, uncovering the contributions of Johannes Kepler and Tycho Brahe. Walk the city's historic streets, discovering how astronomy, maths, music and art shaped early science in this captivating journey.

### Astronomy and tiger conservation safari: India

**12 January 2026 | 11 days**

Embark on a wildlife and stargazing safari in India, exploring Tadoba and Pench reserves for Bengal tigers. Stay in award-winning lodges and visit key historical and modern observatories, blending nature, astronomy and conservation.

### The world capital of astronomy: Chile

**27 March 2026 | 13 days**

Visit Chile, the world's astronomy capital, home to 70 per cent of global telescopes. Visit cutting-edge observatories and stargaze under some of the clearest skies on Earth, experiencing the ultimate astronomical adventure.

### Total solar eclipse 2026: North-central Spain

**10 August 2026 | 5 days**

Witness the total solar eclipse on 12 August 2026, with expert astronomers and guest speakers. Enjoy exclusive views 40km west of Burgos, Spain, and deepen your understanding of this breathtaking natural phenomenon from the perfect vantage point.

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## SCIENCE HISTORY AND INNOVATION

### The science of the Renaissance: Italy

**7 April 2025 | 6 days**

Visit Italy's Renaissance cities – Florence, Pisa and Bologna – uncovering scientific breakthroughs by Leonardo da Vinci, Galileo Galilei and more. Discover art, architecture and collections that highlight the era's intellectual and artistic revolution, all while staying in Florence, the heart of the Renaissance.

### The science of Champagne: Northeastern France

**8 June 2025 | 5 days**

Indulge in a sparkling journey through Reims, exploring renowned champagne houses like Taittinger, Moët and Bollinger. Enjoy exclusive tastings, behind-the-scenes tours of ancient cellars and discover the science that shapes champagne's unique character and terroir.

### The science of the waterways: England and Wales

**28 June 2025 | 7 days**

Discover the engineering marvels of England and Wales' waterways, visiting six of the UK's seven wonders, including Pontcysyllte Aqueduct, Standedge Tunnel and Bingley Five-Rise Locks. Uncover the science and history behind these iconic structures.

### The birth of modern medicine: Paris, France

**20 July 2025 | 5 days**

Explore the birth of modern medicine in Paris, where the "Paris School" of hygiene and hospital teaching thrived. Discover mummified figures, bone-lined catacombs and more, with historian Richard Barnett, delving into medicine's fascinating and gruesome history

### The science history of Scotland: The Enlightenment and beyond

**4 September 2025 | 5 days**

Discover Edinburgh and Glasgow's scientific legacy, learning about groundbreaking thinkers from the 16th century onward. Discover key Scottish Enlightenment sites, where pioneers in geology, medicine, physics and more shaped our understanding of the world through vibrant intellectual exchange.

### The science of pilgrimage: Portugal and Spain

**6 September 2025 | 9 days**

Join us on a unique pilgrimage that blends scientific exploration with ancient tradition. Starting in Porto and ending in Santiago de Compostela, this journey will explore the biomechanics, physiology and psychology behind the pilgrimage experience.

**Find out more**

**newscientist.com/tours2025**

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# ARCHAEOLOGY AND PALAEONTOLOGY

## Temples, fortifications and archaeology: Megalithic Malta

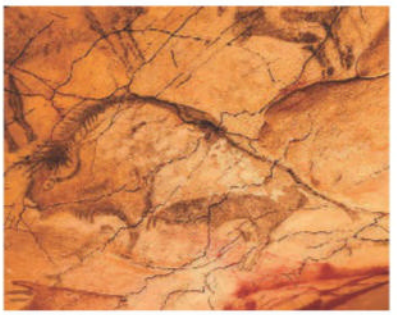
**24 March 2025 | 6 days**

Explore mysterious temples believed to be some of the world's oldest structures, neolithic caves and the resilient fortifications of the Knights of St John.

## Human Origins: Neolithic and Bronze Age Turkey

**24 May 2025 | 10 days**
**11 September 2025 | 10 days**

Take part in a captivating journey through Turkey, uncovering the mysteries of ancient landscapes and human history. Led by an expert archaeologist, explore historical sites and museums filled with priceless artefacts, bringing the past to life in unforgettable ways.



## Ancient caves, human origins: Northern Spain

**17 June 2025 | 7 days**
**26 August 2025 | 7 days**

See some of the world's oldest known cave paintings in this idyllic part of northern Spain. From ancient Palaeolithic art to awe-inspiring geological formations, each cave tells a unique story that transcends time.

## Pre-Historic Origins: Southwest England

**14 July 2025 | 5 days**

Discover the Neolithic, Bronze Age and Iron Age on a scenic walking tour through south-west England. Explore ancient hillforts, stone circles and breathtaking landscapes, uncovering the region's rich history and natural beauty.

## Dinosaur hunting in the Gobi Desert: Mongolia

**16 August 2025 | 15 days**

Embark on an exciting adventure in the Gobi Desert, a top palaeontological hotspot. Join live fossil digs, unearth dinosaur remains and explore key sites with the chance to witness a groundbreaking palaeontological discovery firsthand.

## Mycenae and Peloponnese archaeology: Greece

**29 September 2025 | 8 days**

Join a behind-the-ropes tour of Mycenae, one of Greece's most important archaeological sites. Explore hidden gems and iconic Mycenaean landmarks in the Peloponnese, staying in the coastal town of Nafplio while discovering this stunning region.

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