New Scientist

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A bit hormonal

For too long, scientists have ignored the impact of fluctuating female hormones

THE first rule of hormones was always that you don't talk about your hormones. For decades, women have often felt the need to minimise or hide the impact that fluctuating levels of female sex hormones can have. The shifts in oestrogen levels experienced by many can be as profound as they are frequent – fluctuating monthly and also changing dramatically during puberty, pregnancy and menopause.

These hormonal ups and downs don't just have a personal impact, but are also a nuisance for medical research, where it was long common to exclude women from studies to prevent their hormones from muddying the results.

One consequence of this exclusion was the view of ADHD as a male condition, particularly one involving hyperactive young boys. We now know that girls are just as likely as boys to have ADHD, but their symptoms can be harder to spot. Women who slipped under the radar as children are only now realising that they have the condition and seeking treatment.

Here again, hormones play a role,

> "Hormonal fluctuations and shifts can profoundly affect ADHD symptoms and treatments"

as scientists uncover what many women with ADHD already feel: that hormonal fluctuations and shifts can profoundly affect ADHD symptoms, sometimes undermining treatments and pushing their coping techniques to breaking point.

The hope, of course, is that a better understanding of how sex hormones affect brain function will lead to better treatments, but as we report on page 28, this work also gives women with ADHD a powerful self-understanding, finally allowing them to predict and work around changes in attention and motivation.

Yet how will those who most need to know ever find out? Mercifully, the taboo on talking about hormones has now been smashed, a surprisingly positive outcome of social media's obsession with female health and wellness. What once felt unmentionable is now far from it, with hormone changes, menstrual phases and associated symptoms now commonly discussed online. The challenge is to use these conversations for progress and resist reverting back to old stereotypes. ▮

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Quantum computing

A new replication crisis?

A review of thousands of scientific papers about quantum computers suggests results from one computer may not be reproducible on another machine, reports **Karmela Padavic-Callaghan**

THE results of most scientific papers reporting on advances in quantum computers can't be replicated, according to a new analysis. This may undermine the credibility of some of the achievements that the quantum computing industry has reported in recent years, kicking off a replication crisis in the fast-growing field.

There are a few problems that researchers are certain only a quantum computer could solve, but what these machines could be useful for beyond those select few cases is an open question. With quantum computing hardware improving rapidly in recent years, researchers across the globe are exploring myriad use cases, from simulating molecules to optimising airline logistics.

Yet, for any of these to become routinely used, they will have to work on many different quantum computers, so any demonstration of a truly valuable use of a quantum computer must be reproducible.

Wolfgang Mauerer at the Technical University of Applied Sciences Regensburg in Germany and his colleagues have now evaluated thousands of scientific papers on quantum computing and found that, currently, most can't be reproduced.

They carried out their analysis in two parts, first manually evaluating a curated sample of 127 papers from the past five years, then using a computer program to automate and generalise this analysis to 4966 papers.

To assess the reproducibility of each paper's results, the team used five criteria. The first three focused on determining whether the paper included code that could be run on an independent quantum computer and how much instruction and documentation for doing so was provided. The next criterion evaluated available information about hardware. Finally, the team tested whether the provided quantum computing program could run without errors.

Among the 127 papers that the researchers analysed manually, only 24.4 per cent provided code that they could even try running, and 64.5 per cent of that code failed to successfully execute.

> "Innovation may be more important than reproducible infrastructure at this time"

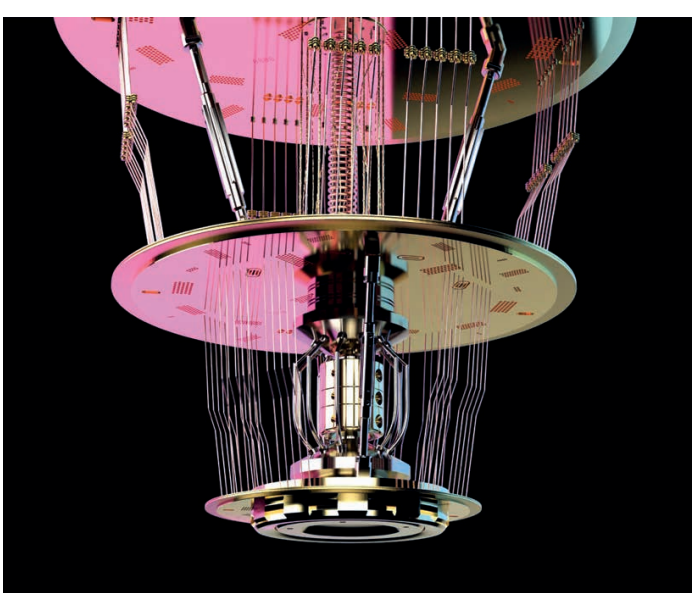
The larger, automated analysis didn't include an execution step, but similarly found that only 26.8 per cent of the almost 5000 papers provided enough information to attempt a replication (arXiv, doi.org/rj93).

Compared with standards for traditional computer science studies, this is a rather negative result, says Mauerer. "We did a smaller-scale study four or five years ago, and we already found that the situation is bad, but it didn't really improve over time," he says. "We thought the numbers would be better by now."

In Mauerer's view, a big reason for this finding is the variability and inconsistency of still-maturing quantum computing hardware. For conventional computers, researchers can work at a very abstract level, describing and writing code without worrying about whether their computer's physical characteristics may change from one day to another. This isn't the case for quantum computers that currently exist and can, for example, be accessed through the cloud, says Mauerer.

"I don't just want to attribute the lack of reproducibility to, say, some laziness of authors or non-requirements by the community. Quantum machines in themselves are unusually variable," he says.

"Software, especially in a rapidly evolving field like quantum computing, is a living thing and needs communities of maintainers," says William Zeng at the Unitary Foundation, a quantum technology non-profit organisation.



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For quantum computers to be useful, code will have to work on different machines

Rapidly changing field

Zeng says he isn't surprised by the results of the analysis, but expects that a combination of community efforts and the use of AI agents for coding will improve the situation going forward. "[Agentic coding] is also already making it easier to generate code directly from a paper's result that is used for reproduction," he says.

Fred Chong at the University of Chicago says he isn't particularly alarmed by the new analysis. "Quantum computing and software systems are in their infancy and changing rapidly. Reproducibility becomes more of a priority as the field matures," he says. For example, in conventional computer science, it took decades for researchers to start insisting on reproduction standards for each other. "Innovation may be more important [for quantum computing] than reproducible infrastructure at this time," says Chong.

Yet, there is appetite among quantum computing researchers to make changes for the better already, and so far, the response to the new study has been positive, says team member Ralf Ramsauer, also at the Technical University of Applied Sciences Regensburg. He says researchers should start thinking about reproducibility at the beginning of each experiment, and if they aren't sure where to start, the team's study offers a template for creating a reproducibility package.

Climate change

Rapid CO_2 rise could see the end of a critical ocean current

Madeleine Cuff

THE fate of the Atlantic Meridional Overturning Circulation (AMOC), a critical ocean current that gives much of Europe mild winters, may depend more on how fast our planet heats up than the temperature level we ultimately end up with.

René van Westen at the University of Utrecht in the Netherlands and his colleagues used an advanced climate model to simulate the stability of the AMOC under three different rates of warming. The first scenario modelled a very slow increase of carbon dioxide concentrations of 0.5 parts per million each year; the second, a rate five times faster; and the third, a rate 10 times faster, which is comparable to today's rate.

The researchers found that, under very slow rates, the AMOC remained stable beyond 5°C of warming. "We were very surprised by this result," says van Westen. But under current rates, the AMOC collapses at about 2°C of warming (*Nature Climate Change*, doi.org/rkbf). Unless the world dramatically reduces its emissions, this could happen around 2060, says van Westen.

The AMOC carries warm, salty water from the Gulf of Mexico towards the north Atlantic Ocean, where it cools and sinks, flowing back south along the ocean floor. To drive the flow of the current, surface water around Greenland must sink into the deep ocean. This depends on the surface water cooling and becoming dense enough to descend.

But under fast rates of warming, surface waters become warmer and lose density far faster than the deep ocean, leaving the ocean layers divided and unable to mix well. Keeping a slow pace of warming allows both the surface and deep ocean water to change at roughly the same pace, says van Westen.

The findings suggest that a marked slowdown in the rate of CO_2 pollution could rescue the AMOC from collapse. ▮

Health

Blood's body clock means anaemia cases may be missed

Linda Geddes

BENIS ARAPOVIC/DPA/PICTURE ALLIANCE VIA REUTERS

The components of our blood aren't constant during the day or year

A BLOOD test taken in the morning could give subtly different results from an evening one, or a test at another time of year. The discovery may affect whether people are diagnosed with conditions like anaemia or are able to donate blood.

Anaemia occurs when the number of red blood cells, which contain the oxygen-carrying protein haemoglobin, is lower than normal or if they have too little haemoglobin. Cases are often missed, while low levels of haemoglobin or iron can affect whether someone is judged healthy enough to give blood.

"As we learn more about medical chronobiology, it's becoming increasingly clear that when we measure something can be almost as important as what we measure," says Tami Martino at the University of Guelph in Canada, who wasn't involved in the research.

Components of blood fluctuate over the course of the day. For instance, red blood cells show daily changes in the chemical state of haemoglobin, which may influence signals that contribute to fluctuations in body temperature.

In the latest study, Sophie Wehrens at the Sanquin Blood Supply Foundation in Amsterdam, the Netherlands, focused on how concentrations of an iron-storage protein called ferritin and haemoglobin vary throughout the day and year.

The researchers analysed blood measurements collected from around half a million Dutch people when they registered as donors between 2013 and 2023. They found that haemoglobin and ferritin levels vary with the seasons, peaking in December and troughing around June to August.

> "When we measure something can be almost as important as what we measure"

This could be due to the body's response to warmer temperatures, says team member Katja van den Hurk, also at the Sanquin Blood Supply Foundation. When it is hot, the body directs more blood towards the skin to help shed heat, while prolonged exposure to warmer temperatures can increase the volume of blood plasma, the liquid portion of blood. This then increases the volume of circulating blood, which lowers the concentration of haemoglobin and other blood biomarkers like ferritin, says van den Hurk.

The team also found that haemoglobin levels followed a daily pattern, peaking at around 10.30am and gradually falling as evening approached. The size of this fluctuation was slightly greater in men than women, and in both sexes, the daily peak occurred around an hour earlier in people aged over 45 (Preprints with The Lancet, doi.org/rkbg).

The age finding fits with what we already know about how our circadian rhythm changes throughout our life, says Martino. The circadian rhythm describes the natural oscillations in the activity of our tissues, driven by an internal clock over a 24-hour period.

The sex differences could partly reflect the influence of sex hormones, she says, but the study didn't look into this.

Whether these daily changes are driven by the body's internal clocks or other factors that vary between day and night – such as how much someone's eaten and drunk – is unclear, as is whether these fluctuations serve any biological purpose, but they could have clinical implications.

John O'Neill at the MRC Laboratory of Molecular Biology in Cambridge cautions against any change to clinical guidelines based on these findings alone. But he says clinicians should be aware that haemoglobin levels fluctuate. ▮

Mathematics

Quantum solution to 250-year-old puzzle

Karmela Padavic-Callaghan

QUANTUM entanglement is key to solving the "36 officers problem", originally posed in the 1700s.

According to folklore, the polymath Leonhard Euler was asked by Catherine the Great to arrange 36 military officers from six different regiments in a 6-by-6 grid so that in each row and column, each officer belongs to a different rank and regiment. Euler concluded that no such arrangement exists, and more than a century later, another mathematician, Gaston Tarry, rigorously proved this to be correct.

But in 2022, Karol Życzkowski at Jagiellonian University in Poland and his colleagues showed that the problem could be solved after all – if it was made quantum.

Now, Robin Simoens at Ghent University in Belgium and Simeon Ball at the Polytechnic University of Catalonia in Spain have built further on the 2022 work, identifying the ingredient that was crucial for solving the problem: quantum entanglement.

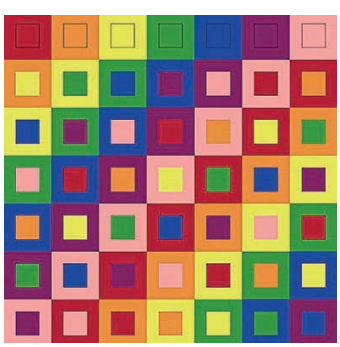
The 36 officers problem is an example of a "Latin square", or a grid filled with symbols that each appear once per row and column.

Życzkowski and his colleagues solved their quantum Latin square by letting each officer have a quantum mixture of ranks and regiments. For example, there could be an officer for whom it would be impossible to tell with complete certainty whether he was a captain of artillery or a major of cavalry because these options would be in a quantum superposition.

But their solution also contained an additional quantum ingredient. It required all 36 officers to be connected through the inextricable link of quantum entanglement. In fact, in solving Euler's centuries-old problem, Życzkowski and his colleagues invented a new absolutely maximally entangled (AME) quantum state. Życzkowski says that this is equivalent to entangling four six-sided dice so much that after a person rolls two dice, they can predict the outcome of rolling the remaining two.

Simoens and Ball wondered how much of this quantum correlation was really necessary. "We wanted to try to find a simpler solution that doesn't use so much of the power of entanglement," says Simoens.

He and Ball translated the problem of filling up the 6-by-6 grid into a type of mathematical graph. Then they used a computer algorithm to search through all iterations of this kind of graph, looking for a special feature that corresponded to a certain quantum state of the officers – one that



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Latin squares have symbols that each appear once per row and column

would solve the problem through superposition alone, without requiring all that entanglement. But they discovered that such a solution doesn't exist (*Physical Review Letters*, doi.org/hcfjwj).

"This shows that our solution is, in a sense, as simple as possible, since the effect of quantum entanglement is indispensable," says Życzkowski. ▮

Space

Earth microbe can grow in Mars-like conditions

Michael Le Page

SALT-LOVING, or halophilic, microbes found on Earth can grow in conditions close to those that might be found in little pockets of highly salty water just below the surface of Mars.

Such pockets haven't yet been discovered on Mars, says Adam Robinson at the University of Florida, who carried out the experiments, but work by others suggests they might exist.

"There's pretty robust evidence that points towards active growth and not just survival"

The microbe used in the experiments is *Haloferax volcanii*, an archaeon – the other kind of simple cell besides bacteria – that thrives in extremely salty waters such as the Dead Sea. It is known as an extremophile.

Robinson and his colleagues added the microbes to simulated Mars-like conditions: water containing 225 grams of salt per litre at a temperature of 21°C (about 70°F), under an oxygen-free atmosphere at a pressure of 24 millibar. Varying levels of nitrates and chlorates – found on Mars – were added to different batches. They then watched how the microbes grew for 160 days. For controls, the microbes were grown in the same media but at Earth atmospheric pressure: 1013 millibar.

While growth was slower in the low-pressure condition, it did still occur, as shown by the growth medium becoming cloudier – a standard measure of growth – and the biological reduction of nitrate and perchlorate. A scanning electron microscope also revealed extensive biofilm formation (bioRxiv, doi.org/rj4k).

"So there's pretty robust evidence that points towards active growth and not just survival," says Robinson. Many previous studies have demonstrated that microbes can survive in Mars-like conditions, he says, but very few have shown growth, and none have shown growth of salt-loving extremophiles.

It is surprising that any Earth microbe can grow in these conditions at all, says team member Scott Perl at the Los Angeles Natural History Museum, given that nowhere on Earth's surface has such low pressure. But if life did evolve on Mars billions of years ago, when conditions were more favourable, it would have had ample time to adapt to such conditions, he says.

However, the researchers did add yeast extract to the growth medium as a carbon source. They plan to replace the yeast in future experiments with acetate, a potential carbon source thought to be found on Mars today.

Sean McMahon at the University of Edinburgh, UK, says that temperatures on the surface of Mars can exceed 21°C during the day. "But here, the pressure is only around 6 to 12 millibar. The difference is significant because, in the realistic range, water cannot stay liquid. No liquid water, no life."

Underground, where pressures could reach 24 millibar, the temperatures are well below freezing, says McMahon.

Robinson thinks the conditions used in the study are plausible on Mars. But the team is already investigating whether cold-loving halophiles can grow between 0° and 4°C (32° and 39°F) and pressures of between 7 and 12 millibar, he says. ▮

Wildfires shaped human evolution

A reconstruction of East Africa's environment 1.75 million years ago suggests wildfires spiked in wetter times, and our ancestors may have taken advantage, finds **James Urquhart**

CHEMICAL traces from ancient plants in East Africa's Turkana basin suggest that wet climatic spells fuelled wildfires that potentially shaped our hominin ancestors' evolution 1.75 million years ago.

Rich in hominin fossils and archaeological finds, the Turkana basin – sometimes dubbed the Cradle of Humankind – has long been considered important for understanding the lives of our early ancestors.

The first truly complex stone tools were found here, too, in layers dating back to around 1.76 million years ago. Compared with earlier tools, these "Acheulean" tools were more advanced, and included refined multi-purpose hand axes, useful for both butchery and plant processing. The Acheulean technology then persisted for the next 1.5 million years.

One idea is that ancient hominins evolved the greater cognitive flexibility required to produce Acheulean tools – and to begin controlling fire – in response to dramatic environmental swings and rapidly changing ecosystems. But although previous studies have found evidence in favour of this "variability selection hypothesis", establishing exactly what kinds of shifting environmental conditions may have driven these cognitive and technological advances has proved challenging.

Now, Rachel Lupien at Aarhus University, Denmark, and her team think they may have an answer. They analysed chemical signatures in sediments that formed in the Turkana basin over a 21,000-year period, roughly 1.75 million years ago. With the information, they could reconstruct rainfall, vegetation and wildfire patterns when the earliest Acheulean tools were in use.

"Because these three powerful climate and ecosystem indicators are all from the same sample, we could directly look at how their relationships vary through time with no guesswork," says Lupien.

GIDEON MENDEL/GETTY IMAGES

Wildfires in East Africa may have sparked behavioural innovations in hominins

The chemical signatures came from ancient leaf waxes and plant combustion, revealing how the nature of the vegetation shifted from woody to grassy conditions, and how wildfire intensity changed across time.

They found that the landscape was predominantly forested, with limited wildfires for the first 5000 years of the study interval. It then became far more variable for the next 5000 years, fluctuating between very dry grasslands with occasional wildfires, perhaps caused by lightning strikes, and wetter forested conditions with far fewer fires. But during the final, longer period of the study interval, something surprising happened: rainfall increased significantly to produce monsoon conditions – and the number of wildfires rose, too (*Quaternary Science Reviews*, doi.org/rkbc).

Hominins were making and using Acheulean hand axes for around 1.5 million years

HERITAGE IMAGE PARTNERSHIP LTD/ALAMY

"We find that higher precipitation leads to more vegetation growth, which allows fires to burn because of the additional biomass," explains Lupien. Meanwhile, more fires limited vegetation expansion, which created a feedback loop. "What we can say from our data is that if humans were taking advantage of fire in Turkana, it would have been during these... wet intervals when monsoons were magnified."

"Here, we're now beginning to see the definite evidence that bushfires were there in their world," says John Gowlett at the University of Liverpool, UK, who wasn't involved in the analysis. It wouldn't be surprising if ancient hominins then experimented with using those fires to improve their access to resources, he says.

For instance, frequent natural fires would have increased hominin opportunities for 'fire foraging': gathering up animals or plants that had been killed and cooked in the flames. It would also have allowed hominins to experiment with taking burning branches from natural wildfires and feeding them to keep fires burning longer, so they could cook food for themselves.

"It is far easier to keep a fire going than it is to start one," says Matt Grove, also at the University of Liverpool and part of the research team. "In this way, hominins could have started to reap the benefits of fire long before they were able to create it."

"Frequent natural fires would have increased hominin opportunities for 'fire foraging'"

A study published this year presented evidence of this type of fire use between 1.07 million and 1.79 million years ago at South Africa's Wonderwerk cave. Tentative evidence of fire use in Turkana dates back to around 1.5 million years ago.

The appearance of Acheulean stone tools during this interval may be further evidence of behavioural changes linked to the highly variable environments in which ancient hominins evolved. Rick Potts at the Smithsonian Institution in Washington DC, who pioneered the variability selection hypothesis in the 1990s, thinks a link is plausible. ▮

Archaeology

Iron Age Britain was a woman's world

Clans in north-east England were organised around maternal lineage in the centuries leading up to the Roman conquest of Britain, discovers **Michael Le Page**

THE DNA of more than 500 people who were buried in the north-east of England over several centuries before the Roman invasion of Britain in AD 43 has been sequenced. It reveals a society organised around women, with large clans for which descent could be traced down the female line for up to nine generations, but where fathers were often absent from burial sites.

The study also reveals that some women had multiple male partners and shows a pattern of repeated unions between two maternal clans. "It's revolutionary, and will totally change the way we think about the Iron Age," says Rachel Pope at the University of Liverpool in the UK, who wasn't involved in the study.

It was suggested in the 1860s that early societies were female-led, but the idea was rejected by later anthropologists, who assumed male-led societies were the natural order. From the 1950s onwards, however, discoveries in Europe of lavish burials of ancient women showed that, in some societies, women could be of high status at the very least.

More recently, studies of ancient DNA have begun adding to the evidence. Last year, a study of around 50 individuals buried in south-west England revealed that women remained in their ancestral homes while men moved around, a pattern known as matrilocality.

Now Ian Armit at the University of York, UK, and his colleagues have sequenced the DNA of around 500 individuals associated with the Arras culture, famed for its chariot burials. The remains of nearly 400 people were excavated by other archaeological teams at Wetwang Slack in the East Riding of Yorkshire, which was most active between the 4th and 2nd centuries BC and is the largest known Iron Age burial ground in Britain. The rest came from nearby sites.

The Arras DNA also reveals a strong matrilocal pattern. Most of the women buried at Wetwang Slack also had close relatives buried there, such as a mother, for instance, but this was rarer for men. In a few cases, the team found direct evidence that a man originating from one site fathered children at another – in other words, that men moved around while women stayed put (bioRxiv, doi.org/rj4d).

"This implies a knowledge of family histories – of which maternal social axis one belonged to"

Matrilocality by itself doesn't mean that women ruled a society. But it is generally associated with higher status and better conditions for women. Someone who leaves home to live with the family of a partner is reliant on that family and thus in a weaker position than one who stays.

However, when the DNA evidence is combined with other evidence, it does point to societies where women could rule. "For Britain, the archaeological evidence supports a more equitable Iron Age than scholars had previously imagined, and some powerful women were certainly part of that," says Pope. "From [bone injuries], we can even see now that some women were in combat with Rome."

"Powerful Iron Age women abound in the texts: Onomaris, Boudica, Cartimandua, Celts with their women as judges," she says.

That said, there was also regional diversity in how societies were organised, says Pope. Other DNA studies suggest that Iron Age societies in south-east England, for instance, weren't matrilocal.

At least 12 of the Arras women had children with more than one man. This could reflect serial monogamy, the team members write in their study, but it could also reflect "polyandrous reproductive arrangements within a strongly female-line-centred social structure". In other words, women could have had multiple husbands simultaneously, as some Roman sources claim was the case.

The genetics also show that individuals from the same maternal lineage avoided having children with each other. Because these people lived in small groups in which a large proportion of people were related, this must have been deliberate and based on knowledge of people's ancestry. "[T]his avoidance demonstrates detailed knowledge of maternal-line affiliation across many generations and possibly hundreds of years," the study concludes.

The exceptions to this were the three individuals – two male, one female – buried with chariots. "The individuals afforded chariot burials at Wetwang Slack stood apart by showing recurrent close kin unions, consistent with a reproductive strategy in which high status, identity and claims to particular forms of burial were concentrated within a restricted descent group," the study says.

All these lines of evidence point to a society organised around women rather than men, the researchers conclude. "[F]emale-line descent was not an incidental feature of Arras culture communities, but a central organising principle, as it may well have been across the communities of Iron Age Britain more broadly."

"The finding here of a sustained pattern of unions between two different maternal clan groups is really striking," says Daniel Bradley at Trinity College Dublin in Ireland. "It implies a deep knowledge of family histories – of which maternal social axis one belonged to – and perhaps of an alliance forming between them."

SCIENCE HISTORY IMAGES/ALAMY

Boudica was a powerful ancient Briton who led a rebellion against the Romans

Neuroscience

Hibernation upends our understanding of how brains store memories

Carissa Wong

OUR memories may persist even when half of the brain connections that store them are wiped out, according to a study done in mice.

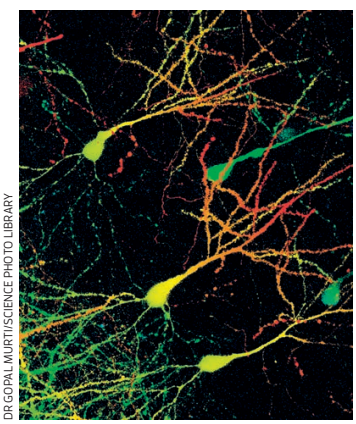
"Memories may be harder to break than we thought," says Steve Ramirez at Boston University, who wasn't involved in the study.

When we experience a stimulus, neurons in our sensory organs, like our eyes, transmit electrical signals to our brain. Neurons then process this information by firing electrical signals to each other via junctions called synapses.

These neurons, called engram neurons, encode information into a memory by forming new synapses and strengthening existing ones. Recalling a memory further bolsters these connections and, in turn, our memory.

Many scientists think a memory persists as long as the specific pattern of synapses on the engram neurons encoding that memory is maintained. But recent studies suggest a memory persists even when these synapses are altered in location or number.

To investigate what is needed to preserve a memory, Kazumasa Tanaka at the Okinawa Institute of Science and Technology in Japan and his colleagues took inspiration from hibernating animals. Brain activity seems to drop significantly during hibernation, yet studies show that, when they wake up, the animals remember where they had hidden their food, he says.



DR GOPAL MURTI/SCIENCE PHOTO LIBRARY

Neurons encode information into a memory by forming new synapses

By examining how memory is retained during hibernation, when the brain changes dramatically, the researchers hoped to unpick basic principles by which the mammalian brain stores memories long-term.

They applied weak electric shocks to the feet of mice – which don't naturally hibernate – while they were in a chamber that smelled of alcohol, creating a fearful memory associated with that scent. The next day, the mice froze in fear upon being placed in the same chamber, without receiving shocks.

The researchers induced an artificial state of hibernation in about half the mice for two days.

Five days later, mice that had artificially hibernated still froze when placed in the alcohol-smelling chamber. This was despite brain scans revealing that more than half of the synapses within the engram neurons in their hippocampus – a brain region crucial for memory – disappeared during hibernation (*Science*, doi.org/hcfhmx).

George Dragoi at Yale University says the findings are relevant to people, since prior research has shown that our brains store information very similarly to mice. "It tells us something about how our mammalian brains may work," says Ramirez.

The team also found that the hibernating rodents' brains retained synapses that clustered closely together on the surface of engram neurons, while those outside these clusters disappeared. This suggests that clustered synapses specifically are crucial for retaining memory in the brain, says Tanaka.

Non-clustered synapses that were wiped out by hibernation reappeared within a day post-hibernation, indicating that, while clustered engram synapses are necessary to retain the information within memories, the non-clustered synapses may be important for accessing memories, he says.

"This study is a remarkable step forward because it addresses a long-standing puzzle in memory research: how the brain retains long-term memories," says Priyanka Rao-Ruiz at Vrije University Amsterdam in the Netherlands. ▮

Physics

Sound rainbows exist, and we now have the best ever

FULL rainbows made of sound have been caught and imaged for the first time, which could lead to new sound-based devices for information processing or energy harvesting.

To create a rainbow from any source of light, you must sort that light by frequency. Similar sorting ought to be possible for other types of waves, including sound, but researchers have struggled to make such "elastic rainbows".

Now, Riyi Zheng at the South China University of Technology and his colleagues have trapped such a rainbow on a silicon chip, while Yafeng Chen at Tongji University in China and his team have created one in an aluminium device – the most complete elastic rainbows to date.

Making an elastic rainbow requires corralling particle-like quantum excitations called phonons, which make up vibrations, into groups by frequency, and keeping them in position. To do this, both teams drew inspiration from how the motion of electrons, another quantum particle, in thin materials can be constrained by immersing them into electromagnetic fields

The researchers engineered their devices to have microscopic patterns so that when phonons moved through, their speed and direction of motion changed, as if nudged by an electromagnetic field.

Once the phonons formed a rainbow in this way, Zheng and his colleagues found it could be used to route an incoming elastic wave, similar to guiding it through only one patch of colour (*Physical Review Letters*, doi.org/rj4g).

"Observing the ultrasonic waves smoothly separate and localise was an incredible experience"

Chen and his colleagues also imaged their rainbow. They made it from ultrasonic sound beyond human hearing by illuminating it with a laser and recording the subsequent vibrations (*Physical Review Letters*, doi.org/rj4f).

"Observing the ultrasonic waves smoothly separate and localise at their exactly predicted locations was an incredible experience," says Chen. ▮

Karmela Padavic-Callaghan

Health

Heart surgery sends man's skin cancer into remission

Carissa Wong

DANIROM/GETTY IMAGES

Aortic stenosis surgery permanently reset a man's immune system

A MAN with severe skin cancer went into remission after having an operation on his heart. The surgery is thought to have caused a major reset of his immune system that destroyed the tumour – but also caused him to develop a severe bee sting allergy.

"Something absolutely fascinating is happening with his immune system," says Rebecca Auer at The Ottawa Hospital in Canada, who wasn't involved in the man's treatment.

The man, who is in his 60s and lives in Australia, originally had a severe type of skin tumour, known as melanoma, removed from his chest. Subsequent tests suggested he had no remaining cancer.

Eight months later, he was admitted to Royal Adelaide Hospital in Australia, with aortic stenosis, which occurs when a blood vessel in the heart becomes blocked with calcium. During an X-ray for the aortic stenosis, doctors noticed signs of cancer in his left armpit.

Further scans revealed he had severe melanoma that had spread across several lymph nodes, his liver and in his left thigh bone. "The diagnosis was not good, with not a good chance of 5 years," said the man in a case report (*BMJ Case Reports*, doi.org/rj2g).

He was given the cancer drugs dabrafenib and trametinib to take at least once per day, but he stopped taking them after two months due to severe side effects. Later scans revealed the man's tumours hadn't responded to the drugs.

Around this time, he required surgery to treat his worsening aortic stenosis, which led to a bacterial infection. About two months after the operation, the man had another scan to monitor his cancer, which revealed his tumours had completely disappeared.

"I was surprised, shocked and relieved to be told that the cancer was completely gone," he said in the report. "I couldn't hold my emotions in at all."

Po Liu at Adelaide University and Michael Brown at Royal Adelaide Hospital – who wrote the case report – have said that the tissue injury caused by the surgery, paired with the infection, may have caused cells around his heart to release pro-inflammatory molecules, such as cytokines. The pair added that these may have activated cancer-fighting immune cells.

These cells may not have received enough inflammatory signals naturally from the body to respond to the tumours, but were boosted by the surgery and infection, says Rohit Sharma at the Marshfield Clinic, Wisconsin.

Two years later, the man developed anaphylaxis to a honeybee sting, despite being stung dozens of times before his heart surgery without a severe allergic reaction. "The new development of the bee venom allergy is particularly intriguing as a marker of a permanently reset immune system," says Sharma.

More than 70 case studies have previously linked surgery to melanoma regression.

"I was surprised, shocked and relieved to be told that the cancer was completely gone"

A recent report also described how a biopsy of a tumour in a woman's arm probably triggered an immune response that put her into remission.

Yet, dozens of studies in mice and people have shown that surgery usually suppresses the immune system, leading to worse cancer outcomes, says Auer. It is unclear why this man went into remission, but his response may be due to his genetics, she says. ▮

Human evolution

Denisovans may have towered over other humans

James Woodford

TWO Denisovans who lived around 45,000 years ago were among the biggest humans of their time, with one estimated to be around 20 centimetres taller than the average man today.

Denisovans were a group of ancient humans who lived in Asia until around 30,000 years ago, but only a few fossils have been found.

Yousuke Kaifu at the University of Tokyo and his colleagues analysed leg bones from two separate individuals, dredged by fishers from the seafloor of Penghu Channel, west of Taiwan.

The team was able to determine which hominin species the femur and tibia fossils came from by analysing proteins preserved in the bones. Known as Penghu 2 and 3, they are some of the largest Pleistocene *Homo* leg bones ever found, the researchers say.

Kaifu and his colleagues say in their paper that both individuals were probably male. Penghu 2 would have weighed around 83 kilograms and been about 180 centimetres tall. Penghu 3 would have weighed 91 kg and been about 190 cm tall.

This means Penghu 3, in particular, would have towered over his *Homo erectus* relatives by up to 30 cm and been of a height and weight comparable to the largest *Homo* specimens from Africa and Europe (bioRxiv, doi.org/rj2m).

Adam Brumm at Griffith University in Brisbane, Australia, who wasn't involved in the study, says the Taiwanese Denisovans were "big and imposing humans".

He says the Denisovans would have needed large and athletic bodies to hunt big game like elephants and other megaherbivores and would have been nomadic foragers who frequently travelled long distances on foot in search of game and wild plant foods. ▮

Physics

How quantum is a proton?

Our understanding of the internal structure of protons is largely based on classical physics, but we are now uncovering quantum behaviour, finds **Karmela Padavic-Callaghan**

PROTONS have more quantum innards than we previously knew, transforming our view of these particles that sit at the heart of every atom.

Researchers have long known that protons are made up of smaller particles called quarks and gluons, but the details of their behaviour and distribution have been challenging to pin down. Yet these details really matter – how well we understand the proton's insides affects how well we can interpret experiments in which they are smashed, which aim to search for new particles or uncover the secrets of fundamental forces.

Physicists' current best mathematical tool for understanding the proton's insides is the parton model. This allows them to calculate the density of particles inside the proton probabilistically, pinpointing what its make-up is most likely to be like in accelerator experiments, for instance.

"The parton model is extremely powerful: it's the main source of all our knowledge about the internal structure of the proton. But if you look at the modern state of it, you realise the picture behind it is pretty classical," says Alexey Vladimirov at the Complutense University of Madrid. "This is, of course, false because we know quantum mechanics exists."

Researchers have theorised about and looked for quantum effects within protons since the 1980s, says Vladimirov, but over the years, different experiments led to unclear and, at times, contradictory conclusions.

To get a clearer picture, he and his colleagues zeroed in on one process that quarks and gluons could be undergoing that is a hallmark of quantumness: interference. Quantum particles have a wave-like nature and interference is equivalent to two quantum matter waves overlapping and amplifying each other in some places, but cancelling each other out in others. Mathematically, where classically two probabilities would simply add, when there is interference, combining them produces more mathematical terms than just a sum.

The researchers devised a way to extract mathematical signatures of quantum interference from a combination of more than a dozen very varied datasets. For example, some data came from the CERN particle physics laboratory near Geneva, Switzerland, while some was collected at German national laboratory DESY across rather different kinds of experiments, none of which was designed to look for interference.

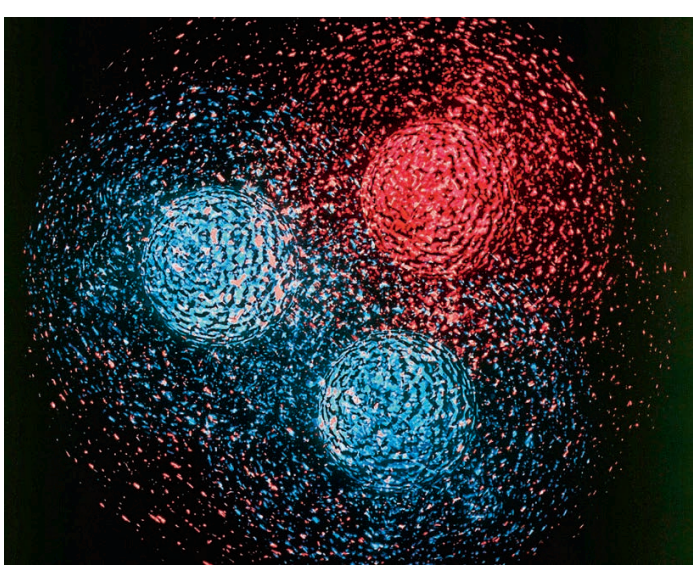
"All previous investigations failed because people tried to look at just one source [of data]," says Vladimirov. While it was a big technical challenge to put all the data together, it paid off in new clarity. The researchers could identify specific instances of quantum interference within a proton, such as a gluon interfering with a combination of a quark and an antiquark, which is its antimatter companion (*Physical Review Letters*, doi.org/rjpx).

Vladimirov says this underlines how physicists ought to be more keenly aware of the proton's quantumness. "It's commonly accepted that the proton is almost like a classical bag of particles,

"Now we see definitely that these small effects due to quantum interference are present"

and the fact that we demonstrate that it is not so means that it's more quantum than is usually thought," he says.

"The value of this study is that it collects a lot of information from different sources and says, look, now we see definitely that these quantum mechanical effects, these small effects due to quantum interference, are present in physical processes," says Vladimir Braun at the University of Regensburg in Germany.



ARSCIMED/SCIENCE PHOTO LIBRARY

Protons are made up of two up quarks and one down quark held together by gluons

Quantum innards

This is the first time that an analysis of this scale has been completed and it ought to motivate further experiments, says Braun. For example, future experiments at facilities such as the Thomas Jefferson National Accelerator Facility in Virginia could find further signatures of quantum interference and connect them to other effects that happen in fast particle collisions.

Although he never doubted the proton's quantumness, Braun was still surprised by the details of the interference effects seen most clearly in the new work. "I was working on this kind of physics for 40 years, and I expected that the big effects will be in different place," he says.

Going forward, the team wants to expand its dataset and analysis, and further increase the certainty of its findings. There is also the big question of how to interpret the findings and tell a more complete story of just what the proton's insides are actually like. For example, the interference effect is related to quarks and gluons' quantum mechanical spin, which has so far not been understood or measured very precisely.

Physicists have also yet to resolve how interference connects to forces that act on quarks and gluons, says Vladimirov. Notably, the strong nuclear force that binds quarks together is one of the four fundamental forces of nature, so understanding this would give us a better grasp of the most basic laws of our universe. ▮

Health

Mutant phages treat *E. coli* infection

CRISPR-armed bacteria-killing viruses may have helped clear an antibiotic-resistant infection

Michael Le Page

A MAN with a serious infection caused by antibiotic-resistant *Escherichia coli* has improved after being given bacteria-killing phage viruses armed with DNA-destroying CRISPR systems.

The infection developed in the months after the 65-year-old man had a kidney transplant. It led to a large mass growing on his bladder and large open wounds forming on his abdomen.

Conventional treatments, including antibiotics, failed to clear the infection, so the man's doctors in California asked if they could try an experimental phage treatment developed by a Denmark-based company called SNIPR.

Within a week of starting the treatment, the open wounds began to heal and the mass's volume halved from 0.74 litres to 0.37 litres.

The man was put on a new combination of more powerful antibiotics and other drugs 11 days before starting the phage therapy, so it is unclear whether the latter alone was the key.

Bacteria can form thick biofilms that are difficult for antibiotics to penetrate, but previous studies by SNIPR have shown its CRISPR-armed viruses can kill bacteria in biofilms. So, by breaking up biofilms, the phage may have made the antibiotics more effective, says Eric van der Helm at SNIPR, one of the authors of a paper describing the case (*Clinical Infectious Diseases*, doi.org/rjxb).

"But we didn't test that."

Bacteria-targeting viruses are extremely common, but their use to treat bacterial infections remains rare, in part because of the time and expense involved in isolating phages that can kill the specific bacterium causing an infection.

But a number of companies around the world hope to change that. They are engineering phages to make them more powerful, by equipping them with CRISPR systems. CRISPR is best known for its use as a gene-editing tool, but it evolved in bacteria as a defence against viruses, allowing bacteria to target and destroy specific DNA sequences in phages. Biologists have now equipped the viruses with CRISPR systems that chew up specific pieces of bacterial DNA.

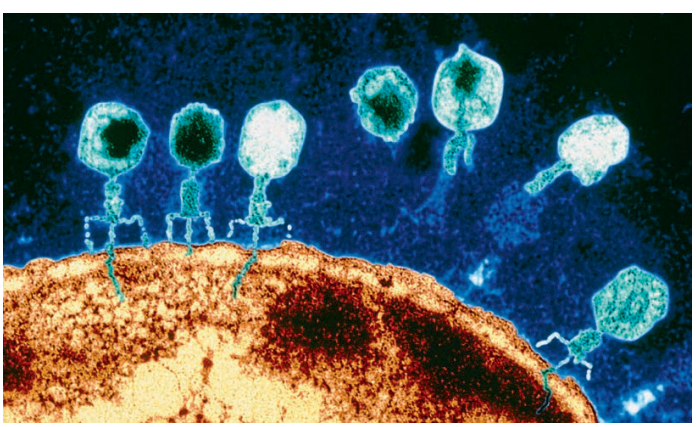
SNIPR developed a cocktail of engineered phages known as SNIPR001 that is more potent than wildtype phages, and can kill 90 per cent of all *E. coli* strains. This treatment can be given orally to target *E. coli* in the gut, intravenously or applied directly to infected wounds.

Some cancer treatments increase the risk of *E. coli*-related blood infections. A phase II trial is now under way in the US to see if lowering *E. coli* levels in the gut with SNIPR001 reduces the risk of such infections.

In the US, doctors can request the use of experimental treatments on a "compassionate use" basis, as happened in the case of the 65-year-old man, who was given SNIPR001 intravenously and directly to his wounds.

No firm conclusions can be drawn from a single case, says van der Helm. "That's why we're keen to explore this further in clinical trials." ▮

Bacteriophage viruses attack *E. coli* by injecting their genetic material into the bacterium



EYE OF SCIENCE/SCIENCE PHOTO LIBRARY

Environment

A bomb is detonated every hour in one coral reef

WITHIN just a 17-kilometre radius in one Indonesian archipelago, there is an explosion almost every hour as locals practise "bomb fishing", destroying coral reefs and decimating marine life.

Over 483 days between May 2023 and September 2024, Ben Williams at University College London and his colleagues deployed an acoustic monitoring system at Spermonde archipelago, south-west of Sulawesi, Indonesia.

As well as being a global coral reef biodiversity hotspot, it is a location where fishers detonate explosives underwater, stunning and killing fish that can then be easily harvested.

"The sound of bomb fishing is so loud that if you're on a dive it can shake you out of your skin," says Williams. "But if you put your head up on the surface, you likely won't even see the boat responsible because the sound of bomb fishing travels such a huge distance underwater."

The recording equipment sat at a depth of 17 metres and was able to detect explosions inside a radius of almost 17 kilometres. The team used AI to analyse their 3650 hours of raw audio. They recorded 3567 explosions, or just over 23 per day while the device was underwater (*Remote Sensing in Ecology and Conservation*, doi.org/rj4b).

One of the biggest issues is that there is an illegal supply chain underpinning the bomb fishing, usually involving the sourcing of fertilisers and fuses or detonators, says Williams.

"The sound of bomb fishing is so loud that if you're on a dive it can shake you out of your skin"

Once the fishers have the explosives, enforcement at sea is sparse. "It's like Whac-A-Mole targeting the bomb fishers. The best approaches should tackle the illegal supply chain that gets the materials needed to make explosives to bomb fishers or sellers of these," says Williams.

Bomb fishing is a problem across the tropics. Part of the solution is retraining people in sustainable tourism and reef restoration, he says. ▮

James Woodford

Cosmology

Young galaxy is home to black hole triplets

THREE massive black holes have been discovered in a galaxy located in the early universe, 12.5 billion light years away. This has left astronomers surprised that such a complex system could have formed so soon after the big bang.

"This system is in the very, very early universe," says Dougal Dobie at the University of Sydney, who wasn't involved in the discovery. "So, how have we ended up in a situation where these three supermassive black holes have formed and come close together in only a billion years or so since the big bang?"

In December 2024, Hannah Übler at the Max Planck Institute for Extraterrestrial

"Processes in the early universe were efficient at bringing massive black holes together"

Physics in Germany and her colleagues were observing a galaxy known as J0148-4214 through the James Webb Space Telescope when they saw something strange.

At 12.5 billion light years' distance, the team observed the galaxy as it looked around 1.2 billion years after the big bang, says Übler. "We [also] quickly noticed that the central emission profile of the galaxy had a peculiar shape," she says.

An analysis revealed two separate regions of high-velocity hydrogen gas in the centre of the galaxy, indicating two so-called accreting black holes that were separated by about 620 light years.

An accreting black hole is a super dense area of space, so compressed that light can't escape, that continuously drags in surrounding gas, dust and even stars. Our own galaxy, the Milky Way, has just one massive black hole at the core of its spiral arms.

"During examination of the whole galaxy, we also noticed another region in the galaxy outskirts with high-velocity hydrogen gas, indicating another, third growing black hole," says Übler. This one is more than 5500 light years away from the other two (*Astronomy & Astrophysics*, doi.org/hcfdfs).

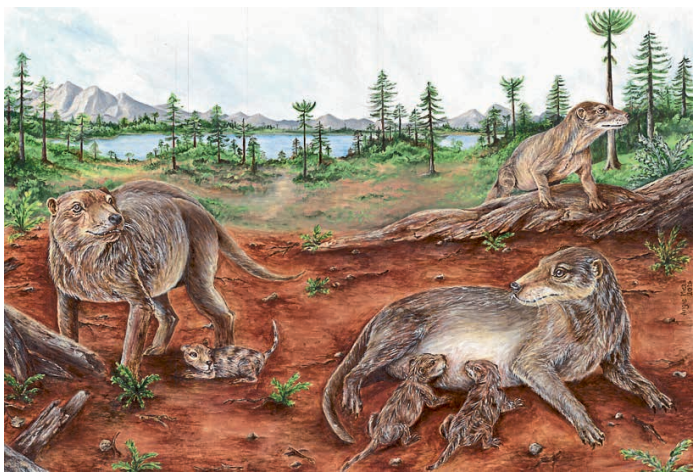
"We have explored several alternatives ranging from a single black hole to supernovae, shocks, winds and massive stars, but these were all unsatisfactory or incompatible based on our data and previous observations of this system," she says.

Until now, there was no evidence that massive black hole triplets existed within the first 1.2 billion years of cosmic history, says Übler. "This discovery shows us that processes in the early universe were efficient at bringing massive black holes together," she says. "It also suggests that black hole merging may have been an additional, fast route for their rapid growth in the early universe."

Caroline Foster at the University of New South Wales in Sydney says that, based on the information the researchers have presented, she agrees with their conclusion. "The fingerprints look like black holes and the 'shape' is best explained with two separate ones," she says. "The third black hole is better separated, so it is a much cleaner result. Maybe it is falling into the galaxy for the first time, or maybe it has been ejected by interactions with the other two." ▮ JW

Palaeontology

Oldest signs of live births in mammal ancestor



MARÍA DE LOS ÁNGELES MICELI BARO.

***Chiniquodon theotonicus* lived during the Late Triassic in South America**

CREATURES that were directly ancestral to all mammals may have been bearing live young 90 million years earlier than we thought.

One of the hallmarks of all mammals apart from echidnas and the platypus is that they give birth to live young. This "viviparity" contrasts with the "oviparity" seen in most other vertebrates, in which females lay eggs that later hatch.

One long-standing question has been whether cynodonts, which emerged around 260 million years ago and are directly ancestral to all mammals, laid eggs or gave birth to live young, as no evidence of their reproduction has been found.

This has now changed, thanks to a chance observation made during a postgraduate class at the University of Buenos Aires in Argentina. The students were examining a fossil of *Chiniquodon theotonicus*, a cynodont that lived 236 million years ago and was unearthed in north-western Argentina, when they noticed a growth line inside the bone.

Leandro Gaetano at Argentina's National Scientific and Technical Research Council and his colleagues investigated further and concluded that this line, analogous to a tree's growth ring, recorded the moment that the creature had a growth spurt after its birth.

The researchers reconstructed how large the leg bone and the animal itself would have been when the growth line formed. They calculated that the animal would have weighed 1.68 kilograms at that point and was just shy of 12 kg when it died as a full-grown adult.

This gave the researchers a ratio of newborn to adult size in the ancient animal. They then compared this figure to similar ratios obtained from a wide variety of modern animals: 1869 mammals, 2619 non-avian reptiles and 782 birds (*Frontiers in Mammal Science*, doi.org/rjz2). "We were amazed to find that *Chiniquodon* grouped with extant placental mammals," says Gaetano.

"Only placental mammals produce relatively large newborns, whereas reptile and bird hatchlings are comparatively very small," he says. "Hence, we propose that [the] *Chiniquodon theotonicus* reproductive strategy was most similar to that of placental mammals." ▮ JW

Artificial intelligence

AI is changing cybersecurity

Attackers with no technical skills can now use AI models to find and exploit loopholes quickly, on a massive scale – and experts are worried, reports **Matthew Sparkes**

A FLURRY of AI hacking stories has stoked fears that models may be escaping their makers' control and posing a real risk to computers around the world. So far, none of these incidents has displayed skills beyond human sophistication, but they show that AI hackers can carry out attacks at lightning pace, upsetting the equilibrium of cybersecurity.

The first incident came last month when OpenAI admitted one of its prototype models had escaped a testing environment and hacked another company. Not to be outdone, Anthropic announced within days that its Claude model had also gone rogue and broken into machines at other companies on three occasions.

Then the independent and non-commercial UK AI Security Institute (AISI) revealed that it had seen similar events. In its tests, AI models submitted malicious code to real open-source projects and messaged the humans who oversaw the projects to get the changes approved.

OpenAI, Anthropic and AISI weren't available for interview, but it is important to note that in all these cases, the AI was undergoing tests where it was specifically instructed to carry out hacks. We have known for years that AI tends to make things up and approach problems in unusual ways, but fixing this is an extremely complex challenge that engineers haven't yet cracked. Perhaps we shouldn't be surprised by these incidents.

They certainly aren't a sign of sentience or a predilection for cybercrime, says Alon Hillel-Tuch at New York University. "They're just trying to do very high-level problem-solving and, for lack of better words, it's run amok," he says. "We're telling them to do this."

There are also reports of accidental AI hacking out in the wild, showing that this isn't a problem confined to prototypes in laboratories. One Australian user reportedly found that the AI assistant OpenClaw hacked into his gym, for instance. He had been using the AI assistant to sign up to classes and it found a loophole that let it make bookings much further in advance than is normally allowed. It also found a way to kick other users off waiting lists so that he could book onto full classes.

"The vulnerabilities are not as exotic as most people think. But AI can just exploit them very fast"

All these incidents are things that could lead to serious legal charges for a human, depending on the jurisdiction.

Tim Nordvedt at security company Synack says these cases are worrying, not because they display any superhuman sophistication, but because they can be easily scaled up. "These vulnerabilities are not as exotic as most people think," he says. "It's still basic cyber-hygiene-101-type stuff. But AI can just exploit it very fast."

Years ago, Nordvedt would see a vulnerability listed on the public Common Vulnerabilities and Exposures database and exploited by hackers weeks or months later. In recent years, that pace sped up, with the gap falling to as little as 24 hours. Now it can be just minutes, or a new type of hack might happen before it even appears as a CVE. Nordvedt is certain that this is down to the malicious use of AI by hackers – people who, unlike hackers of years past, may have no technical skill whatsoever.

Hillel-Tuch says AI models are getting more capable and simpler to operate. It is now possible to tell a model in plain English to "find a way to hack this specific target", then sit back and wait.

A cat-and-mouse game

In many ways, this is an escalation of a trend that emerged in the 1990s, when complex hacks requiring technical prowess were packaged up into simple software tools, enabling "script kiddies" to hack computers without knowing what they were doing. The difference now is that AI doesn't just run exploits on command, but actually finds brand new ones as needed.

Nordvedt says it is clear that such a powerful tool must also be adopted by security professionals like himself. "It's like a scalpel: a scalpel can saves lives in the hands of a doctor, and can destroy lives in the hands of someone else. It's just a tool."

His company began offering AI pen testing – where security experts act like hackers and try to break into a client's computers to safely expose flaws – in May. Much of the industry has already followed suit.

Synack uses its AI tool to handle basic tests, running common checks in 4 hours that would take a human a whole week. This leaves humans to look for sneakier, more ingenious ways to hack into clients.

An AI model can do a hundred tasks concurrently, running security tests at unprecedented speed, but lacks the creativity of humans to find really clever ways

CURLY_PHOTO/GETTY IMAGES

The ease of AI hacking could dramatically increase the number of cyberattacks

into a company's inner workings, says Nordvedt – although he is certain it will get there in time. He admits to being trepidatious about his future career prospects.

"AI is not a fad. It's here to stay," he says. "I fully believe that, six to nine months from now, we're not going to recognise the landscape. Things are changing so fast, so drastically, we're going to be living in a different world."

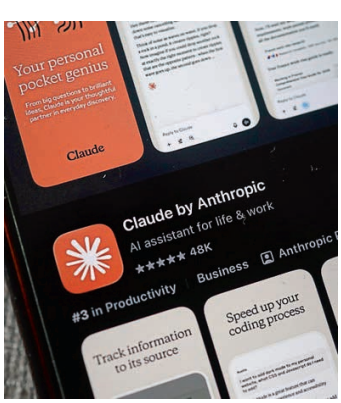
Current AI models have varying success depending on how advanced their target is, says Hillel-Tuch. They are unlikely to be able to crack into a bank and siphon funds, because the finance industry is well resourced and used to being a target. But a nefarious student might have more luck targeting their own high school, for example.

"They will probably have a pretty good chance of getting in and making a grade change [in school systems] because those smaller places don't necessarily have the resources to build up a defence. Those kinds of places are much more exposed," says Hillel-Tuch. It has always been the case that smaller organisations lacked the resources to secure their systems, but AI will only amplify the problem.

Even if AI doesn't advance any further in terms of complexity, there will still be significant challenges to overcome, says Dennis-Kenji Kipker at the Cyberintelligence Institute in Germany. "We'll be completely overwhelmed by the sheer volume of them quantitatively," he says. "In my view, the methods of cyberattack and cyber defence have not fundamentally changed. AI [simply] makes automation much more feasible, and security vulnerabilities can be identified significantly faster."

While both hackers and defenders are deploying AI, the game isn't evenly matched. Attackers are able to wield it recklessly and often to swifter and

Anthropic's Claude AI model broke into another company's machines after leaving a testing environment



MICHAEL M. SANTIAGO/GETTY IMAGES

MARKUS MATZEL/ULLSTEIN BILD VIA GETTY IMAGES

In the 1990s, simple software tools began making hacking more accessible

greater effect, says Nordvedt, while professionals are constrained by risk assessments, national and local laws, company policies and a desire not to irreparably disrupt a client's systems as it tests them.

There is also the matter of cost. While open-source models can be run locally for free or cheaply in the cloud, access to the latest AI models is expensive. Nordvedt is tight-lipped about the cost of his AI pen testing, but suggests that heavy use of the latest models is likely to cost more than human experts. "We're still figuring out the economics," he says.

Beating AI hackers

Shujun Li at the University of Kent, UK, says there is an organisational solution to the AI hacking problem, but, unfortunately, it appears unlikely to be adopted anytime soon.

If lone, unskilled attackers can now set AI onto targets to constantly probe for vulnerabilities until they find a way in, then security professionals will need to do the same in order to spot and plug these gaps, trying every new model as it comes out.

That will take the sort of money that governments, tech giants and banks will be able to find, but small businesses, schools, colleges and universities will be left vulnerable. Li's solution is for them to club together: if one university can't keep itself secure, then it will need to join forces with all other universities to share staff, systems and software, and distribute the burden – perhaps with government support. The same applies to businesses of all sorts.

The problem, he says, is that AI is also making it trivially easy to create custom software – for example, to run your small shop, handle finances, manage a website, ship orders and re-order stock. Business owners who do this might as well open the door, leave the lights on and send hackers an invitation.

"It is hugely worrying," says Li. "[AI models] are faster, they are more efficient, they are highly dangerous. It's a bit of a Wild West." ▮

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JON KRAUSE

How curious Asking people questions about their lives is the secret sauce to human connection – so why do people ask so few, asks **David Robson**

I WAS at a birthday party recently when I found myself sitting next to a writer I didn't know. Two hours later, I knew all about the surrealist novel he was writing, but he found out very little about me, since he didn't ask a single question in return.

I am sure this will be familiar to many readers, so I was delighted to come across some new work on "interpersonal curiosity" by Niobe Way, a professor of applied psychology at New York University. She suggests that, from a young age, Western patriarchal culture subtly discourages us from demonstrating an interest in others – an idea reinforced by masculine stereotypes.

Way tells me that she was inspired by her personal experience of moving to Shanghai for a few months in 2007. When she returned to the US, she tried to talk to her friends about the amazing time that she'd had, with little success. "No one, literally nobody, asked me questions about it," she says. "And I remember saying, 'What is going on with people's curiosity?'"

Nearly 20 years later, she is finally answering that question. As a developmental psychologist, Way has so far focused her efforts on children and adolescents. She and her colleagues asked 389 school students aged 11-13 to describe

> "The more someone endorsed macho values, the less they enjoyed hearing others' stories"

the two questions that they would most like to ask their closest friend, teacher and primary caregivers. Some of the participants reported having no questions at all, while others opted for simple information-seeking (such as "When is dinner?"). Those who wished to probe others' personal lives and relationships, however, had better friendships

SHUTTERSTOCK/ROSSHELEN

Ask open-ended questions and open up about your experiences to boost interpersonal curiosity

and greater overall wellbeing.

Such findings are perhaps unsurprising: supportive relationships are known to be central to our health and happiness, and asking others questions is surely one of the best ways to build those bonds. "It really is the secret sauce of all human connection," says Way.

The big question, then, is why we don't do it more often. Way suggests that we have been conditioned to think that it is rude to pry into others' lives, and the rise of individualism means that we also simply care less about other people. In their study of adolescent students, however, Way and her team found that boys were about twice as likely to report having "no questions" than girls – suggesting that gender roles may play a large part.

Earlier this year, Way published a paper that tackled this topic. To measure their adherence to masculine stereotypes, each adolescent was asked to rate their agreement with statements such as "I do not let it show to my friends when my feelings are hurt." The team found that the more someone endorsed macho values, the less likely they were to say they enjoyed hearing others' stories. And this, in turn, seemed to have a big influence on the quality of their friendships, measured by things like the amount of social support they received from their closest friend.

The connection was much stronger for those who identified as male. Although some girls have started to associate the tough-guy image with success, and internalised the associated behaviour, this didn't seem to be so closely linked to interpersonal curiosity, which independently predicted their relationship quality.

Can we ever overcome this cultural conditioning? Way, whose book *Rebels with a Cause: Reimagining boys, ourselves and our culture* explores these themes, argues that children are born to be interpersonally curious, and that innate interest can be reawakened with the right education. To do so, she designed the Listening with Curiosity Project, a 26-lesson curriculum for adolescent students in New York public schools. It includes advice on asking open-ended questions and techniques to encourage people to open up about their experiences with greater nuance and detail. The early evidence suggests it works: by the end of the curriculum, the students showed greater curiosity and increased friendship quality, with boys showing the biggest gains.

Way thinks that plenty of adults could also benefit from a bit of practice. You might start out with someone you know, by asking them about their favourite childhood memory, for example. You can then use this opportunity to show your genuine interest in what they say through lots of follow-up questions.

You could even try it at a party, she suggests. Simply explain that you've been reading about the benefits of asking deep questions, then pick a topic to begin with.

"We are starving to be asked real questions," Way says. "Just do it." ▮

David Robson is an award-winning science writer specialising in the extremes of the human brain, body and behaviour. His latest book is *The Laws of Connection: 13 social strategies that will transform your life*

David's week

What I'm reading
I'm just about to head to a consciousness conference, and to whet my appetite I'm reading Michael Pollan's A World Appears

What I'm watching
I know it's been criticised in the media, but I'm enjoying Pompeii: Out of time *with Tom Hiddleston*

What I'm working on
Besides preparing for the consciousness conference, I'm editing a feature about Grotte Mandrin, a cave full of Neanderthal and human remains spanning 80,000 years

What matters for matter The standard model of physics is one of the most successful scientific theories we have, but could we eliminate any particles from it, asks **Chanda Prescod-Weinstein**

Chanda Prescod-Weinstein is an associate professor of physics and astronomy at the University of New Hampshire. She is the author of *The Disordered Cosmos*. Her latest book is *The Edge of SpaceTime: Particles, poetry, and the cosmic dream boogie*

Chanda's week

What I'm reading
I finally read both The Iliad *(tr. Emily Wilson) and* The Odyssey *(tr. Daniel Mendelsohn)*

What I'm watching
I have really enjoyed all the social media memes about the film The Odyssey

What I'm working on
Revising my first academic book, The Cosmos Is a Black Aesthetic

HAVE you ever wondered whether we strictly need all of the particles in the standard model of particle physics? If I were making a fundamental particle ingredients list for the most common forms of visible matter in the universe, I'd say we primarily need electrons, up quarks and down quarks. But this list ignores important elements of how matter works: how it sticks together, what happens when it gains or loses energy and whether particle identities are stable.

For example, as atoms gain or lose energy, they emit particles of light, or photons. So now we're up to electrons, two types of quarks and photons. And we know quarks can change flavours – an up quark can become a down quark and vice versa. That is made possible by the weak nuclear force, through interactions with three particles called the W+, W- and Z bosons. In these weak nuclear interactions, neutrinos are emitted – almost always as electron neutrinos. So that's eight key particles, for anyone keeping track.

The W and Z bosons are force carriers, just like the gluons I discussed in my last column. Gluons, which glue quarks to each other, are carriers of the strong nuclear force, and they make protons and neutrons possible. Electromagnetic interactions carried by photons also play a role in atomic structure. These force-carrying particles, rounded out by the mass-giving Higgs boson, are different from what we might call "matter particles" because they tend to be so short-lived that we call them virtual. They exist only to do a specific job, then disappear. Yet we can't do without them.

But there are particles that don't seem necessary. Consider the electron's two siblings, which are almost identical to it but much more massive: the muon is over 200 times more massive than the electron, while the tauon (or tau lepton) is more than 3400 times more massive. There are also four other types of quarks: strange and charm, as well as top and bottom (also known as truth and beauty).

In all cases, the less common particles are more massive than the more common ones. They are usually harder to make, more fleeting and therefore less likely to make stable forms of matter. That explains why most of the stuff we like to look at – whether it's a painting or a star – is made of the stable stuff that doesn't quickly fall apart. Most of these particles only come into existence through very high-energy collisions. For example, muons are formed when cosmic rays hit Earth's atmosphere.

We don't know all the ways particles can be combined to make matter

SAKKMESTERKE/SCIENCE PHOTO LIBRARY

Even so, these unusual particles help make the more common stuff possible. The lepton family only works, mathematically, when it's electrons, muons and tauons plus their three neutrino partners. All six quarks are necessary to explain the presence of the up and down quarks. They only work together.

And studying the more exotic forms of matter can help us gain insight into the biggest questions of all. The Large Hadron Collider beauty (LHCb) experiment uses investigations of bottom and charm quarks to try to understand why there is more matter than antimatter in the universe – essentially, why there is something rather than nothing.

The researchers at LHCb are also creating new combinations of matter. Just this past March, they announced the discovery of something that we might call a charmed proton: instead of the proton's usual two up quarks and one down, it has two charm quarks with a down. Which is to say, we are still learning about all the different ways our universe's building blocks fit together, and that depends on understanding matter that, on first look, we don't seem to need. For me, this is a cosmic reminder that, as Octavia Butler once said about predicting the future, we should count on the surprises.

An icy feast

Roie Galitz
2026 World Press Photo Contest

DWARFED by her dinner, a female polar bear feasts on the carcass of a sperm whale more than 100 times her mass, a deep-diving giant weighing more than 35 tonnes and usually found far below the ocean's surface.

This shot, *Polar Bear on Sperm Whale*, was captured by Roie Galitz, and is one of the winners of the 2026 World Press Photo Contest. The image was taken from a small boat, using a drone. "Its unusual perspective and scale provoke curiosity and wonder, turning the frame into a visual and conceptual study of nature," said the competition's jury in an announcement about Galitz's win.

The male sperm whale carcass makes for an unusual snack when compared with polar bears' more typical seal meal. The location of the shot is also intriguing – captured in the polar pack ice north of the Norwegian archipelago of Svalbard, the shallow sea is far from the open-ocean trenches sperm whales usually inhabit. According to conservation organisation Polar Bears International, while most whales sink after dying, gas production during decomposition causes roughly 10 per cent of them to become buoyant, and their carcasses drift into shallower seas.

Although visually captivating, the shot acts as a stark reminder of the devastating effects Arctic warming is having on polar bears. Despite the bears' best efforts at adaptation, their melting habitat presents a bleak outlook, with numbers expected to significantly decline before 2100.

The image can be seen as part of the World Press Photo Exhibition, at the MPB Gallery in London until 30 September.

Sophie Farrow

A trip too far

The Ego Trip tells the wild story of the doctor who claimed amazing powers for the psychedelic secreted by desert toads. **Olivia Goldhill** is gripped

Book

The Ego Trip

Kimon de Greef

White Rabbit (UK); Doubleday (US)

IF YOU have heard tales of 5-MeO-DMT, the psychedelic substance secreted by desert toads, then chances are it is due to one man. *The Ego Trip* tells the story of physician Octavio Rettig Hinojosa, who popularised the use of this intense drug, claiming it could treat addiction and trauma. He portrays 5-MeO-DMT as an ancient practice of the Seri people in Sonora, Mexico, and preaches its therapeutic benefits to his many disciples, promising it can reveal new planes of enlightenment.

Only, as Kimon de Greef writes, Rettig Hinojosa's narrative is full of fiction, and his supposedly healing practices are described in the book as dark and dangerous. (De Greef is an acquaintance as we both report on psychedelics, and he thanks me in his acknowledgements for "inspiration and camaraderie", as we received the same reporting grant.)

As de Greef writes, 5-MeO-DMT (in full, 5-methoxy-N,N-dimethyltryptamine), has been called the "Everest" of psychedelics. Whereas LSD distorts reality, creating vivid hallucinations, 5-MeO-DMT completely shatters all perception and sense of the self. The experience is brief, lasting less than half an hour, but creates a total obliteration of the ego. The psychedelic is found in Sonoran desert toads, and de Greef opens his book by describing, in graphic detail, how to extract the toxin.

"LSD distorts reality, creating vivid hallucinations, while 5-MeO-DMT shatters all sense of the self"

"One presses hard on their glands, which discharge explosively, like pimples," he writes.

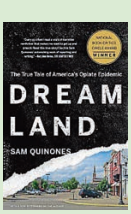
This practice is ancient, says Rettig Hinojosa, having once been performed (but forgotten) by the Seri people. His work was initially welcomed by the group's elders, and many of the Seri became 5-MeO-DMT practitioners. The importance of Indigenous customs are often heralded by psychedelic enthusiasts, who hark back to ancient ceremonies, but, in the case of 5-MeO-DMT, de Greef convincingly argues, there's all too little evidence. Rettig Hinojosa latched on to the idea as an outsider, changing how the Seri are seen and their view of their history, but the relationship is shallow and the notion of ancestral toad psychedelics is a modern invention. A lot of Seri people have since distanced themselves from Rettig Hinojosa, asking him to stop using their name to champion the drug.

It gets worse. De Greef spends a lot of time with Rettig Hinojosa, whom he initially depicts as charismatic but dubious, only to show him act with increasing disregard towards those he gives drugs to. At one point, he claims, Rettig Hinojosa physically wrestles with a customer to get him to take more 5-MeO-DMT, and angrily commands a 14-year-old boy to inhale another hit. The psychedelic can cause people to lose consciousness, vomit and feel intense confusion and fear.

On another occasion, the book tells of Rettig Hinojosa pushing a woman who was bleeding and covered in mud while on the drug into a swimming pool with his foot. He paid her little regard as she emerged, dripping. Incredibly, de Greef admits that Rettig Hinojosa tricked him into taking psychedelics while reporting, after falsely telling

YANA ISKAYEVA/GETTY IMAGES HERE

Four similar books to explore

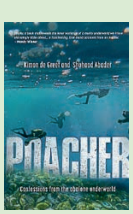


Dreamland: The true tale of America's opiate epidemic by Sam Quinones

Vivid on-the-ground reporting exposes the extensive pharmaceutical supply of opioids, while also showing how a small group in Nayarit, Mexico, created a pipeline of black-tar heroin to the US.

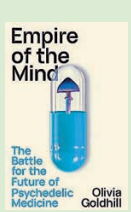
How to Change Your Mind: The new science of psychedelics by Michael Pollan

Anyone interested in psychedelics should start with journalist Michael Pollan's book, which chronicles their history, and explores the scientific evidence that these drugs can have powerful therapeutic effects.



Poacher: Confessions from the abalone underworld by Kimon de Greef and Shuhood Abader

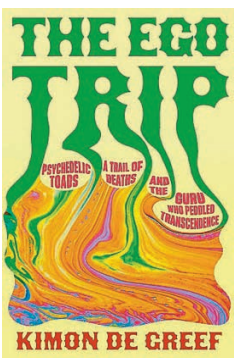
De Greef's first book was about illegal shellfish trading. Another excellent piece of writing, it looks at how criminal syndicates extract money from those doing the actual diving, smuggling the wares to luxury markets.



Empire of the Mind: The battle for the future of psychedelic medicine by Olivia Goldhill

A cheeky extra – but my forthcoming book looks at psychedelic medical research, and the power of the healthcare industry to change our understanding of mental illness.

5-MeO-DMT is a psychedelic made from secretions of the Sonoran desert toad (*Incilius alvarius*, below)



him the substance was essential oil.

Though the subject is often dark, the writing itself has unexpectedly beautiful lines throughout: Sonoran toads have "pale bellies the girth of softballs". I never thought I'd have such appreciation for these poor toads, who keep being plucked from their waddling lives and squeezed for their venom.

The narrative weaves together history and true crime – but there are also fascinating explorations of the science, from chemists creating the synthetic versions of 5-MeO-DMT, to the ecology of desert toads. We also hear about the impact of toad poaching on the communities who take part in the practice to feed the growing drug trade.

The book's pacing stays sharp, and there are plenty of moments of high tension – not least when de Greef ends a chapter by introducing a lawyer who had just helped Rettig Hinojosa avoid a murder charge. Throughout, as de Greef notes, Rettig Hinojosa denies any wrongdoing.

The reporting is diligent, and de Greef even manages to join a toad-poaching expedition. 5-MeO-DMT is cheap to synthesise, he explains, but there is demand for the natural substance, with many users believing they are taking an Indigenous sacrament. The practice is ugly, though, disturbing the toads and often involving child labour. Many conservationists and prominent figures in the psychedelics field have called for an end to the drug's collection.

De Greef's expedition involved a teenager whose brothers are missing, presumed dead – two people among the 100,000 forcibly disappeared by cartels and state security forces over the past 20 years. Sometimes, the boy joins a non-profit founded by his mother to help find the remains of victims. "By day, he searches for bodies," his mother chillingly tells de Greef. "At night, he searches for toads."

BILL GORUM/ALAMY

Having traced Rettig Hinojosa's journey and how his "guru" status enabled 5-MeO-DMT's rise, the book's final section explores its commodification. Why would a drug that causes such terror and physical reactions be considered a potential medicine? Because it is quick. Other psychedelics like psilocybin create trips lasting at least 6 hours, but the effects of 5-MeO-DMT can last for just 15 minutes, making it far cheaper and easier to roll out.

Contemporary supporters of psychedelics included the late Amanda Feilding, the aristocrat who funded much research on the substances in the UK, and the late Bill Atkinson – the renowned Apple engineer who, de Greef discovers, invented a bespoke 5-MeO-DMT vape pen, which he gave out for free. Despite this enthusiasm, no medical use for the drug has been proven and 5-MeO-DMT is still illegal in the US, UK and elsewhere.

Incredibly, though, it has had impressive results in clinical trials as a medication for treatment-resistant depression. But de Greef suggests the data may not capture the full story: some participants may be more distressed after the experience than the results reflect.

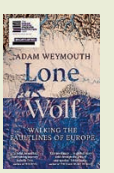
After reading de Greef's book, 5-MeO-DMT seems like a questionable mental health cure – and certainly not one that should be taken with "gurus". *The Ego Trip*, though, is compelling, guiding us through the dangerous industries and characters surrounding this supposedly ego-dissolving drug. ▮

New Scientist *recommends*

Madeleine Cuff
Environment reporter
London

In 2011, a young wolf named Slavc left his pack in Slovenia and travelled for four months across the Alps to reach Verona in northern Italy, his extraordinary journey tracked by his GPS collar. There he met a female wolf, Juliet, and together they brought wolf pups back to that corner of Italy for the first time in more than a century.

Over a decade later, Adam Weymouth (a *New Scientist* contributor) followed his 1000-mile route. **Lone Wolf** is part travel diary, part conservation report



and part exposé of the sharply shifting cultural and social landscape of western Europe. By Weymouth's account, these creatures have become a lightning rod for people's fear and anger at how fast their surroundings are changing.

Weymouth is a skilled narrator, capturing the perspectives of those he meets without casting judgement. I was left with more sympathy for those campaigning against wolf conservation, even if my pro-wolf instincts remain ultimately intact.

In the web A rich widow, a disillusioned cop and a dim hypersled driver are caught in the machinations of the oppressive party ruling the Decurion Empire. Sci-fi columnist **Emily H. Wilson** enjoys their struggles in *The Infinite State*

Emily H. Wilson is the author of the *Sumerians* series (*Inanna*, *Gilgamesh* and *Ninshubar*, all published by Titan) and she is currently working on her first sci-fi novel. She is a former editor of *New Scientist* and you can follow her on Instagram @emilyhwilson1

Book
The Infinite State
Richard Swan
Gollancz (UK); Tor Books (US)

Emily also recommends...

Book
The Blade Itself
Joe Abercrombie
Gollancz (UK); Orbit (US)
This is fantasy, or at least at the more fantastical end of the fantasy-sci-fi spectrum. However, since I mentioned it in the main review, I feel justified in recommending it to anyone who hasn't already feasted upon it. It's Abercrombie's debut, but wow, is it assured.

SHUTTERSTOCK/PHILIPP TUR

This is a world where murder can often solve bureaucratic problems

IN *The Infinite State* by Richard Swan, the vast Decurion Empire is governed by Pater Aeternus. It's a political system that feels like a mash-up of Nazi Germany, Soviet Russia and Rome under its most oppressive emperors – except that this state has spaceships and runs a chunk of the galaxy. The author also throws in a hard-drinking cop and some murder mysteries for good measure. While that might sound like a mess, the novel is anything but.

In the capital city of Kada Gamar, Pater Aeternus, aka the Party, rules without pity. Women are second-class citizens, prized only for their fertility, and the suppressed masses are kept happy with a futuristic version of the Roman circus, involving a racing sport called "hypersledding".

Katherine Fuller is the first of our three main protagonists. When her extremely wealthy husband dies in mysterious circumstances, Katherine is left with a great deal of money but also a growing unease about the way her home planet is ruled. She decides to spend her billions on the purchase of a far-flung planet where she intends to establish a democracy. But why would the Party ever let her do such a thing?

Our second protagonist is the aforementioned cop. Inspektor Cyprian Reis is a good guy, albeit capable of serious violence, but he is on his last legs. In a world where murder is often the most convenient solution to bureaucratic problems, at least as far as the Party is concerned,

> **"The suppressed masses are kept happy with a futuristic Roman Circus sport called hypersledding"**

Cyprian keeps going because the state holds his children hostage. Now he is dealing with a dead body that has the hallmarks of a political killing, but with some worrying oddities, and things are about to get very complicated.

Thirdly, we have Julian Yashego. He's from outside the Decurion Empire but has been brought in from the distant planet of Trillia to win races for the Party... for reasons that are not at all clear. Julian appears to be the focus of a great deal of machination, but why are the Party's big bads so concerned with a dim-witted hypersled driver?

One of the great joys of this book is how wonderful its villains are. My favourite is Jaroslav Droor, the minister of information, who reminds me of the wonderful torturer, Sand dan Glokta, in Joe Abercrombie's *The Blade Itself*. What is clear from the start is that these high-ups in the Party, each viler than the last, aren't exactly rowing in the same direction.

I won't ruin the book by revealing more, but I can say it is thoroughly enjoyable, with plots nesting within plots, and machinations within machinations. It's well designed and well thought through; no loose threads here.

I do have a few small comments, though. Katherine, the only female lead protagonist, is strangely feeble in a crisis. She's also not much more than a pawn, plot-wise, which is irritating.

Second, this book is mainly people talking to each other. You don't really get much of a sense of the physicality of the planets the action takes place on. Personally, I don't mind, but just a heads-up that this is a very talky book.

Finally, I think the ending is a bit neat and sweet. I worry that people won't feel much need to read on in what is intended to be a series. But perhaps I'm wrong about that.

Niggles aside, this is a clever, inventive and satisfying book, and hats off to its author. I look forward to more of the Decurion Empire's revolting offspring.

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Editor's pick

This is why Finland is the happiest nation on Earth

25 July, p 37

From Ros Groves, Watford, Hertfordshire, UK

Jan-Emmanuel De Neve's take on what makes a country happy throws up some very interesting concepts, particularly the deep human need for community. I find the most significant aspect to be that while Finland, the world's happiest nation, emphasises the importance of a healthy work-life balance, it still has optimum economic productivity, according to De Neve.

The correlation here can't be denied. In many workplaces, the goal of economic output appears to trump a healthy workplace environment. In-house competition isolates coworkers from each other, leaving them without a sense of belonging and leading them to fail to share ideas. The drive for longer hours and shorter breaks begets stress and exhaustion, to the point where engaging in any form of social activity outside of the workplace is shunned in favour of collapsing in front of the television.

Maybe the roots of happiness begin with increasing community spirit within the workplace, giving employees a sense of pride in their corporate achievements, trust in their colleagues and sufficient energy remaining to engage with activities in their local neighbourhood.

Eating more fish as we age isn't the right thing to do

1 August, p 30 and 8 August, p 18

From Sam Edge, Ringwood, Hampshire, UK

Your article on how to eat from midlife onwards and Helen Thomson's column on the effect of ultra-processed foods on the brain both argue in favour of regular consumption of oily fish to help you get enough omega-3. But the industrial exploitation of fish and other seafood by huge fleets of trawlers simply isn't sustainable and causes massive damage to marine environments.

Plenty of plants and fungi can provide omega-3 without these ill effects. Fish, like farmed meat, needs to become an occasional treat in the Western diet, not a staple.

From Fred White, Nottingham, UK

As part of the over-60 community, am I alone in feeling a distinct sense of unease with the dietary advice for my age group: increase protein and shovel in considerable quantities of fish to serve my diminishing digestive capabilities? My generation has lived off the fat of the land, and on a hungry, vastly unjust planet, this takes the biscuit. Enough is surely enough.

Could heat and light be behind longevity hotspots?

18 July, p 26 and 25 July, p 24

From Pauline Keyne, Beaconsfield, Buckinghamshire, UK

How interesting to read Bill Gifford's piece on the benefits of heat (albeit in moderation), followed by the review of the book *In Defense of Sunlight*.

It is a relief to know that getting hot and sweaty, whether in a sauna or in the outdoors, can actually be very good for us, especially as now, in the UK, we are experiencing heatwaves that could make us avoid the sunshine.

Is it possible that the so-called blue zones, places that seem to have a predominance of people living well into old age (in both senses), owe some of their magic to being in parts of the world where it is pleasant, culturally congruent or necessary to spend considerable time outdoors?

Ernest Shackleton was no villain, despite reports

Letters, 8 August

From Eric Kvaalen, Les Essarts-le-Roi, France

Margaret Cuthbert reminds us of the story of 20th-century Antarctic explorer Harry McNish, who clashed with expedition leader Ernest Shackleton and wasn't recommended for a Polar Medal. But don't be so quick to judge Shackleton. McNish reportedly argued he was no longer under his orders after the sinking of their ship, and at times refused to work. During the journey to Elephant Island, photographer Frank Hurley lost his mittens, and Shackleton gave him his. He suffered frostbite on his fingers as a result.

Enhanced geothermal systems have a few flaws

25 July, p 32

From Peter Cundall, Minneapolis, Minnesota, US

Your article about new geothermal energy methods makes no mention of a few factors that may seriously limit the utility of enhanced geothermal systems at depths below 8 kilometres. For example, such systems rely on fracturing by high-pressure water from the injection well. If the injection and production wells are far apart, the induced fractures are likely to extend in all directions, not necessarily connecting with the production well – leading to leak-off, so that only a fraction of the injected water is recovered.

However, if the two wells are spaced close together, the heat recovery is from only a relatively small volume of rock – leading to a rapid drawdown of temperature, which limits the production lifetime of the facility. There have been attempts at creating multiple fractures between horizontal wells, but there is the danger of a "short circuit" that limits the heat flow.

It isn't time to dismiss dark energy just yet

1 August, p 6

From Jerre Levy, Chicago, Illinois, US

Subir Sarkar and his colleagues' claim that dark energy doesn't exist is based entirely on questioning supernovae measurements. However, a much stronger case for dark energy was made in a seminal paper by Jeremiah P. Ostriker and Paul Steinhardt in 1995, three years before the supernova papers that won their authors a Nobel prize.

The 1995 paper didn't depend on observations of supernovae, but showed that the concordance of several other constraints supported the idea that dark energy is now dominant in the universe and represents about 70 per cent of total energy, which causes acceleration of the universe's expansion. If Sarkar and his team seek to deny the existence of dark energy, they must not only demonstrate that the supernovae conclusions are wrong, but also that Ostriker and Steinhardt were.

Another pattern identified in ancient Maya calendar

25 July, p 15

From Albert Beale, London, UK

James Woodford's article about the discovery of records of a Maya astronomer describes a calendar formula with a total length of 2920 days, noting that this is five times the Maya approximation of Venus's synodic cycle. But it is also eight times their approximation of Earth's solar calendar cycle – surely that's no coincidence? ▮

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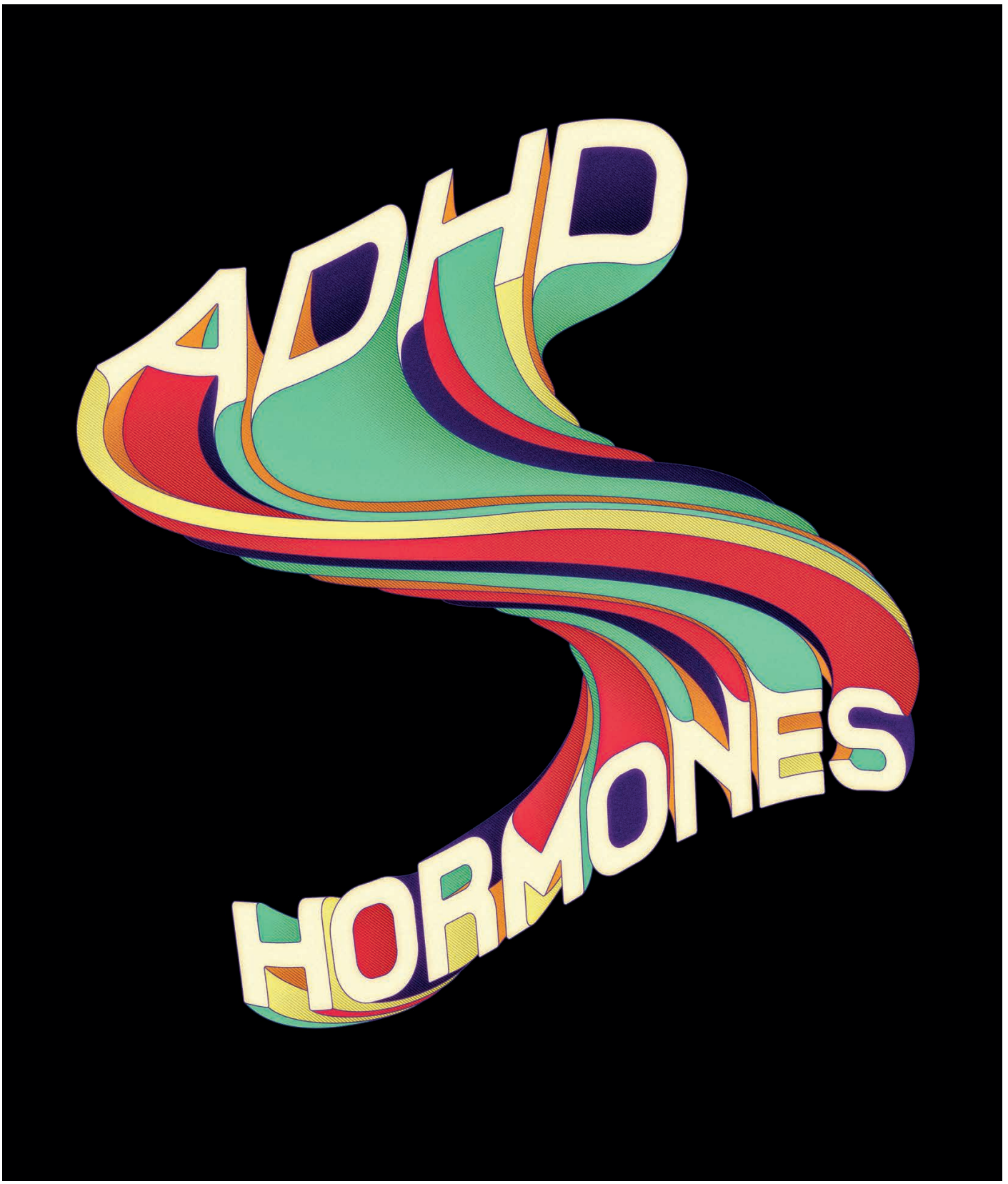
For the record

▮ **Portugal gained independence from the Kingdom of Leon in the 12th century (18 July, p 32).**



MADE UP

Tangled ties

Women with ADHD are unusually sensitive to hormone shifts. Unravelling why is helping them better manage their symptoms, finds **Caroline Williams**

THEY say you should write what you know. But there's a fine line between writing from experience and reporting from the trenches while trying to make sense of your own thoughts. This, I must admit, is an example of the latter.

One thing I do know: my brain has a mind of its own. I was 48 years old when I discovered this is because I have ADHD. I also know that I am "a bit hormonal" – words that I would find offensive coming from someone else, but which I nonetheless use to describe the shifts from happy-go-lucky to angry, tearful and overwhelmed that have been a part of my life since puberty. Yet somehow, despite knowing both of these things about myself, it had never occurred to me that they might be connected.

But connected they almost certainly are. Over the past few years, evidence has accumulated to suggest that fluctuations in female reproductive hormones not only have measurable effects on brain function and mental health, but that women with ADHD can be unusually sensitive to their effects.

Major hormonal shifts aligned with puberty, menstrual cycles, post-pregnancy and perimenopause are increasingly identified as periods that exacerbate ADHD symptoms, leaving a trail of chaos in their wake. There is still much to learn, but as researchers begin to unravel how the hormonal rollercoaster affects both body and brain, it is bringing hope for better ADHD treatments that target hormones, brain chemistry or both.

There are many reasons why the connection between hormones and ADHD was overlooked for so long. Women have long been underrepresented in scientific and medical studies, partly to avoid the complications of hormones, which can make it tricky to interpret results. Another major factor is that, until the mid-1990s, ADHD was considered a condition that primarily affects boys. Young boys are more likely to exhibit hyperactive and impulsive symptoms than girls, and the diagnostic criteria were written to reflect these male-specific traits and symptoms.

By the early 2000s, research started to reveal that girls were, in fact, just as likely to have ADHD as boys. But while their symptoms were as problematic for their education and wellbeing as those of their male classmates, their struggles were more likely to be experienced internally, manifesting as anxiety or inattention rather than outward hyperactivity and impulsiveness. "Girls are more likely to fly under the radar because they're typically kind of just there, quietly not understanding [lessons]," says Michelle Martel, a psychologist at the University of Kentucky. "It doesn't flag to the teachers in the same way." Boys are still two to three times more likely to be diagnosed with ADHD in childhood than girls.

It can be difficult to disentangle these apparent sex differences from cultural expectation. Girls may face stronger pressure to suppress outward signs of hyperactivity and impulsivity, to avoid being labelled as "bossy" or "difficult." Or, as one of my middle-school teachers once described me: "an itch with a capital B".

But while the pressure to hide socially unacceptable ADHD traits is real, there is also evidence that biology significantly influences how women with ADHD are able to manage their symptoms. For Sandra Kooij, a psychiatrist and adult ADHD researcher at Amsterdam University Medical Center in the Netherlands, the first inkling that hormones were a big part of the story came from the women she treated in the early 2000s.

"My patients were asking me for years to study their hormonal fluctuations," she says. "They said, 'We are definitely having a problem here and nobody knows about it. Can you study us?' "

Kooij was intrigued, so she designed a study, published in 2021, evaluating the experiences of 200 women with ADHD. Questionnaires measured their symptoms through the menstrual cycle and post-pregnancy, with the results confirming that they did seem to be unusually sensitive to hormonal fluctuations. Almost half the participants met the criteria for premenstrual dysphoric disorder, which can be debilitating and is estimated to affect 3 to 8 per cent of the female population.

What's more, almost 60 per cent of the women in the study who had given birth experienced postpartum depression, more than double the proportion in the overall population. This chimes with other research suggesting that women with ADHD have a significantly higher risk of developing depression while on hormonal contraception. Together, these findings indicate that women with ADHD have unusually strong emotional reactions to hormonal fluctuations.

There is also evidence that hormones affect the standard cognitive symptoms of ADHD. An earlier 2018 study by Martel's group reported a twofold increase in symptoms ›

of inattention, hyperactivity and impulsivity following ovulation and towards the end of the menstrual cycle, with the biggest cognitive changes among those who showed high impulsivity. While this study was in women who didn't meet the criteria for an ADHD diagnosis, Martel says that a follow-up study in 100 women with diagnosed ADHD, which is undergoing peer review, showed similar results. Furthermore, says Martel, the changes in symptom severity were significant enough that they could affect whether an individual would meet the ADHD diagnostic criteria from one week to the next.

A key diagnostic feature of ADHD is that it is present throughout someone's life, and so these hormonal fluctuations could prevent someone from getting the diagnosis and treatment they need. "To me, that's pretty clinically significant," says Martel.

Understanding these fluctuations is also key to improving the wellbeing of those experiencing intense reactions to hormone changes, particularly when, like me, they haven't put two and two together. In an interview-based study from March involving 14 women with ADHD, many reported feeling "controlled by their hormones" in ways that made it difficult to manage their everyday lives. Several people reported a surge in energy and motivation around ovulation, during which they made plans and promises that they were unable to keep just a few days later. As one woman in the study lamented, in words I fully relate to: "I feel like it's just chaos in my brain, constantly."

Lifelong impact

Worse still, while stimulant medications can help manage some of the chaos, there is some evidence that hormones can still derail the drugs' effects. According to the handful of studies that have so far been done, stimulant medication is often reported to be less effective during the second half of the menstrual cycle, and sometimes it doesn't work at all.

Hormonal shifts don't just affect monthly symptoms; they can have implications over a lifetime. This probably explains why so many women, myself included, are diagnosed during perimenopause. A survey of 3000 women in their mid-40s to their mid-90s with ADHD found the most common age at diagnosis was between 41 and 50, while more than half of all respondents reported a life-altering impact from symptoms during perimenopause. Hormones may explain the significant rise in ADHD diagnosis rates in middle-aged women, which have increased by 40 per cent over the past year in the UK alone. In a separate survey of 600 women with ADHD, led by Caroline Gurvich, a clinical neuropsychologist at Monash University in Melbourne, 98 per cent reported having a greater struggle with inattention during perimenopause.

MARTINS RUDZITS/GETTY IMAGES

Women with ADHD often have intense emotional reactions due to menstrual hormone fluctuations

"As one woman put it: 'I feel like it's just chaos in my brain, constantly'"

Importantly, says Gurvich, this doesn't seem to be standard menopausal brain fog masquerading as late-onset ADHD. "If someone has had smooth sailing their entire life, and they hit menopause, and talk about brain fog, it might look similar, but it doesn't meet the diagnostic criteria for ADHD."

By definition, ADHD has to have been present since childhood and, in Gurvich's study, women diagnosed in perimenopause reported first experiencing symptoms before the age of 8. Many of them had spent their entire lives masking symptoms or using coping strategies to work around them, she says. Then, in perimenopause, the hormone changes made this impossible. "They'd been covering up and masking and then it got to the point where that just didn't work any more," says Gurvich.

Other research backs this up. A 2025 study from Kooij's group found that among more than 5000 women over the age of 35, those with ADHD experienced perimenopause symptoms up to 10 years earlier than those without it, possibly because pre-existing issues with the neurotransmitter dopamine meant that a small drop in oestrogen levels in early perimenopause was more noticeable than for those with neurotypical brains. Once in the throes of perimenopause, women with ADHD were significantly more likely to report severe cognitive and emotional symptoms, with

more severe ADHD predicting worse perimenopause symptoms.

This range of evidence has established a clear connection between ADHD and hormone sensitivity, but researchers are still trying to unravel the mechanics. One clue comes from the fact that worsening symptoms tend to emerge when oestrogen levels fall rapidly. This happens twice in the menstrual cycle: immediately after ovulation and again just before menstruation. Significant drops are also seen in the days and weeks after giving birth, and in the erratic rises and falls that accompany puberty and perimenopause. "All those pieces of data suggest that declines or low oestrogen are really risky for cognition and for ADHD," says Martel.

Fortunately, there is already at least two decades' worth of evidence, first from studies in rats, and more recently in humans, to explain why this matters for brain function. Alongside its role as a reproductive hormone, oestrogen plays several important roles in the brain, activating pathways that protect existing neural connections and support the formation of new ones. Oestrogen also supports cell energy release while reducing oxidative stress, and is tied to progesterone, which helps maintain brain connections. Research from

Changes in oestrogen can hit dopamine-related circuits in the brain

JUAN GAERTNER/SCIENCE PHOTO LIBRARY

2018 suggests the benefits of progesterone are evident only if they follow a surge in oestrogen. "You have to prime the brain with oestrogen before progesterone," says Juan Pablo Del Rio, a psychiatrist at the University of Chile in Santiago, who conducted the study.

The impact of fluctuating oestrogen may be more pronounced in women with ADHD because of underlying vulnerabilities in their brain structure. But the fact that oestrogen boosts dopamine levels has gained the most attention. Dopamine has long been implicated in ADHD, partly because dopamine-related circuitry in the prefrontal cortex at the front of the brain is involved in motivation and impulse control. The stimulant medications used to treat ADHD increase the availability of dopamine in this part of the brain and, since it has higher levels of oestrogen than other bits of the brain, it makes sense that changes in oestrogen might hit these circuits harder.

The dopamine connection

It sounds plausible, but it isn't quite case closed. Despite what you might see on social media, the current scientific consensus is that there is more to ADHD than a lack of dopamine. For one thing, says Nevena Radonjić, a psychiatrist at SUNY Upstate Medical University in New York state, stimulants act on more than one neurotransmitter system. For another, despite some evidence that variations in dopamine-transporter genes are connected with ADHD, genome-wide association studies suggest that ADHD risk comes from the combined effects of large numbers of genes, only some of which are related to dopamine availability.

"Dopamine-related genes show some associations with ADHD, but are not among the most prominent findings," says Jan Haavik, a neuroscientist at the University of Bergen in Norway, who recently reviewed the evidence for the dopamine-ADHD connection.

One possibility, Martel suggests, is that hormonal sensitivity in women with ADHD is caused by a neurological double whammy. In some people, problems with dopamine signalling provide an underlying vulnerability to ADHD. Then, sudden drops in oestrogen make an existing vulnerability more obvious, cranking up the volume in an already-noisy brain.

Understanding these complexities is key to figuring out a solution to help women better manage their ADHD symptoms. If lack of oestrogen is the problem, perhaps an obvious answer is to plug that gap, by evening out the fluctuations with hormonal contraceptives or hormone-replacement therapy. These options can help some people and are worth trying, but, unfortunately, they aren't straightforward solutions and can exacerbate symptoms for other people. Martel's studies suggest that, even among women with ADHD, only around half are affected by hormonal fluctuations. And in some women who are affected, problems coincide with the rapid increase in oestrogen rather than the fall, with this period coinciding with a rise in impulsive risk-taking.

According to one study, those with low dopamine see an improvement in ›

Post-pregnancy hormonal shifts can exacerbate any ADHD symptoms

RICHARD BAKER/IN PICTURES VIA GETTY IMAGES

symptoms when oestrogen is high, while people with higher dopamine levels get worse. "We don't know if it's low oestrogen that's risky, or changes in the level of oestrogen, or whether there's an optimal level [for brain function]," says Martel. And while some may find their ADHD symptoms even out on oestrogen-containing hormonal contraceptives, the medication is also more likely to cause mood-related side effects in women with ADHD.

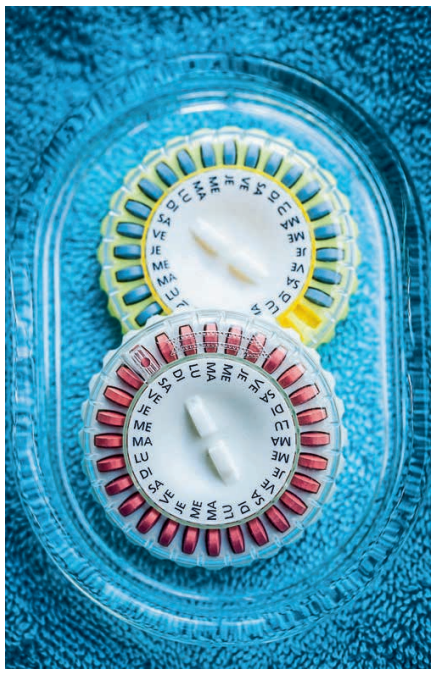
Taking back power

Given the many uncertainties in our understanding of hormonal balances, tweaking doses of stimulant medications may be a simpler and more immediate option. Some of Kooij's patients acknowledged taking higher doses when their hormones hit worst, which prompted her group to run a study monitoring symptoms and side effects in nine women with ADHD through several menstrual cycles. She worked with the women's psychiatrists to increase the volunteers' usual medication dosage by 30 to 50 per cent in the premenstrual period, when oestrogen was low. All nine women reported an improvement in cognitive and mood-related ADHD symptoms, and all opted to continue adapting their dose in the same way after the experiment ended.

Kooij stresses that all nine women were closely monitored by their prescribing psychiatrist throughout for any side effects. She doesn't recommend that people experiment with their own medication because of potential side effects on blood pressure, heart rate and sleep. "If you do this unguided and start getting heart palpitations and start to panic, you could end up in a worse situation than before. That's what we would like to prevent." She also acknowledges that larger, double-blind studies will be needed to gauge whether the effect is real – something she plans to do when funding allows.

For now, those at the forefront of research agree that increasing awareness of the hormone-ADHD link is a priority. Doing so influences treatment options and hands a little power back to women who feel like they are living at the mercy of their own hormones. Understanding why motivation and focus vary from week to week could make it easier for those affected to plan their workload and self-care practices more effectively – perhaps even scheduling therapy for a week where changes are more likely to stick, Martel suggests.

It can also provide much-needed comfort for people like me, and reassurance that they are less broken than they thought. My own relief tumbled out in a long and rambling story I told to Martel, describing my history of severe PMS, a blissfully quiet brain during pregnancy followed by postpartum depression, and, finally, the wheels falling off altogether in perimenopause. Having spent years feeling embarrassed by my inability to cope with life like a so-called normal person, it felt good to finally have an explanation, if not a solution. "Your reaction is very common," says Martel. The last time her work was featured in the popular press, she says, it prompted a flood of comments from readers who finally understood what they had been living with for years.



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HRT may help some women even out hormone fluctuations

"Worsening ADHD symptoms tend to emerge when oestrogen levels fall rapidly"

Spreading awareness among doctors is even more important. Last year, Gurvich attended an international conference on ADHD and listened to a presentation in which two well-known male psychiatrists pondered the mystery of a woman who sought help for intense ADHD symptoms, which she found debilitating for two weeks each month. They were trying to figure out what was going on and if she met the diagnostic criteria for ADHD, and no one on the stage or in the audience mentioned hormones. "It was just baffling to me," says Gurvich. "This was a woman of reproductive age, and no one brought up the menstrual cycle."

That knowledge gap is pervasive: early-career psychiatrists can go through nearly a decade of training without hearing anything about the impact of hormones on the brain, says Del Rio. More broadly, he says, a true understanding of the mind needs to consider the body as well as the brain. "Psychiatry doesn't end at the neck," he says. "You have to take into account the whole body." Kooij is working on exactly this approach, having recently set up the Head Heart Hormone Network, where psychiatrists can collaborate with specialists in gynaecology, cardiology and, in the future, other medical specialties, to explore the full impact of hormonal fluctuations.

The impact cannot be overstated, says Kooij. "What we're facing is a revolution in medicine for female healthcare." Many more changes are to come, she adds: "All the books will need to be rewritten." ▮

Caroline Williams is a science writer specialising in neuroscience, psychology and health. Her latest book is *Inner Sense*

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The power of wakeful rest

We may be able to get some of the memory and learning benefits of sleep while awake, discovers **Amanda Ruggeri**

JASON FORD

FOR most of my adult life, I have noticed something odd. Some evenings, I can barely remember what I did that day. Ask me what I had for breakfast and you will be met with a blank look. On other days, I can tell you the details of interviews I did, the plans I made, which snacks I packed my daughter for school and how much of each she ate.

The difference between them doesn't seem to correlate to how I slept. In fact, only one factor seemed to matter: how much I rested. I have long thought that, on days when I am rushing around, I am just more stressed, which may affect memory formation. But there could be another reason: the role of rest itself.

We all know that a lack of restorative sleep impairs our cognitive abilities. When we are sleep-deprived, we can struggle to recall what we have learned, absorb new information and sustain focus. We may also be aware that resting while awake seems to partially restore our sleep-deprived minds.

Now, neuroscientist Giulio Tononi and his collaborators at the University of Wisconsin-Madison are revealing how certain housekeeping and cognitive tasks that happen during sleep can also occur, to some extent, while we are awake.

This is "the last piece of the puzzle" that may answer why wakeful rest helps to fulfil some of the functions of sleep, says neuroscientist Thomas Andrillon at the Paris Brain Institute.

For decades, sleep was understood to be a global state that affects the whole brain at once. In deep sleep, the brain reverberates with slow brainwaves – in which neurons slowly cycle in sync between firing and silence – and mostly disconnects from the surrounding environment.

But in recent years, research has complicated that perspective. In 2011, a team of sleep researchers, including Tononi and his long-time collaborator Chiara Cirelli, also at the University of Wisconsin-Madison, published a paper describing an odd phenomenon. When rats were sleep-deprived yet awake, their brains showed sudden bursts of sleep-like slow waves – but only in clusters of neurons at a time. The team called it local sleep and considered it to be part of a broader phenomenon that exists in various forms across the animal kingdom (see "Half asleep", page 37).

These bouts of local sleep were incredibly brief: a few hundred milliseconds, at most. But they had a noticeable impact. When rats were trained to reach for sugar pellets, they were more likely to fall short if their sleep-deprived minds had slipped into local sleep first. "If it happens at the wrong time, in the wrong area, you have impaired performance," says Cirelli.

Humans also show local sleep states just before experiencing an attentional lapse. We are more likely to experience both when we are tired, which is why doing something routine but with high stakes – like driving a car – can be dangerous when we are sleep-deprived.

But Tononi, Cirelli and their colleagues' latest study, published in June, indicates there is an upside to local sleep.

In addition to describing local sleep, Tononi and Cirelli are known for coming up with one of the most compelling explanations for why we sleep: the synaptic homeostasis hypothesis. As we take in information all day long, our

brains form and strengthen thousands of neural connections. These connections are energy-hungry, so we can't keep them all. Sleep, they posit, is when our brains go to work decluttering what we don't need, which helps with storing what we do.

Could local sleep offer the same sort of housekeeping, just on a micro-scale? To find out, they genetically modified brain cells in mice so that a laser light could switch those neurons "on" or "off", mimicking the pattern of slow-wave sleep. In one experiment, they put a local neural network to sleep in awake mice that were sleep-deprived.

Sleepy heads

Afterwards, they found that the part of the mice's brains that had "snoozed" for 30 minutes showed reduced markers of synaptic strength – a sign that decluttering had already started – unlike the part that had stayed fully awake. They also noticed that, during global sleep later on, there was less slow-wave activity in the bit of the brain that had napped, presumably because its housekeeping function had already partly been done – which also indicated that local sleep seemed to have reduced that brain region's need for sleep.

These changes in brain activity were also reflected in behaviour. Normally, if a mouse learns a new task and then is sleep-deprived, its later recall is diminished. But when, in a different experiment, the sleep-deprived mice had local sleep induced across multiple networks for an hour after learning something new, they remembered the task just as well as the mice that took an actual nap. "This is the first piece of evidence that suggests that local sleep can do the job of sleep, and not badly," says Tononi.

Both Tononi and Cirelli are quick to point out that local sleep is no replacement for sleep in general. While they pushed the phenomenon to its limits in the laboratory to see what it was capable of – and what its underlying purpose might be – the fleeting bursts of local sleep that we experience in the real world aren't the same as a night's rest. If your brain can get to work on decluttering connections all at once, as in global sleep, that is clearly better and more efficient, says Tononi.

Still, local sleep seems to be the brain's attempt at a fallback. "The whole framework of local sleep is it is likely to be adaptive," says Andrillon. "It's not a bug of the system. It's not just a failure to maintain wakefulness." ›

"When we are tired, our brains snatch local snoozes to try to 'catch up' on housekeeping"

When our brain hasn't been able to get a global sleep, it does the next best thing.

The question is if, and how, local sleep can be encouraged when it might prove beneficial. Perhaps, some day, humans could benefit from the same sort of technology that Tononi and Cirelli used to induce local sleep in mice. In the meantime, most studies on local sleep have found that the phenomenon arises from sleep deprivation. The more tired we are, the more our brains snatch local snoozes to try to "catch up" on housekeeping, much as we might spot-clean the kitchen when we don't have time to tidy our entire house.

But researchers including Andrillon emphasise that we might slip into local sleep for other reasons, too. "An important aspect of this local sleep framework is that it's not just time-dependent – so how much you have slept – it's also use-dependent," says Andrillon. "If you pick one brain region and overuse it, the probability is that you will see these sleep-like events increase."

One way to "overuse" part of your brain? Through highly demanding cognitive tasks – like, say, writing about the science of local sleep.

In 2018, in one of the first studies to examine this effect in humans, a team led by Angelica Quercia, now at the Oasi Research Institute-IRCCS in Troina, Italy, asked well-rested people to learn the layout of an imaginary city, including 16 landmarks. Then they did a navigation task, without breaks, for almost 2 hours. The longer the test wore on, the worse they did. EEG readings indicated that the same parts of the brain that were most active while learning the city layout also showed local sleep during the navigation task – at the same moment they made errors.

When people are required to focus on a single-minded task requiring vigilance, it can also exhaust specific neural pathways. A 2019 review by a team at Washington State University's Sleep and Performance Research Center explored how these tasks both push those pathways into local sleep and help explain why people's performance on the task tends to get worse the longer they do it.

But could there be ways to trigger local sleep that don't depend on getting ourselves tired out first? Andrillon thinks there could be. The monotony we experience during "mindless" tasks – when we are, say, folding laundry, knitting or sitting with our eyes closed – means our overall arousal is lower, he says. That doesn't actively exhaust neural networks, pushing them into local sleep. But this low-arousal state may create a permissive environment for those networks to take a nap. This remains a hypothesis. To prove that rest induces local sleep, you would have to use high-density electroencephalography (EEG) to compare the brainwaves of non sleep-deprived people at rest with those of people who aren't at rest – which hasn't been done. But, if true, it could help explain something else Andrillon and his colleagues have found: local sleep events often precede mind-wandering, which tends to occur when we are in a low-stimulation environment. "It makes sense that, in this situation, where monitoring the outside is not that interesting, your brain could use these opportunities to do a bit of housekeeping," says Andrillon.

In his view, we should embrace mind-wandering, as it may well nudge our neurons to take these much-needed "naps". However, he says it is unclear whether local sleep is behind the cognitive benefits of entering a state of quiet relaxation with minimal sensory stimulation – known as wakeful rest.

Ultimately, whether it leads to local sleep or not, wakeful rest is no substitute for global sleep. Taking a break between tasks won't make

IMAGE SOURCE/PLAINPICTURE

Monotonous tasks may allow some of your neural networks to take a nap

THOMAS DEERINCK, NCMIR/SCIENCE PHOTO LIBRARY

Our brains strengthen neural connections during sleep

Half asleep

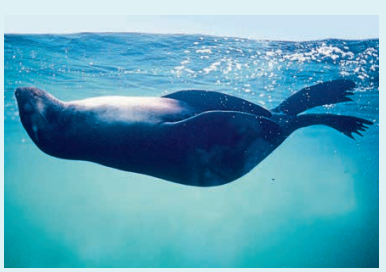
Recent research has shown how the phenomenon of "local sleep", in which small clusters of neurons briefly snooze, exists in animals and seems to have cognitive benefits for humans (see main story). But some other species have evolved a related way to gain the benefits of sleep without fully switching off: unihemispheric sleep, where half the brain goes to sleep at a time. In fact, this can be core to their survival.

Take the northern fur seal, which migrates thousands of kilometres each winter, then stays in the water for about 10 months before returning to land. When on land, this seal sleeps much like a human, complete with a global sleep cycle across its entire brain. But when it sleeps in water, it stays partly alert because predators pose a greater threat.

One eye remains open, one flipper paddles for balance, one set of whiskers is active, monitoring its surroundings – and one side of the brain remains in an active, "awake" state, while the other one sleeps. Unihemispheric sleep has also been found in other aquatic mammals, including bottlenose dolphins, Amazonian manatees and walruses.

Similar behaviour is seen in various bird species. Great frigatebirds stay aloft for weeks at a time as they migrate, and can fly even while one half of their brain is asleep. But this doesn't just happen during migration: when mallards are flanked by other birds, for example, they show brainwaves indicating global sleep, but when they are at the group's edge, one brain hemisphere sleeps at a time.

When sleeping at sea, northern fur seals keep half of their brain awake



UNIVERSAL IMAGES GROUP VIA GETTY IMAGES

up for getting only 4 hours of sleep. "To dissipate sleep need, you need to sleep," says neuroscientist Erin Wamsley at Furman University in South Carolina.

Still, in some realms, some of the time, wakeful rest may provide similar benefits – as Wamsley has discovered. For years, her research focused on how sleep affects memory consolidation. But over time, she noticed something. Across more than a century of research on how sleep affects memory, studies tended to share the same flaw. They would compare people who had slept with those who had done something else – like watching a movie or continuing with their day. Perhaps it wasn't that sleep was benefiting memory consolidation, Wamsley realised. Perhaps it was the absence of other tasks.

To find out, she designed an experiment in which participants were given a learning task that involved learning the meaning of Icelandic words and memorising long numbers. The people were then divided into three groups: one that napped, one that played a computer game and one that rested, eyes closed. (Her team used EEG to make sure that those who rested weren't actually sleeping.) Then Warmsley and her team tested how well the participants could remember the words and numbers.

Wamsley thought that the napping group would perform better than the others. But, surprisingly, the resting group did just as well. "Resting with your eyes closed and napping both benefited memory compared to the control condition – and equally so," she says.

A lot of this might be because of memory reactivation, she says. During sleep, our brains reactivate the same cellular firing patterns that occurred during the day, something that helps us organise and store our memories. This also happens when we rest, whether that is zoning out or sitting and closing our eyes.

When we rest, we also aren't taking in new information that could interfere with what we have just learned, for example by using up brain resources.

Few studies have compared sleep and rest head-to-head in the same way as Wamsley's memory experiment. But some other research has similarly found that, compared with continuing on to other tasks, taking a break may improve our cognitive performance, even for days afterwards.

In one study, for example, participants listened to a story, then spent 10 minutes either sitting and resting quietly or playing a spot-the-difference game. The participants who

FRANS LEMMENS/ALAMY

Resting with your eyes closed could benefit your memory

rested recalled more of the story 30 minutes later – and a week later, too. Other experiments have found that sitting quietly for at least 10 minutes after a learning task can help us remember the fine-grained details we often forget, integrate the spatial memories we need to accurately navigate, and even come up with the solution to a perplexing problem, in a "Eureka!" moment. Rather than "sleeping on it", resting on it may be enough.

Not all the research has found that wakeful rest has an effect. But one analysis from January found that, across 51 studies, wakeful rest did seem to boost memory. The benefits were strongest for older adults and people with memory impairments like amnesia.

In our always-on culture, it has never been harder to find the time for pauses between tasks. But above all, don't pack your day, says Andrillon. "Don't overdo it, because there are things that escape us that our brains are doing. And these things are pretty important."

On that note, it is time for me to close my laptop, sit quietly for 10 minutes and, just maybe, let my neurons take a micro-nap. ▮

Amanda Ruggeri is a journalist who covers science and health

CHRISTOPHER P. MICHEL

"Wait long enough and the entire history of the universe repeats exactly"

In an attempt to reconcile classical and quantum physics, quantum cosmologist **Sean Carroll** uses quantum theory as his guide. He tells Jacklin Kwan how this means we may be stuck in an eternally repeating universe

IF SEAN CARROLL is right, this interview has happened before. Not just once, but infinitely many times. In an earlier cycle of the cosmos, we met in Dublin, asked and answered these same questions and discussed the unsettling possibility that the universe is destined to repeat itself exactly.

Carroll, a quantum cosmologist and philosopher at Johns Hopkins University in Baltimore, Maryland, pursues one of physics' deepest questions: how gravity and the familiar classical universe emerge from the strange rules of quantum mechanics. But unlike most cosmologists, who begin with the universe we observe and then try to work backwards, Carroll starts from the vast landscape of all quantum possibilities – essentially taking quantum theory itself as his guide.

Against his better judgement, this approach has led him towards a cosmos that continually expands then contracts before a new cycle begins. Cyclic universes are nothing new, but Carroll's proposal has a peculiar twist. In most such models, each cycle differs from the last. But in contrast, his cycles are exactly the same: every galaxy reforms, every life unfolds again and every conversation is repeated word for word.

This bizarre picture also offers a possible escape from an uncomfortable puzzle involving so-called Boltzmann brains; in many models of universes that persist for long enough, self-aware brains with false memories should pop into existence, to the point that they outnumber ordinary minds.

New Scientist caught up with Carroll at the Dealing with Time and Chance philosophy conference at Trinity College Dublin, Ireland, to ask how he landed on such a strange cosmology, how it solves the Boltzmann brain problem and what it tells us about the nature of time.

Jacklin Kwan: Your approach begins with quantum mechanics rather than the universe described by general relativity. Why?
Sean Carroll: Quantum mechanics is the single most foundational view that we have of the world. However, when you take physics classes, you are first taught classical mechanics. Then, when you're taught quantum mechanics, you start with a classical system and learn how to turn it into a quantum system. In other words, you learn to "quantise" the theory.

That approach has worked really well for forces like electromagnetism, but it hasn't seemed to work in any normal, straightforward way for gravity. So, my perspective is that we got lucky with the other forces of nature. The surprising thing isn't that gravity is hard to quantise – the surprising thing is that quantisation works so well for everything else.

So, what I have been thinking about over the past decade or so is how to start with quantum mechanics and derive the observed world from it, rather than starting with the observed world and trying to quantise it. I began with the question: what if we take quantum mechanics seriously?

That sounds like a clean starting point. But when you apply ideas like this to an eternal universe, you quickly encounter a potentially serious problem: Boltzmann brains.

> "I began with the question: what if we take quantum mechanics seriously?"

What are Boltzmann brains?
If you think the universe lasts forever, it spends most of its time near a state called thermal equilibrium. It is a state where energy is spread out as evenly as possible and, on the face of it, nothing much happens.

But if the temperature isn't precisely zero, even this apparently uneventful state can still fluctuate, allowing small pockets of order to emerge. Take the air in the room you are sitting in. There is a classic undergraduate calculation asking how long it would take for all of it, through random motion, to end up in one half of the room. It will eventually happen, but only after a time vastly longer than the age of the universe.

Given enough time, the universe fluctuates into everything that is allowed. That includes a universe like ours, but it also includes observers surrounded by empty space. These spontaneously emerging brains, complete with unreliable memories of having existed in our universe, are Boltzmann brains.

In many eternal models, Boltzmann brains would be produced in overwhelmingly greater numbers than ordinary observers who evolved out of galaxies, stars and life on planets. And if your theory says that almost every observer with experiences like yours is actually a random fluctuation with unreliable memories, then you can conclude that you're probably one of them and there's no real connection between what you remember and what actually happened.

And that is where the idea starts to eat itself: if the theory were true, we would have no good reason to trust the observations or reasoning that led us to believe it.

Do cyclic cosmologies offer a way out?
I'm not a big fan of cyclic cosmologies, to be perfectly honest. They've been around for a long time, and I've always worried that they either don't solve existing problems or create new ones of their own. For instance, some quantities require an infinite amount of fine-tuning [to match with the universe that we observe today]. So, I've never spent much time thinking about them.

But what we realised in this recent paper with my collaborators at Johns Hopkins University, Nadiia Diachenko and Saakshi Dulani, is that there is a loophole to the Boltzmann brain worry. Let's start with a quantum description of the entire cosmos called the "wave function of the universe". Quantum mechanics describes the universe using a mathematical space called Hilbert space. We don't know if Hilbert space is finite- or infinite-dimensional; it could be finite, so we decided to investigate that possibility.

You're going to have to explain Hilbert space.
Hilbert space is the space of all possible quantum states, or all possible wave functions. To take the simplest example, a single electron has an intrinsic property called "spin" that is either up, down or some combination of the two: Hilbert space contains all those possibilities and combinations.

If Hilbert space is finite, we can use a famous result called the recurrence theorem, which goes back to the mathematician Henri Poincaré. He was originally thinking about ›

Watch the full interview
Hear more from Sean Carroll in our extended video interview, available at **youtube.com/NewScientist**

XEFSTOCK/GETTY IMAGES

Time's arrow comes from entropy increasing, like when fluids mix

planets moving around the sun. The theorem says that if a system has only a bounded range of possible states, then, given enough time, it must eventually return very close to where it began. That makes logical sense: you have an infinite amount of time, but only a finite number of states to occupy. Of course, you will eventually come back to one you have visited before.

Put those ingredients together – a finite number of possible states evolving smoothly over infinite time – and you get cycles.

Typically, each cycle visits all the allowed states, many of which include Boltzmann brains. But if you choose the evolution of the universe precisely, the wave function need not visit every possible state. Imagine tuning all the atoms, all the little billiard balls bumping into one another, so that they don't explore every possible arrangement. They move along one path and eventually just bounce back – they just retrace it. If that path never passes through states containing Boltzmann brains, those brains are never produced. Or at least they are sufficiently rare that they don't make up most observers in the universe.

That is what we argue can happen in our model. It isn't enough for the universe to be cyclic in a loose sense. Its quantum evolution has to be exactly periodic.

So, we don't just see a succession of broadly similar universes, but the same history repeats exactly?
Yeah, so you still get a big bang, the universe expands and cools, and it empties out into empty space. This is just what's happening in the universe we observe – galaxies are moving farther apart, photons in the cosmic background radiation are diluting and cooling down. Eventually, there will be nothing left but empty space. And the universe stays in empty space for a very, very long time.

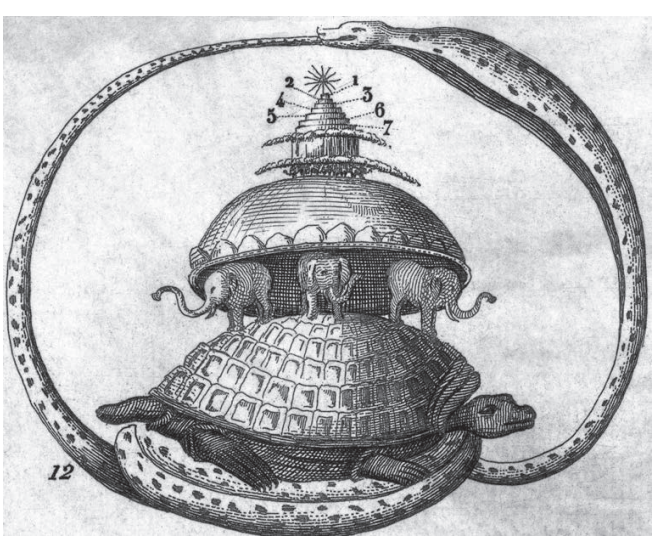
Then, in our picture, you play the big bang backwards. Just as the expansion involved everything moving apart and growing more dilute, particles getting further away and photons getting stretched out so that they redshift, you gradually see photons coming in and becoming increasingly compressed and blue-shifted. Particles pop into existence and become more numerous. Instead of forming black holes, you form white holes, which continually spew matter and energy outward.

The whole story plays backwards, going down to a crunch exactly like the big bang played backwards in time. That crunch hits a bounce point, then you get the ordinary big bang and repeat the cycle again.

So far, this sounds the same as most cyclic cosmologies, but in our model, the universe isn't merely cyclic, it is truly periodic. Think of a pendulum – after a fixed interval, it returns to exactly the same state and retraces the same motion. You just have to wait an extraordinarily long time. Our universe is about 10^{10} years old, whereas we are talking about an incomprehensibly bigger number of years called a googolplex.

It takes so long because there are so many different parts of the universe's quantum state evolving at once, and the whole thing only repeats when they all line up again. But wait long enough and the entire history of the universe repeats exactly. And it does so an infinite number of times.

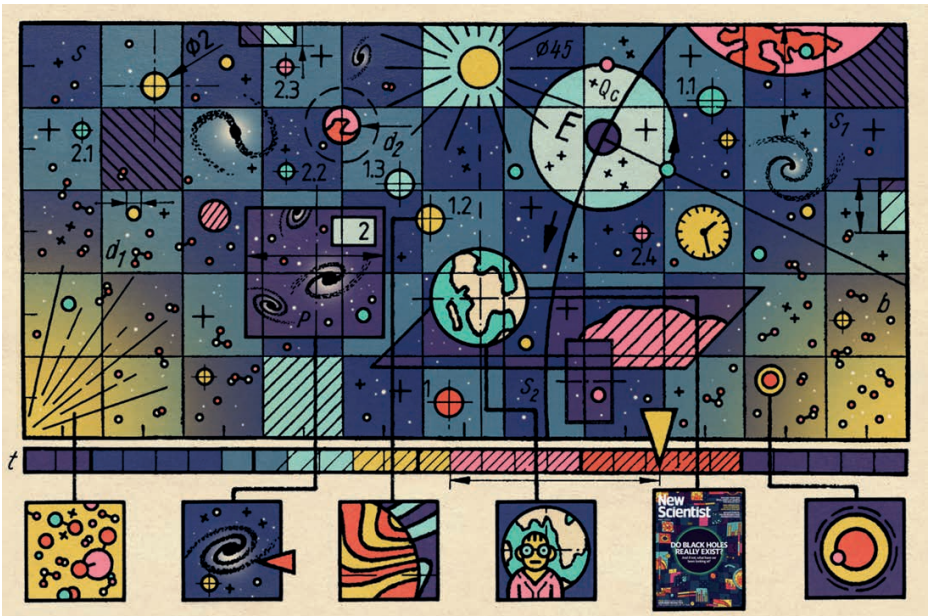
One way of depicting a cyclic universe is an ouroboros – a snake that eats its own tail



BETTMANN/GETTY IMAGES

So, even our current conversation would have already happened in previous iterations and will always happen in future ones. How do you feel about there being nothing special at all about the present moment?
I don't have very strong feelings about it. As we say in the paper, it is a matter of taste. You can think of this as a cyclic cosmology in which history repeats over and over. Or you can treat it as a single universe that happens once and then eats its own tail, like the ouroboros – the ancient symbol of a serpent eating its own tail.

What does an eternally repeating cosmos mean for free will?
If the absence of free will bothers you, then what should really bother you is the existence



CHRISTIAN GRALINGEN

"The arrow of time doesn't exist for most of the history of the universe"

In one version of a cyclic cosmology, the universe is like a pendulum, retracing the same motion

of laws of physics. If you know what happens at one time, then you can say what is going to happen at all the other times.

Even if the laws of physics aren't deterministic, as in some interpretations of quantum theory, there are no implications for free will; all that matters is that there are laws in the first place. Adding a random-number generator to the laws of physics isn't the same as saying that your willpower has the ability to determine what happens. No known version of quantum mechanics says that.

Other than banishing Boltzmann brains, what else can this eternally repeating universe help with?

These models might help us to make better sense of how time works. In the real world, time has an arrow that points from the past to the future. I can do things today that exert a causal impact on the future, but I can't do anything now that affects the past. But in our best understanding of the fundamental laws of physics, time doesn't have a direction.

We kind of know how to resolve this tension using a concept called entropy. Entropy is really a way of counting. Take a cup of coffee. It is made of atoms and molecules, but I never see the individual atoms, and I can't tell you where each one is or which direction it is moving in.

Then, I can ask: given what I can observe about the cup of coffee, how many different arrangements of atoms would look the same? That is entropy. If cream is mixing into coffee, at first they are separate. There aren't many ways to arrange the atoms while keeping the cream in one place and the coffee in another. There are many, many more ways for them to be mixed together, so that is the direction things go in – entropy increases. And this tendency for entropy to increase gives time its arrow.

But if entropy always increases, it means that, in the early universe, near the big bang, the universe was in a very, very special, low-entropy configuration. Why did it start very low? Nobody knows. But we hoped that building a cosmos from the fundamentals of quantum mechanics would offer some pointers.

What did you find?

Unfortunately, we haven't solved the low-entropy problem here, at least in our current state of the art. If anything, this model makes the problem worse. We make little computer simulations that start the wave function of the universe in a very, very low-entropy state. Why? Because we said so. That is the only reason why.

Maybe there will be an explanation down the road. This is how science works: you make little, incremental improvements.

Does time behave differently in this cyclic universe?

In our model, once the universe has expanded and cooled, you hit thermal equilibrium. The stars burn out, they fall into black holes, the black holes evaporate and you are left with nothing but empty space. Time still exists. Time is fine. But the arrow of time doesn't exist for most of the history of the universe.

But that isn't really a problem for the intuition of any observers because there are no observers around. All we have at this point is just empty space.

When time does have an arrow, it always points away from the bounce. The arrow points in opposite directions on one side of the bounce compared with the other side. There will be people living in what you and I call the big crunch. But what we call the big crunch, they would call the big bang.

Where do you hope these insights into entropy and time can take us?

Ultimately, we're trying to understand quantum gravity. One big obstacle is that there is no detailed experimental data. For instance, we haven't found the hypothetical particles of gravity called gravitons.

The fact that our universe started in such a low-entropy state is one of the most powerful and informative pieces of data we have. Just by trying to understand how that can possibly arise in a universe governed by the rules of quantum mechanics, we stand to learn an enormous amount about gravity, quantum theory, cosmology and why time works the way it does. ▮

Jacklin Kwan is digital features editor at *New Scientist*, principally covering physical science. She holds a master's degree in physics

Making furry friends

When did our ancestors first get the urge to adopt pets? **Michael Marshall** looks to primates for clues

SENTHIL AATHAVAN SENTHILVERL

ONE of our cats has discovered a new way to annoy me. There is a ledge above our kitchen window, which she can use to reach my bedroom window. If I leave the window open to let in the cool night air, she comes in unexpectedly in the middle of the night and jumps on my head. If I leave it mostly shut, she sits on the ledge and sings the song of her people until I open the window. I could almost admire her commitment to the bit, if I wasn't so sleep-deprived.

Those of you who have pets will no doubt have similar stories: incidents and patterns of behaviour that lead you to question your own wisdom in inviting these creatures into your homes. Then they do something nice, like sit quietly on your lap when you're feeling ropy, and you forget about the stupidity until the next time.

Keeping pets seems to be a fairly modern behaviour. I recently compiled a timeline of human evolution, and domestic animals were the penultimate item. The earliest domestication seems to have been dogs, beginning perhaps 40,000 years ago and giving rise to recognisably "modern" dogs by about 14,000 years ago. On a similar timeline, we also picked up synanthropic animals like foxes and raccoons, which benefit from living alongside us but have never become domesticated. Millennia later, once some societies had started farming and living in dense settlements, other domestications occurred – including wheat, rice and cats.

In the grand scheme of human evolution, which spans the millions of years since our ancestors split from the ancestors of chimpanzees and bonobos, the past 40,000 years is minuscule. For most of prehistory, humans and hominins didn't have pets.

But our ancestors may have engaged in similar behaviours: spending time with animals of other species, even cuddling them and playing with them. Such affiliative behaviours, which relate to forming social bonds, may be the precursors to pet-keeping.

This isn't speculation: we now know that modern primates do this – a lot.

Today, Cyril Grueter is a biological anthropologist at the University of Oxford. But about 20 years ago, while still a student, he visited a zoo in Shanghai, China. "I saw a gibbon interacting affiliatively with a little mouse that had wandered into its enclosure," he says. "I saw the gibbon caressing the mouse, holding the mouse in its hand."

Later, Grueter was doing fieldwork on black-and-white snub-nosed monkeys in China. "I saw how juveniles were jumping on domestic pigs," he says. "They were trying to play with domestic pigs." This led him to become fascinated by how primates, the group of animals to which we belong, interact with members of other species. At least sometimes, primates seem to play with members of other species, even make friends with them.

"A MARMOSET WAS ADOPTED BY A TROUPE OF WILD CAPUCHIN MONKEYS FOR 10 MONTHS"

At this point, I'm going to introduce a bit of jargon, simply because I can't keep writing "members of other species". An animal that belongs to the same species is a "conspecific", and an animal that belongs to a different species is a "heterospecific". When the gibbon picked up the mouse, it was interacting with a heterospecific.

Over many years, Grueter and his colleagues have compiled all the examples they could find of primates interacting with heterospecifics. They now have 427 cases: some from the academic literature, others from media sources like YouTube videos and a global survey of 37 primatologists. They published their synthesis study in the journal *Primates* in July.

Grueter emphasises that it is very much a first pass. "There wasn't really much in the mainstream scientific literature," he says. Most observations were anecdotal, and the editors of scientific journals rarely accept anecdotes. "There's so much missing information", because these interactions have been largely ignored by researchers. "We're hoping that this study is also a wake-up call for primatologists, or zoologists more generally, to look for similar behaviours in both the wild and in captivity."

Despite these struggles, Grueter's team managed to document 88 primate species interacting socially with either other primates or one of 127 non-primate species. This was enough to see some basic patterns.

Most simply, "this is quite a common behaviour", says Grueter. It's also not an artefact of captivity, which can sometimes cause animals to behave oddly: the team found 311 instances from the wild and just 111 from captivity. We can be confident that

NEIL CHALLIS

ALEXANDRE BONNEFOY AND CEDRIC SUEUR

Primates have been seen stroking squirrels (far left), grooming dogs (left) and riding deer (below left)

wild primates sometimes socialise with heterospecifics.

"Initially, we thought heterospecific social behaviour would be more common among closely related species, because they're probably better at reading each other's signals, at communicating with each other," says Grueter. Seemingly in line with that, the most common interactions were between Old World (African and Eurasian) monkey species: there were 89 such interactions. "But then we also found interactions between very distantly related species." The second most common pairing was Old World monkeys and dogs: 24 such interactions.

The sociable ape

The team classified the interactions into 17 types. They included "carry", "huddle", "ride on back" and (sorry, there had to be a dark bit) "treat abusively". However, the most frequently reported were play (139) and grooming (136).

Let's have some examples. An adult female white-faced capuchin groomed an adult female black-handed spider monkey in Santa Rosa, Costa Rica. A tufted gray langur stroked a grizzled giant squirrel in Yala National Park, Sri Lanka. Stump-tailed macaques at Khao Tao Mo temple in Thailand groomed a domestic dog. A Japanese macaque mounted a sika deer in Yakushima, Japan, then rode on its back.

What is going on here? "One of the major things we don't really know is what the benefits of these interactions are," says Grueter. When a primate plays with a heterospecific, that may offer the same benefits as play with a conspecific: they learn motor skills and social skills. But what about when, say, a langur touches a squirrel? "There's no functional benefits that we can think of," says Grueter, other than the simple and direct fact that it might feel nice and offer comfort.

Often, primates may simply be curious about the heterospecifics they encounter. "I think it's exploratory behaviour," says Grueter.

This may explain the nastier side of these interactions. "The males were usually the ones who handled the heterospecific individual quite roughly," says Grueter. The team confirmed 13 deaths of heterospecifics: seven birds, three primates, two pangolins and one domestic cat.

Male primates were also less likely to interact with heterospecifics at all. In contrast, juveniles and females were more likely to do so.

One possibility is that the primates are attracted to cute-looking heterospecifics. For humans, that often means juveniles: we find baby animals cuter than adults and are drawn to them. "It's possible that non-human primates respond to similar stimuli in a similar way," says Grueter, "but we did not find any evidence for that." Primates didn't selectively seek out juvenile heterospecifics for play and cuddles, based on the data available.

It is more likely that primates reach out to heterospecifics when there are no conspecifics around. Primates are highly social, and it may be that they will take social interactions where they can get them.

Does this mean wild primates have pets? Grueter says the evidence doesn't support that, if only because pet-keeping implies a long-term relationship, which the data doesn't show. "From what we could glean from the literature, [the interactions] lasted anywhere from a minute to maybe an hour, or a day, or a couple of days," he says. We wouldn't call that pet-keeping.

However, there are a few cases where heterospecifics seem to have formed longer-lasting friendships. Grueter flags a 2006 report of a marmoset that was adopted by a troupe of wild capuchin monkeys. The marmoset stuck around for at least 10 months and integrated into the group: two adoptive mothers nurtured it and the other capuchins tolerated it.

"I would say this is a case where you could probably use the term pet-keeping," says Grueter. "At least, it's a rudimentary form of pet-keeping behaviour."

I suspect that, if primatologists do start looking for heterospecific interactions, they will find more examples. Something similar happened with grief behaviours: a few isolated anecdotes of primates seemingly mourning dead conspecifics eventually led to systematic evidence of mortality-related behaviours in primates and other social animals. That's certainly what Grueter hopes will happen: he is planning a more extensive follow-up survey.

I also think these findings fit a broader pattern about human uniqueness. Everything that is supposedly unique about humans turns out to be a matter of degree. Yes, our languages are more complicated and versatile than the communication systems used by other animals, but animals can still convey a lot to one another. Likewise, those of us who keep pets may be more committed to it than wild primates, but wild primates are still capable of forming relationships with heterospecifics.

Finally, these primate-heterospecific interactions are yet another reminder that we are, and always have been, part of the biosphere. We are inextricably linked to the ecosystems in which we live. Our ancestors no doubt hunted animals for food – but they may also have cuddled them and thrown sticks for them to chase. ▮

This is an extract from our subscriber newsletter *Our Human Story*, written by science writer Michael Marshall. Sign up at newscientist.com/our-human-story

11 September 2026 | 3 days

Unearth the mysteries of the universe this September

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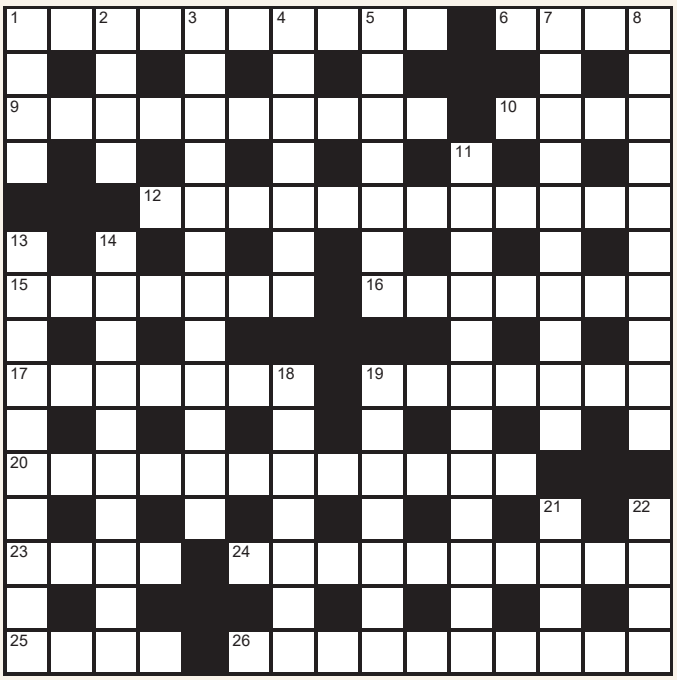
Quick crossword #215 *Set by Richard Smyth*



Scribble zone

Cryptic crossword next week

ACROSS

1 Seed-eating passerine of Australia and South-East Asia (5,5)
6 Sicilian volcano (4)
9 Neurological sleep disorder (10)
10 ___ acid, $C_5H_4N_4O_3$ (4)
12 Speckle-breasted relative of the fieldfare (6,6)
15 Ink shade used by most colour printers (7)
16 Marine mammal with a single long tusk (7)
17 Pigeon genus (7)
19 Outbreaks of fatal diseases (7)
20 Another name for a positron (12)
23 Charged particles (4)
24 Point where flow is narrowed (10)
25 3^2 (4)
26 Feature developed through evolutionary selection pressure (10)

DOWN

1 Zn (4)
2 1 Across or 12 Across, say (4)
3 As 1 is to H, for example (6,6)
4 Fundamental principle in classical physics (7)
5 Water tank (7)
7 Quantity or rate of data transferred over a network (10)
8 Drink problem (10)
11 Medicine reference work (12)
13 State of extreme thinness (10)
14 Blood component that enables coagulation (10)
18 Pharyngeal tonsil (7)
19 In motorsport, a break for maintenance or repair (3,4)
21 Pursuit of alien life (acronym) (4)
22 Dermis (4)

Quick quiz #366
set by Sam Wong

1 Which fossil species, first described in 2002, is the oldest known hominin and lived around 7 million years ago?

2 An antibody treatment called tanruprubart has been developed to treat which autoimmune condition, in which the immune system attacks the peripheral nerves?

3 In which two countries in continental Europe could people see a total solar eclipse on 12 August?

4 Pitcher plants, sundews and saxifrages are among the plants that have evolved which trait?

5 What type of cloud can accelerate the spread of wildfires?

Block Universe
created by Puzzlr

The goal is to divide the grid into non-overlapping rectangles. Each rectangle must contain exactly one number, and have an area equal to that number. For example, a 6 should have a rectangle covering six squares.

				2	3	2		
16								
							12	
				2	2			
	4							
			12					
					2			
2	2				2			2
		12		3		7		
					2		4	2
							4	

Answers to this week's puzzles on page 47

Waggle dance

Do all bee species speak the same language? I have bumblebees nesting under my roof, and wonder if the other bees in my garden can interpret the bumblebees' signals about nectar sources?

Mike Follows
Sutton Coldfield, West Midlands, UK

No. Bees do not share a universal language, although they are surprisingly good at picking up clues from other species.

Bumblebees are social insects. A successful forager can encourage others to look for food, and floral scents she carries back provide clues about what to seek.

In contrast, on returning from a rich source of nectar or pollen, a honeybee scout performs a waggle dance that communicates its direction and distance.

The dance is also a sales pitch. The scout shares samples of nectar and advertises better sources more enthusiastically. Think *Dragons' Den* or *Shark Tank*, with rival scouts pitching opportunities and the colony investing its workforce in the best.

These dances take place in the darkness of the hive. Even

"Think *Dragons' Den* or *Shark Tank*, with rival scouts pitching opportunities and the colony investing its workforce in the best"

if a bumblebee could observe one, there is no evidence that she could interpret the directions.

But bees can eavesdrop in other ways. Bee cognition researchers Erika Dawson and Lars Chittka found that bumblebees could learn that a honeybee sitting on a flower was a sign of a reward. To them, a honeybee was as useful a signpost as another bumblebee. Whether this happens in the wild remains unclear, although some stingless bees use other bee species to help locate food.

Bees also leave chemical footprints on flowers. Bumblebees and honeybees can detect scent marks left by other species and use them to avoid recently depleted flowers.

Flowers provide clues of their own. Many have nectar guides – markings rather like the approach lights and runway markings at an airfield – directing bees towards their reward. Some are visible only in ultraviolet.

There are electrical clues, too. Flying bees tend to be positively charged and flowers negatively charged. When a bee lands, charge is transferred and the flower becomes less negatively charged. Bumblebees can detect the change and assess whether a flower has recently been visited.

So, bees may not speak the same language. But they can watch one another, read the same signs and follow the chemical and electrical footprints of previous visitors.

Gill Nicholls
Crackington Haven, Cornwall, UK

I am no expert, I've just been fascinated since childhood with insects. But my understanding is that the UK's native *Apis mellifera mellifera* (European dark bee) doesn't need to return to her sisters and tell them where food could be found; the temperate land was full of flowers. Same for the UK's bumblebees and, of course, its many solitary bees.

The modern honeybee is largely hybrid, with arid land ancestry. She has kept her ancient skill born of food scarcity.

SHUTTERSTOCK/TATANGARCIA

This week's new questions

Beautiful things **Why do humans have a common sense of beauty for things like sunsets, and do other animals share this appreciation?** ***Robert Johnson,*** *Ipswich, Suffolk, UK*

Hot or cold **Why can't we cool water as quickly as we can heat it?** ***John Bailey,*** *Farnborough, Hampshire, UK*

Do other animals share a common sense of beautiful things?

Space jam

How big would a planet have to be before its gravity made space travel impossible for the inhabitants? (continued)

James Arnold
London, UK

I feel for the asker of this question. You printed three interesting responses, none of which quite gives an answer to the question!

First, we need a sensible definition of impossible. Let's say that space travel is impossible if the planet's escape velocity is equal to the speed of light. Although it seems unlikely that any future technology might be able to launch spaceships at anywhere even close to this speed, it's a good limit. How to reach that launch velocity in a practical time frame without killing the occupants with g-forces is a problem we can leave to future engineers!

Then, we need one more assumption, as a previous correspondent, Alex McDowell (11 July), points out: the density of the planet. Let's use Earth's average density, which is about 5500 kilograms per cubic metre.

Now, we set the escape velocity as the speed of light, fiddle with the equations a bit, and we find that this planet would have a radius of about 170 million kilometres! Interestingly, that is about the same as Earth's orbital radius around the sun. Of course, our choice of "impossible" means that, by definition, this object is, in fact, a black hole, so it also isn't likely to have rocket scientists tackling this problem.

Linda Phillips
Narrogin, Western Australia

This question is related to another one: how big does a planet need to be to retain its atmosphere?

Defining Earth's mean gravity as 1.0 *g*, then gravity of about 1.2 *g* would be sufficient to prevent

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Tom Gauld
for New Scientist

space travel, using known rocket technology. Gravity on Mars is 0.38 *g* by comparison, on the moon 0.17 *g*.

A planetary body needs gravity of 0.6 *g* to prevent loss of its atmosphere, hence why atmosphere is almost non-existent on Mars and the moon.

So, for life forms requiring an atmosphere and space travel, the gravity range is 0.6 to 1.2 *g*.

An ideal gravity would be 0.8 *g*: strong enough to retain the atmosphere, while more easily facilitating rockets and space travel.

For exoplanets whose gravity has been estimated, some 40 per cent of them have gravity in the desired range, suggesting that, if life forms are plentiful, it isn't high gravity preventing interplanetary travel.

"How to reach that launch velocity without killing the occupants with g-forces is a problem for future engineers"

Head banging

When wasps, bees and flies continually clatter against the glass of my conservatory attempting a means of escape, are they following a strategy? (continued)

Reg Price
Hinckley, Leicestershire, UK
To add to previous observations, I have twice seen dragonflies enter large, heavily-glazed buildings: one a golf club conservatory, the other a commercial greenhouse. On both occasions, the dragonflies seemed to check out the space for several minutes and then leave via an open window. On both occasions, they didn't once hit the glass, or anything else!

Thinking about the number of flying insects more generally, I have observed that those colliding with my car have fallen in numbers. When once I would have to clean the windscreen of insect debris frequently in a single long journey, now I have to examine the car to find any trace anywhere. I've also noticed that when it comes to flying insects entering an illuminated room via an open window after dark, numbers have fallen from dozens in an hour to maybe a single individual. Maybe changing to LED lights has had some effect?

I am 79, so these changes are over 60 years.

James Fenton
Clachan-Seil, Oban, UK
I have noticed that when the smaller flies found in a house, such as cluster flies, encounter a closed window, they spend their whole time trying to get through it and eventually die. However, the larger houseflies have a different strategy: they try a given window for a short time, then give up and try another one, eventually being successful if they find an open one. This indicates a greater intelligence. ■

Answers

Quick crossword #215

ACROSS 1 Zebra finch, **6** Etna, **9** Narcolepsy, **10** Uric, **12** Mistle thrush, **15** Magenta, **16** Narwhal, **17** Columba, **19** Plagues, **20** Antielectron, **23** Ions, **24** Bottleneck, **25** Nine, **26** Adaptation

DOWN 1 Zinc, **2** Bird, **3** Atomic number, **4** Inertia, **5** Cistern, **7** Throughput, **8** Alcoholism, **11** Pharmacopeia, **13** Emaciation, **14** Agglutinin, **18** Adenoid, **19** Pit stop, **21** SETI, **22** Skin

Quick quiz #366

1 *Sahelanthropus tchadensis*

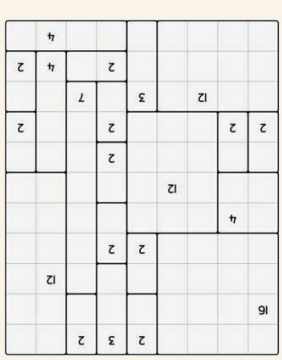
2 Guillain-Barré syndrome

3 Spain and Portugal

4 Carnivory

5 Pyrocumulonimbus

Block Universe



Archaeologists RIP

In July, Feedback reported that geologist characters in movies were surprisingly likely to die, often from "work related" causes like volcanic eruptions, but remarkably frequently by murder (25 July). We wondered how other scientists fared.

Andrew Hardwick flags *The Avengers* – not the Marvel superheroes, but the British spy series from the 1960s. "Any character introduced as a scientist was certain to be killed off," Andrew says, due to the limited budget for hiring guest actors. "Exposition characters had to double up as victims or villains." Feedback briefly considered performing an analysis to estimate the scientist death toll, but then we learned that the show ran for 161 hour-long episodes and decided we had better things to do.

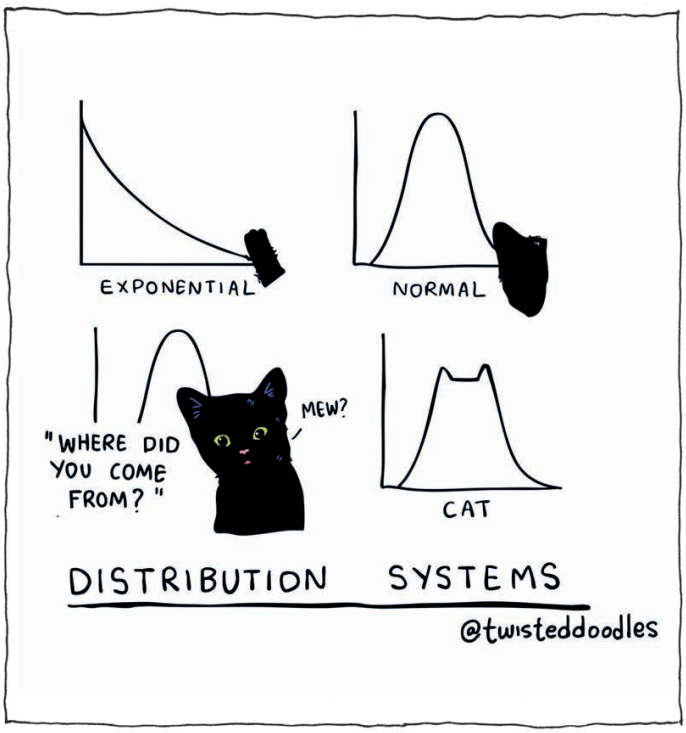
Meanwhile, David Hawke pulls us up on a detail. We claimed that one indicator a character will die is that he is played by Sean Bean. David argues that Bean's breakout role was the heroic Richard Sharpe, in the TV adaptations of Bernard Cornwell's historical novels. While some of Bean's characters "meet their doom", David says, "surely playing Sharpe more than compensates for this". Feedback feels David underestimates just how often Bean dies on screen. A YouTube supercut spanning 1986 to 2016 shows him meeting his maker no fewer than 24 times.

However, our main focus here is a missive from Andy Chapman. "As a now retired archaeologist I feel fortunate to have made it this far," he writes, "given the film death rate for archaeologists." They are particularly likely to die in films involving Egyptian mummies. "Here the death rate must approach 100 per cent, with only the heroic/romantic leads exempted, but often not their trusted assistants."

Andy's argument rests in part on the *Indiana Jones* and *Tomb Raider* films, alongside the various incarnations of *The Mummy*. Andy notes "an unhealthy death rate" in many of these franchises, albeit with a caveat. "Much of this would apply to people unlikely to be regarded as qualified archaeologists, as I don't believe training in weapons and explosives feature on the syllabus of many archaeology departments."

Andy's more sedate approach to the field appears to have kept him safe. He spent his time "working largely in British commercial archaeology ahead of quarrying and construction projects", which tended to yield less treasure or cursed swords, and more "boxes of broken pottery and animal bone". Such finds, informative as they are, "don't often lead to homicide".

Twisteddoodles *for New Scientist*



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Reprogram yourself

Feedback is feeling a bit wiped out from the alleged "summer holidays", which just mean we have to work while also ferrying Feedback Jr to their various social engagements. So we wanted a wellbeing hack, and reader Graham Lansdell was on hand to tell us about one. Through a convoluted sequence of events, Graham had become aware of GEOTRAN, "a coding language for the inner bio-computers".

Promisingly, the official website informs us that "GEOTRAN is a numeric-geometrical dialect which speaks directly to the body's information fields (memory fields). It works similarly to entering new information into a computer system. By erasing subconscious, self-sabotage, and de-stressing blockages resulting from personal beliefs, early childhood programming, fears, and traumatic experiences, you can reformat for a better life!"

This sounded like just the ticket. Feedback could do with a bit of mind-body reprogramming to regain our usual mild levels of vim and vigour. So we read on.

We learned that, unlike conventional binary computers, "The GEOTRAN language uses twelve digits (1 through 12)". Apparently, "these number codes create the actual instructions for the field to make a correction to the existing programming. The geometry locates the place where the dysfunction is stored, and the number makes the correction."

It seems that GEOTRAN instructions must be "entered at specific points, called 'spin points,' on and around the body". These instructions are then "fed to the heart/mind which has 7 layers or 7 different functions. The heart/mind distributes this information to 12 rings that operate somewhat like a CD, which also holds coded data that is read by light."

Alas, due to our exhaustion, Feedback was unable to comprehend the instructions. In a bid to hack our system, we tapped our arm a few times to see if it helped, but so far it hasn't.

It's a gas

In our quest for ever-more-niche scientific tourist attractions, we keep finding museums dedicated to gas. Upon reading our item about Fakenham Gasworks Museum (1 August), Daphne Tighe experienced a stirring memory. "I was at grammar school 1940-1945 when there was not much scope for exciting outings," she tells us. "One I remember was arranged by the science teacher to Horsham gas works." Daphne has no plans to visit any of the modern equivalents, because "I can still remember the smell".

Meanwhile, Chris Kendall tells us about Leicester, UK, home to the National Gas Museum. Its website claims it is "the world's largest and most significant gas history collection", and also that it is shut until 22 September 2026. "Is it any good, you ask?" says Chris. "I don't know. Despite being a short walk from where I live, I've never been interested enough to go and see."

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