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JANUARY 2026

ScienceNews

OUR EPIC ORIGINS

Strange microbes offer clues to the rise of complex life on Earth, and maybe beyond

Thermo Fisher Scientific
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A program of Society for Science

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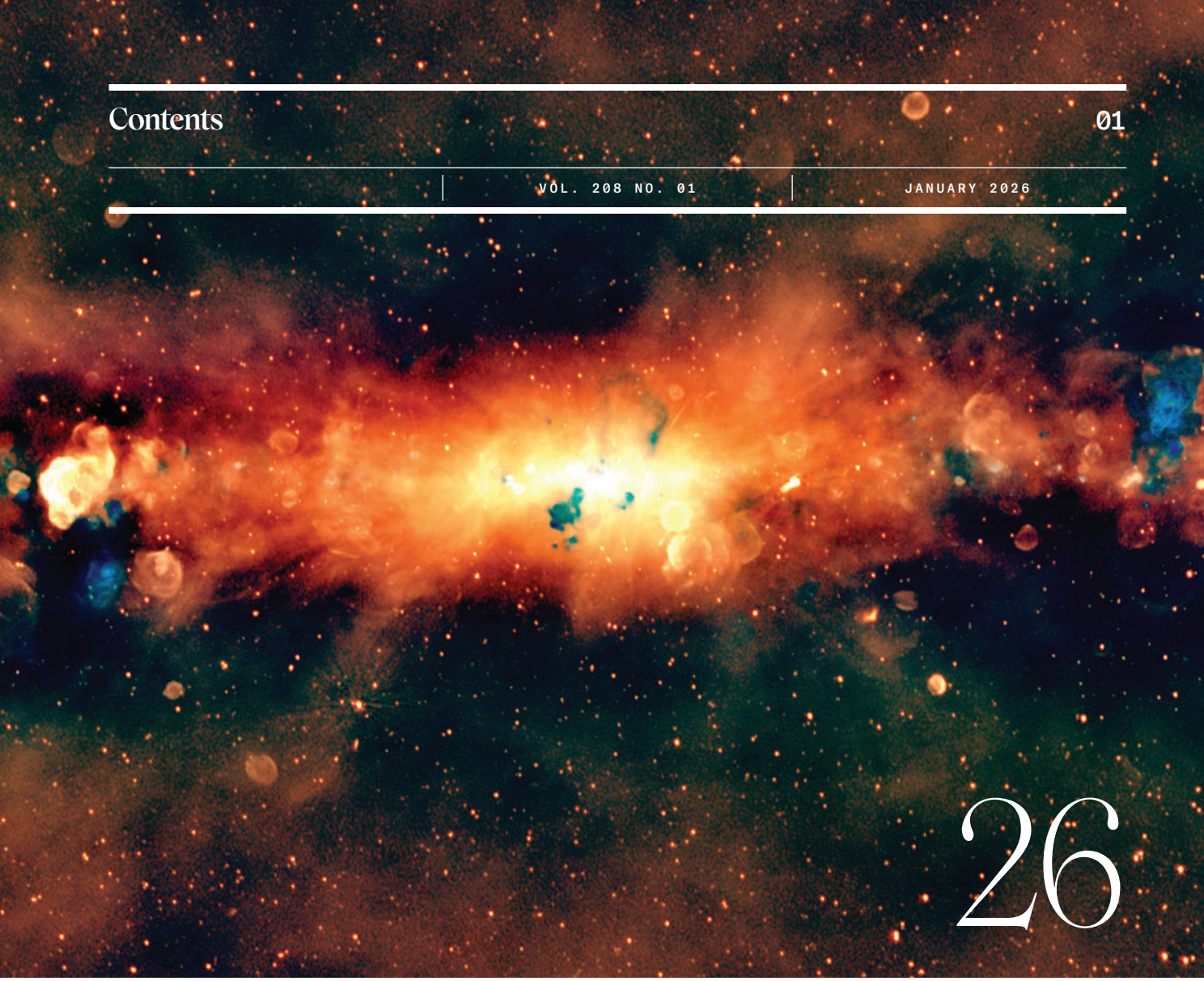

S. MANTOVANINI AND THE GLEAM-X TEAM

News

On the Cover

Illustration by Marina Muun

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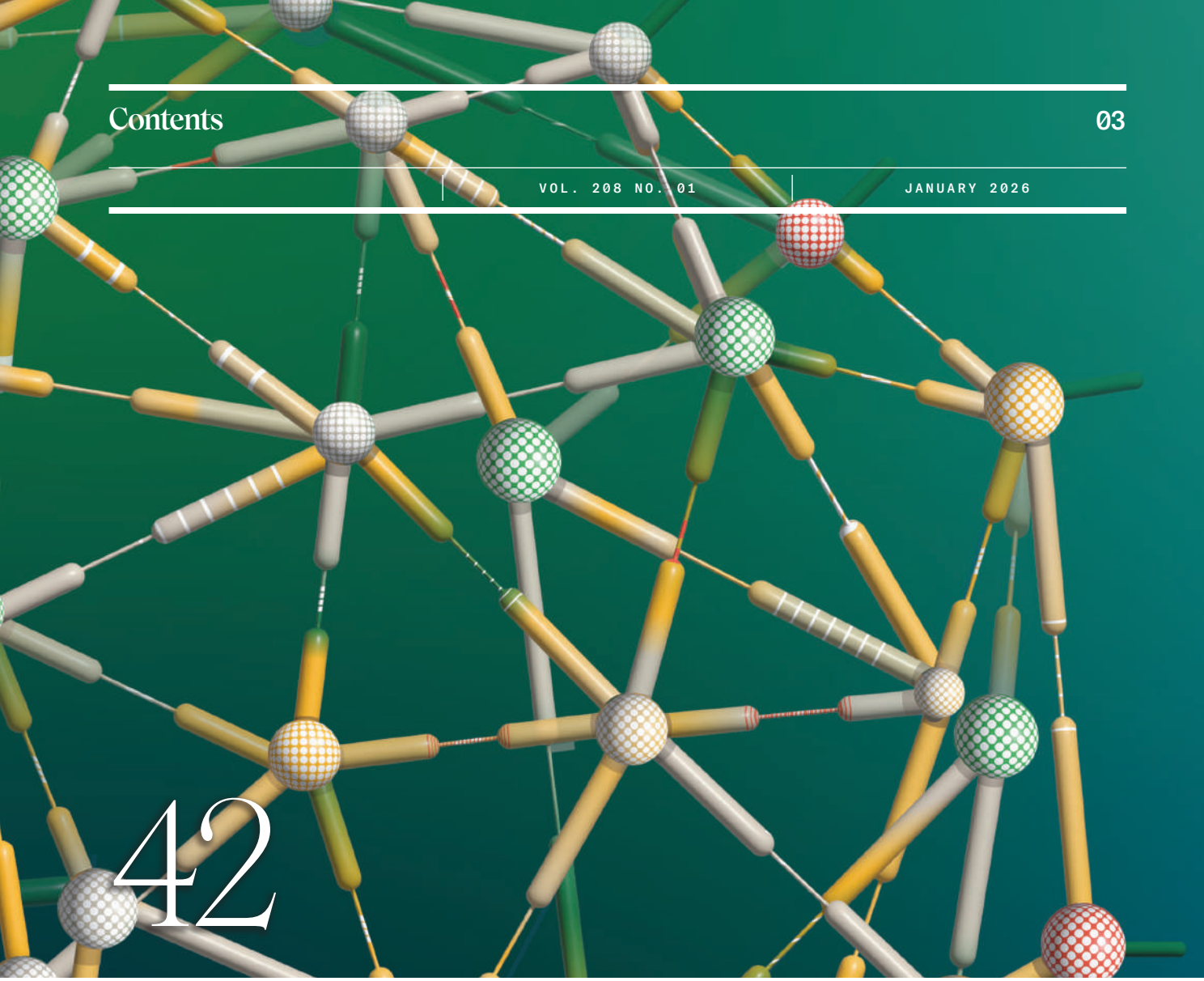


Features

Curiosities

FROM TOP: HAWAII; LILI DES BELLONS

Life in all of its complexity

The other day I walked along the bank of the Potomac River upstream of Washington, D.C. The trees had shed most of their leaves, but they were vehemently alive. A giant sycamore, easily 4 meters in diameter, had sprouted new shoots from its base. A hickory that lost its top to a windstorm had produced nuts. The lone remaining leaf on an oak tree rattled in the breeze, as if refusing to succumb to winter.

It's hard for me to grasp that this forest, and much of the life that blankets our planet (including me), probably arose from a single-celled microbe that developed a unique ability to evolve. For the last decade, researchers have been studying the Asgard archaea, microbes first identified in deep-sea hydrothermal vents in the Arctic (Page 32).

Scientists have since discovered them in multiple sites around the world, and are trying to reconstruct the backstory of how they could have given rise to the first complex cells on Earth. The existence of Asgard archaea also raises questions about how likely it is for similarly advanced life-forms to evolve on planets beyond our solar system. That's a lot of big questions sparked by tiny blobs we can't see without a microscope.

Also in this issue, we explore the science of two human behaviors: gambling and drinking. Dry January is upon us, and it's part of a long trend, with American adults consuming less alcohol now than they have in almost 90 years. Alcohol poses health risks, social sciences writer Sujata Gupta notes, but history suggests that it may have long provided social benefits. She reviews research on whether social drinking contributed to the evolution of complex societies and how that may inform our present-day decisions about drinking (Page 60).

And in a time when the legalization of online sports betting has made it possible to place wagers 24/7 on your phone, we report on how gambling came to be recognized as an addiction (Page 50). In 1972, psychiatrist Robert Custer opened the first inpatient program for gambling disorder treatment. He used data to persuade the medical community that problem gambling was a treatable condition, not a moral failing. More research is needed, as is the need for more treatment options, at a time when an estimated 80 million adults worldwide have gambling problems. Custer's pioneering approach, informed by empathy and compassion, is as relevant today as ever.

Nancy E. Shute

Nancy Shute
Editor in Chief
nshute@sciencenews.org

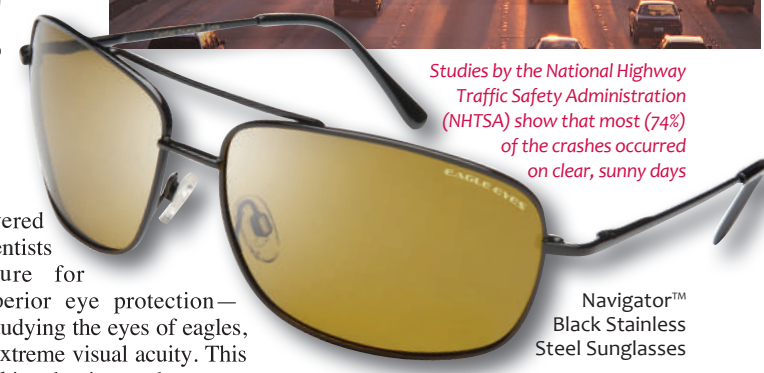
Urgent: Special Summer Driving Notice

To some, sunglasses are a fashion accessory…

But When Driving, These Sunglasses May Save Your Life!

Drivers' Alert: Driving can expose you to more dangerous glare than any sunny day at the beach can… do you know how to protect yourself?

Studies by the National Highway Traffic Safety Administration (NHTSA) show that most (74%) of the crashes occurred on clear, sunny days



Navigator™ Black Stainless Steel Sunglasses

The sun rises and sets at peak travel periods, during the early morning and afternoon rush hours and many drivers find themselves temporarily blinded while driving directly into the glare of the sun. Deadly accidents are regularly caused by such blinding glare with danger arising from reflected light off another vehicle, the pavement, or even from waxed and oily windshields that can make matters worse. Early morning dew can exacerbate this situation. Yet, motorists struggle on despite being blinded by the sun's glare that can cause countless accidents every year.

Not all sunglasses are created equal. Protecting your eyes is serious business. With all the fancy fashion frames out there it can be easy to overlook what really matters—the lenses. So we did our research and looked to the very best in optic innovation and technology.

Sometimes it does take a rocket scientist. A NASA rocket scientist. Some ordinary sunglasses can obscure your vision by exposing your eyes to harmful UV rays, blue light, and reflective glare. They can also darken useful vision-enhancing light. But now, independent research conducted by scientists from NASA's Jet Propulsion Laboratory has brought forth ground-breaking technology to help protect human eyesight from the harmful effects of solar radiation light. This superior lens technology was first discovered when NASA scientists looked to nature for a means to superior eye protection—specifically, by studying the eyes of eagles, known for their extreme visual acuity. This discovery resulted in what is now known as Eagle Eyes®.

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MICHAEL MARSHALL

FREELANCE SCIENCE WRITER

● AS A CHILD in the late 1980s, Michael Marshall owned a book about dinosaurs. On the book's opening pages was an evolutionary timeline. A huge empty space labeled "Precambrian" spanned nearly all of Earth's history. "Something about this made me question how life might have begun," Marshall says. And this query has never left him, leading the journalist to this issue's cover story about Asgard archaea, microbes that hold the key to the origins of complex life (Page 32). Marshall has been closely following research on the mysterious single-celled organisms since the first study was published in 2015. So when a study detailing how researchers in Japan cultivated the microbes for the first time came out in 2019, "I pretty much jumped out of my chair when I saw it," he says. "I was one of the handful of reporters that broke the news."

Judith Lavelle
Freelance science writer Judith Lavelle always wondered why gambling disorder research gets relatively little attention compared with research on substance use disorders. That curiosity led her to Robert Custer, who put gambling disorder research on the map (Page 50). Lavelle thought highlighting Custer and his work was important, given the soaring popularity of sports betting apps and the fact that gambling disorder is considered a hidden addiction, with so few signs early on. "Even today, I hear people dismiss gambling disorder as a vice, but Custer very clearly saw how this 'hidden illness' could have very real consequences for someone's health and life," she says.

Tracee Tibbitts
When *Science News* decided to redesign the magazine, "our aim was to better serve our readers through a more sophisticated design and better visuals, while not abandoning our primary goals of communicating science and delivering the highest quality journalism," says design director Tracee Tibbitts, who led the project. One year since the new and improved magazine's debut, reader feedback has been largely positive. But the work continues. It was "a big change, but the entire team has risen to the occasion," Tibbitts says. "I hope that in 2026, we can continue this work and deliver amazing visuals that tell important science stories."

Pete Ryan
Editorial illustrator Pete Ryan is no stranger to hard-to-visualize concepts. For this issue, Ryan was tasked with illustrating a physician's pursuit of helping people breathe through the butt instead of the lungs (Page 22). The best way to tackle such a challenging assignment is to "explore the topic with the most open mind possible and see what ideas find me," Ryan says. Butt breathing as a topic gave him a chance to bring in a little humor. "I trust that the readers will enjoy a little silliness," he says.

CLOCKWISE FROM TOP LEFT: SARAH MARSHALL-MAUN; CHRISTOPHER KAMPMEYER; SOCIETY FOR SCIENCE; ANGELA LEWIS

ANIMALS

A TINY TREASURE FROM A DIRTY WINDOWSILL

By Carly Kay

● **This staged snapshot** of a rice weevil on a grain of rice won first place in the 2025 Nikon Small World photomicrography competition. Photographer Zhang You discovered the dead insect while cleaning his house and memorialized its posthumous "final flight" by stacking over 100 images shot with a camera and microscope lens.

The rice weevil (*Sitophilus oryzae*) is a pest that devours grains and seeds. While You has seen infestations before, spotting the dead beetle with wings outstretched was a lucky find. "Their tiny size makes manually preparing spread-wing specimens extremely difficult, so this naturally preserved individual is rare," says You, who has dedicated years to insect photography and education. "To me, a standout work blends artistry with scientific rigor, capturing the very essence, energy and spirit of these creatures."

PHOTO BY ZHANG YOU

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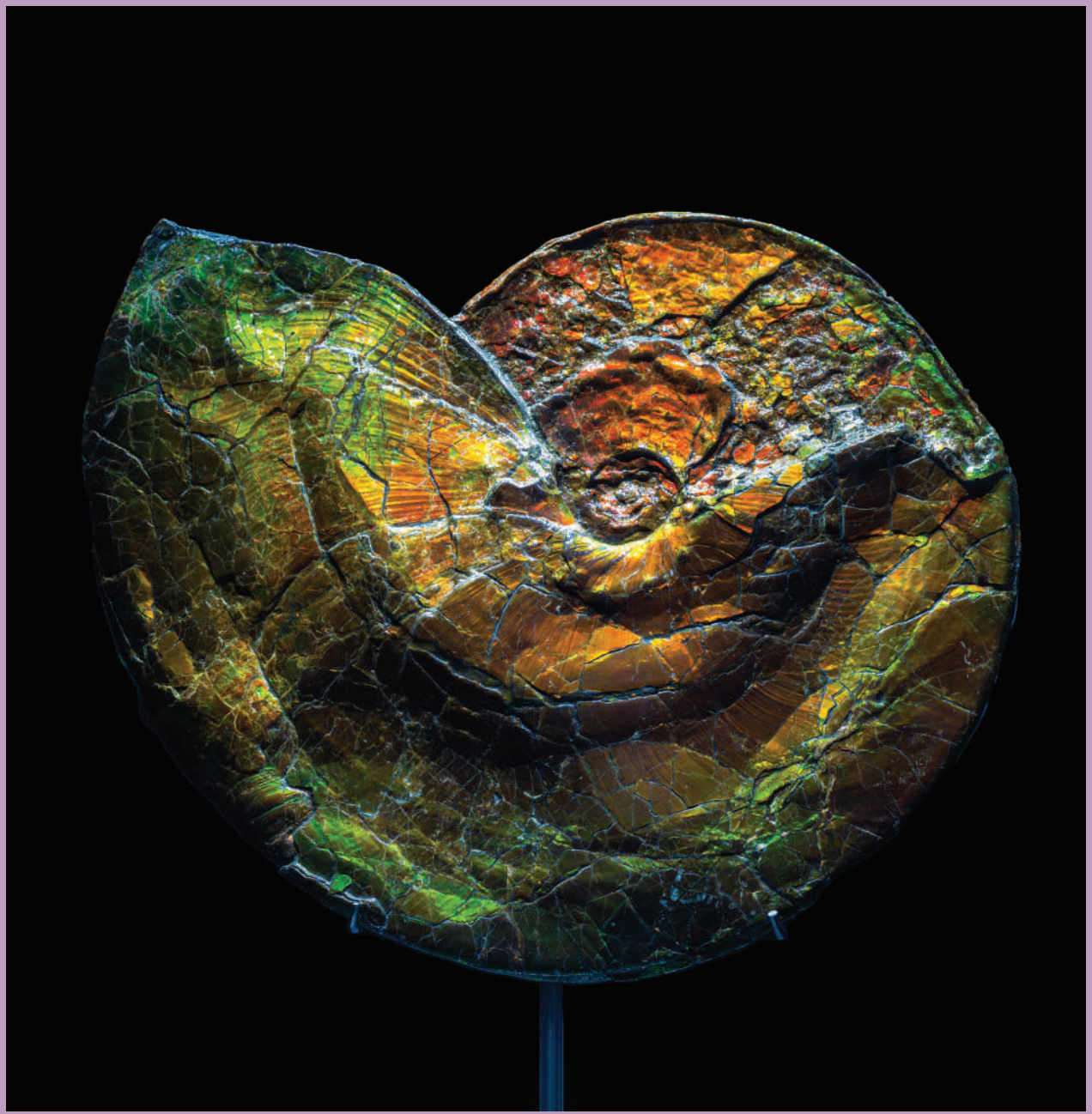
News



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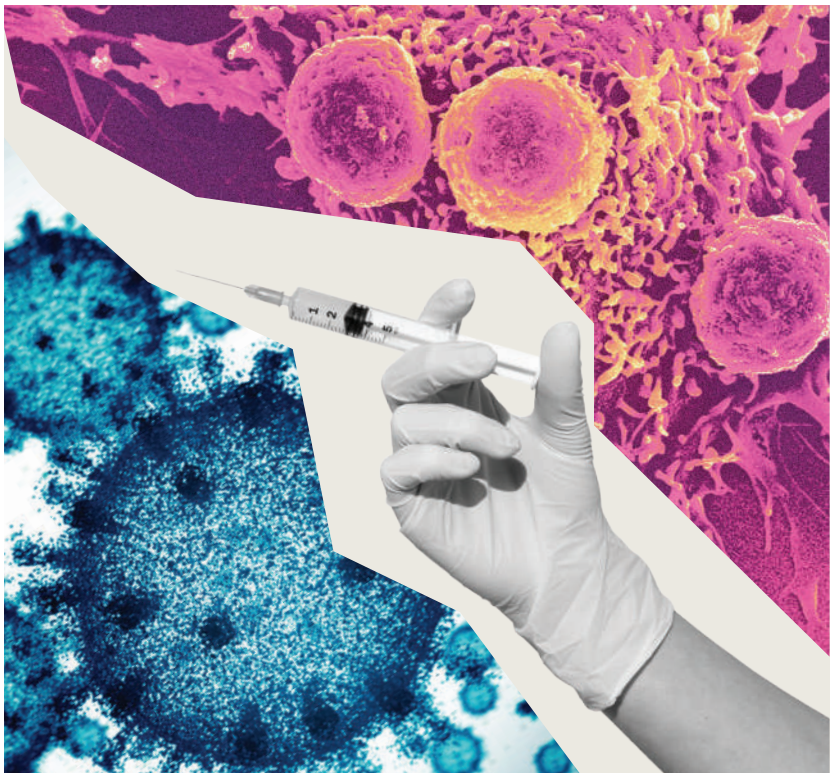
MATERIALS SCIENCE

HOW AMMOLITE GEMS GET THEIR SHIMMER

● Scientists have solved a gemstone mystery: what gives ammolites their rainbow shimmer. The gems form in fossilized shells of extinct marine animals called ammonites. Colors arise from uniform crystal layers separated by gaps of just the right width, a team describes in *Scientific Reports*. Thin layers reflect light with shorter wavelengths, creating deep blues, while thick layers reflect longer wavelengths, creating rich reds. A separation of 4 nanometers is crucial for bright, distinct colors. Any closer, colors dull. Any farther, they become muddled. —*Maria Temming*



HEALTH & MEDICINE

mRNA COVID vaccines may give cancer therapies a boost

By Meghan Rosen

● **The mRNA COVID-19 vaccines** might make some cancer treatments more effective.

Lung cancer patients who received the vaccine within a few months of immunotherapy, which revs up the immune system, lived nearly twice as long as unvaccinated patients, researchers report in *Nature*. The team observed something similar in people with melanoma, says pediatric oncologist Elias Sayour of the University of Florida College of Medicine in Gainesville.

That correlation suggests that mRNA vaccines — even those not designed for cancer — could make tumors more sensitive to current therapies.

In a time when mRNA COVID vaccines face increasing public and government skepticism, the study offers new evidence that their benefits may extend beyond infectious disease protection, says cancer vaccine researcher Hua Wang of the University of Illinois Urbana-Champaign.

Scientists already had clues about the anticancer effects of mRNA vaccines. An experimental mRNA vaccine given to tumor-bearing mice, for instance, made immunotherapy drugs work better, Sayour's team reported last summer in *Nature Biomedical Engineering*.

mRNA vaccines are often thought of as the immune system's teachers. For example, the COVID-19 vaccines include mRNA that carries the code for assembling a harmless bit of the coronavirus spike protein. The body uses that mRNA to build the protein, which the immune system then learns to recognize. mRNA cancer vaccines work similarly, but encode snippets of tumor proteins rather than viral proteins.

Sayour's experimental vaccine was entirely different. It didn't include tumor mRNA but still had antitumor powers. When paired with immunotherapy drugs, the mRNA itself — not what it encoded — rallied the mouse immune system to fight cancer, his team discovered.

That finding inspired the latest study. If the experimental mRNA vaccine could trigger an anticancer response, maybe other mRNA vaccines could, too. Millions of people, including cancer patients with electronic health records, have received the COVID-19 shots. Sayour's team just had to look at the data.

The team analyzed the records of roughly 1,000 people with non-small cell lung cancer, all of whom had

↖ **Cancer patients given an mRNA COVID vaccine within a few months of immunotherapy treatment fared better than unvaccinated patients.**

T. TIBBITTS, STEVE GSCHMEISSNER/SCIENCE PHOTO LIBRARY/GETTY IMAGES, FRANCESCO CARTA FOTOGRAFO/MOMENT/GETTY IMAGES, YUICHIRO CHINO/MOMENT/GETTY IMAGES

received a type of immunotherapy drug called a checkpoint inhibitor. Nearly 200 of these patients had also received an mRNA COVID vaccine within 100 days of their drug treatment. Three years after diagnosis, 56 percent of vaccinated patients were still alive, compared with 31 percent of unvaccinated patients. Patients with advanced melanoma had a similar outcome.

Such results "were not at all expected," writes Eric Topol, a cardiologist at Scripps Research in La Jolla, Calif., who covers biomedicine in the newsletter *Ground Truths*. He calls the work a "seminal paper" that provides "compelling data."

Still, it's too early to say whether combining immunotherapy with nonspecific mRNA vaccines is beneficial for cancer patients, Wang says.

Sayour agrees. "It's important for people to understand that this isn't proven yet," he says. For that, scientists need a clinical trial, which his team is working on. If mRNA COVID vaccines do make certain immunotherapies work better, Sayour says, it would mean that doctors already have at their fingertips a widely available, tried-and-tested option to help treat aggressive cancers. ✖

31 percent

Unvaccinated patients still alive three years after cancer diagnosis

56 percent

Vaccinated patients still alive three years after cancer diagnosis

HEALTH & MEDICINE

A NEW PILL CUTS CHOLESTEROL BY NEARLY 60 PERCENT

BY AIMEE CUNNINGHAM

A new cholesterol-lowering pill made a big difference for people with an inherited cholesterol disorder, a clinical trial has found.

In the phase 3 trial, adults with familial hypercholesterolemia, which leads to high levels of "bad" cholesterol, took the oral drug daily for 52 weeks. At 24 weeks, their levels of low-density lipoprotein, or LDL, cholesterol had dropped by 58 percent on average, researchers reported at the American Heart Association meeting in New Orleans and in the *Journal of the American Medical Association*. That's compared with a slight rise of almost 3 percent for those on a placebo pill. After a year, the group on the drug saw an LDL reduction of 55 percent on average versus an increase of close to 9 percent in the placebo group.

The drug, enlicitide, targets a protein called PCSK9 that binds to and degrades LDL cholesterol receptors in the liver, leaving more LDL cholesterol in the blood. Enlicitide inhibits PCSK9, keeping more LDL receptors in place. That means the liver can ramp up LDL cholesterol removal. Injectable drugs that take this therapeutic approach are available but aren't widely used due to cost and other barriers.

Due to a faulty cholesterol processing system, people with familial hypercholesterolemia have elevated LDL levels soon after birth, leading to a high risk of cardiovascular disease. Even with statins and other cholesterol-lowering drugs available, it is difficult for these patients to meet target cholesterol levels, which can vary based on risk factors.

The international clinical trial focused on adults who inherited the disorder from one parent. This type affects about 1 in 250 people. The roughly 300 participants, ages 18 and up, were already on statin therapy.

Two other clinical trials of the drug will assess whether it reduces harmful cardiovascular events and if its cholesterol-lowering effects extend to those without the inherited disorder. Initial results for the latter trial, also presented at the meeting, found enlicitide sharply reduced LDL levels for people who had previously had — or were at high risk for — a heart attack or stroke but didn't have familial hypercholesterolemia. ✖

CLIMATE

AUSTRALIA'S TROPICAL FORESTS ARE NOW CARBON EMITTERS

BY CAROLYN GRAMLING

Tropical forests in Australia are the world's first to flip a worrisome switch: They now put more carbon dioxide into the atmosphere than they take out, researchers report in *Nature*.

Tropical forests absorb billions of metric tons of climate-warming carbon dioxide each year, making them the largest land-based bulwark against climate change. But about 391 million of the world's 1.6 billion hectares of tropical forest are now at high risk of loss.

An analysis of monitoring data collected from 1971 to 2019 revealed that the woody biomass of Australian tropical forests has been shrinking since around 2000. Tree mortality has soared due to the effects of human-driven climate change, including rising temperatures, droughts and damaging tropical cyclones, report ecophysiologist Hannah Carle of Western Sydney University and colleagues. As a result, the dying trees are adding CO_2 back to the atmosphere.

Climate models have suggested that additional CO_2 in the atmosphere might encourage more plant growth, possibly slowing the decline of forests. But the additional carbon emitted from dead trees didn't increase growth significantly, the team found. That could be due to limited availability of nutrients that plants need for growth. If so, nutrient limitation is a factor that needs to be considered when projecting the fate of forests and how their loss might impact future climate.

The Amazon rainforest, for example, shoulders a quarter of the land-based CO_2 absorption each year. But it could face extensive dieback as soon as 2035, scientists have warned. Such losses are not just bad for the climate; the forests also provide food, recycle rainfall, filter pollutants and buffer against natural hazards.

"The Amazon forest carbon sink is passing a tipping point as we speak," says forest ecologist Wannes Hubau of Ghent University in Belgium. "It shows that our planet's natural climate buffers [are starting] to meet their limits."

In 2020, Hubau and colleagues reported that Africa's tropical forests lag behind others in terms of tree loss but are showing signs of strain.

Protecting tropical forests will require global financial investments to triple to $300 billion by 2030 and to increase to $498 billion by 2050, according to the U.N. Environment Programme. Those investments would go toward sustainable agriculture and supply chains as well as increased regulation and law enforcement.

All tropical forests need more protection, even those that are no longer carbon sinks, Hubau says. "They are all huge reservoirs of carbon.... If we don't protect them, they'll be a 'bomb' of additional CO_2 to the atmosphere." ✖

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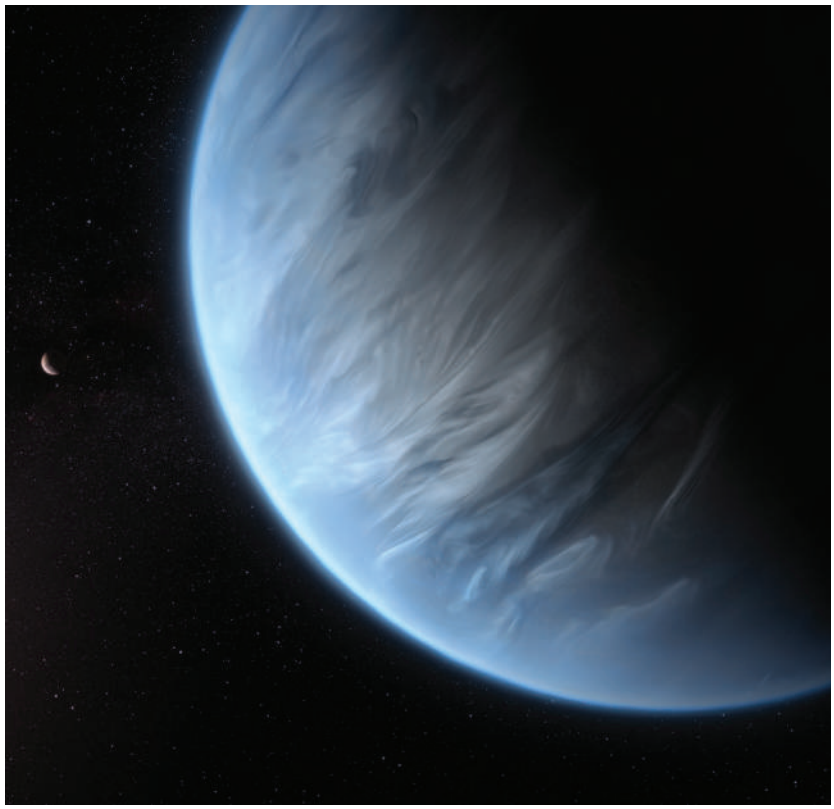
Australia's tropical forests (one shown) are now a net source of carbon to the atmosphere. Other tropical forests around the world are not far behind. ↙



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PLANETARY SCIENCE

Some planets might home brew their own water

By Javier Barbuzano

● **Some planets' water might come** from within.

In laboratory experiments, researchers simulated extreme conditions found within certain exoplanets by blasting a mineral abundant in planetary interiors with high-energy lasers in the presence of hydrogen gas. Hydrogen strips the minerals of their oxygen atoms, which then react with the hydrogen to form water, the team reports in *Nature*.

The finding offers a viable explanation for water-rich exoplanets orbiting close to their host stars, the researchers say. The process might even account for the origin of some of Earth's water.

Hundreds of exoplanets with sizes and masses between Earth and Neptune have been discovered, many of which orbit far closer to their stars than Earth orbits the sun. Their estimated densities suggest they possess rocky interiors covered by a thick layer of water or hydrogen.

However, it's unclear how some of these planets could be so water-rich. In the solar system, there's a clear divide between planets formed on either side of the "snow line." Inside that line, water is scarce, vaporized by the sun. Planets formed outside the snow line, such as Saturn and Neptune, are rich in water and gas.

Astrophysicists had thought that watery exoplanets must form far from their star and then move inward. The new study suggests that under the right conditions, chemical reactions between hydrogen and minerals can produce water locally.

To achieve the required temperature and pressure in the lab, planetary scientist Harrison Horn and colleagues placed olivine samples in a diamond anvil cell. After blasting the samples, the scientists were shocked by the amount of water produced. "There was no rock left. All I had was metal and water," says Horn, now at the Lawrence Livermore National Laboratory in California. About 18 percent of the initial mass turned into water.

The researchers think this water-generating process can occur at the boundary between a planet's molten rock interior and its gaseous hydrogen envelope, where high pressures and temperatures could drive the reaction. The final water content of these planets could range from about 5 percent to 28 percent of the planet's mass, they estimate.

The study could mean these planets have more surface water, says astrophysicist Remo Burn of the Observatoire de la Côte d'Azur in Nice, France. "It's maybe good news for life on those planets." ✖

↑ **New experiments suggest a way worlds like K2 18b (illustrated) could make lots of water internally.**

PALEONTOLOGY

Nanotyrannus was not a teenage *T. rex*

By Carolyn Gramling

● **For decades, researchers have debated** whether a fossil of a small, fierce theropod belonged to a teenage *Tyrannosaurus rex* or was a separate species. Now they know: *Nanotyrannus* can stand on its own two feet. The tiny tyrannosaur wasn't just a young *T. rex*, according to two studies in *Nature* and *Science*.

An exquisitely preserved skeleton of a small tyrannosaur from Montana's 67-million-year-old Hell Creek Formation ends the debate, researchers report in *Nature*. The skeleton is part of a famous fossil known as Dueling Dinosaurs, featuring a small tyrannosaur entangled with its possible prey, a horned ceratopsian dinosaur.

↑ **A fossil thought to be a teenage *T. rex* is in fact an adult specimen of a distinct tyrannosaur species.**

That tyrannosaur, the new analysis reveals, is a kind of holy grail, a long-sought-after missing link for researchers who've hoped to demonstrate that *Nanotyrannus* exists: It's the first identified adult specimen of *Nanotyrannus*. And that is allowing researchers to at long last disentangle it from *T. rex*.

The identity mystery started in 1942, when researchers unearthed the skull of a small, sharp-toothed dinosaur initially thought to be a *Gorgosaurus*. But in 1988, scientists reinterpreted that fossil as a new type of tyrannosaur, which they dubbed *Nanotyrannus lancensis*.

Others contested that description, noting features in the small skull that strongly resembled *T. rex*; this skull, they suggested, belonged to a juvenile version of that dinosaur. Since then, several other small tyrannosaur fossils discovered in the Hell Creek Formation have been assumed to be young *T. rex*es. The burden of proof was on *Nanotyrannus* to forge its own identity.

Now, paleontologists Lindsay Zanno of North Carolina State University in Raleigh and James Napoli of Stony Brook University in New York report that the newly analyzed fossil is the first demonstrably adult specimen of *N. lancensis*. The tyrannosaur is just about 6 meters long, but analyses of growth rings within its leg and arm bones reveal that it was skeletally mature, and therefore fully grown. By comparison, adult *T. rex* can get up to 14 meters long from snout to tail.

The fossil also contains the first preserved tail and arm bones of a *Nanotyrannus*, both of which were distinct from *T. rex*. A *T. rex* tail had about 40 vertebrae while *N. lancensis* had just 35.

EMILE HOLMEWOOD

Perhaps the most obvious difference is in the arms. "The arm of our *Nanotyrannus* is already [a bit] bigger than a *T. rex* arm," Zanno says.

Other telling anatomical differences between *Nanotyrannus* and *T. rex* include patterns of cranial nerves on the skull and the structures of sinuses and the respiratory system. These are features that don't change as the creatures grow, Zanno says.

With the aid of the newly identified adult *N. lancensis* specimen, the team also reexamined another long-debated dinosaur, known as Jane. Jane's bones reveal that the animal was a juvenile of a new, larger species dubbed *N. lethaeus*, the researchers suggest.

NANO VS. MEGA

Here's how a newly identified tyrannosaur species measured up to the iconic *T. rex*.

Nanotyrannus lancensis	***Tyrannosaurus rex***
	
Length	
5.5 meters	**12.8+ meters**
Weight	
680 kilograms	**8,165 kilograms**
Number of tail vertebrae	
35	**40–45**
Right arm	
	

NORTH CAROLINA MUSEUM OF NATURAL SCIENCES, ADAPTED BY B. PRICE

The bone analysis of the Dueling Dinosaur tyrannosaur "appears to show that the specimen is approaching adult size, and I am fine with that conclusion," says paleontologist Holly Ballard of Oklahoma State University in Tulsa. But Ballard, who published a previous analysis of Jane, is not convinced that the specimen represents a new species of *Nanotyrannus*, or that it was a *Nanotyrannus* at all. Even as a juvenile, Jane was already bigger than *N. lancensis* — and the animal was still growing, she notes.

Meanwhile, other researchers were looking at the original fossil proposed as *N. lancensis* in the 1940s. The fossil consists of a skull and an intact hyoid apparatus, a set of bones in the throat involved in feeding in reptiles. Like limb bones, hyoid bones are tubular, showing distinct growth rings as the animal ages. An analysis of the growth rings showed that this creature was already full-grown, paleontologist Christopher Griffin of Princeton University and colleagues report in *Science*.

Nanotyrannus and *Tyrannosaurus* could have lived alongside one another at the twilight of the dinosaur era — not just coexisting in time but occupying different ecological niches in the same Hell Creek region, Zanno says. "*Nanotyrannus* was a completely different kind of predator: small, slender, extremely fast, with large predatory arms," while *T. rex* was bulky, heavily built, with a huge head and powerful bite force. That adds to growing evidence that dinosaurs were still diverse and flourishing right up to the end of the Cretaceous Period 66 million years ago, when an asteroid slammed into Earth (see Page 58).

"Every other tyrannosaur-bearing community had a couple of different tyrannosaurs in it," says paleontologist Thomas Holtz of the University of Maryland in College Park. "It actually makes Hell Creek less weird."

Holtz, who was not involved in either study, says he has been a *Nanotyrannus* doubter, but the new work has "done a far better job advocating for [it] than anyone in the past. That's all we wanted, those of us who were skeptics."

The findings throw a massive wrench into much of what we've come to understand about the life and times of *T. rex*, Zanno says. "Several decades of basic research [on *T. rex*] — locomotion, diet, life history and growth — all contain data that comes from two different types of dinosaurs," she says. "These need to be pulled apart and reexamined in light of this new conclusion."

Then there's the other side of the coin, Holtz adds. "If *Nanotyrannus* is real, and it looks like it is, we now once again do not know what a teen *T. rex* looks like," he says.

But we might soon. Holtz and Zanno both alluded to a fossil currently in preparation at the Denver Museum of Nature & Science that is thought to be a true teen *T. rex*. If so, it'll offer up yet another line of evidence on anatomical differences for researchers to wrangle over. ✖

ARTIFICIAL INTELLIGENCE

AI chatbots can be risky for teens in crisis

By Laura Sanders

This story contains references to sexual assault and suicide.

● **Just because a chatbot** can play the role of therapist doesn't mean it should.

Conversations powered by popular large language models can veer into ethically murky territory, two new studies show. The new research comes amid recent high-profile suicides of adolescents in mental health crises. By scrutinizing chatbots that some people enlist as AI counselors, scientists are putting data to a larger debate about the safety and responsibility of these new digital tools, particularly for teenagers.

Chatbots are as close as our phones. Nearly three-quarters of 13- to 17-year-olds in the United States have tried AI chatbots, a recent survey finds; 21 percent use them a few times a week. In some cases, these chatbots "are being used for adolescents in crisis, and they just perform very, very poorly," says clinical psychologist and developmental scientist Alison Giovanelli of the University of California, San Francisco.

For one study, pediatrician Ryan Brewster and colleagues scrutinized 25 of the most-visited consumer chatbots across 75 conversations. These interactions were based on three distinct patient scenarios used to train health care workers. These three stories involved teenagers who needed help with self-harm, sexual assault or a substance use disorder.

The researchers interacted with the chatbots as one of these teenage personas. Some of the programs were general assistance large language models or LLMs, such as ChatGPT and Gemini. Others were companion chatbots, such as JanitorAI and Character.AI, which operate as a person or character.

The team didn't compare the chatbots' counsel with clinicians', cautions Brewster, of Stanford University School of Medicine. Still, the chatbots failed to refer users to important resources in a quarter of conversations and had other potentially harmful responses, the team reports in *JAMA Network Open*.

Another study, conducted by Brown University computer scientist Harini Suresh and colleagues, also turned up cases of ethical breaches by LLMs. The scientists used old transcripts of real people's chatbot chats to converse with LLMs anew. They used publicly available LLMs, such as GPT-4 and Claude 3 Haiku, that had been prompted to use a common therapy technique. A review of the simulated chats by licensed clinical psychologists turned up five sorts of unethical behavior, including rejecting an already lonely person and overly agreeing with a harmful belief. Cultural, religious and gender biases showed up in comments, too.

Part of these chatbots' allure is their accessibility and privacy, valuable things for a teenager, Giovanelli says. It's "more appealing than going to mom and dad and saying, 'You know, CONT. ON PAGE 20

↖ **AI chatbots are appealing, but using the tools for mental health help comes with risks, two new studies suggest.**

REBBEKA DUNLAP

Actual Size
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CONT. FROM PAGE 18 I'm really struggling with my mental health,' or going to a therapist who is four decades older than them, and telling them their darkest secrets."

But the technology needs refining. "There are many reasons to think that this isn't going to work off the bat," says Julian De Freitas of Harvard Business School, who studies how people and AI interact. "We have to also put in place the safeguards to ensure that the benefits outweigh the risks." De Freitas was not involved with either study and serves as an adviser for mental health apps designed for companies.

For now, he cautions that there isn't enough data about teens' risks with these chatbots.

Last summer, the American Psychological Association released a health advisory on AI and adolescents that called for more research, in addition to AI-literacy programs that communicate these chatbots' flaws. Education is key, Giovanelli says. "I think a lot of parents don't even realize that this is happening."

Some efforts to regulate this technology are under way, pushed forward by tragic cases. A new law in California seeks to regulate AI companions, for instance.

Good mental health care is hard to access, Brewster says. "I don't think it's a coincidence or random that people are reaching for chatbots." But for now, he says, their promise comes with big risks and "a huge amount of responsibility to ... recognize the limitations of what a platform can and cannot do." ✖

If you or someone you care about may be at risk of suicide, the 988 Suicide and Crisis Lifeline offers free, 24/7 support, information and local resources from trained counselors. Call or text 988 or chat at 988lifeline.org.

PHYSICS

THE WORLD'S HOTTEST ENGINE ILLUMINATES STRANGE PHYSICS

BY EMILY CONOVER

The hottest engine ever created is, by some definitions, not an engine and not that hot. But it reveals the weird physics of extreme temperatures at the microscale.

The engine is made of a glass sphere just 5 micrometers across that is levitated by an electric field in a near-vacuum. A jittery voltage jiggles the sphere so violently that it behaves as if it's superhot, physicist James Millen and colleagues report in *Physical Review Letters*. It reached the equivalent of 13 million° Celsius, nearly as hot as the sun's core.

But you wouldn't singe your finger if you touched the sphere. The effective temperature is based on the energy of the sphere's overall motion rather than the jiggling of molecules that normally determines temperature. "It is moving as if you had put this object into a gas that was that hot," says Millen, of King's College London. "It moves around like crazy."

The sphere is a heat engine, a machine that performs mechanical work as it takes in heat from a high-temperature source and sends waste heat to a lower-temperature heat sink. Reaching high temperatures matters for engine performance: A larger ratio of hot to cold temperatures corresponds to a higher efficiency. For commercial heat engines, that ratio goes as high as about 3. This engine had a ratio of about 100.

The engine's properties fluctuated wildly. Sometimes this engine was 10 percent efficient, sometimes 200 percent. Sometimes it ran in reverse, cooling instead of heating.

Thermodynamics at the microscale is really weird and unintuitive, Millen says. But it's crucial to understand: It's the reality inside the cells of living organisms, where tiny structures such as proteins are buffeted around by the random jostling of their surroundings. The team hopes that the engine could help scientists study tiny, biological engines such as motor proteins. For example, the temperature the sphere experienced changed as it moved about the electric field. This phenomenon, called position-dependent diffusion, is important for protein folding.

Creating an engine with just position-dependent diffusion or extreme temperature or a large temperature ratio would be nice, says physicist Uroš Delić of TU Wien in Vienna. "This work combines all three, so that's quite cool — or hot." ✖

VOL 208 NO. 01

ANIMALS

Woodpecker hammering is a full-body affair

By Anna Gibbs

● **Hidden beneath** all their rum-pum-pumming, woodpeckers are quietly grunt-grunt-grunting.

The birds exhale with each strike, much like a tennis pro groaning through a stroke. Elaborate coordination between those breaths and muscles across the body keep the hammering at a perfectly consistent rate, researchers report in the *Journal of Experimental Biology*.

Research into the extraordinary abilities of woodpeckers — which can strike hundreds of times per minute at forces 20 to 30 times their body weight — has largely focused on how they're able to percuss without getting concussed. The new analysis simply asks *how*, at all?

While pecking might look like a simple back-and-forth head motion, "it's actually a very difficult, skillful behavior that involves the movement of muscles across the body," says behavioral physiologist Nicholas Antonson of Brown University.

Antonson and colleagues humanely captured eight wild downy woodpeckers (*Dryobates pubescens*) from the Brown campus and surrounding area. They carefully inserted electrodes into eight muscles to measure electrical signals that indicate muscle contraction. Then, for up to a half hour at a time, the researchers observed the woodpeckers as the birds drilled (a behavior used to probe and excavate) and tapped (a behavior used to communicate). Each bird wore a tiny bespoke backpack that recorded the electrical signals, which the team synced with high-speed video taken at 250 frames per second. The researchers released the birds after several days of observation and recovery.

A complex choreography of muscle contractions and breath turns the downy woodpecker into the equivalent of a hammer, the analysis revealed. When humans use a hammer, the muscles in the wrist stiffen, reducing energy loss at impact; the researchers observed a similar stiffening in some woodpecker neck muscles. "It's crazy just how similar it is to the way we hammer," Antonson says.

Other muscles play distinct roles throughout the striking motion. The birds appear to brace themselves with their tail muscles in the moments preceding a strike, while the contraction of a single hip muscle largely determines the power of the strike itself. Distinct head and neck muscles help to pull back the head after each beat, activating before other muscles complete their forward movement. The overlapping contractions may help smooth out the woodpeckers' back-and-forth movements during a rapid drum solo.

The team also looked at airflow through the syrinx — a structure similar to a voice box — to determine whether woodpeckers hold their breath upon a strike, like a weightlifter might, or exhale through the movement, more like a tennis player. Both strategies help stabilize core muscles during a movement, but downy woodpeckers take after tennis players.

The birds can strike and exhale as many as 13 times per second, indulging in a 40-millisecond inhale between each blow. The movement's timing stayed remarkably consistent over multiple taps, Antonson says.

Songbirds take minibreaths to support their lengthy tunes. That woodpeckers do the same during repetitive tapping suggests that the birds' percussive behaviors, when done socially, "might be more akin to singing than we had realized," says behavioral neuroscientist Daniel Tobiansky of Providence College in Rhode Island.

Nonvocal acoustic communication is often overlooked in research of the animal kingdom, Tobiansky says, and connections like these provide insights into how it may have evolved.

Having taken a look under the hood of downy woodpeckers, Antonson plans to continue exploring the mechanics of extreme behaviors performed by other species to see what insights they might serve up. ✖

↑ **The secret to a downy woodpecker's forceful blow is coordinated muscle movements and breaths.**

NEAL LEWIS/U.S. NATIONAL PARK SERVICE

CHEMISTRY

HOW CIVETS TWEAK COFFEE'S FLAVOR

By Carolyn Gramling

● The world's most prized coffee comes from partially digested beans pooped out by the Asian palm civet. Now, chemical analyses suggest that fermentation in the civet's innards adds a little something extra to the coffee's flavor, researchers report in *Scientific Reports*.

Asian palm civets are catlike mammals that love ripened coffee beans. As the beans pass through the civet digestive system, the animals absorb the pulp and deposit the worked-over beans as dung.

The resulting coffee beans may cost $600 to $1,300 a pound—a price that has led to concerns about civet captivity and animal welfare.

Zoologist Ramit Mitra, then at the Central University of Kerala in India, and colleagues collected 68 fecal matter samples from wild civets on estates in India growing *Robusta* coffee beans, as well as uneaten beans from the same estates.

The civet-consumed beans had higher fat content, which affects coffee's aroma and taste, and higher levels of two fatty acids, which could add a dairylike flavor.

But take these flavor notes with a grain of salt, the team cautions. The beans tested were not roasted, and most civet coffee uses the more flavorful *Arabica* bean. ✖

AKKHARAT JARUSILAWONG/GETTY IMAGES

HEALTH & MEDICINE

'Butt breathing' might help patients who need oxygen

By Maria Temming

● **Takanori Takebe is on a mission** to find out if people can breathe through their butts.

As a medical doctor and stem cell biologist, Takebe spends most of his time trying to develop lab-made livers to treat organ failure. His side quest to explore backside breathing began several years ago, when his father caught pneumonia and had to be put on a ventilator.

"I was really shocked by how invasive it is," says Takebe,

PETE RYAN

↖ A procedure aimed at improving the body's oxygen levels via the gut showed promise in pigs.

of Cincinnati Children's Hospital Medical Center in Ohio and the University of Osaka in Japan. He wondered if there was a way to help patients get oxygen into the body without involving the lungs.

Inspiration struck when a graduate student brought in a book that described how various animals get oxygen through their skin, genitals or guts. Freshwater fish called loaches, for instance, can swallow air to supplement gill breathing in low-oxygen water.

Takebe knew that the human intestinal tract is rich in blood vessels. That's why enemas can deliver medicine to the bloodstream. Perhaps oxygen could pass from the intestines into the bloodstream, too.

Takebe and colleagues developed an enema-like treatment that sends a liquid called perfluorodecalin up the rectum. This liquid, which is already used in some medical procedures, can be loaded up with oxygen.

In experiments with mice and pigs, enemas of this liquid helped the animals survive low-oxygen conditions. Takebe watched samples of pigs' blood change from a muddy, low-oxygen hue to a brighter, oxygen-rich red. "That was my aha moment," he says, that this wild idea might actually work.

Takebe's team shared those findings in *Med* in 2021. Further pig tests reported in 2023 showed the technique could improve animals' oxygen levels for up to half an hour. In 2024, the work won an Ig Nobel Prize — a cheeky award for science that makes people laugh, then think. "Thank you so much for believing in the potential of [the] anus," Takebe said at the awards ceremony while wearing a loach-shaped hat.

Now, the researchers have tested the safety of butt breathing in people. Twenty-seven healthy male volunteers in Japan each took a dose of unoxygenated perfluorodecalin up the anus and were asked to hold it for an hour. Those in the smallest dose group got a squirt of 25 milliliters. The biggest dose was a whopping 1.5 liters.

Four of the six men in the 1.5-liter group had to stop receiving liquid early due to stomach pain. But most of those who got up to 1 liter fared well, bloating and mild tummy discomfort aside, Takebe's team reports in *Med*. The research was funded by EVA Therapeutics, a start-up that Takebe cofounded to pursue the project. Future clinical trials will show whether an oxygen-loaded version of the liquid delivers oxygen to the bloodstream.

The work gets mixed reactions. John Laffey, a clinician and researcher specializing in acute respiratory distress syndrome at the University of Galway in Ireland, thinks researchers should work to improve treatments that support the lungs rather than enlist other body parts to do lungs' job. "The lung, even an injured lung, will always exchange gas way better than any other organ, because that's what it's designed for," he says.

Kevin Gibbs, a pulmonary critical care physician at Wake Forest University School of Medicine in Winston-Salem, N.C., is more intrigued by the proposal. "It definitely raised my eyebrows," Gibbs says. "I tend to think of myself as an above-the-waist doctor." But sending oxygen in the back entrance — if it works — could be useful in short-term or emergency cases, he says.

How does Takebe's father feel about butt breathing? "Dad is pleased," Takebe says. "He's always offering to be our experimental subject." That would of course be a huge conflict of interest, Takebe adds. But he appreciates that his dad has his back. ✖

GENETICS

THE OLDEST KNOWN RNA TELLS A WOOLLY MAMMOTH'S TALE

By Meghan Rosen

● In the final moments of Yuka the woolly mammoth's life, he may have been trying to outsprint cave lions.

Yuka's hind legs bear scratches, and in his muscle tissue, scientists have detected molecular signs of stress. Molecules called RNA hint that the mammoth's muscles may have been exhausted. Sequences of those RNA molecules, which offer peeks into Yuka's life 40,000 years ago, are the oldest yet recovered, scientists report in *Cell*.

Until now, the oldest RNA sequenced was about 14,000 years old, from a Pleistocene wolf. The new work suggests that ancient RNA may be able to persist far longer than scientists suspected, says biologist Love Dalén of Stockholm University. RNA has long been considered DNA's more delicate cousin, degrading very soon after death. But in certain conditions, like the freezing environment that mummified Yuka's remains (shown), ancient RNA may stick around long term.

Dalén's team analyzed RNA from 10 woolly mammoths whose tissue was frozen in Siberian permafrost. Such ancient RNA could help uncover new details about the lives and deaths of the iconic animals that once roamed Earth's chilly tundra. ✖

↗ A polar bear in Norway picks at its seal prey. Gulls nearby and other animals will eat the leftovers.

ANIMALS

POLAR BEARS' TRASH IS OTHER ARCTIC SPECIES' DINNER

BY GENNARO TOMMA

In a single year, one polar bear can leave roughly 300 kilograms of prey for other animals to dine on. Altogether, the bears provide about 7.6 million kilograms of carrion for scavengers throughout the Arctic, large carnivore scientist Nicholas Pilfold and colleagues report in *Oikos*.

Polar bears typically eat the blubber of their prey (usually seals) and leave the rest. The biomass of those leftovers and their importance to the food web have been overlooked, says Pilfold, of the San Diego Zoo Wildlife Alliance. His team's calculation is based on data on scavenging activity around carcasses as well as data on how many calories seals can provide and how many seals polar bears consume each year. Scavengers including arctic foxes, gulls, ravens and even wolves couldn't access this kind of food if the polar bears didn't leave it behind, the team says.

The leftovers are probably an important food source for these species, "particularly at a time of the year when alternative food is not so easy to get," says polar bear expert Jon Aars of the Norwegian Polar Institute in Tromsø.

But global warming is endangering polar bears — and their leftovers. About 324,000 kilograms per year have been lost in two regions where polar bear populations have been declining, Pilfold's team calculates. Such losses will impact scavenger species, though how exactly is unclear. ✖

FROM LEFT: VALERI PLOTNIKOV; DAVID MERRON PHOTOGRAPHY/MOMENT/GETTY IMAGES PLUS

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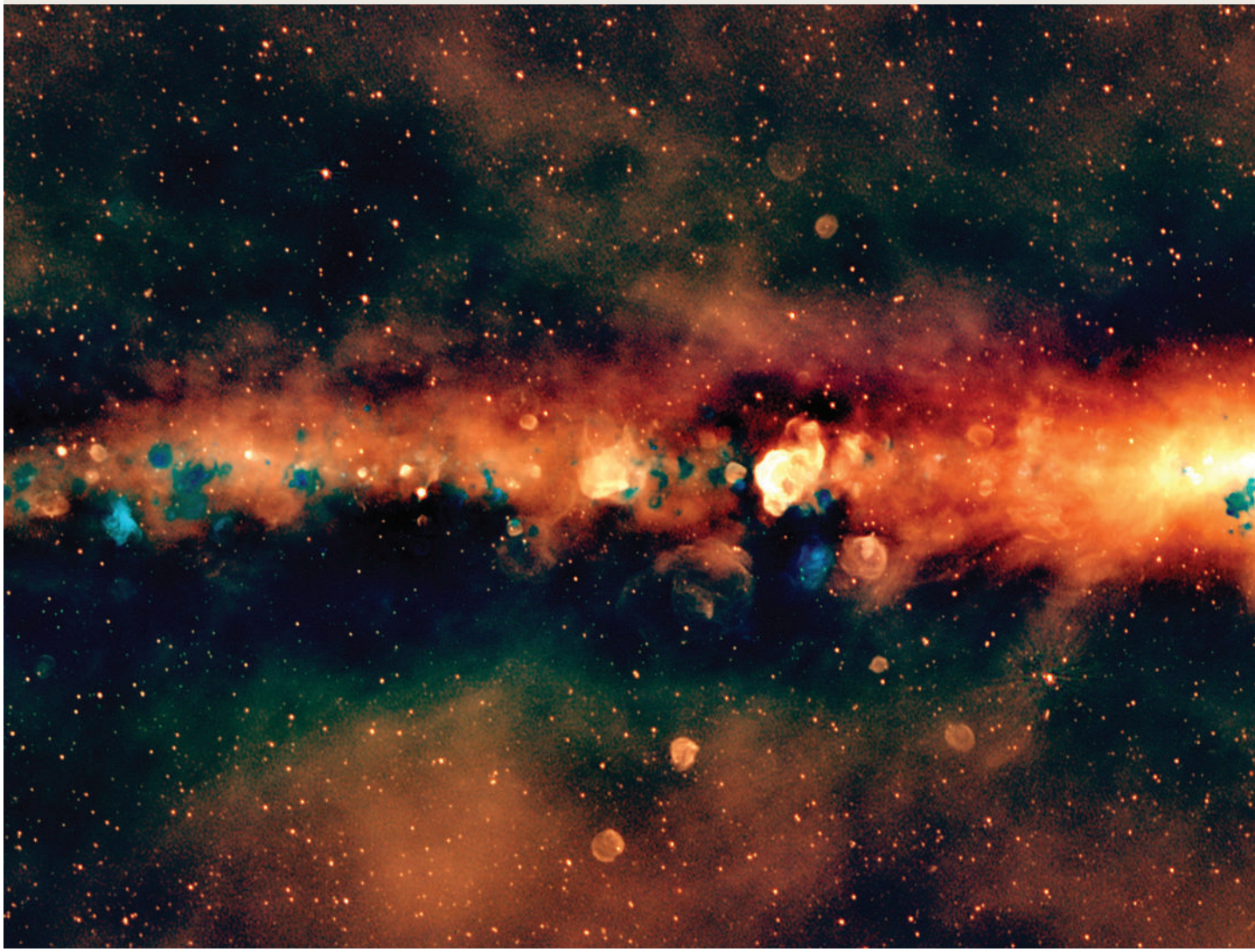


ASTRONOMY

Astronomers unveil a new Milky Way portrait

By McKenzie Prillaman

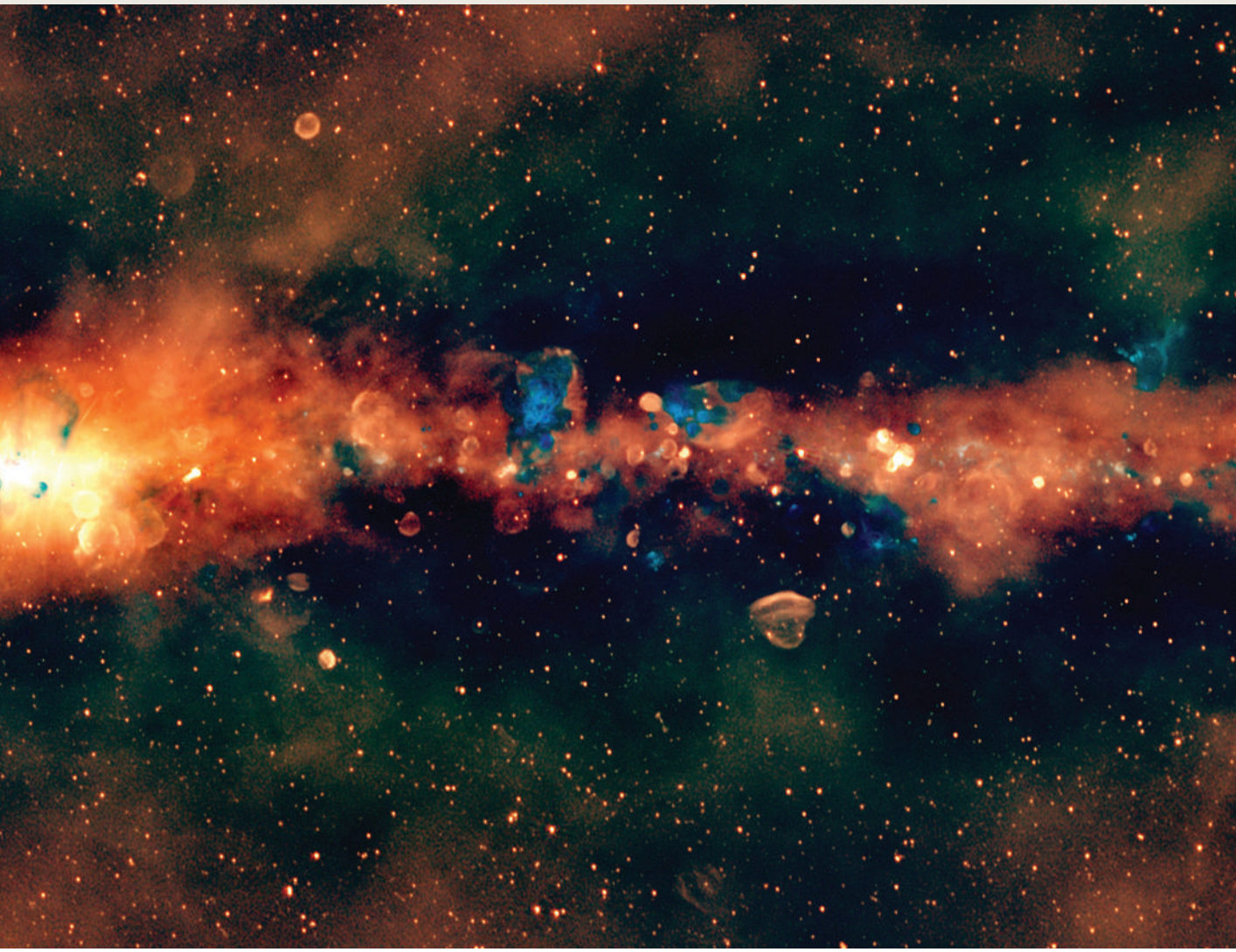
↑ In this image of the Milky Way, blue bubbles are stellar nurseries. Red bubbles are supernova remnants.

● **A ribbon of red splotches** interspersed with blue dots marks the largest, most detailed image of the Milky Way in radio wavelengths ever assembled, researchers report in *Publications of the Astronomical Society of Australia*.

This new side view of our fairly flat spiral galaxy, as seen from Earth's southern hemisphere, will help astronomers find and classify objects within it and better understand ongoing processes, says Silvia Mantovanini, an astronomer at Curtin University in Perth, Australia.

The new image was prompted by the search for supernova remnants, leftover bubbles of gas and dust from exploding stars. Most of these objects have been discovered in radio light because they can continue emitting radio waves for tens of thousands of years after an explosion, Mantovanini says.

Researchers have detected about 300 supernova remnants in the Milky Way but estimate that roughly 2,000 exist. Studying more stellar



S. MANTOVANINI AND THE GLEAM-X TEAM

remains will shed light on the last evolutionary stages of stars and their grand finales, Mantovanini says. However, it was difficult to distinguish supernova remnants from other objects with past telescopes and surveys.

Mantovanini and colleagues compiled observations of radio waves captured over more than 140 nights from 2013 to 2020. The data came from the Murchison Widefield Array telescope in Western Australia during two surveys mapping the southern hemisphere sky. Each observation took a snapshot of one section of the sky and lasted about two minutes, capturing a specific range of radio wavelengths.

Stitching together almost 2,000 of these observations using supercomputers revealed a dazzling edge-on view toward the center of the Milky Way, spanning roughly 60,000 light-years, or just over half the galaxy's width.

The team stacked 20 versions of the image, each a different color to represent a specific range of radio wavelengths, with longer wavelengths depicted in red and shorter wavelengths in blue.

The colors hint at the mechanisms behind the radio emissions, such as heat-related radiation from stellar nurseries, which look like blue bubbles, and emissions from supernova remnants that don't come from heat, which appear as red bubbles.

This view of the Milky Way makes it easy to distinguish goings-on within the galaxy, Mantovanini says. The image's creation, she says, "reminded me that we're just a small part of something incredibly complex." ✖

TECHNOLOGY

AN AVALANCHE AIRBAG MAY INCREASE CHANCES OF SURVIVAL

By Aimee Cunningham

● When a person is trapped in an avalanche, there is very little time before their oxygen supply runs out. A new safety device may extend survival and increase the chance of a successful rescue.

The safety device, called the Safeback SBX, has a fan that draws air from the surrounding snow and directs it to the face. The device, integrated into a backpack, weighs about a pound.

In a clinical trial reported in the *Journal of the American Medical Association*, volunteers were buried face down under at least 50 centimeters of snow. The goal was to remain there for 35 minutes. Researchers monitored participants' oxygen levels, heart and respiratory rates and other health measures during burial, which ended if anyone's blood oxygen level dropped below 80 percent. This did not happen for the 12 people in the safety device group. In contrast, seven of the 12 using a sham device had to stop prematurely because their blood oxygen levels fell below the cutoff. Another four requested an early end: Three felt short of breath and one had a panic attack.

Avalanches kill an average of 100 people in Europe each year, including skiers and mountain climbers. ✖

ANTHROPOLOGY

MICROBES MAY HAVE PLAGUED NAPOLEON'S RETREATING ARMY

BY MEGHAN ROSEN

In 1812, the French Emperor Napoleon Bonaparte led a doomed army on a disastrous retreat from Russia. With food scarce, winter approaching and diseases running rampant, hundreds of thousands of soldiers perished. Scientists have now pinpointed some microbes that may have played a part in their demise.

Ancient DNA extracted from the teeth of Napoleonic soldiers revealed two species of fever-causing bacteria, geneticist Nicolás Rascovan of the Institut Pasteur in Paris and colleagues report in *Current Biology*.

The results align with eyewitness accounts from over 200 years ago, says Rafe Blaufarb, a historian specializing in Napoleonic history. Doctors back then chronicled soldiers' symptoms, which included fever, diarrhea, pneumonia and other signs of bacterial infection. The new work brings some "DNA-level biological details to the story," says Blaufarb, of Florida State University in Tallahassee.

There's not much debate about how so many soldiers died. Subzero temperatures, lack of nourishment, exhaustion — "any of this could kill you," Blaufarb says. "It's just a bad, bad, bad scene. It's as bad as it can be."

Rascovan and colleagues analyzed the teeth of 13 soldiers buried in a mass grave in Lithuania, searching for DNA from any known pathogen. In four soldiers, the scientists detected a type of *Salmonella enterica* that causes paratyphoid fever. In two soldiers, the team saw evidence of the louse-borne *Borrelia recurrentis*, bacteria responsible for relapsing fever.

Rascovan emphasizes that it's impossible to say how widespread infections were. But combined with cold and hunger, it's probable that these and other pathogens played a role in the soldiers' downfall.

As Blaufarb puts it: "The real mystery is how any of them got out at all." ✖

↑ DNA extracted from the teeth of soldiers in Napoleon's army (the skull of one shown) revealed two species of pathogenic bacteria.

FROM TOP: OLIVIER CHASSIGNOLE/AFP/GETTY IMAGES; MICHEL SIGNOLI/AIX-MARSEILLE UNIVERSITÉ

THE HEALTH CHECKUP

POLAR PLUNGES AREN'T JUST FOR THE DARING

BY JAMIE DUCHARME

ERIK TANNER FOR TIME

On January 1, some hardy souls greet the new year not by nursing a champagne hangover in bed, but by plunging into frigid water. In New York City, thousands of people participate in a seaside "polar plunge" held annually since 1903. Similarly bone-chilling swims take place across the country and overseas on New Year's Day.

These brave revelers may be on to something. Icy immersion isn't without risk, and there's no single temperature range used to study dunking or swimming. But a growing body of science suggests cold water may hold benefits for mental and physical health alike.

Lee Hill, an exercise physiologist at the McGill University Health Centre in Montreal, has a long history with cold-water swimming. A former competitive swimmer and coach, Hill used to take kilometers-long swims, sometimes in water below 10° Celsius, in their native South Africa. Though not for the faint of heart, these chilly dips create an unmatched feeling, Hill says. "You feel Zen.... You feel every part of your body. You're aware of your breathing. You forget about everything [else]."

Diving into icy cold water triggers a pair of conflicting physiological responses, says physiologist James Mercer of the Arctic University of Norway in Tromsø, who has studied cold-water immersion. One is the diving response, which is meant to conserve oxygen underwater. Heart rate slows, breathing is inhibited, blood vessels constrict and blood flow is shunted to critical organs. The second is the cold shock response. "Your heart rate goes through the roof. Your blood pressure goes through the roof. You're gasping for breath," Mercer says.

That push-and-pull may sound hard on the body, and it can be dangerous, particularly if you have underlying heart issues or aren't prepared for the strain on your system. (If you're polar plunging for the first time, go with a buddy, ease in slowly, get out of the water within five to 10 minutes and know the warning signs of hypothermia, Hill says.) But stress isn't always a bad thing, Mercer says. It's how the body builds resilience.

The research on cold-water exposure isn't perfect, Mercer says; studies tend to be small and poorly controlled, and their designs vary widely in terms of participant characteristics, water temperature, and duration and type of activity. That makes it hard to definitively prove the practice has benefits, or to say whether swimming in cold water is better for you than, say, taking an ice bath or a quick plunge.

Nonetheless, some research finds that regular, prolonged immersion in cold water makes the body more resilient. For example, young men who endured daily hour-long baths in 13° to 15° C water for seven days got a physiological boost at the end of the trial, researchers reported in 2024 in *Advanced Biology*. Specifically, their cells did a better job of clearing out old or damaged parts, a process thought to help prevent various diseases and maintain overall cellular function.

Other research suggests regular cold-water immersion may activate the immune system, potentially boosting white blood cell counts and plasma concentrations of immune proteins.

It may be hard for science to pin down what exactly makes cold-water swimming so powerful, says psychobiologist Mark Wetherell of Northumbria University in England. Wetherell recently published a small study in *Lifestyle Medicine*, finding that cold-water swimmers report lower anxiety, higher self-confidence, better sleep and other psychological benefits on days they dip.

Rather than a single mechanism, Wetherell thinks many factors contribute to those boosts: cold water, exercise, time outdoors, social support (since most people swim with others), the thrill of doing something wild enough to win bragging rights — and an adrenaline rush. ✖

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Understanding science has never been more important — or more challenging. While science advances at breakneck speed, so do sensationalized headlines, AI-generated fakery, and misinformation.

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Nancy E. Shute

Nancy Shute, Editor in Chief, Science News

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Features

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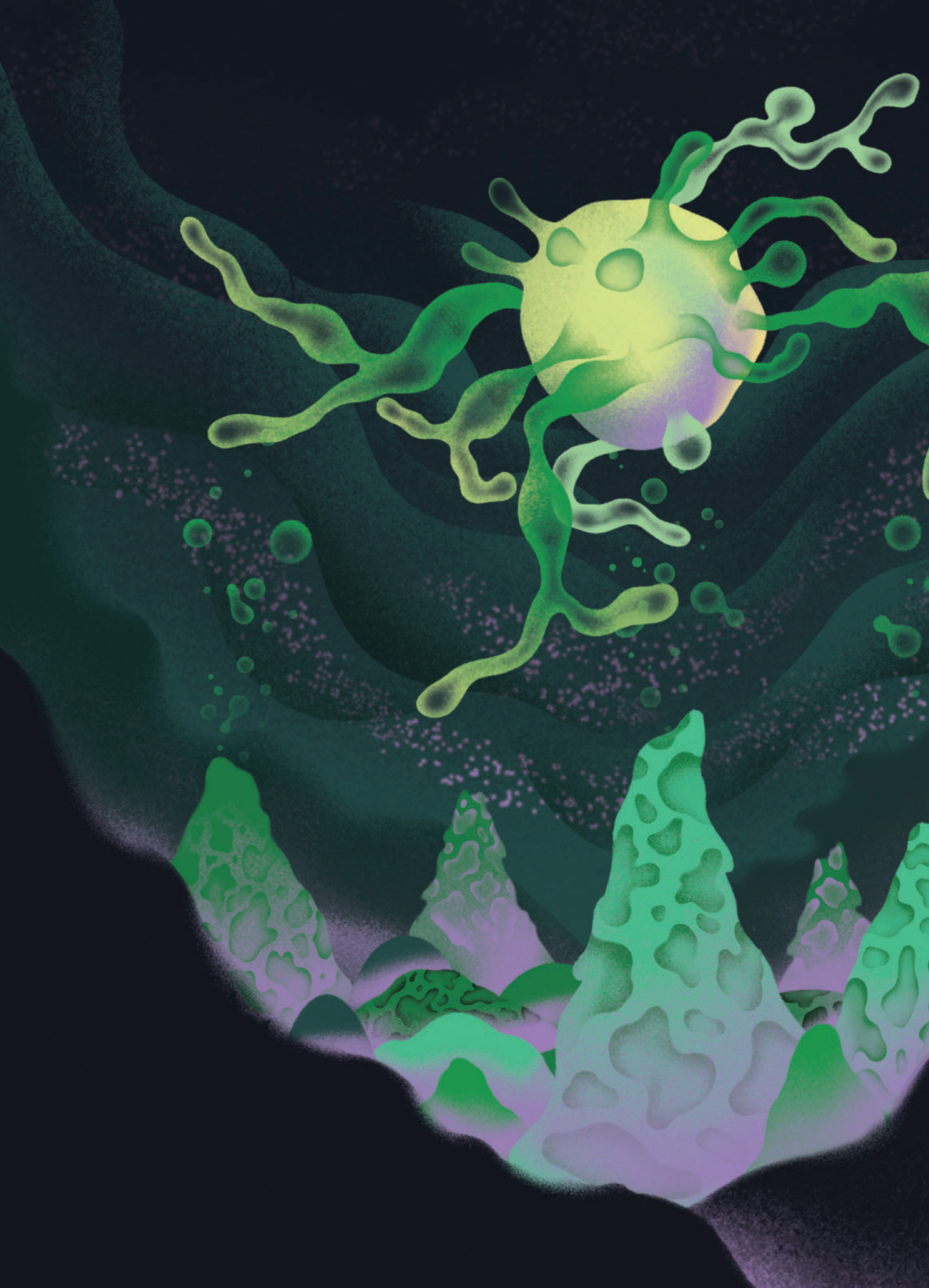
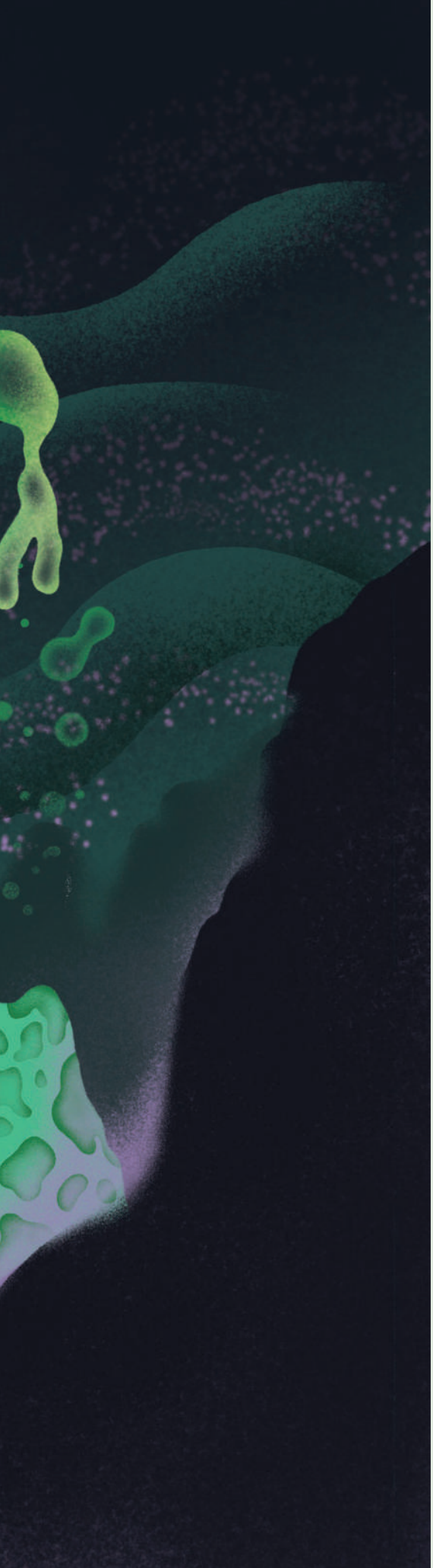
PSYCHOLOGY

TWO RISKY BEHAVIORS MAY BE INTERTWINED

● Alcohol consumption and sports watching often go hand in hand. And it turns out, drinking and sports betting often do, too. A survey of more than 4,000 adults in the United States revealed that sports gamblers tend to be binge drinkers at a higher rate than nongamblers, psychologists reported in 2024 in *JAMA Network Open*. The findings suggest that sports gambling's recent rise in popularity — in part due to mobile betting apps — may impact the prevalence of alcohol use disorders as well as gambling addiction (see Page 50). — *Karen Kwon*



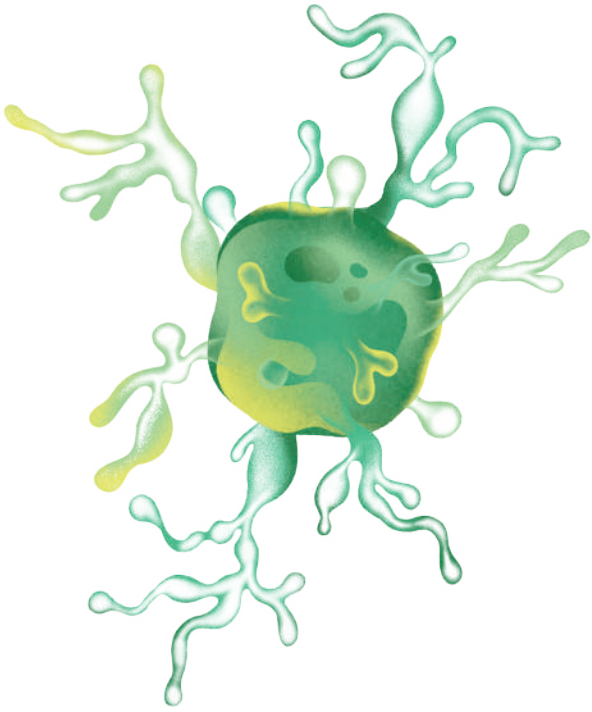


Strange cells may explain the origin of complex life

The tiny pantheon known as the Asgard archaea bear traits that hint at how plants, animals and fungi emerged on Earth

BY MICHAEL MARSHALL

ILLUSTRATIONS BY MARINA MUUN



In many submerged regions, murky mud shelters strange life-forms that seem to be the key to one of the biggest mysteries of life on Earth.

These creatures belong to a domain of life called the archaea: single-celled microorganisms that look much like bacteria under a microscope.

Ten years ago, a new group called the Asgard archaea was identified in sediments from the North Atlantic Ocean. They are nothing like us: They live mostly in places with little or no oxygen, and they are almost unbelievably ancient, with a lineage tracing back perhaps 3 billion years. Yet their DNA shows that the Asgard archaea sit startlingly close to humans on the tree of life.

In 2015, game-changing research made the case that these odd microbes can explain the origin of eukaryotes, the domain of life that includes organisms made of cells containing a membrane-bound nucleus. Since then, an explosion of studies has added to evidence that the Asgard archaea are the key to the birth of all known complex life.

The rise of the eukaryotes was one of the most important events in Earth's history. If it had not occurred, there would be no great white sharks, no towering redwood trees, no hovering hummingbirds and no people. Just slimy layers of bacteria and archaea, everywhere. And the Asgard archaea may have started it all.

"I think it's the most exciting thing that's happened in microbiology in a long time," says geobiologist Daniel Mills of Heinrich Heine University of Düsseldorf in Germany.

Exactly how the Asgard archaea gave rise to eukaryotes, and why it happened when it did, is still being thrashed out by researchers. But based on the evidence so far, the Asgard archaea seem to have evolved in multiple ways that primed them to birth eukaryotes. This suggests that the origin of complex life on Earth wasn't an incredibly lucky chance, but something that built up over evolutionary time.

That, in turn, implies complex life may evolve more easily than many biologists suspected, in which case — if there is extraterrestrial life somewhere in the cosmos — at least some of it might be complex like us.

THE FIRST CELLS

The oldest known living things are simple, single cells. There are two major domains: bacteria, which are familiar in part because some of them cause diseases, and the less well-known archaea. Scientists didn't recognize how distinct the two domains are until the advent of DNA analysis in the 1970s.

The third domain, eukarya, arose later in Earth's history. Compared with the older groups, eukaryotic cells are usually much larger. They also have more internal structure. Each eukaryotic cell has a nucleus, an enclosure where the DNA is stored. Most also have many stubby structures called mitochondria, which supply them with energy. Unlike bacteria and archaea, eukaryotic cells can group together to form large multicellular organisms with distinct tissues like muscle and bone.

"If eukaryotes never originated, we wouldn't be here," Mills says.

How and why eukaryotes formed are profoundly difficult questions because the differences between eukaryotes and their bacterial and archaeal cousins are vast. One group of microbiologists in the 1960s called the divide "the greatest single evolutionary discontinuity to be found in the present-day world."

For many biologists, the origin of eukaryotes also seemed extremely unlikely. All eukaryotes today are descended from the same common ancestor, and nobody has ever observed new eukaryotic cells forming, either in the wild or in the lab. This has long implied that eukaryotes formed only once, and that it was "a chance event," Mills says.

Then came a crucial clue.

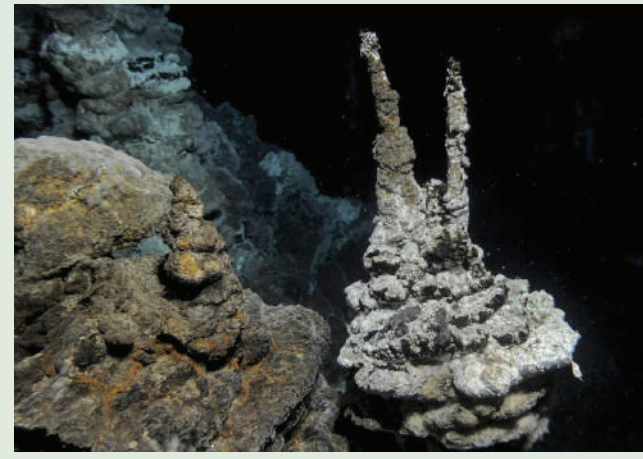
LOKI'S CASTLE

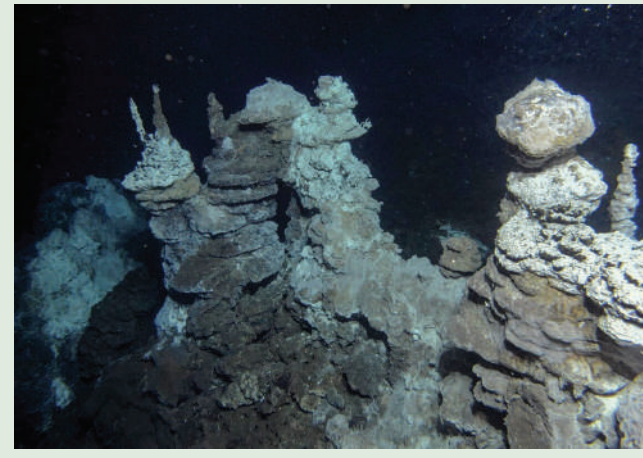
In July 2008, researchers discovered a series of hydrothermal vents on the Arctic Mid-Ocean Ridge, between Scandinavia and Greenland. Each vent is a chimney that pumps out black, chemical-rich water at temperatures of 310° to 320° Celsius. The team that found the vent system called it Loki's Castle, after the Norse trickster god.

Subsequent expeditions collected sediments from the surrounding seabed, which were home to communities of archaea. Initial genetic studies suggested there was something unusual about these archaea. They "seemed to be somehow closer to eukaryotes than what we knew before," says Anja Spang, now an evolutionary microbiologist at the Royal Netherlands Institute for Sea Research in Den Burg.

AN EPIC SEAFLOOR

At hydrothermal vent systems like Loki's Castle, seen below, volcanic activity sends plumes of hot, nutrient-rich fluid into the deep, cold water. Such environments are hot spots for finding extreme new forms of microbial life.





BOTH: R.B. PEDERSEN/CENTRE FOR GEOBIOLOGY/UNIV. OF BERGEN

"I think it's the most exciting thing that's happened in microbiology in a long time."

—Daniel Mills

"I've always been fascinated by the question of how eukaryotic cells evolved," says Spang, who at the time was doing a postdoc at Uppsala University in Sweden. The newfound microbes looked potentially relevant, so she resolved to "reconstruct the genomes of these organisms."

The group's initial attempts to isolate the archaea failed inexplicably, so Spang and her colleagues turned to a technique called metagenomics. They collected as much DNA as they could from the sediments and used computer programs to reconstruct the genetic instruction book, or genomes, of the mystery archaea. They could then compare these mystery genomes with those of other microbes and figure out their closest relatives.

When Spang and colleagues finally generated a reliable family tree, the new group of microbes, which they dubbed the Lokiarchaeota, proved to be the closest known living relatives of eukaryotes. Their results, published in *Nature* in May 2015, caused a scientific sensation.

"It was a game changer," says microbial ecologist Burak Avcı of Aarhus University in Denmark. Three things stood out. The simple fact that the Lokiarchaeota were so closely related to eukaryotes immediately raised the possibility that a member of the same group gave rise to the first eukaryotes billions of years ago. Furthermore, their genomes contained many genes that are hallmarks of eukaryotes. These genomes partially crossed the divide between complex life and simple bacteria and archaea. And crucially, some of the eukaryotic genes the team found seemed to point to an explanation for how the first eukaryotic cells formed.

WHERE IN THE WORLD

First found at Loki's Castle in the North Atlantic, Asgard archaea have since been identified in samples from other watery ecosystems, such as hot springs, microbial mats and estuaries. They've been found at sites around the world, including Yellowstone National Park in Wyoming, the Bay of Aarhus in Denmark and cold seeps in the South China Sea.

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ENDOSYMBIOSIS

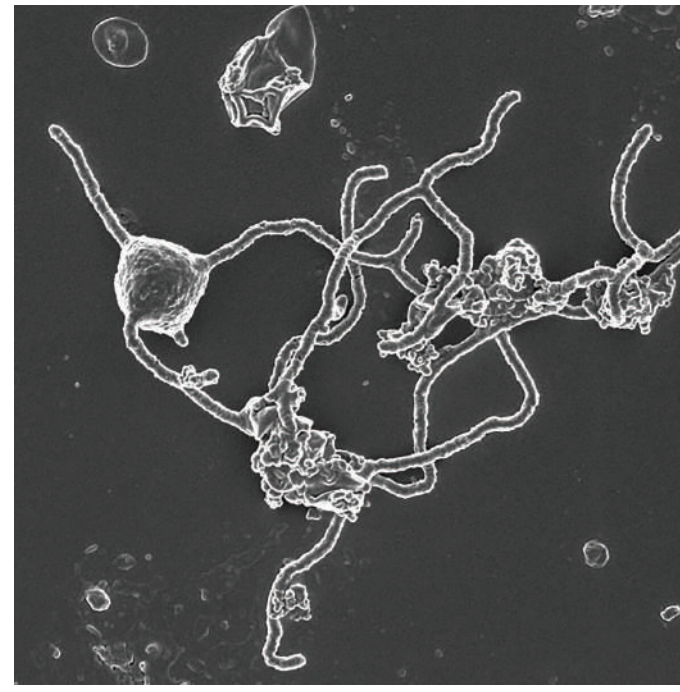
The basic idea for how eukaryotes may have formed goes back over a century. In 1910, Russian biologist Konstantin Sergejewitch Mereschkowsky suggested that some of the complex structures in what we now call eukaryotic cells were once free-living cells. The first eukaryote formed when one cell took up residence inside another. The intruder eventually fused with its host to such an extent that the two became inseparable.

This partnership came to be called endosymbiosis. The idea languished in obscurity for half a century until it was revived in 1967 by microbiologist Lynn Margulis. Writing as Lynn Sagan (she had been married to astronomer and author Carl Sagan), Margulis argued that the energy-giving mitochondria and two other eukaryotic structures had been formed from separate cells.

Margulis' proposal was "groundbreaking, revolutionary work" at the time, Mills says, and today, the basic idea of endosymbiosis is textbook orthodoxy. Still, the theory of endosymbiosis raises a plethora of intractable questions, beginning with an obvious one: Which types of microbes were involved? Was the host cell an archaean or a bacterium? What about the cell that was absorbed and became the first mitochondrion?

"We did not have the host. We did not have the partner," says microbiologist Christa Schleper of the University of Vienna in Austria.

Based on careful analyses of the genomes and biochemistry of eukaryotic cells, researchers gradually concluded that an archaeal host absorbed a bacterium. But nobody knew what kind of archaean, or how it could have achieved this. That's where Lokiarchaeota comes in. These microbes seemed to be ideally placed to be the host



Seen under a microscope, the Asgard archaean initially called strain MK-D1 shocked researchers with its unusual branching tentacles.

cells that assimilated the bacterial ancestors of mitochondria.

Some of the eukaryote-like genes in Lokiarchaeota code for proteins that, in eukaryotes, are involved in changing the shapes of cell membranes. Using these proteins, eukaryotes can deform their cell membranes, twisting and thrusting them into new shapes.

Crucially, many eukaryotic cells can perform phagocytosis — they can engulf a large particle or another cell, trapping it inside a special compartment. In the human body, some of our white blood cells engulf harmful bacteria in this way and then digest them.

If Lokiarchaeota could perform phagocytosis, then maybe a similar archaean billions of years ago used it to engulf a bacterium.

"That's how you get a bacterium within an archaean," Mills says.

It was a beautiful idea. But was it true? Spang and her colleagues still didn't have any living Lokiarchaeota cells in their lab, just a reconstructed genome in their computers.

To flesh out their picture of these archaea, they looked for more. They took samples from seven watery sediments, including Loki's Castle, Yellowstone National Park in Wyoming and the

Radiata Pool in New Zealand. The DNA revealed a host of Lokiarchaeota-like microbes, such as Thorarchaeota (named by another group after the god of thunder) and Heimdallarchaeota (named after the sentinel of the Norse gods). Even more eukaryote-like genes turned up in these newfound microbes. The team decided to call the entire group the Asgard archaea, after the home of the gods in Norse mythology.

Other researchers were also identifying new Asgard archaea using similar methods. But still nobody had grown one in the lab or seen one under a microscope. Or so everyone thought.

A CELL WITH TENTACLES

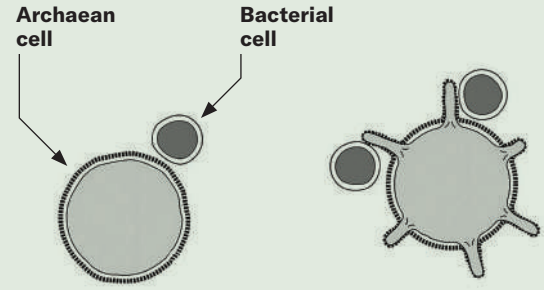
On May 6, 2006, microbiologist Hiroyuki Imachi and two colleagues were on the bottom of the ocean in the submersible *Shinkai 6500*, 2,533 meters below sea level in the Nankai Trough off Japan. There, methane seeps on the flat plain of the seabed feed a community of unusual microorganisms.

Imachi, of the Japan Agency for Marine-Earth Science and Technology in Yokosuka, had relatively modest ambitions. He hoped to identify and culture the microbes and learn how they survived in this peculiar environment. Using the submersible's robotic arm, the crew collected a cylinder of sediments from the seabed. They were mostly gray, with some black dots.

Imachi spent years figuring out how to grow the microbes from the sediments in a reactor in his lab. It was slow work, because the microbes lived slow lives, doubling in number over 14 to 25 days. He had previously worked on biological treatment of wastewater, and he stuck with the methods he knew. Instead of trying to grow isolated strains in test tubes and glass plates, he used a continuous-flow bioreactor to replicate the environment of the deep-sea methane seep, trickling in methane and sulfate to feed the microbes living inside.

THE ARCHAEAN EVOLUTION?

Asgard archaea have traits that could have allowed them to take part in endosymbiosis. This theory for the origin of complex cells holds that one type of cell fused with another until they became inseparable.



The archaean cell forms protrusions that allow it to exchange material with nearby bacteria

With biologist Masaru Nobu and other colleagues, Imachi had analyzed the genome of the microbes, and the pair was planning a paper about their ecology. Then Imachi saw Spang's supervisor Thijs Ettema give a presentation about Lokiarchaeota, not long before Spang's 2015 *Nature* paper was published. Imachi realized he was growing what would soon become known as an Asgard archaean — and he was the only person on the planet who had worked out how to do so.

Imachi and Nobu were shocked. "Neither of us had a background in evolutionary biology," Nobu says, and they certainly hadn't been working on the origins of eukaryotes. But they had stumbled onto a huge discovery.

Instead of their planned ecology paper, they would "go all the way," Nobu says, and propose a new theory for how archaea evolved towards eukaryotes using the Asgard archaea that Imachi had cultured.

First, they had to take a proper look at their microbes, which they were calling strain MK-D1. The team managed to identify individual MK-D1 cells in the culture and

"If eukaryotes never originated, we wouldn't be here."

— Daniel Mills

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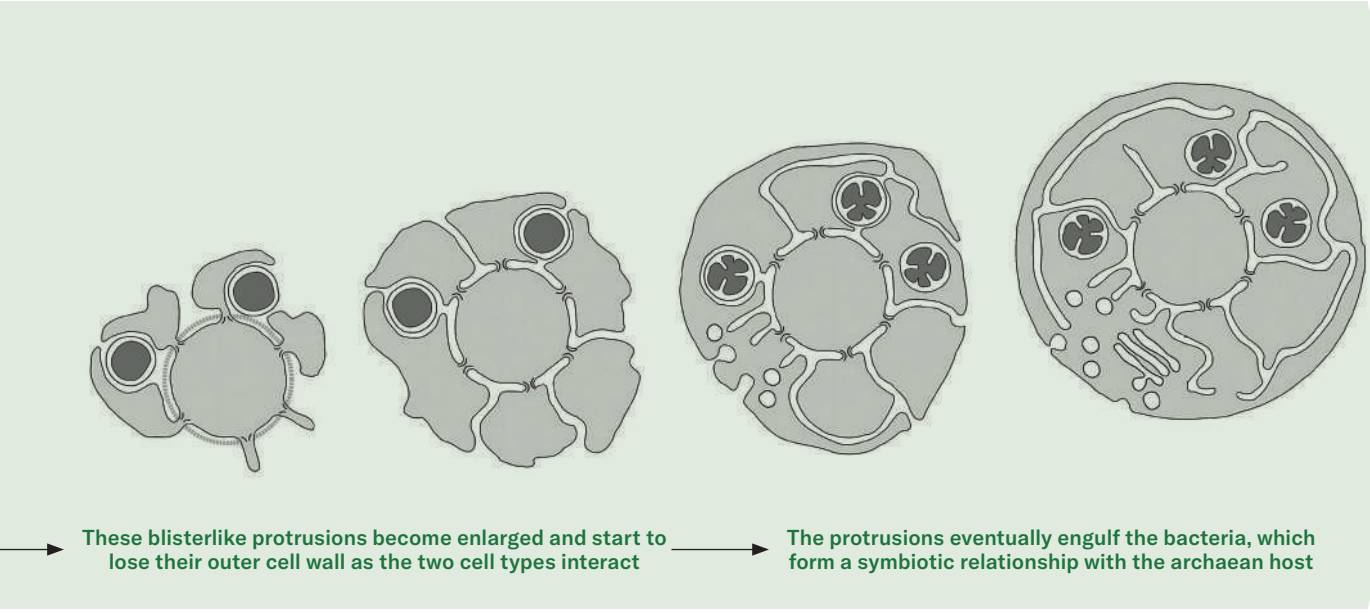


examined them using an array of methods, including electron microscopy. The cells proved to be small and spherical, about 550 nanometers across: not unusual for an archaean, and much smaller than a eukaryote. They showed no sign of the kinds of internal structures found in eukaryotes, such as a nucleus.

What they did have was tentacles. Long tendrils extended from the cell body, often dividing into multiple branches. When Imachi first saw them, he thought he must have contaminated the culture, ruining years of work. "But then, as we looked at it closely together, we realized that these filamentous structures were growing from the spherical cells that we're familiar with," Nobu says. In the electron microscope images, each cell looked rather like a squashed mosquito.

The team called their archaean *Candidatus* Prometheoarchaeum syntrophicum — breaking with the Norse theme by naming it after the Greek mythological hero who stole fire from the gods. The team published their findings on bioRxiv.org in 2019, and it appeared in *Nature* the following year.

Crucially, *Prometheoarchaeum* could not grow in isolation. It exists in a special kind of symbiosis in which it can feed only in partnership; in the culture it grew only with another archaean called *Methanogenium*. The partner produces amino acids and vitamins that *Prometheoarchaeum* cannot make, and in return *Methanogenium* receives essential chemicals in the form of hydrogen and formate.

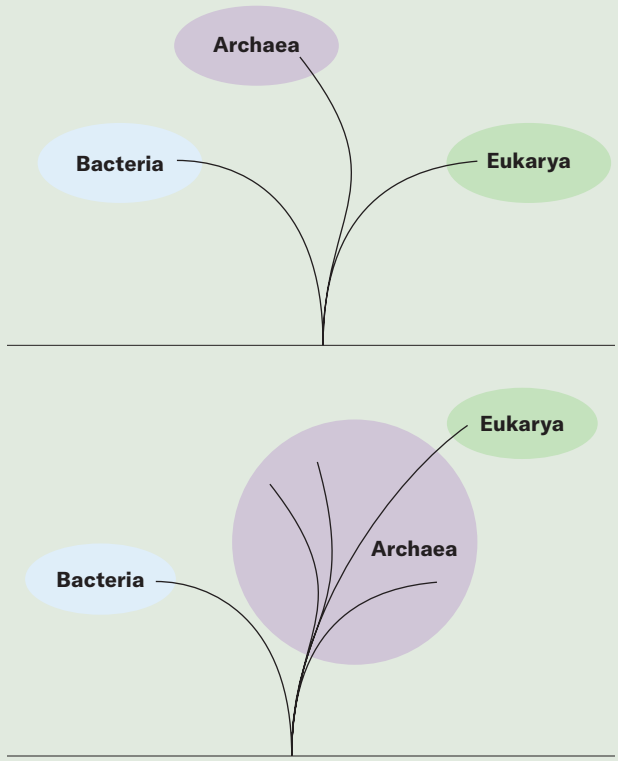
Putting all this together, Imachi, Nobu and their colleagues proposed a significantly different scenario for the formation of the first eukaryotic cell. The Asgard archaean was the host, but it did not capture its partner using phagocytosis. Instead, it had a bacterial feeding partner. The Asgard archaean's tendrils gripped this partner, holding it close. As the two cells became more interdependent, the tendrils slowly fused around the partner — until it was entirely enclosed.

For many researchers, including Spang, this now seems like a far more plausible scenario than phagocytosis. Although the Asgard archaean that merged with a bacterium billions of years ago had some of the genes required, "I don't think it had a fully fledged phagocytosis machinery," Spang says. In contrast, subsequent studies have shown that other Asgard archaea live with a feeding partner.

In April 2019, Schleper collected sediments from a shallow, brackish canal near

SPLITTING THE TREE

Traditional models for the tree of life split organisms into three domains: bacteria, archaea and eukarya (top). But if theories about Asgard archaea are true, life may be reshuffled into a two-domain tree, with eukarya branching off the archaea.



Piran, Slovenia. Three years later, she and her colleagues reported that they had successfully cultured a second Asgard archaean, *Candidatus* Lokiarchaeum ossiferum. Like *Prometheoarchaeum*, it had long tendrils. Within the cells, the team identified a protein called actin, which in eukaryotes is a major component of the internal scaffolding called the cytoskeleton.

"This actin is really interesting because it is found in all Asgard archaea," Schleper says, suggesting it was present in the earliest members of its group. It may be the key to the cells' ability to form long, branching tendrils.

HARD STEPS

The question of exactly what structures and abilities Asgard archaea possess is crucial to understanding how endosymbiosis could have happened. But there are uncertainties about even basic biological traits. One big example: Do Asgard archaea have internal structures similar to those of eukaryotes, or are they internally simple like other archaea and bacteria?

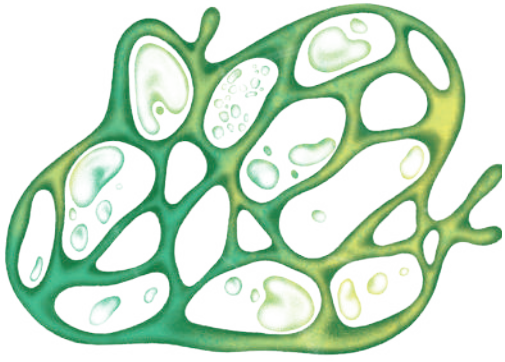
The initial DNA study suggested they were capable of remodeling their membranes, which hinted at complex structures. Avcı and colleagues gathered sediments containing Asgard archaea from Denmark's Aarhus Bay. They found that the archaea's DNA appeared to be separated from the machinery for making proteins. This could suggest that the cells store their DNA in a nucleus, with the protein-making machinery elsewhere, like eukaryotes.

However, Schleper says the existing data don't show this. "I don't think they have ever seen a membrane, so I don't think we have a nucleus here," she says, adding that other archaea do separate DNA and ribosomes, the cellular machinary that forms proteins.

More evidence of a simple internal structure, typical of archaeans, emerged in a study posted in February 2025 by Imachi, Nobu and their colleagues. They reported culturing two more Asgard archaeans, in a group called Hodarchaeales, named for Hodr, the blind son of Odin in Norse mythology. Both had similar shapes and lifestyles as *Prometheoarchaeum*, and no sign of internal structures like nuclei.

However, two months later Avcı and his colleagues reported that they had imaged archaea closely related to Hodarchaeales, again gathered from Aarhus Bay. The cells were very different. For starters, they were around 3 micrometers across, several times the size of *Prometheoarchaeum*. They were shaped like stubby sausages, with a swollen "bulb" at one end containing dense DNA.

F. MACLEOD *ET AL/AIMS MICROBIOLOGY* 2019, ADAPTED BY B. PRICE



"It is most likely we see the first form of the nucleus organized in Asgard archaea," Avcı says.

Avcı notes that the Asgard archaea are already a highly diverse group, and scientists have barely scratched the surface. The first ones cultured might not be representative of their ranks.

The debate is likely to grind on for some time, if only because it takes so long to culture a new strain. But as more Asgardians are identified, researchers are trying to discover the group that gave rise to eukaryotes. A 2023 analysis highlighted the Heimdallarchaeia as the most promising subgroup. For the first time, scientists have something that looks like the host cell that became a eukaryote. "That makes it more graspable," Schleper says.

Plus, the mere discovery of Asgard archaea carries exciting implications for extraterrestrial life.

The more we understand about Asgard archaea, with their tentacles and their close partnerships with other microbes, the more the birth of eukaryotes seems almost inevitable. That calls into question the long-standing assumption that the rise of eukaryotes was an astronomically rare event that happened only once in Earth's history.

"This is just my own intuition," Spang says, but "it happened more than once." She suggests that multiple groups of Asgard archaea took in symbionts, "but one lineage somehow really made it to the stop where it became an integrated cell over time."

"It is most likely we see the first form of the nucleus organized in Asgard archaea."

—Burak Avcı

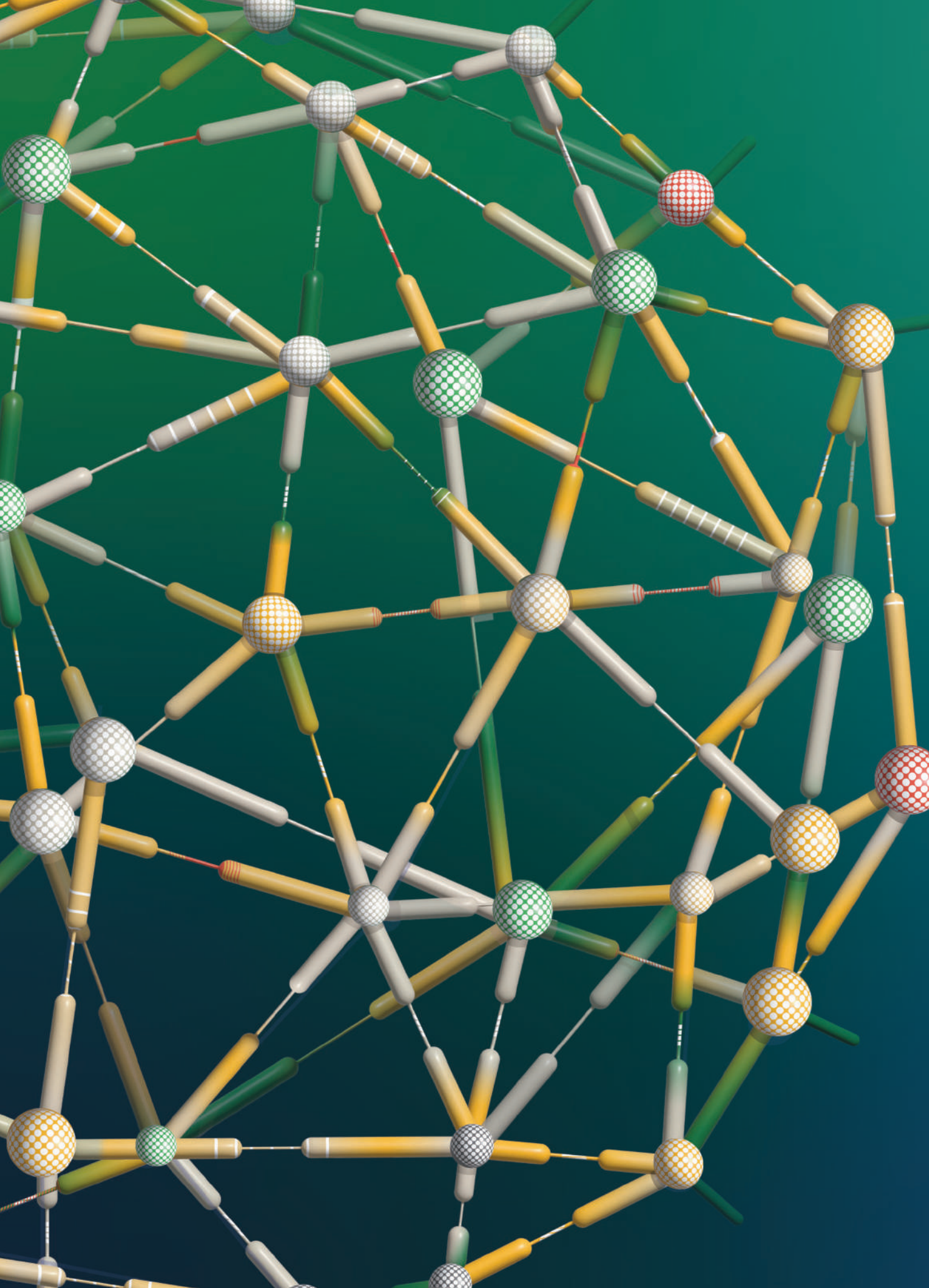
If eukaryotes really arose more than once, then we will have to rethink a key idea about evolutionary history — and our expectations for the kinds of life that might exist on other planets. In a study published in February 2025 in *Science Advances*, Mills and colleagues reconsidered whether the origin of eukaryotes, and other supposed "hard steps" in the evolution of complex life, are really that hard. The birth of eukaryotes looks like a singular event because all modern eukaryotes are descended from one shared ancestor. But there are other explanations.

"It could be that … a eukaryotic organization evolved many times, and all these other examples have gone extinct," Mills says. Or it may be that the first group to become true eukaryotes was so successful that they prevented other Asgard archaea from following suit, effectively "pulling up the ladder" behind them.

If the origin of eukaryotes was truly unlikely, we might never find plants and animals anywhere else, just worlds covered in unicellular slime. However, if one of the alternative explanations Mills highlighted is the truth, then we might expect to find complex life on other Earthlike planets where it has had time to evolve.

One day in the far future, a space probe may gaze down on an exoplanet with liquid water and a thick atmosphere. If the planet has been around for a few billion years, perhaps we'll find alien eukaryotes. Maybe there'll even be complex animals wondering about the strange new star in the sky. ✖

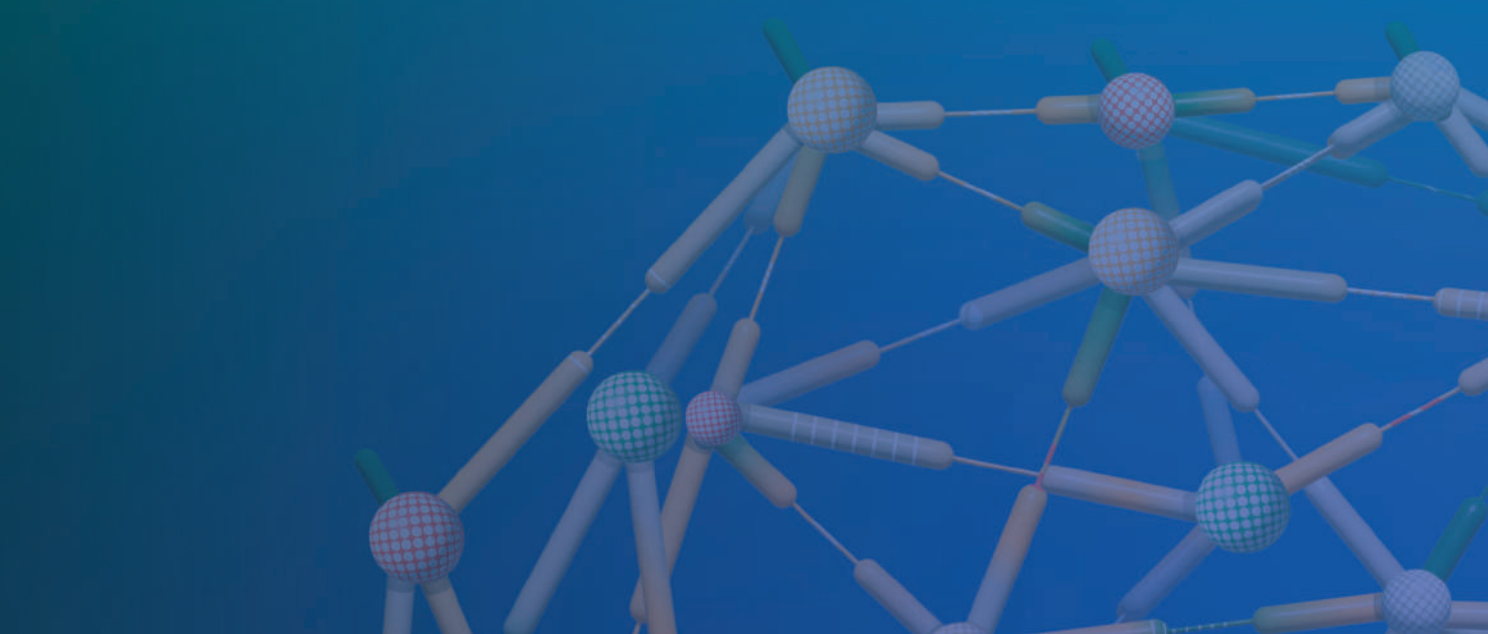
Michael Marshall is a science journalist and author based in the United Kingdom.



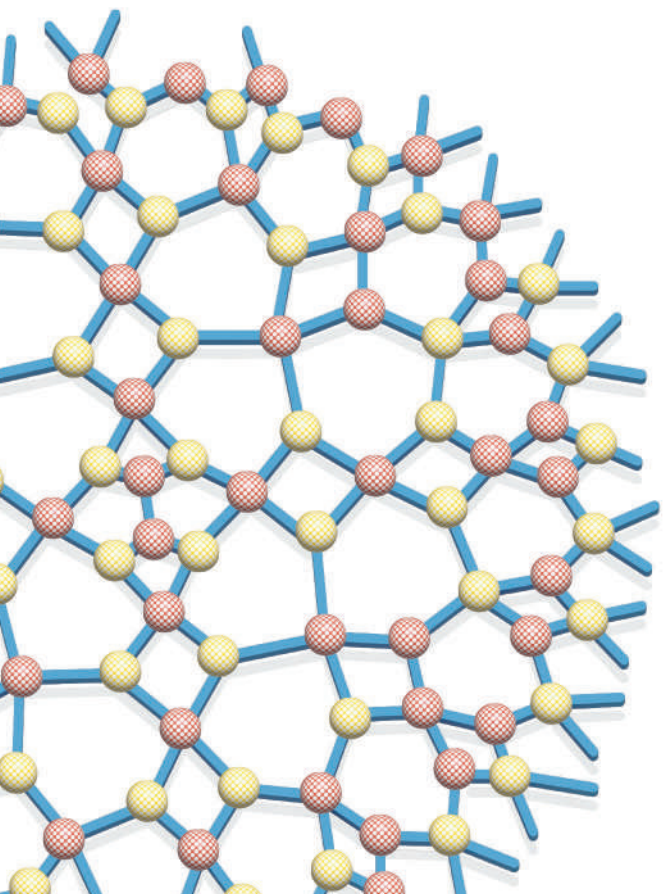
Quantum math shrinks AI models

Tensor networks grapple with the complexities of both quantum particles and machine learning

By Emily Conover | Illustrations by Hawaii



A hunk of material bustles with electrons, one tickling another as they bop around. Quantifying how one particle jostles others in that scrum is so complicated that, beginning in the 1990s, physicists developed an esoteric mathematical structure called a tensor network just to describe it. A decade or so later, when quantum physicist Román Orús began studying tensor networks, he didn't envision applying them to the seemingly unrelated concepts of artificial intelligence.



But with the advent of enormous, energy-hogging large language models like those behind ChatGPT, "we realized that by using tensor networks we could address some of the bottlenecks," says Orús, of Donostia International Physics Center in San Sebastián, Spain. Tensor networks can help squish bloated AI models down to a more manageable size, cutting energy use and improving efficiency without sacrificing accuracy. That's Orús' aim in his work at Multiverse Computing, a startup he cofounded. It's an appealing prospect: AI currently gobbles so much energy that tech companies are hatching plans for a future generation of small nuclear power plants. And the need to power AI data centers may already be helping to drive up electricity costs in some areas.

Smaller models also boast the potential to be crammed onto personal devices like cell phones or household appliances. The ability to put AI on the devices themselves — rather than running it through the cloud — means users wouldn't need an internet connection to use the AI.

There are other ways to compress AI models. But tensor network proponents argue that the technique's basis in physics and math can provide more of a guarantee that the compressed model will perform as well as — or even better than — its big sibling. "It seems like kind of a slam dunk every time people try it," says physicist and tensor network enthusiast Miles Stoudenmire of the Flatiron Institute in New York City.

But Stoudenmire wants to push tensor networks even further.

Most popular AI models are based on a framework called an artificial neural network that is inspired by the neurons of the human brain. Whereas Orús and colleagues are recasting those existing models as tensor networks, Stoudenmire and others aim to make AI models that bypass neural networks entirely, basing them on tensor networks from the get-go. Neural networks are powerful and flexible tools, but training them demands lots of energy and computer time. And they produce AI models with inner workings that are difficult to comprehend. Starting from a tensor network foundation, instead, could make AI faster and easier to train and understand.

"Let the tensors breathe," Stoudenmire says. "I want to free them from the neural network and let them do their own thing ... because I think they have a lot of latent power to offer."

How the tensor network sausage is made

Tensor networks are physicists' answer to a hair-raising concept called the "curse of dimensionality." It's the idea that, as data become more complex and involve many variables, they dramatically explode in size, making computer storage impossible.

The building blocks of tensor networks are mathematical objects known as tensors. If you've ever used a spreadsheet, you may understand how powerful tensors can be. A spreadsheet is, effectively, a matrix, an array of numbers in two dimensions. Tensors generalize this idea to multiple dimensions.

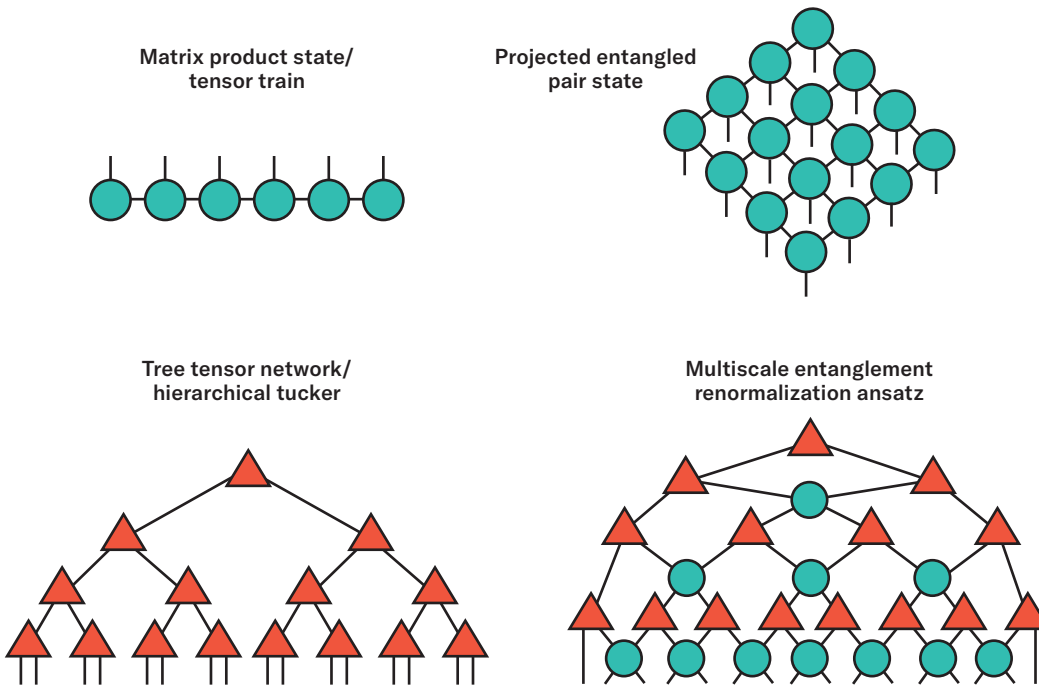
Say you want to describe 10 people and their rankings for 10 possible pizza toppings. Jared gives pepperoni a 10, and Kate gives it a 3, and so on. You'd fill out a 10 by 10 spreadsheet.

But what if you wanted to describe not just toppings, but different sauce types, too: white sauce, marinara, pesto. What you'd need is an order-3 tensor. One number gives Kate's ranking for a pizza with red sauce and pepperoni, another for Jared's ranking of pizza with white sauce and mushrooms.

When dealing with a small number of variables — people, pizza toppings, sauces — such tensors are manageable. If you did a massive pizza survey, polling 100,000 people with 100 choices for toppings and 100 sauces, that would result in a tensor with 1 billion numbers, easily storable on a computer. But once you start dealing with many variables — if on top of people, pizza and sauce you add crust, cheese and many other options — the size of a tensor quickly balloons.

Once a tensor has more than a few tens of variables, "it would take ... as much memory as has

TENSOR NETWORKS



Scientists use diagrams to represent tensor networks. Here, triangles and circles represent tensors, and lines indicate indices. Connecting lines represent contractions, operations that combine tensors. Tensor trains (top left) are used in AI and other applications. Projected entangled pair states (top right) generalize them to higher dimensions. Hierarchical, treelike networks (bottom) can describe correlations across different length scales.

C. CHANG

ever been produced in the history of computing to store," Stoudenmire says. That's the curse of dimensionality. For computer scientists — who tend to huck around huge clods of data — it's a vexing problem. And for quantum physicists, the curse rears its head when describing many particles interacting with one another in complex ways.

Enter tensor networks. Harnessed by physicists in the 1990s and 2000s, they represent one colossal tensor by breaking it up into smaller, more manageable tensors. Those smaller tensors are linked by contractions, operations that combine two tensors into one.

Stoudenmire compares it to taking a giant sausage — too much for one person to cook, let alone eat — and twisting it in places to make perfectly portioned hot dogs, sized for the grill.

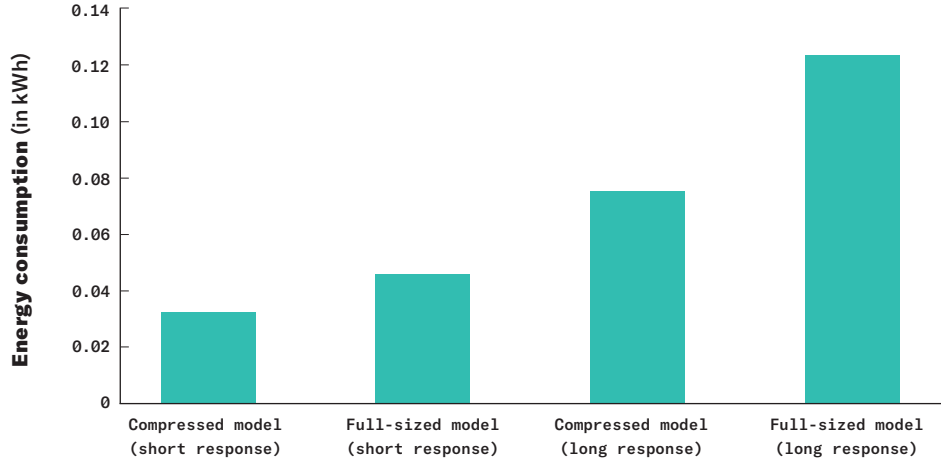
Here's how that sausage is made. Tensor networks are adept at representing correlations, connections between the results of different measurements. In a pizza survey, for example, people who like white mushrooms on their pizza probably also like cremini mushrooms — the two survey responses are correlated. Tensor networks are an efficient way of representing data that have correlations.

In AI, there are correlations between the billions of numbers called parameters that determine, for example, how a chatbot processes users' prompts. And correlations in data can signal redundancy. By eliminating that redundancy, tensor networks can compress a model without weakening its power.

The synergy between AI and quantum physics also comes down to correlations. Quantum particles are paragons of correlation through the effect of quantum entanglement, which links the fates of two seemingly distinct particles.

"We are just finding here, in AI models, what we learned in physics, that correlations matter, period," Orús says. "Everything is about correlations."

TOTAL ENERGY CONSUMPTION OF A COMPRESSED AND UNCOMPRESSED AI MODEL



Multiverse's compressed version of the large language model Llama 3.1 8B produced responses to 104 questions using less energy than the full-sized model. The energy saved was more dramatic for longer responses (right) than shorter responses (left). Source: D. Rovet *et al*/arXiv.org 2025

C. CHANG

A llama gets littler

Models based on neural networks typically already contain simple tensors, such as those spreadsheet-like matrices. Matrices or other tensors hold the parameters that tell the model how to process data via nodes, individual components of the model that are inspired by neurons. In a deep learning model, there are multiple layers of nodes, with associated tensors that contain parameters. But tensor networks have the power to represent data more efficiently than those individual tensors on their own.

Orús' startup has commercialized a tensor network–based compression technique for AI models, called CompactifAI. When applied to the large language model Llama 2 7B, CompactifAI reduces the memory required to store the model by more than 90 percent, going from about 27 gigabytes to about 2 gigabytes. It shrinks the number of parameters by 70 percent, taking it from 7 billion parameters to about 2 billion with an accuracy drop of just a few percent, Orús and colleagues reported in a paper presented last April at the European Symposium on Artificial Neural Networks, Computational Intelligence and Machine Learning in Bruges, Belgium.

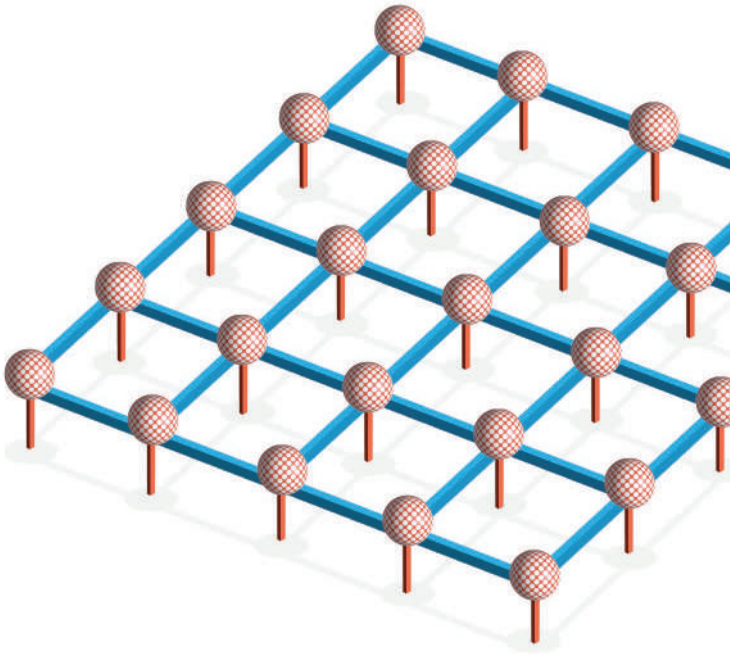
A report by the European consulting firm Sopra Steria found that Multiverse's compressed version of a different model, Llama 3.1 8B, used about 30 to 40 percent less energy than the original version, depending on the length of the response.

Other methods for shrinking AI models can also improve energy efficiency. A technique called pruning removes the least important parameters or nodes from the model, and a method called quantization reduces the precision of the parameters, for example by going from decimal numbers to integers. But machine intelligence researcher Danilo Mandic of Imperial College London says those techniques are reliant on trial and error. "There is no guarantee of good or improved performance."

Tensor networks, designed to tease out the hidden structure in data, allow the model to be compressed and still perform well. Compressed models can even surpass the big ones in accuracy, Mandic says. That's because big models are trained on large swaths of data from the internet, containing plenty of redundancies and irrelevances that get filtered out by the tensor network compression.

A tensor network–compressed version of OpenAI's GPT-2 large language model performed similarly to or even better than full-size GPT-2, Mandic and colleagues reported in a paper published in 2023 at arXiv.org. And the mini model ran on a Raspberry Pi — a cheap, credit card–size computer often used for computer science education.

Multiverse has continued developing smaller models. Two released in August 2025 are named after animals that Multiverse says have similarly simple neural architecture in their brains. The company is marketing the models — SuperFly and ChickenBrain — for personal devices and appliances such as refrigerators and washing machines. For example, a clueless teenager could ask a washing machine which type of cycle to run.



"Tensors ... may offer a new type of platform to study the behavior of deep networks, to understand the science behind deep learning."

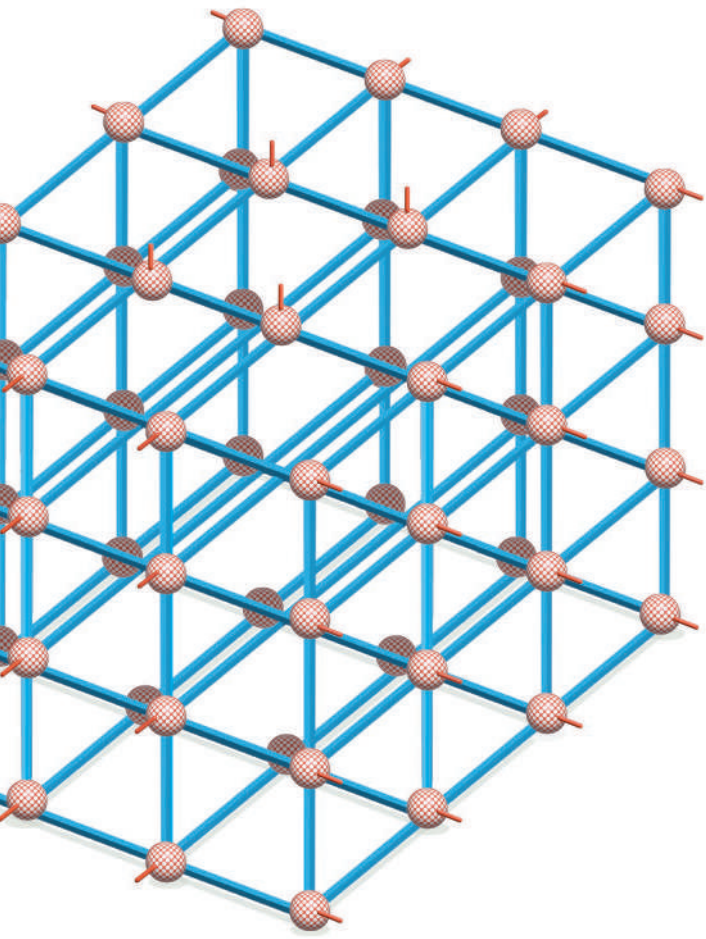
—Rose Yu

Letting tensors breathe

To compress an AI model, you have to have one to start with. Creating and training that original model is itself an energy-sapping saga. Using tensor networks from the beginning could ease energy needs in that stage, too.

Training the neural network in an AI model like that of ChatGPT requires a lengthy process of optimization, tweaking parameters and checking the resulting performance, in order to find the best values for the parameters. This step typically relies on a process called gradient descent, originally devised in the 19th century. Stoudenmire likens it to looking for a plate of food in your house by wandering around hoping you can catch a whiff. "It's not stupid, but it's pretty basic."

Right now, deep neural networks are the basis for the most successful AI models out there. But some researchers are working to create an alternative that could complement that technology. Models based on tensor networks would eliminate the neural network entirely. And it could eliminate that process of optimization, that groping about the house searching for your forgotten leftovers. "We don't want to use optimization at all," says applied mathematician Yuehaw Khoo of the University of Chicago. "This is the main selling point of using tensor networks over deep learning architecture, the possibility of completely bypassing the use of optimization."



To avoid the need for optimization, tensor network methods can use a "divide and conquer" strategy. Parts of the tensor network are frozen while others are adjusted to each solution.

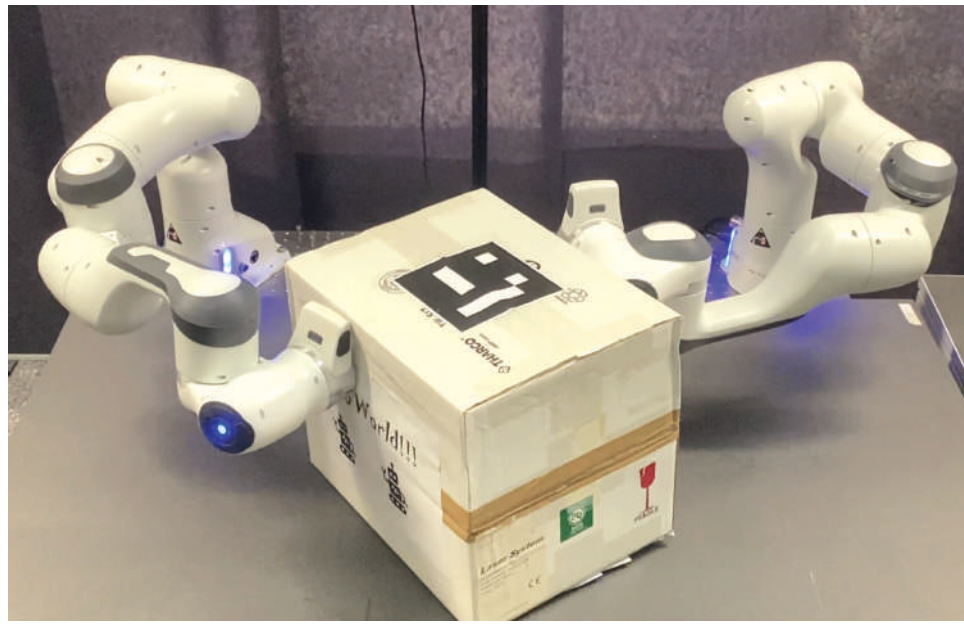
A related tensor network technique involves zooming in and out to help find a solution. For example, imagine that rather than roaming around searching for a plate of food, you could isolate individual floors. Maybe you sample the air of the entire first floor of the house all at once for the scent of food. If present, you zoom in, searching each room, then the different surfaces in the room.

In these ways, tensor networks can settle, not on the location of the food, but on values of parameters in the tensor network. The techniques mean models can be trained within seconds. In a scientific flex, Siyao Yang, an applied mathematician in Khoo's group, demoed training a tensor network–based model in the middle of a scientific talk. It took four seconds. A similar model based on neural networks took about six minutes, nearly 100 times as long.

But the divide and conquer strategy also means that tensor networks have a limitation. They work best if the structure of the problem is well understood, in order to know how to divvy the problem up. For example, when searching for that plate of food, perhaps you know the layout of the house with its floors and rooms.

That makes the technique work best on problems that have some known structure, like those that are described by laws of physics. For example, an AI based on tensor networks can evaluate complex equations related to the properties of materials such as copper, argon and tin, researchers reported last August in *Physical Review Materials*.

AI based on tensor networks is useful in robotics too. In a paper published last July at arXiv.org, researchers at Idiap Research Institute in Martigny, Switzerland, used tensor networks to teach two robotic arms to manipulate a box.



Robots can benefit from tensor networks too. Scientists used tensor networks to enable these two robotic arms to rotate and lift a box. Structuring data in tensor networks can allow for more efficient robot training than standard methods.

Explaining the inner workings of AI

Tensor networks can also make for more understandable AI. Deep learning models, with their myriad parameters, are infamous for being black boxes, with little possibility to extract the reason behind a model's response.

"There's very little theoretical understanding about what's actually happening with deep learning," says computer scientist Rose Yu of the University of California, San Diego.

That obscurity holds neural networks back from tasks where a slipup would be disastrous. "You cannot employ a neural net to run your nuclear power plant if you don't understand how it works," Mandic says.

Yu has used tensor network methods to analyze information such as climate data and the shooting success of basketball players from different places on the court. The mathematically well understood tensor networks, she argues, lend themselves to results that are easier to grasp.

"Tensors, because they're tools that are very well understood from a theoretical perspective ... may offer a new type of platform to study the behavior of deep networks, to understand the science behind deep learning," Yu says.

Meanwhile, tech companies continue to release bigger, more complex models, trained on more data. "The current trend in AI seems to be [that] the ultimate answer to everything is just scaling," Yu says.

But the era of improving performance simply by going bigger may be petering out. Tensor networks provide an alternative paradigm to explore. "Can we derive new insights from tensor networks that can help guide a new wave of development for AI?" Yu asks.

Neural networks still outperform tensor networks on most tasks. But perhaps, Khoo says, that's partly due to the intense focus on neural networks over the past decade, and the relative neglect of tensor networks.

Putting more effort into tensor network research could mean we eventually get more out of them, Khoo says. "With enough tuning, I'm pretty sure tensor networks can win." ✖

Gambling studies pioneer Robert Custer bet on compassion

The late psychiatrist's work provides timely insights as technology transforms the way we gamble

BY JUDITH LAVELLE

ILLUSTRATION BY TAVO MONTAÑEZ

Arriving at a 1987 Gamblers Anonymous event in Dallas, Chris Anderson was at a low point. After years of losing money on high-risk stock option trades, his mental health had deteriorated and he had filed for bankruptcy. Fed up with the chaos and dishonesty, his wife had left him. Like many people contending with a severe gambling disorder, Anderson regularly experienced suicidal thoughts. Still, he couldn't stop placing bets. He related his desperation to an older gentleman with kind eyes who nodded patiently.

"What he said to me was, 'You're really hurting, aren't you?'" Anderson recalls nearly four decades later. "I knew at that moment I found somebody who could help me, who helped me give a name to what was true. I'd never heard of Bob Custer. I had no clue that he really put gambling addiction treatment on the map."

This understanding man was Robert Custer. As a psychiatrist, Custer advocated throughout the 1970s and '80s for the medical community to address gambling disorder as a treatable psychological condition and boosted its reputation beyond a moral failing or a simplistic compulsive behavior. Custer established the first specialized inpatient treatment programs, collected early clinical data and played a vital role in influencing the diagnostic criteria psychiatrists rely on today. By the time he died at 63, Custer's colleagues estimate he worked with thousands of people with gambling problems and presented the science of disordered gambling to countless researchers, clinicians, gaming industry employees and legal experts.

Despite this outsized influence, Custer is not as well-known today as some drug and alcohol addiction researchers. Yet his insights may be as salient as ever. Since Custer's time, many more physical casinos have sprung up beyond Las Vegas and Atlantic City, N.J., and the expansion of mobile sports betting and casino apps has brought new forms of 24/7 gambling into people's pockets. A nationwide survey from the National Council on Problem Gambling and Ipsos found the number of adults who reported gambling online in the past year rose from 15 percent in 2018 to 22 percent in 2024.

For Anderson, meeting Custer was life changing. He became his patient and later a friend and mentee. Now decades into his own recovery, Anderson treats clients with gambling disorder as a licensed clinical therapist in Austin, Texas. He says Custer's findings inform his work daily, even as the nature of gambling changes dramatically. Today, video slot machines and mobile gaming options may be more potent and accessible than older forms of gambling. "A lot of people I'm talking to are gambling in ways that nobody could ever have imagined in 1990 when [Bob] died."

Legitimizing an unsung field

Scientific interest in gambling was scant until the rise of psychoanalysis in the early 20th century. Even then, there was little agreement or rigorous inquiry on what caused gambling problems or how they should be addressed. In the 1920s, Sigmund Freud proposed that compulsive gambling could be a substitute for masturbation—a theory Custer would later reject.

Around the time Freud was speculating about gambling, Custer was born in 1927 in Midland, Pa. He began his undergraduate education at Ohio State University in Columbus before joining

Despite this outsized influence, Custer is not as well-known today as some drug and alcohol addiction researchers. Yet his insights may be as salient as ever.

the Army in 1945. After completing his military service, he returned to graduate from OSU. He then earned a medical degree from Western Reserve University in Cleveland in 1953.

By the late 1960s, Custer had completed his training as a psychiatrist and began treating patients with alcohol use disorders at the Veterans Administration Hospital in Brecksville, Ohio. He developed an interest in gambling disorder and became involved with the mutual support organization Gamblers Anonymous, or GA.

Custer officially opened the doors of the first inpatient treatment program offering gambling disorder treatment in 1972. Open only to veterans, the 30-day program provided individual counseling and group psychotherapy alongside GA meetings. This novel multipronged approach applied a format familiar to drug addiction treatment alongside Custer's growing insights about gambling disorder.

While Custer did not conduct lab research or placebo-controlled clinical trials, he catalyzed the burgeoning field by laying the groundwork to gather some of the first robust clinical data on gambling disorder. Because Brecksville graduates remained in the VA system, Custer and his colleagues were able to track their progress. A 1984 study by Custer's VA colleagues found that 55 percent reported complete abstinence from gambling one year after completing the program.

With the help of his wife Lillian, Custer surveyed GA members about their experiences and identified common themes across their addictions and recovery. Many of these gamblers, he found, had difficult childhoods and began gambling in adolescence. Curiously, many were athletic at some point in their lives and often shared competitive tendencies. He also found that few people sought help until the late stages of their disorders and commonly experienced depression and suicidal thoughts.

Colleagues say Custer was an empathetic listener who valued the lived experience of patients and their families. He favored a pragmatic approach to his patient's problems, such as combining therapy with debt repayment plans and vocational counseling.

Custer eventually established two civilian programs in Ellicott City, Md., and Las Vegas. He mentored health care providers entering the field and offered workshops. Throughout these campaigns, he explained that, if untreated, gambling addiction typically becomes more severe, like alcohol and drug use disorders. Custer emphasized that serious harm could be avoided if professionals and lay people recognized the signs early on. These insights would culminate in his 1985 book, *When Luck Runs Out: Help for Compulsive Gamblers and their Families*, written with author Harry Milt.

"He really had the beginnings of describing what's happening in the mind of the gambler," says Anderson. "I know he would have developed that much further had he lived longer."

To shore up support for the field, Custer cofounded the National Council for Compulsive Gambling in 1972 with chaplain Joseph Dunne. The organization would later become the National Council on Problem Gambling, which advocates for research funding and initiatives to improve treatment and prevention.

46.2

Percent of adults worldwide who had engaged in gambling of some form within the previous year

17.9

Percent of adolescents worldwide who had engaged in gambling of some form within the previous year

80 million

Estimated number of adults worldwide who experience gambling disorder or problematic gambling

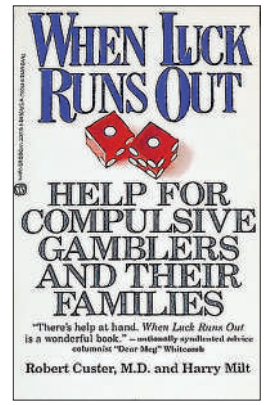
Online gambling is the fastest growing sector of the gambling industry. Globally, online gamblers are estimated to lose about $205 billion by 2030; the amount lost for all forms of commercial gambling is projected to grow to nearly $700 billion by 2028.

SOURCE: H. WARDLE *ET AL*/*THE LANCET PUBLIC HEALTH* 2024

A rippling impact

Among Custer's most significant achievements was his influence on the American Psychiatric Association's *Diagnostic and Statistical Manual of Mental Disorders*, or DSM. Now in its fifth edition, the DSM is the principal atlas of psychological diagnoses. Several tributes to Custer credit him for including pathological gambling in its third edition in 1980. The truth, however, is more complicated, according to Richard J. Rosenthal, who studies both clinical treatment for gambling disorders and the history of behavioral addictions at UCLA.

The DSM-III committee writing the impulse control disorders section brought Custer on board after they already decided to include "pathological gambling." Before Custer's input, the committee's original drafts framed pathological gambling as a relatively simple impulse control problem similar to pyromania and kleptomania, Rosenthal explained in an *International Gambling Studies* article in 2019. People with these disorders start fires or steal items they don't want or need as part of a pattern of building up and releasing tension. Clinicians supposed that pathological gamblers may be caught in the same cycle.



When *Luck Runs Out*, the 1985 book Robert Custer coauthored with Harry Milt, was among the most widely cited sources in the gambling disorder research field, according to a 1991 tribute to Custer.

"The field could have gone in that direction; it did for a while," Rosenthal says. "But Custer, I think, had a really prominent role in focusing on it as an addiction."

Custer argued that pathological gambling was not just a matter of an individual's building and releasing tension. Rather, pathological gambling followed a progressive course from slightly unhealthy gambling behaviors to increasingly problematic wagering with tangible financial and social consequences. As a result, the committee incorporated the common consequences Custer saw in his clinical experience — such as defaulting on debts, borrowing money and struggling with family relationships — as diagnostic criteria to better identify those suffering. So, while pathological gambling remained alongside impulse control disorders in the DSM-III, its description and diagnostic criteria more closely mirrored the way the manual approached substance use disorders.

Custer argued that pathological gambling was not just a matter of an individual's building and releasing tension. Rather, pathological gambling followed a progressive course from slightly unhealthy gambling behaviors to increasingly problematic wagering with tangible financial and social consequences.

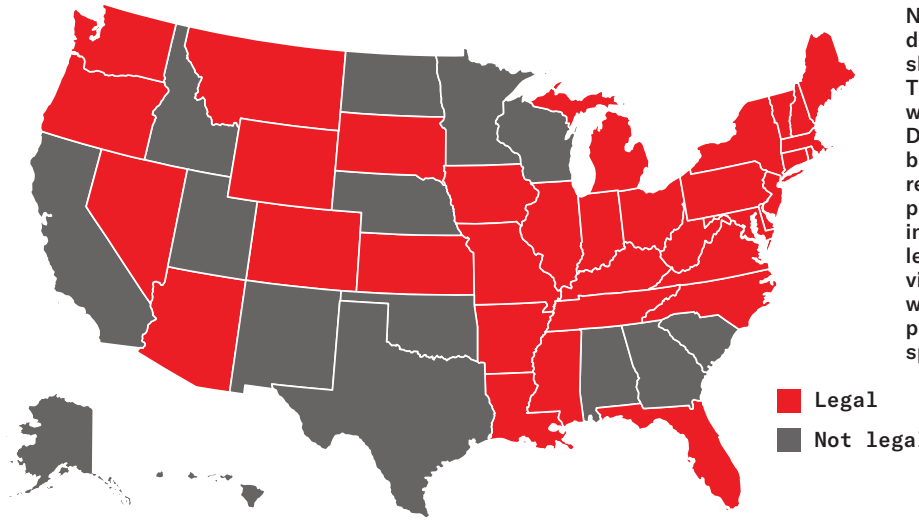
"The work of people like Custer and his colleagues has a long legacy," says Heather Wardle, a social scientist who studies gambling policy and practice at the University of Glasgow in Scotland. The diagnostic criteria, informed by Custer's work, have been adapted into surveys the field uses to measure and articulate how people experience gambling addiction, she says.

Wardle emphasizes that while this was crucial groundwork, there were blind spots. "[Custer's] work was based on self-referred, often white men of a certain background," Wardle says. This legacy may contribute to a bias in modern screening tools that may not adequately capture how gambling disorder presents in women and other populations less likely to enter treatment.

Why Custer would be "profoundly disappointed"

Custer remarked that public attitudes toward gambling disorder were decades behind those toward alcohol addiction, and that the relative

ONLINE SPORTS BETTING IN THE UNITED STATES



Legalization of online sports betting has been expanding throughout the country since Nevada became the first state to do so in 2010. The map on the left shows where the states stand. The states marked in red, along with Puerto Rico and Washington, D.C., allow adults to place sports bets online, though some states require the bettors to be at certain physical locations. Sports gamblers in states where the activity is not legal, however, can still wager via so-called prediction markets, where users can buy financial products tied to the results of sports games.

paucity of research was similarly stark. While more researchers and clinicians now focus on gambling disorder, experts say scientific research has not kept up with gambling's expansive impacts.

"So much of what we still do is actually informed by that early work," says Wardle, who co-led a *Lancet Public Health* commission on gambling report published in 2024. "And because there hasn't been a vast amount of investment in gambling research, the field hasn't particularly progressed." For example, the field still lacks widely accessible treatment options or any medications approved by the U.S. Food and Drug Administration.

Anderson agrees. "I think [Custer] would be profoundly disappointed at the lack of progress that has occurred in understanding and funding of the treating of this addiction."

Some advances have been introduced. Helplines are now ubiquitous in casinos and advertising. At least one "gambling court" in the United States integrates treatment into the criminal justice system. Anderson believes Custer would be especially pleased to know that, in the fifth edition of the DSM released in 2013, gambling disorder was moved from the ill-fitting impulse control disorder section to the substance-related and addictive disorders section.

Still, the field faces an uphill battle. Much of the limited research is sponsored by state gaming commissions and the gambling industry, which many experts argue has held back breakthroughs in treatment and prevention. The Americans with Disabilities Act specifically excludes gambling disorder from its protections, despite including protections for substance use disorders. And, perhaps of most concern, little is known about the potential pitfalls of new and rapidly expanding gambling technology.

"This notion that you can gamble on your phone, that you can carry a 'casino in your pocket' ... is mind-boggling," Rosenthal says. "It's very different from what Custer saw."

But while the tools for gambling evolve, Custer's prescription of compassion and curiosity hardly feels dated. As Cait Huble, communications director of the National Council on Problem Gambling, explains, "If you are truly interested in ... solving the problem — on a holistic society level or even just helping one individual — starting with a place of judgment is no way to build trust or make any progress." ✖

Judith Lavelle is a science and health writer based in Washington, D.C.

If you or someone you know is struggling with a gambling problem, call or text the National Problem Gambling Helpline at 1-800-522-4700. If you or someone you know is facing a suicidal crisis or emotional distress, call or text the 988 Suicide & Crisis Lifeline at 988.

T. TIBBITTS

This train in Shanghai uses magnets to levitate above the tracks and can reach a top speed of 501 kilometers per hour (see Page 62).

Curiosities

CHINA IMAGES/ALAMY

EXHIBIT

A NEW DINOSAUR DOOMSDAY EXHIBITION SHOWCASES SURVIVAL AFTER DESTRUCTION

By Erin Garcia de Jesús

IMPACT: THE END OF THE AGE OF DINOSAURS

The American Museum of Natural History | *New York City*

About 66 million years ago, an asteroid slammed into Earth and the planet suddenly went dark.

The impact and its aftermath were catastrophic. Tsunamis inundated coastlines, earthquakes rattled the ground, acid rain poured from the skies and wildfires scorched the terrain. Roughly 75 percent of species went extinct.

That day is the center of "Impact: The End of the Age of Dinosaurs," a new exhibition at the American Museum of Natural History in New York City. Visitors first step into life before doomsday. Inside a dimly lit hall, a life-size model of a mosasaur, a marine reptile, attacks a long-necked plesiosaur. Nearby, a *Triceratops* adorned with quills — a controversial hypothesis based on fossilized skin — tears down a small tree. That diorama, based on fossils from the United States, includes other animals such as turtles, birds and a *Didelphodon*, an extinct predatory mammal reminiscent of a Tasmanian devil.

There's more to do than look at dioramas. One interactive display quizzes visitors on their daily habits to find out what Cretaceous critter they are most like. Another plays sounds of *Beelzebufo*, an extinct predatory frog.

Then, impact. A short film describes the destruction wrought by an asteroid crashing into Earth with the force of 10 billion atomic bombs. The asteroid instantly vaporized in a blast zone hotter than the sun's surface. The collision sent rocky debris into the sky, blocking most sunlight for nearly two years. Many plants, and the animals that ate them, died.

In the next room, the *Triceratops* is now a pile of bones and visitors can smell the wildfires. Spotlights draw attention to displays describing how researchers have built the case that an asteroid caused the mass extinction event, including the discovery of the Chicxulub crater in Mexico. A globe shows the hundreds of spots where scientists have found a distinct layer of iridium, a rare metal and a sign of extraterrestrial impact.

Missing is mention of another hypothesis: volcanism. That's because the broad scientific consensus is that the asteroid impact was responsible, says museum curator Denton Ebel. "We don't need volcanoes. The impact alone explains it," Ebel says. "Explains the timing, explains the knife edge in history that's recorded in the rock record."

The asteroid's destruction made way for new life. Across the hall, visitors learn how traits such as the ability to break open nuts helped some animals survive and how rainforests filled emptied landscapes. Visitors can also find out whether their creature from the earlier quiz lived or died. As the world recovered, an age of mammals began that persists today.

There is a small chance that a similarly massive asteroid could threaten Earth. But with today's technology, we would see the space rock coming and hopefully prevent its impact, the exhibit notes. Visitors can practice redirecting an asteroid with lasers or with a probe akin to NASA's DART mission.

For those who may worry about another asteroid apocalypse, "Impact" is a reminder that a thriving world thrown into chaos can eventually thrive again. ✖

An exhibit at the American Museum of Natural History in New York City shows visitors what life was like before, during and after an asteroid slammed into Earth and wiped out all nonavian dinosaurs. ↙

ALVARO KEDING AND DANIEL KIM/© AMNH

Missouri Teacher's Research Program Redefines What Students Can Achieve

At Lebanon High School in Lebanon, Mo., science teacher Ryne Emerick has turned a former computer lab into a thriving research hub where students pursue ambitious scientific questions. Now in his 15th year of teaching, Emerick has built a program grounded in creativity and student ownership, guiding young scientists toward presenting their work beyond the classroom and competing in science fairs.

Emerick's experience in Society for Science's Advocate Program has transformed how he helps his students reach new heights, he says. The program is a year-long professional development initiative that supports teachers and mentors working to expand young people's access to opportunities in STEM and increase the number of students who enter STEM research competitions. Advocates receive specialized training from Society for Science staff, a $3,000 stipend and an all-expense-paid trip to Washington, D.C., for the Advocate Training Institute.

"I'm honored to be selected as a Society for Science Advocate," Emerick says. "It allows me to better support rural students who often don't have access to high-level research opportunities. This program equips me with the tools, training and networks to help my students dream bigger, compete nationally and see themselves as real scientists. It's a game changer for our small-town kids with big ideas."

Emerick is one of 70 exceptional educators, representing 34 states and Puerto Rico, selected to the Advocate Program this school year. In addition to the 2025 – 2026 school year, Emerick was an Advocate during the 2023 – 2024 and 2022 – 2023 school years.

Educators and mentors like Emerick are essential in shaping pathways into STEM for the next generation of scientific innovators. Since the Advocate Program's founding in 2015, students of Advocates have completed more than 11,000 unique entries to STEM competitions.

For many educators, the support and community the program provides are instrumental in building and strengthening research programs in their schools. Emerick's science research program at Lebanon High School is a testament to the influence and impact STEM educators can have. Through the Advocate Program, he continues to expand research opportunities for young scientists in rural Missouri, helping them access resources and navigate competition pathways that once felt out of reach.

"Participating in the Advocate Program has profoundly shaped both my professional growth and the trajectory of my students," Emerick says. "Each year, I gain deeper insight into how to guide independent research and support students as they pursue opportunities they never knew existed."

SOCIETY FOR SCIENCE

WWW.SOCIETYFORSCIENCE.ORG/ADVOCATE-PROGRAM

OUR RELATIONSHIP WITH ALCOHOL IS FRAUGHT. ANCIENT CUSTOMS MIGHT INSPIRE A RESET

BY SUJATA GUPTA

Dry January is upon us. The month provides an opportunity to drink less, or not at all. But for people evaluating their long-term relationship with alcohol, what happens once the month is over? Back in the heady 1990s and 2000s, word on the street was that a drink or two a day, especially red wine, was good for health. "Everyone loved that story," says psychiatric researcher Anya Topiwala of the University of Oxford. Now the pendulum has swung.

Drinking even a few times a week has been linked with an increased risk for cancer, dementia and other health problems. The World Health Organization now says no amount of drinking is safe. Current U.S. guidelines suggest a maximum of two drinks a day for men and one for women. But those guidelines are due for an update. So U.S. health officials will have a choice: stick with the status quo, follow WHO's lead or chart a different course.

It's complicated. Even scientists who believe drinking causes health problems don't necessarily advocate for teetotaling. "I'm not telling people not to drink," Topiwala says. "But to make an informed choice, you have to know the evidence."

Maybe history can be informative, too. After all, humans have been drinking for millennia. It might have bolstered cooperation, creativity and social bonding, historical and anthropological accounts suggest. Yet ancient drinking practices bear little resemblance to modern ones, says philosopher Edward Slingerland of the University of British Columbia in Vancouver.

One theory for why people drink is that the ethanol in alcohol hijacks a reward system in the brain that enhances behaviors related to motivation and learning. Given the health harms associated with alcohol, drinking is, in that view, a painful evolutionary mistake.

Slingerland rejects that idea. Evolutionary mistakes with high survival costs tend to die out, he says. Perhaps drinking persisted because the benefits offset the costs.

Consider the human brain. The prefrontal cortex, which fully develops by early adulthood, gives people the cognitive control to do adult things like pay bills and get to work on time. But that same control can impede creativity, research shows. By dulling prefrontal activity, booze can free people to write poetry and make art, Slingerland says.

More than a creativity amplifier, Slingerland posits that drinking and loss of executive control may also have helped humans get along. Other primates don't tend to cooperate with strangers, he says. "How do [humans] trust each other? I argue one way is alcohol."

This "drunk hypothesis" is hard to test, but researchers are trying. One team dug into the literature on 186 largely nonindustrial societies to see if the presence of alcohol correlated with more complex societies. About half the societies in the sample drank, and drinking correlated with about a third of a point increase in complexity, evolutionary anthropologist Václav Hrnčíř and colleagues report in *Humanities and Social Sciences Communications*.

Hrnčíř, of the Max Planck Institute for Evolutionary Anthropology in Leipzig, Germany, suspects that alcohol is just one factor that facilitated the evolution of complex societies, alongside other bonding activities such as music, dance, ritual and shared religious beliefs.

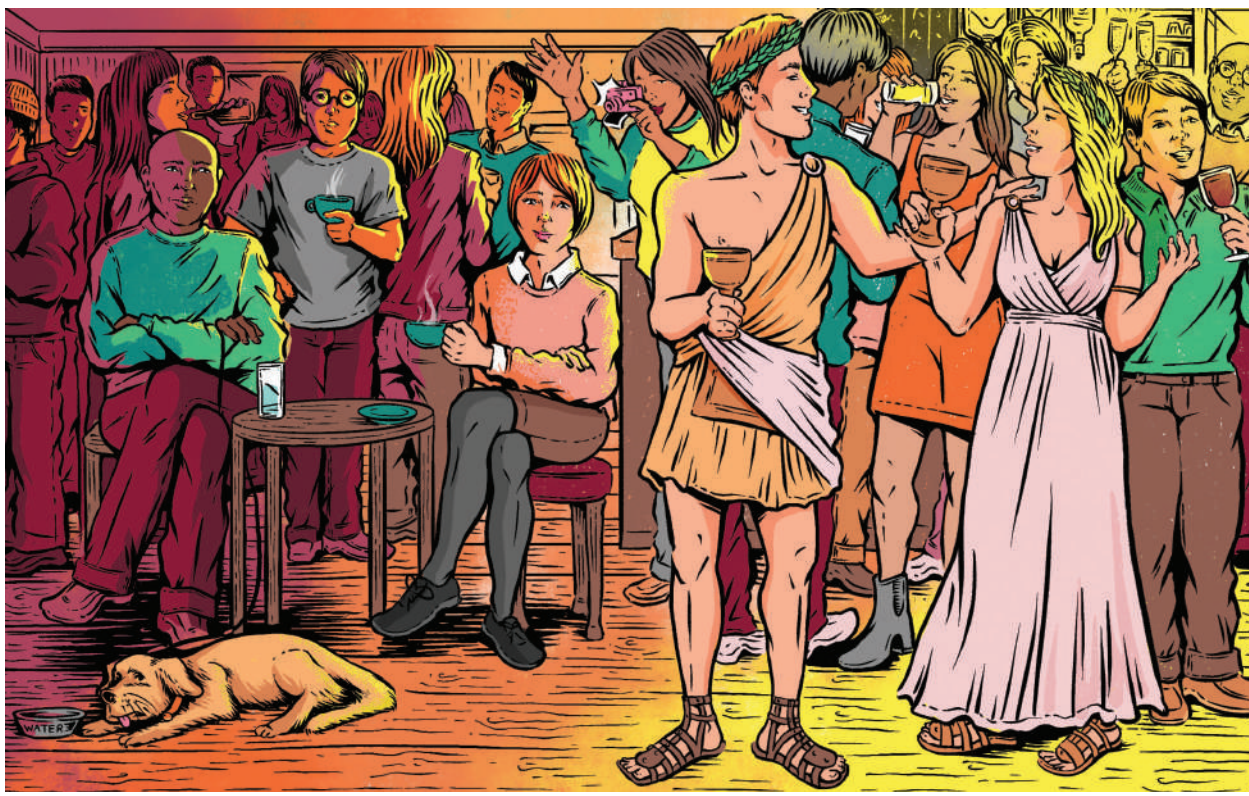
The drinking story isn't all good cheer. For instance, drinking parties among the Colombian Cubeo were intended to bind siblings but often ended in quarrels. But tight social and logistical constraints around drinking seem to have protected

people from booze's worst effects, Hrnčíř says. In ancient Sumer, elites largely controlled access to beer. They offered the beverage to the gods in exchange for prosperity and to construction workers as a form of payment. They also poured beer at celebrations to bolster camaraderie and reinforce social ranks. Ancient Greeks, meanwhile, threw wild parties known as symposia, featuring acrobats, musicians, poetry readings, lewd jokes and sex. Overseeing all the debauchery was a symposiarch. As rowdiness increased, the symposiarch would dilute the wine with water.

Drinking over the last few centuries, though, has undergone dramatic changes. Booze has gotten stronger. Wines and some beers contain double or even triple the amount of alcohol by volume that ancient spirits did. And hard liquors that range from 35 to 95 percent alcohol by volume have become popular. Drinking has also become more solitary. In the United States, the percentage of 19- and 20-year-olds who reported drinking alone increased five points from 2010 to 2022. Young solo drinkers tend to seek relief from negative emotions. And they are more likely than social drinkers to develop alcohol problems.

Unlike in the past, people have unlimited access to alcohol with no elite gatekeeper. And they can drink any type and quantity of alcohol with anyone—or no one. Left to sort out for themselves if drinking does more harm than good, many people have become interested in trialing sobriety via Dry January or the "sober curious" movement, which emphasizes mindful drinking.

Given mounting evidence that drinking harms health, some experts suggest that people reflect on whether they are drinking for relief, like many solo drinkers, or reward, like the ancient Greeks. Keeping that framing in mind can help people reset their relationship with alcohol after Dry January ends. And designating a symposiarch, or friend, to manage the revelry can't hurt. ✖



Drinking in the past was more social and ritualized, with less potent brews, than it is today.↓

CAT SIMS

LEVITATION IS REAL, BUT IT TAKES MORE THAN A FLICK OF THE WRIST

BY MARIA TEMMING

In fiction, magic makes levitation easy. With a simple swish-and-flick of his wand, Ron Weasley yanks a troll's club high above its head in *Harry Potter and the Sorcerer's Stone*. Through graceful martial arts, element benders in TV's *Avatar* series launch boulders and waves of water skyward. And a casual gesture is all Marvel hero Scarlet Witch needs to fling away enemies. In the real world, sound, magnets and electricity can all create upward forces strong enough to cancel out gravity. Just don't expect these levitation techniques to toss boulders or bad guys. At least, not without some outrageous — and dangerous — upgrades.

Acoustic levitation devices use vibrations to hold objects aloft. These machines typically blast sound waves too high-pitched for humans to hear. The waves create alternating regions of high- and low-intensity "noise" in the air. Noisier areas push objects away, trapping them in pockets of relative quiet — but only if the objects are very small and lightweight. Some of the heaviest stuff to ever surf sound waves are Styrofoam beads.

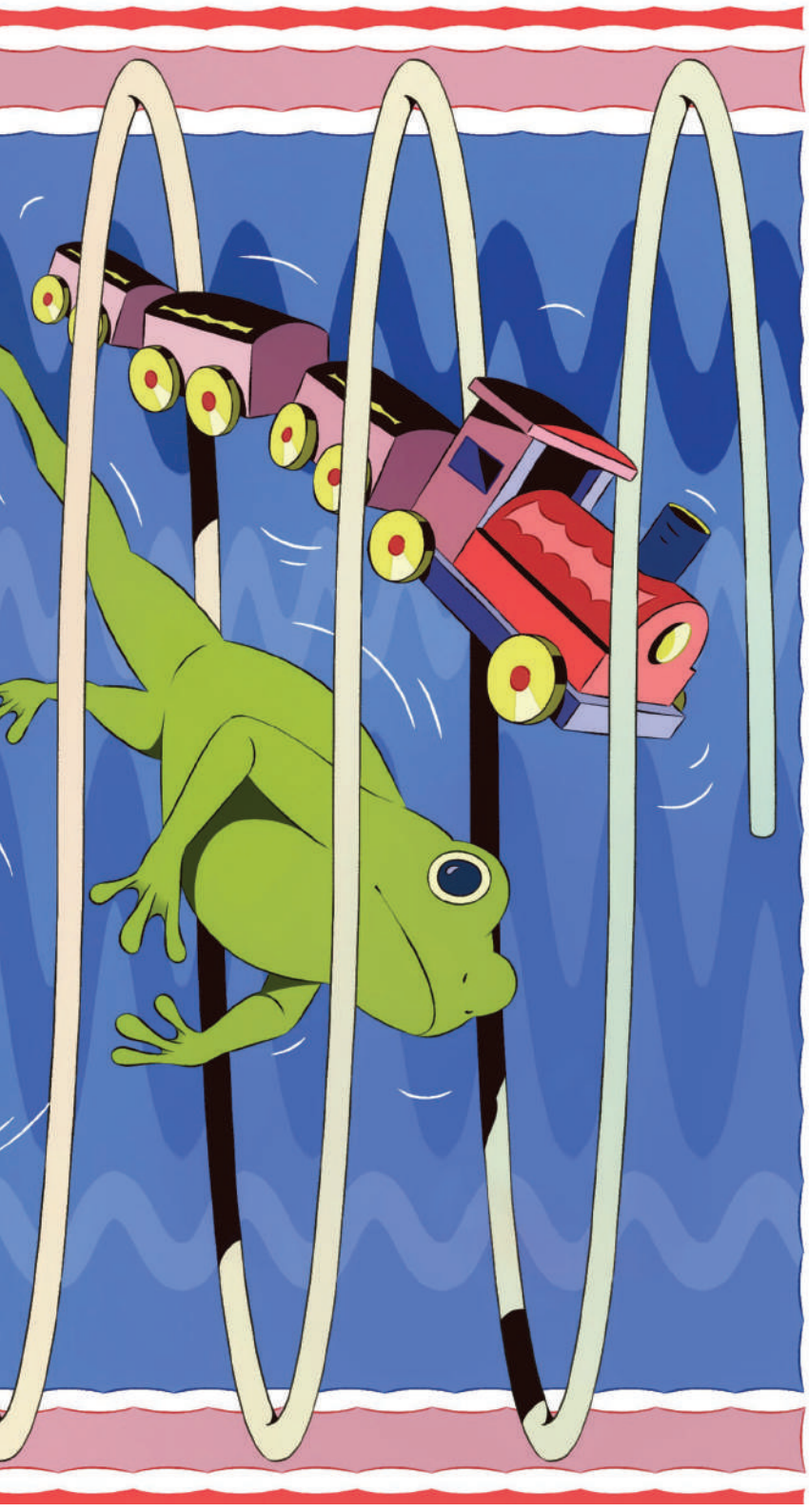
Bigger objects need longer, lower-frequency sound waves to cradle them, says Luke Cox, a mechanical engineer who heads Impulsonics in Bristol, England. He estimates you would need at least 275-hertz sound waves with 1.25-meter wavelengths to levitate a person. A bass guitar plays notes about that low. But it would have to be devastatingly loud to lift someone off their feet.

You'd probably need the energy output of a nuclear power plant to run such a device, Cox muses. Plus a shield to protect anyone you levitated from the heat generated by that amount of power. Otherwise, your gnarly, nuclear-powered bass solo might literally melt their face off.

Magnets get objects much bigger than people off the ground without destroying them. For instance, the ones on maglev train cars and rails interact to make the trains hover just centimeters above their tracks.

Using magnetism to levitate something not strapped to a magnet is trickier, but not impossible. Many seemingly nonmagnetic materials, including water and proteins, are

LILI DES BELLONS



diamagnetic: In a strong magnetic field, they become weakly magnetized and start to repel the field.

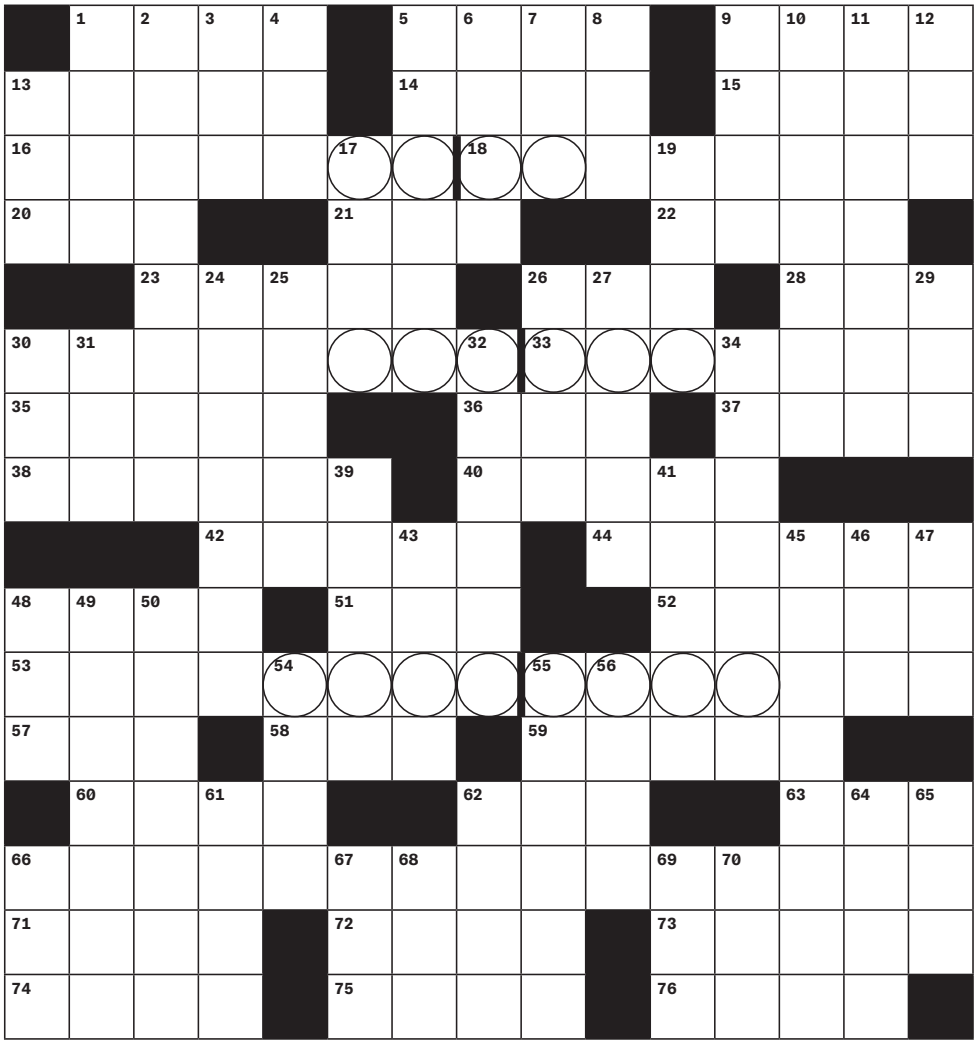
In 1997, scientists famously used that fact to levitate a frog. They placed the creature inside nested coils of wire that created a magnetic field 16 teslas strong — or about 10 times the strength of magnets used to pick up cars in junkyards. That was just enough to buoy the frog to near the top of the 18-centimeter-tall inner coil of wire.

You could theoretically levitate a person this way. It would take one heck of a magnet, though. One of the frog floaters estimated in 1998 that you'd need a 40-tesla field created by a magnet running on 1 gigawatt of power — roughly half the output of the Hoover Dam.

Ballooning spiders use a different way of levitation. They electrically charge themselves up by spinning out long threads of silk, says Igor Bargatin, a physicist at the University of Pennsylvania. That charge allows the spiders to lift off in Earth's electric field and then ride the wind up to kilometers high.

The spidey way of levitation won't work for large objects like people, Bargatin says. You'd have to build up so much charge that you'd end up triggering lightning strikes around you and fry yourself before ever taking off.

Even if real-world levitation never measures up to on-screen superpowers, it can still be useful. Acoustic levitation could provide hands-off handling of lab samples to avoid contamination. Magnetic levitation could make parts of motors float, allowing them to spin faster without wearing down. And scientists continue dreaming up new uses for levitation — ones that don't cause deadly collateral damage. ✖



BREAKING GROUND

BY SHANNON RAPP

Across

1 Australian birds that lay blue-green eggs
5 Package brought to a birthday party
9 "I need it now!" letters
13 Wise saying
14 Hit Ctrl+Z
15 What might be hard to read over text
16 Raw sushi bar dish
18 Stealthy Batman foe
20 Insurance grp.
21 Spanish article
22 Multicolored gemstone
23 Flu shot clinic staffer
26 Seek answers
28 Sodium hydroxide, familiarly
30 Marble mausoleum built for an emperor's wife
33 Break down for an invoice
35 Become more fit to the environment over time
36 "Without further ___…"
37 App store customer
38 Small, quick fish
40 Fruits often poached
42 Alters the wording of
44 Some bottom lines
48 Ready for the job
51 Contend
52 Chinese region home to the Guia Lighthouse
53 Sitcom in which George pretends to be a marine biologist to impress an old crush
55 Flier on a city street?
57 Area of study?
58 Deep anger
59 Timeshare option
60 Scaloppine meat
62 Fluid in plant tissues
63 Body smaller than a gulf
66 Property of minerals that break along smooth flat planes, or a hint to the circled squares in this puzzle
71 Opera house highlight
72 Enjoy a novel or magazine
73 Tiny arachnids
74 Former Russian leader
75 Thanksgiving tubers
76 Choose not to answer

Down

1 Cheese in queso relleno
2 Holder for homemade jam
3 "This stinks!"
4 Six, in Italian
5 ___ pig (furry rodent)
6 South American empire with a system of knotted strings for recordkeeping
7 Org. that regulates vaccines in the U.S.
8 Tater ___
9 Perched on
10 Ethnic group indigenous to the Horn of Africa
11 Look at in detail
12 Space ___ (writing tool with pressurized ink)
13 Product of some exothermic reactions
17 Cornmeal ___ (dish similar to polenta)
19 Tuned in to social issues
24 Countless
25 Given 4 stars, say
26 Classroom assistant
27 Weasel relative
29 Poetic contraction that means "always"
30 Just a bit
31 Programmer Lovelace
32 Expired
34 Condiment made from *Brassica* seeds
39 Missouri or Mississippi
41 Like IV or MD
43 Scrabble piece
45 Some Cirque du Soleil performers
46 Cuisine with sticky rice
47 Boar's counterpart
48 ___ interpreter (person whose face and hands may be televised)
49 Caltech athletes
50 Monrovia's country
54 Nail tech's tool
55 Heats to just under a boil
56 Title for Leo XIV
61 Nowhere near
62 Many a suspicious-looking email
64 Bronze and Iron, for two
65 "Absolutely!"
66 Butter serving
67 React to a sad scene, maybe
68 Beverage made from *Camellia* leaves
69 Electric violin hookup
70 By way of

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