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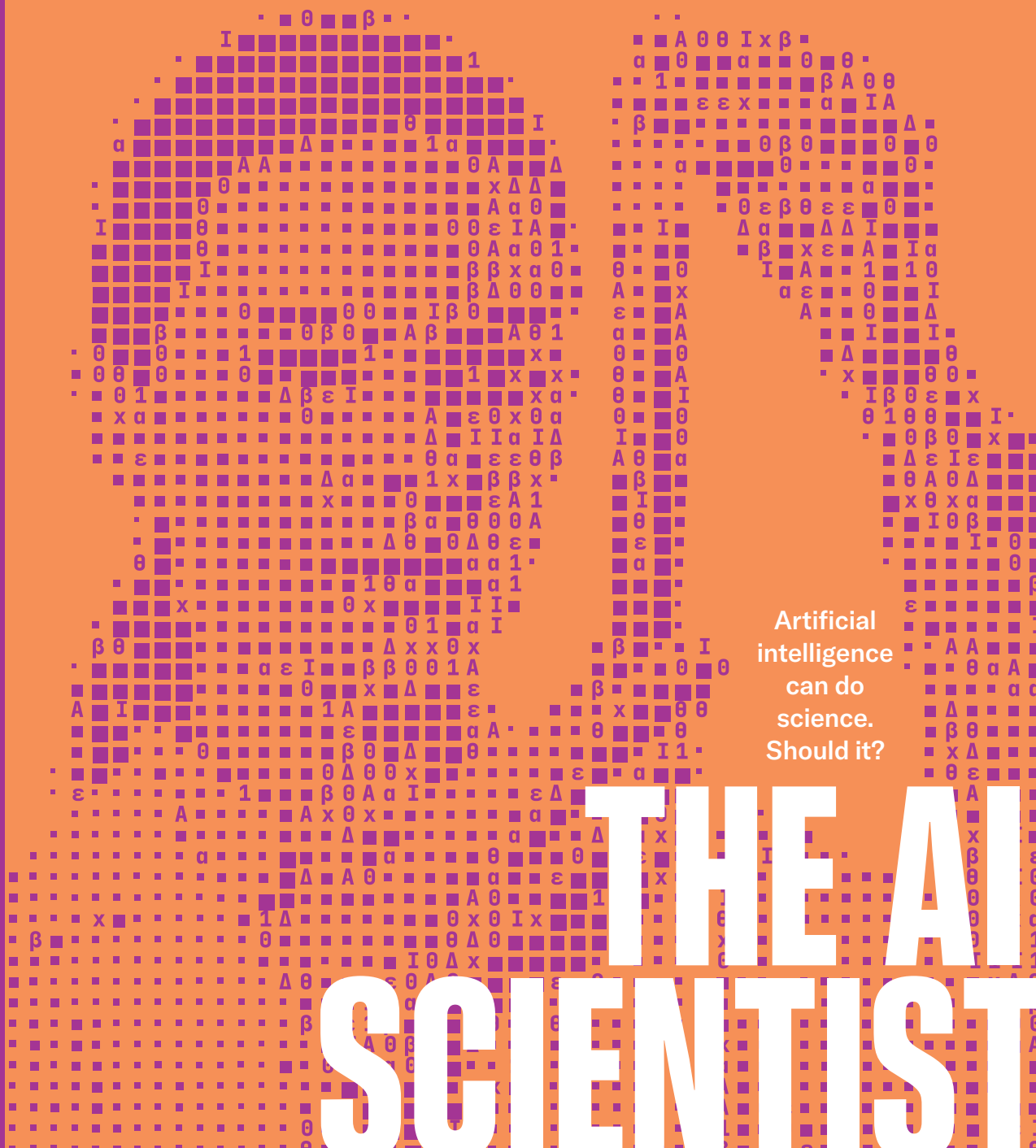

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THE AI SCIENTIST

SCIENCENEWS.ORG

VOL. 208 NO. 3

MARCH 2026

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Illustration by Outlanders Design

LUKE JEFFREY

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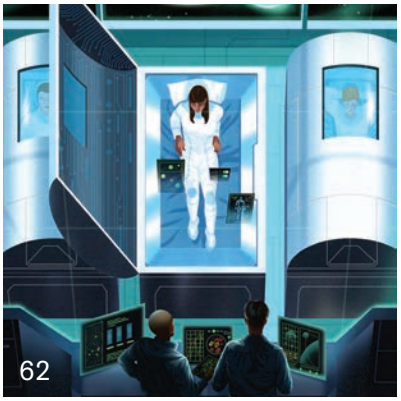

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FROM TOP: KEVIN COUGHLIN/BROOKHAVEN NATIONAL LABORATORY; GLENN HARVEY

Finding the story

Having a nose for news may be a cliché. But it's key to a reporter's ability to sniff out stories that are important and unique. This issue's coverage of a scientist intent on using yeast to create vaccine beer (Page 48) is a prime example of this style of enterprise journalism.

Senior molecular biology writer Tina Hesman Saey first encountered Chris Buck, a researcher at the National Cancer Institute, when she attended the World Vaccine Conference in Washington, D.C., last April. He was in the midst of a battle with his employer over his plan to test a home-brewed vaccine against polyomavirus on himself.

"There were so many layers to this story that I wanted to explore," Saey told me. "Who gets to decide whether a scientist can experiment on themselves? Is it legal and ethical to market a vaccine as a food or a dietary supplement? What could this approach do to public acceptance of and confidence in vaccines? What is the science behind this potential vaccine, and would it work for other diseases?"

Saey pressed Buck on these questions, researched them herself, interviewed other scientists and investigated the potential benefits and risks of Buck's approach, both to people and to public trust in vaccines. We leave it to our readers to decide whether Buck's vaccine beer is ill-advised or visionary.

This issue also includes a unique take on nuclear physics, using the sunsetting of a pioneering particle collider at the Brookhaven National Laboratory on Long Island to update readers on advances in the field (Page 40). Senior physics writer Emily Conover grew up near Brookhaven and took part in a summer program there as a teenager. That experience started her on a path to becoming a physicist herself, and eventually a science journalist. Her tour of the lab as it switches from one type of particle collider to a new, more advanced one highlights the challenges of advancing science that requires long-term investments.

And for the cover story, we look at how scientists are experimenting with using artificial intelligence as a research tool, one that might evolve to conduct research itself. Freelance writer Kathryn Hulick investigates AI's potential for making science more efficient, but also its dangers (Page 32). Risks include the flood of junk research papers scripted by AI that are threatening the integrity of scientific publishing. Stay tuned; we'll continue to report on this important and fast-moving issue.

Nancy E. Shute

Nancy Shute
Editor in Chief
nshute@sciencenews.org

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KATHRYN HULICK

FREELANCE SCIENCE JOURNALIST

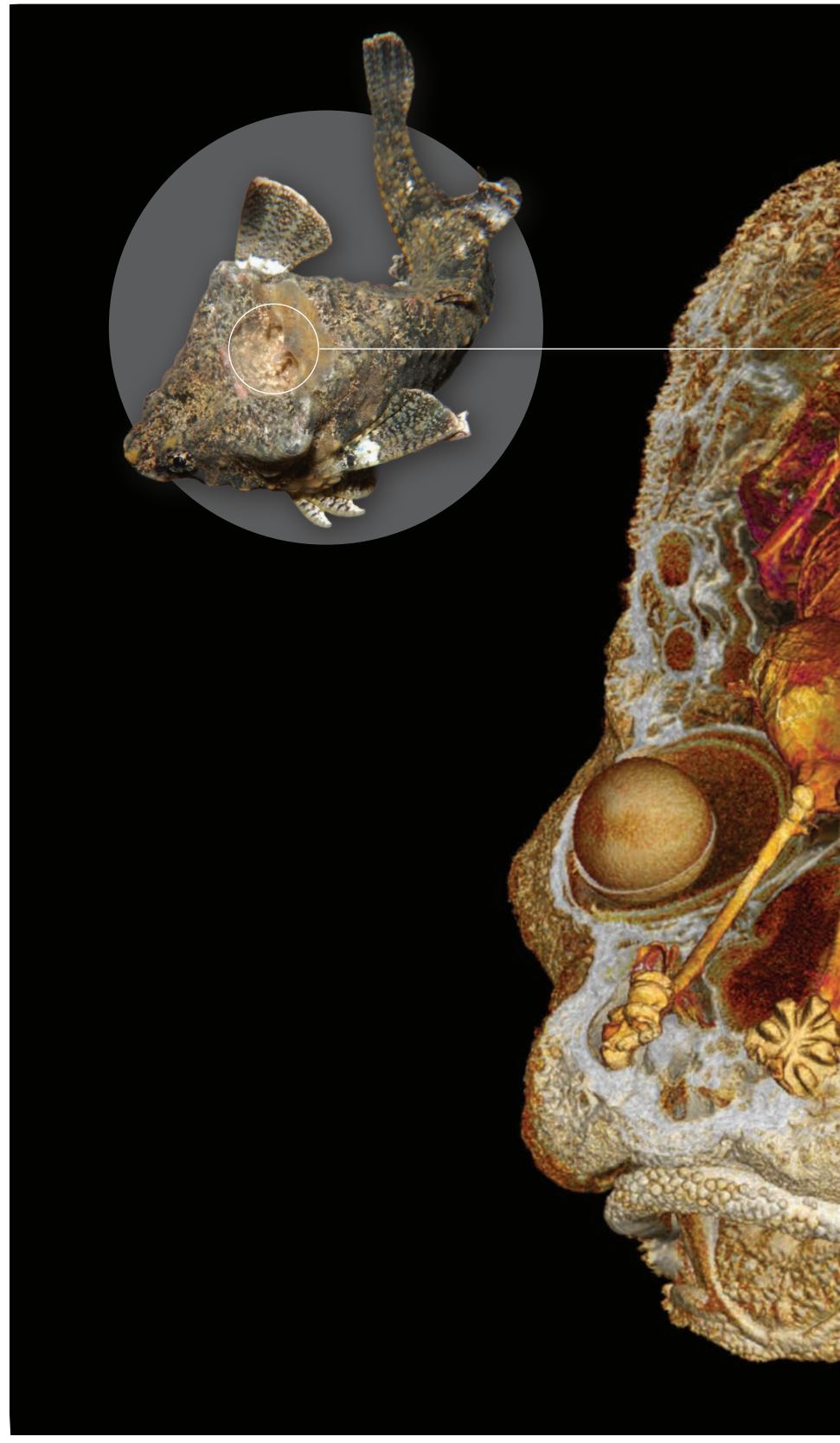
● IN THIS ISSUE'S COVER STORY, Kathryn Hulick digs into scientific discoveries made thanks to AI. Some combinations of AI and robotics are becoming less like tools and more like scientists. They can devise and run experiments, collect and analyze data, and determine next steps—all on their own (Page 32). "AI is not very good at this yet. It's certainly not going to change the world as an independent scientist at this point," says Hulick, who's been pondering about computers' ability to reason since she was in high school. But artificial intelligence is rapidly evolving. If it ever reaches a point where it could take people's jobs, Hulick doesn't think that human scientists will go extinct. "People are still going to have this urge to understand the world. I don't think that's going to go away."

Emily Conover
After more than a quarter century, Brookhaven National Laboratory's Relativistic Heavy Ion Collider ran for the last time. Senior physics writer Emily Conover was there to report on the final days of the collider—and a plan for a new one (Page 40). The visit was nostalgic for Conover, who was raised nearby and attended the lab's summer program as a high schooler. Growing up near BNL meant being able to casually bump into esteemed physicists, which was "cool for a little suburban town," Conover says. "It was an environment steeped in physics if you knew where to look."

Danielle Beurteaux
It's rare that a research paper describes the work as "genuinely amusing." So when freelance journalist Danielle Beurteaux stumbled upon one, about a role-playing game where people act as predators or prey (Page 14), she knew she had to write about it. During the interview, the researchers made the game sound so fun that Beurteaux asked if she could join the next time. The team isn't planning on repeating the game, but Beurteaux thinks if she were to play a prey, she could move quickly to find places to hide. But if she were a predator? "I would have to tap into some level of aggressiveness that is not in my daily pace," she says.

Cassie Martin
There's a new managing editor in town and her name is Cassie Martin. But Martin is no rookie: She has worked at *Science News* for a decade. "I've had a hand in every part of the newsroom," Martin says, though her focus has always been the print magazine. "I am invested in making it the best it can be." To her, that means well-rounded issues that balance vital news across science fields, thoughtful columns and gee-whiz findings that cultivate wonder. "Science should be relevant and accessible to everyone," she says. "Hopefully each issue leaves readers feeling more informed and deeply satisfied."

CLOCKWISE FROM TOP LEFT: K. HULICK; SOCIETY FOR SCIENCE; BELATHÉE PHOTOGRAPHY; C. MARTIN



ANIMALS

THIS FISH SWIMS TO THE BEAT OF ITS OWN DRUM

By Jake Buehler

● **For the rockhead poacher,** headbanging comes from within. A divot in the skull of *Bothragonus swanii* (right, inset) might function like a drum. High-powered, 3-D X-ray scans of a preserved specimen reveal flattened, mobile ribs beneath the pit, which may strike its underside to produce sound, functional morphologist Daniel Geldof of Louisiana State University reports in his master's thesis. The sound may help the small fish communicate in turbulent shallows along North America's West Coast, from Alaska to California, possibly by sending vibrations into the rocks they rest on. A visualization of the head shows the brain (dark orange) and skull pit (white arrow, behind the brain), which is so large the fish's entire brain could fit inside. ✖

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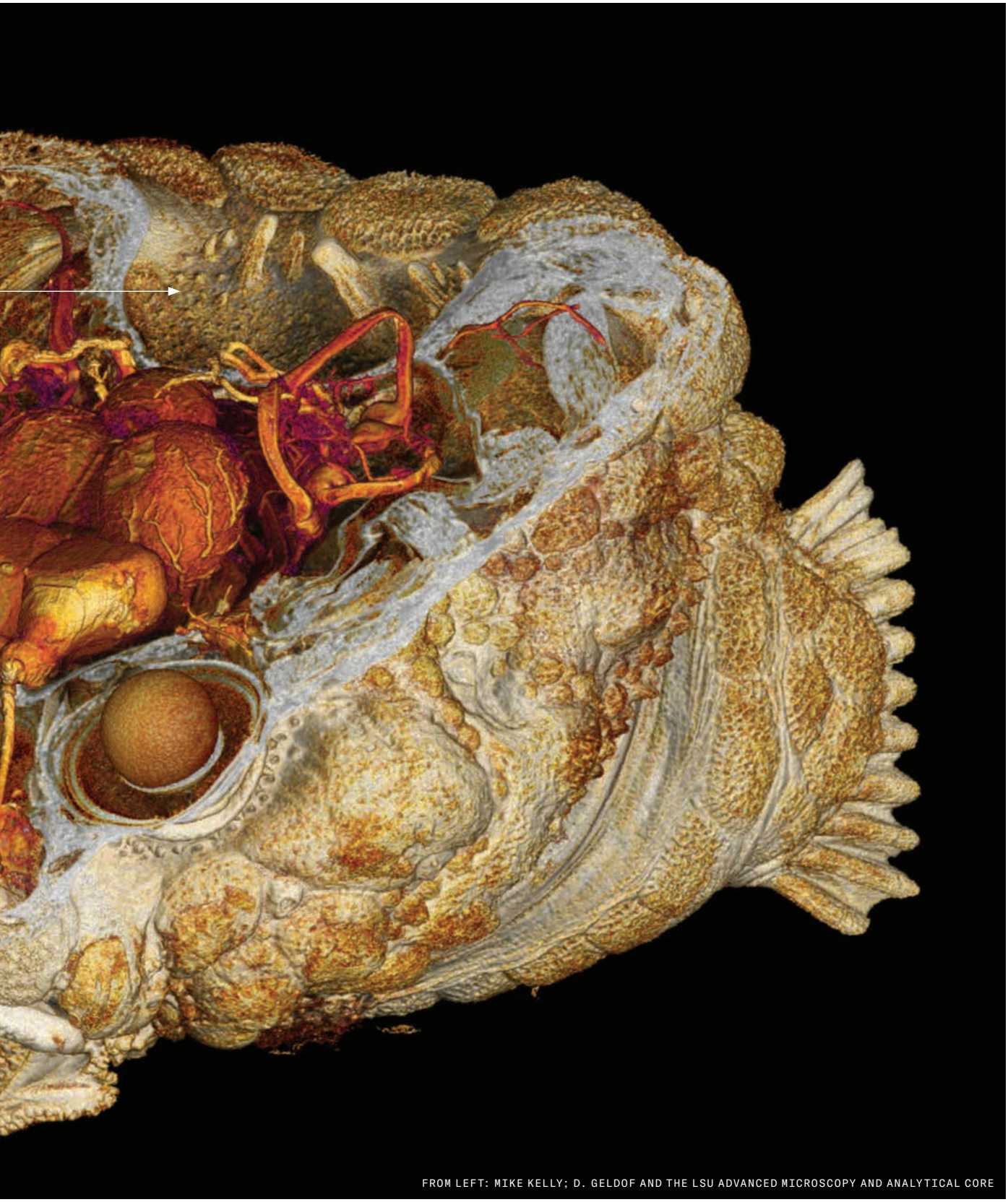

FROM LEFT: MIKE KELLY; D. GELDOF AND THE LSU ADVANCED MICROSCOPY AND ANALYTICAL CORE

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An invasive wasp is spreading among North America's elms. The wasp's larvae chew telltale zigzags into leaves (see Page 18).

News

ESTEBAN SANCHEZ/GETTY IMAGES

ANIMALS

CHEETAH MUMMIES MAY HELP THE CATS RETURN TO ARABIA

BY JAKE BUEHLER

The fastest land animal on the planet lies frozen in time beneath blistering desert sands. Researchers have discovered dozens of ancient cheetah skeletons and dehydrated bodies preserved in caves on the Arabian Peninsula, where the species hasn't been spotted for decades.

The cats' DNA may someday help conservationists reintroduce cheetahs to the region. A new genetic analysis of the naturally mummified and skeletal remains, published in *Communications Earth & Environment*, suggests the lost cheetahs were most closely related to two living subspecies rather than just one. These subspecies could provide more options for founding new populations on the peninsula, researchers say.

Cheetahs (*Acinonyx jubatus*) used to sprint after prey across most of Africa and large tracts of South Asia. Today, over 90 percent of that territory has been lost. The cats are now mostly restricted to Africa, though a population of less than 70 Asiatic cheetahs resides in Iran. A combination of habitat and prey loss, conflicts with humans and the pet trade probably led to cheetahs' extinction on the Arabian Peninsula, where they were last seen in the 1970s.

But their legacy remains in some surprising places. In 2022 and 2023, wildlife biologist Ahmed Al-Boug and colleagues conducted a wildlife survey in a network of 134 underground caves in northern Saudi Arabia. In five caves, the researchers found preserved cheetah remains: 54 skeletons, but also seven mummies, set and desiccated by the desert's extreme aridity. Long ago, the cheetahs may have fallen into the caves and were unable to escape, Al-Boug, of the National Center for Wildlife in Riyadh, Saudi Arabia, and his team suggest.

Molecular ecologist Liz Kierepka says the discovery is quite the rarity. "The fact that they went into over one hundred caves and were able to find mummies, that's highly unusual outside of [things like] permafrost," where natural mummies of Ice Age megafauna abound, says Kierepka, of the North Carolina Museum of Natural Sciences in Raleigh.

Carbon dating of some of the remains revealed that the cats lived about 125 years to over 4,200 years ago. Al-Boug's team also collected genetic samples, which allowed the researchers to reconstruct the genomes of two cheetah skeletons and one of the mummies.

↗ This naturally mummified cheetah may help provide a road map to reintroduce the felines to the Arabian Peninsula.

A. AL-BOUG *ET AL*/*COMMUNICATIONS EARTH & ENVIRONMENT*

One of the cats was closely related to Asiatic cheetahs, *A. jubatus venaticus*, thought to be the only subspecies once found on the peninsula. Surprisingly, the other two were genetically allied with a subspecies from northwestern Africa, *A. jubatus hecki*.

The findings give researchers and conservationists a second gene pool to seed any reintroduction effort in the region, including ongoing efforts by the National Center for Wildlife to breed cheetahs and let them loose in the wild in Saudi Arabia. When bringing back species to habitats where they've been

ZARA PICKEN

extinguished, it's ideal to use populations that might have adaptations to local conditions, Kierepka says. The northwest African cheetahs might be adequately related to the ancient Arabian cats to have some of those crucial adaptations.

However, both subspecies are critically endangered. Relocating animals from these already struggling populations should be carefully considered since it has the potential to cause problems for the donor pools, Kierepka says.

She would be curious to see more genetic analyses looking for traits that could be helpful when selecting cheetahs to relocate. "If they really want to pursue rewilding," Kierepka says, that could make reintroduction more likely to succeed. ✖

CLIMATE

Earth's climate scores a troubling hat trick

By Carolyn Gramling

● **The last three years** were the hottest on record, a new analysis of global climate data finds. They also mark the first three-year period in which the global average temperature exceeded 1.5 degrees Celsius above preindustrial levels — a threshold associated with weather extremes and increased risks to human health and biodiversity.

"1.5 degrees C is not a cliff edge, but we know that every half a degree matters," climate scientist Samantha Burgess said at a news event announcing the report. Burgess is the strategic climate lead for the European Centre for Medium-Range Weather Forecasts, or ECMWF, which released the report.

Although 2025 was slightly cooler than the two previous years, averaging 1.47 degrees above preindustrial temperatures, Earth is warming faster than it was a decade ago. The planet is now on track to consistently exceed the 1.5-degree threshold by 2029.

2024 remains the hottest year on record, averaging 1.6 degrees above the preindustrial period, with 2023 still in second place. While the tropics in 2025 were somewhat cooler than in 2024, Antarctica saw its hottest year on record and the Arctic its second hottest. Sea ice at both poles CONT. ON PAGE 14

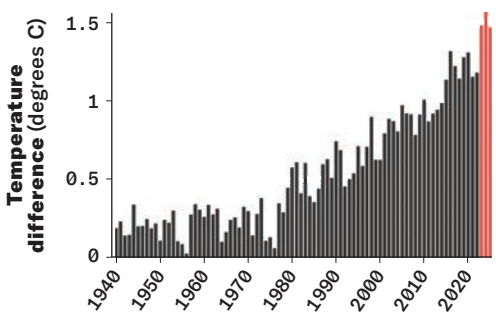
CONT. FROM PAGE 13 was also at record lows. Accumulating greenhouse gases in the atmosphere, dominated by the burning of fossil fuels, is primarily driving these temperatures, Burgess said.

Tropical air temperatures in 2023 and 2024 were boosted by a strong El Niño. But in 2025, the planet entered a La Niña phase of that climate oscillation pattern, generally bringing cooler temperatures. However, 2025 still ranked as the warmest La Niña on record, Burgess said.

Extreme weather events exacerbated by rising temperatures, including wildfires, heat waves and heavy rainfall, were widespread in 2025, a World Weather Attribution analysis found. Over half the globe experienced an increase in days with strong heat stress: temperatures that feel like 32° C or higher.

"Will 2026 be more exceptional? It's too early to tell," Burgess said. But the overall trend is clear, and there's an 80 percent chance that at least one of the next five years will replace 2024 at the top, she said. ✖

GLOBAL AIR TEMPERATURE RELATIVE TO THE PREINDUSTRIAL AVERAGE, 1940–2025



The last three years (in red) were Earth's warmest on record, averaging 1.53 degrees Celsius above the average preindustrial global air temperature from 1850 to 1900.

FROM TOP: BRETT AFFRUNTI; C3S/ECMWF

ECOSYSTEMS

Predator–prey dynamics take center stage in a new game

By Danielle Beurteaux

● **The predator was closing in.** The prey had to make a potentially life-altering choice: find food or flee?

That prey was ecologist David Bolduc. And he was one of many other researchers in a forest in Canada just trying to stay alive. "It's so fun," he says.

Bolduc, of Université Laval in Quebec City, was playing a game designed to explore predator–prey behaviors in the wild, but with people in place of animals. And following some basic

rules, the players did indeed make decisions similar to animals, Bolduc and colleagues report in *Methods in Ecology and Evolution*.

Alluding to animals' positions on a food chain, the Trophic Interactions Experiment, or TrophIE, game began as a summer school project in 2023 to teach advanced techniques for analyzing big datasets.

"The game became kind of an intermediate" between mathematical models of ecosystems and field studies, says biologist Frédéric Dulude-de Broin, also of Université Laval. "We could have a lot of realism, having real players evolving in a real landscape, but still control a lot of the parameters and being able to measure everything."

↖ **During a simulation game in a Quebec forest, players took on the role of prey (yellow shirt), mesopredator (blue) or apex predator (red).**

The researchers hosted nine 30-minute games, each with between 23 and 31 players, in a park about two hours north of Montreal. Players took on roles of prey, mesopredator (an animal that preys on smaller animals) and apex predator. Each role was identified by shirt color.

The goals of the prey players were to find food and mates — and not "die." The mesopredators had to hunt but not be caught by apex predators, while apex predators had to hunt both prey and mesopredators. The researchers tracked each player with GPS.

"To do this with animals requires capturing both predators and prey and hoping that they interact," Bolduc says. With the game, "you have the whole population [of animals], which is something quite challenging to do in the field, if not impossible," he says.

The players described what they felt, saw and heard — like the sounds of footsteps on leaves — which animals can't do. Just like many wild animals, players preferred areas they already knew, prey players avoided the more exposed and riskier main trails, and safety and competition dictated what they chose to do.

And while the players kept to the rules, there were some interesting interpretations the researchers hadn't thought of, like prey players staying in a designated safe refuge and calling for mates.

Playing for fun and research isn't the same as a wild animal surviving in nature, says wildlife ecologist Liana Zanette of Western University in London, Canada. But TrophIE seems like a great learning tool for students, she says. "That is really quite brilliant for that purpose."

It can't get any more concrete than choosing some criteria and getting students to act them out, Zanette adds. But, she cautions, any findings that come from a TrophIE game should be backed up with an experiment that manipulates different factors using real animals in the wild.

At a game's end, the players' excitement was obvious, with frenetic discussions between the prey and the predators about what they experienced, Bolduc says. "These are things we read about, but feeling them really kind of unlocks another part of your brain." ✖

PLANTS

THIS YAM'S BERRY CLEVER DISGUISE HELPS IT GO FAR

BY ELIZABETH PENNISI

Deception and intrigue are not limited to people or even animals. Plants, too, have evolved ways to fool their pollinators, their enemies and even the organisms that disperse their seeds. Now scientists have uncovered trickery in a climbing vine that fooled even them. The black-bulb yam (*Dioscorea melanophyma*) makes fake berries that help the species spread to new locations, ecological biologist Gao Chen and colleagues report in the *Proceedings of the National Academy of Sciences*.

The story "feels refreshingly new," says Kenji Suetsugu, an evolutionary ecologist at Kobe University in Japan. These yams have lost the ability to produce seeds via sexual reproduction and must clone themselves. Clonal plants typically reproduce with bulbils, detachable buds that fall off and sprout near their parents. But by transforming the buds into fake berries that some birds eat, this yam now has a way to spread far and wide, a hedge against its local environment changing. "It's a clever evolutionary workaround," Suetsugu says.

Chen and colleagues mistook the yam's bulbils for berries while collecting seeds in Southwest China in 2019. Seeds are usually inside berries, but there were none when the team cut open one of these bulbils. If "they can cheat me, then, I think they can cheat birds," Chen, of the Chinese Academy of Science's Kunming Institute of Botany, recalls thinking.

Bulbils are usually white and dull, not black and shiny like the yam's. But proving these bulbils mimic berries took a lot of work. Chen's team analyzed and compared the appearance and color of berries found near the yam, identifying 15 species with berries that were indistinguishable from bulbils. Three years' worth of camera trap photos showed that 22 bird species visit these bulbils and a few even eat them.

The most frequently fooled visitor, the brown-breasted bulbul (*Pycnonotus xanthorrhous*), picked a berry over a bulbil most of the time in lab tests. But when berries get scarce, say in winter, the birds frequently eat bulbils. A bulbil passes through the gut in about a half hour, during which the bird may have transported it up to 750 meters, Chen calculates.

"The results extend the mimicry concept to nonreproductive structures," says ecologist Pedro Jordano of the Spanish National Research Council and the University of Seville. Other examples come from sexually reproducing species. Japanese dogbane lures flies with flowers that smell like dying ants, while a South American vine can change its leaves to match its host.

Biologists as far back as Charles Darwin noted that there are certain seeds that appear to be encased in the same fleshy fruit as other species but really offer no food reward. Some types of beans practice this kind of deception, Chen's team reported last year in *Plant Diversity*.

"Birds are foxed into dispersing the bulbils because of their resemblance to fruits [the birds] are used to eating," says evolutionary biologist John Pannell of the University of Lausanne in Switzerland. The birds get nothing in return.

That the yam's bulbil has evolved to look like berries, Jordano says, "is amazing for any sensible naturalist." ✖

FRUIT FAKE-OUT

Can you tell a real berry from an impostor? The doppelgänger (circled left) is actually a yam reproductive organ. It looks so much like a berry (right) that scientists thought it was the real deal.

ZHI CHEN

For the Man Who Gives Everything and Expects Nothing

If you're anything like my dad, you give your family everything. Your name, your time, your values — the people in your life know they can depend on you for practically anything. In exchange for imparting all of this energy and experience, you expect nothing in return.

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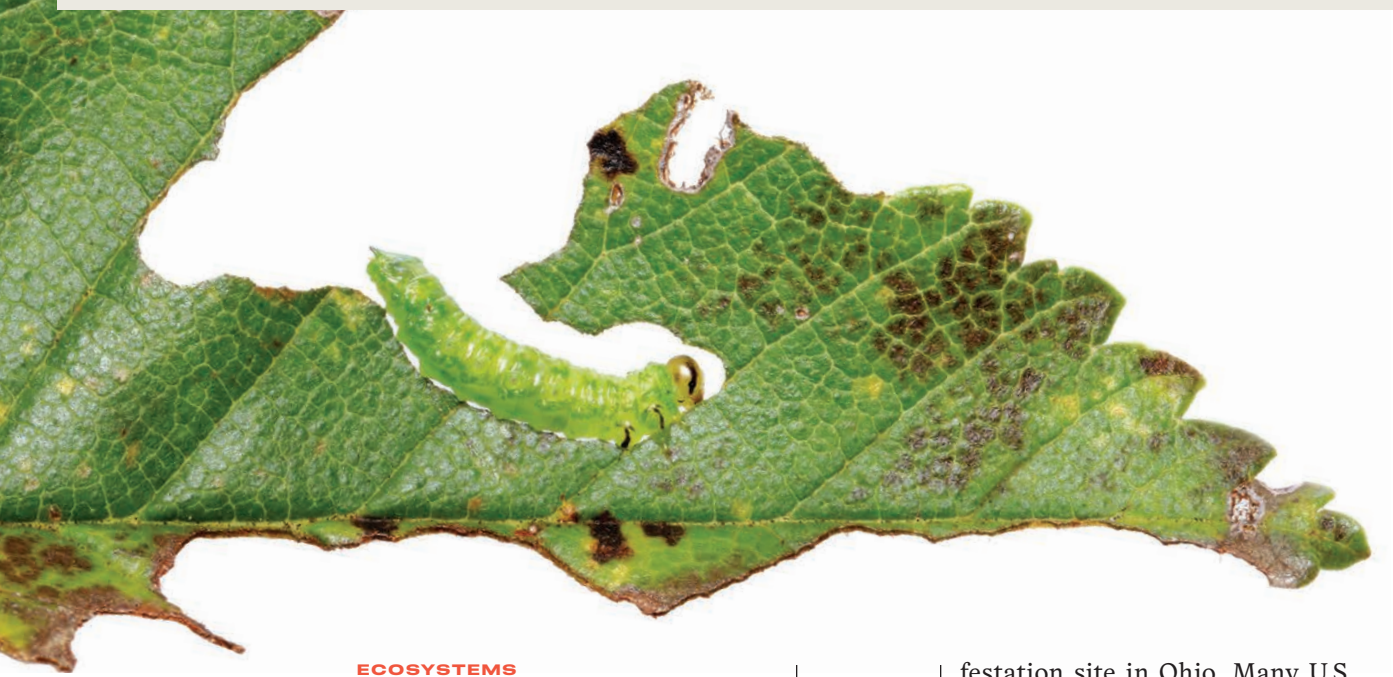

ECOSYSTEMS

Invasive wasps are coming for North America's elms

By Ute Eberle

● **She's less than** a centimeter long, produces only daughters and is conquering the continent without a single male. Meet the elm zigzag sawfly, named for the delicate zigzag patterns she carves into elm tree leaves.

Despite her name, the elm zigzag sawfly (*Aproceros leucopoda*) is not a fly; she is a type of wasp first found in North America in 2020. Originally from East Asia, the species has expanded its range at an "alarming" rate, researchers report in the *Journal of Integrated Pest Management*. For cities still recovering from elm canopies lost to a fungal disease, it's an unwelcome second wave of assault. And newly emerging evidence suggests the wasp won't stop at elms.

In just over five years, the pest has spread to 15 U.S. states, from New Hampshire to Minnesota and south to North Carolina, says entomologist Kelly Oten of North Carolina State University in Raleigh. "We just had to add Indiana," says Oten, who maintains a map of sawfly sightings.

Freshly hatched elm zigzag sawflies cut zigzagging lines into leaves. "The feeding pattern is oddly cute," Oten says. But as the larvae mature, they can strip enough foliage from a tree to leave it almost bare.

To see if the wasps would attack other tree species, Oten's team planted Japanese zelkova (*Zelkova serrata*) near an infestation site in Ohio. Many U.S. municipalities are planting zelkovas, an elm relative, since they appear resistant to Dutch elm disease, the fungal affliction that has killed tens of millions of American elms in the last century.

The team found evidence of the wasps laying eggs, feeding, pupating and emerging as adults on zelkova saplings, which produce new leaves earlier than elms do in the spring. As the season progressed, the wasps switched back to elms, suggesting that zelkova may serve as an alternate host when elm foliage isn't available, the researchers hypothesize.

The finding surprised Véronique Martel, a forest entomologist with Natural Resources Canada who reported North America's first elm zigzag sawfly detection in Quebec in 2020. "It is rare that insects can switch hosts," she says.

Martel, who was not involved in the study, suspects that feeding on zelkovas could allow the wasps to start multiplying earlier in the year. "They can make a lot of generations within a summer," she says.

A crucial driver behind the zigzag

↑ **An elm zigzag sawfly larva chews on a leaf. The pest is spreading across North America and broadening its diet.**

MATT BERTONE

sawfly's rapid spread is an unusual reproductive strategy called thelytokous parthenogenesis. Females lay unfertilized eggs that produce only more females, which means that even a single egg hitching a ride on firewood or a car can start a new infestation. No males have ever been found.

For reasons researchers don't yet understand, zigzag sawfly larvae cut only minor zigzag patterns in some elms while severely defoliating elms in other areas. "At this point, we do not know if [the dieback] will kill the tree or just stress it greatly," Oten says.

Unwitting human accomplices have probably aided the sawfly's rapid spread. Oten's team documented cocoons with elm zigzag sawfly pupae clinging to truck mirrors and wheel wells, which can carry the insect far beyond its natural dispersal range of 45 to 90 kilometers annually. Researchers think the pest may have arrived in North America in the soil of imported plants.

With elms native across most of the eastern United States and Canada, elm zigzag sawflies have a vast territory available. "I do think we will have many more reports in additional counties and likely more states" in 2026, Oten says. Temperature extremes may eventually limit the insect's range. "But as of right now, it's North Carolina to Canada," she says. That's pretty wide."

Oten is testing pesticides to help protect trees. Early trials of two soil-applied insecticides show promise, and she expects to publish the full results later this year. For now, she recommends checking vehicles for cocoons before leaving infested areas and reporting zigzag patterns to local officials. ✖

ANIMALS

KILLER WHALES AND DOLPHINS MIGHT BE FISHING BUDDIES

BY GENNARO TOMMA

Orcas are renowned hunters known for taking down other dolphins, sharks and whales. Now, it appears some orcas get a helping fin from their would-be prey.

In the waters off British Columbia, marine ecologist Sarah Fortune and colleagues regularly spotted killer whales (*Orcinus orca*) and Pacific white-sided dolphins (*Lagenorhynchus obliquidens*) swimming together. "The killer whales and the dolphins weren't going for the same fish, kind of at the same time, in a competitive way. Instead, what we saw was there is a little bit of organization," says Fortune, of Dalhousie University in Halifax, Nova Scotia.

Fortune's team used a drone to film the marine mammals' behaviors and a sonar device to identify salmon nearby. The team also attached monitoring devices via suction cups to nine killer whales that recorded their movements as well as audio and video. Over four days, the killer whales followed the dolphins on deep dives 25 times, possibly eavesdropping on the dolphins' echolocating calls and using them as scouts to find schools of Chinook salmon (*Oncorhynchus tshawytscha*). Drone footage also showed the whales and dolphins swimming in a coordinated way. In hundreds of instances, the dolphins swam near the heads of the killer whales.

In all the interactions between the orcas and dolphins, the orcas were either hunting, killing or eating salmon. The dolphins were present for four out of the eight occasions in which killer whales were sharing the captured salmon; during one of those times, the dolphins were seen eating the leftovers.

Altogether, the data suggest that the two marine mammals hunt salmon together, Fortune and colleagues conclude in *Scientific Reports*. The dolphins might benefit from the orcas' leftovers, as they cannot swallow adult Chinooks whole. At the same time, the dolphins might gain protection from other orcas that hunt them, the team suggests.

The behavior may not be intentional, says marine mammal specialist Heather Hill of St. Mary's University in San Antonio. But, she says, "it's cool that the killer whales can potentially utilize what the dolphins are doing. And the dolphins are basically taking advantage of the killer whales." ✖

ASTRONOMY

GRAVITATIONAL WAVES HINT AT A 'SUPERKILONOVA'

BY LISA GROSSMAN

Astronomers have spotted a distant star that seems to have exploded twice. The blast may be the first-ever known "superkilonova," a chimera of a supernova and a neutron star merger, researchers report in *Astrophysical Journal Letters*.

"The reason it would be amazing if true is that this would be producing objects we've never seen before in the universe," says astronomer Cole Miller of the University of Maryland in College Park.

In August of last year, the gravitational wave detectors LIGO and Virgo recorded ripples in spacetime seemingly produced by merging neutron stars about 1.3 billion light-years from Earth.

At least one of the stars had less mass than the sun. "It was really puzzling," says Caltech astronomer Mansi Kasliwal. Stellar physics predicts that neutron stars — ultradense remnants of supernova explosions — should have masses greater than about 1.4 times that of the sun. And every other neutron star astronomers have found is more massive than the sun.

Kasliwal and colleagues followed up on the event at the Palomar Observatory in California. Within a few hours, they found a smear of red light that seemed to come from the same distance and direction as the merger. Eleven other observatories gathered data over the next several days.

The event initially looked like a previous neutron star merger. That 2017 event produced a kilonova, characterized by the reddish glow of heavy elements being forged.

The new event was also reddish and faded quickly. As days passed, the object brightened and showed signs of hydrogen, a trait more characteristic of a supernova. "That's when we realized, if you put these two pieces together, what this could be was a kilonova inside a supernova," Kasliwal says.

The team proposes a star went supernova, leaving behind a spinning neutron star that split into two smaller ones. Those smaller neutron stars could have collided, producing the kilonova.

Miller isn't convinced. More work is needed to verify the gravitational wave signal. Also unclear is whether the light and the gravitational waves came from the same event.

Finding similar events could help confirm the hypothesis, but they're rare, Kasliwal says. This is only the second kilonova ever observed after the first one in 2017. ✖

↑ **In a proposed superkilonova, a star explodes (left), leaving behind two small neutron stars (middle) that merge and produce a kilonova (right).**

K. MILLER AND R. HURT/IPAC/CALTECH

FOUND!

Cache of 1,193 First-Year 1964 Silver Kennedy Half Dollars

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CLIMATE

Microbes hidden in tree bark munch on climate gases

By Douglas Fox

● **Trees are known** for capturing carbon dioxide as they grow. But they also soak up other gases implicated in climate change through microbes in their bark.

The tree bark microbes feast on hydrogen, methane and carbon monoxide, researchers report in *Science*. Methane is a greenhouse gas that is 28 times as potent as carbon dioxide over a 100-year period and responsible for 30 percent of human-caused global warming. CO, which is lethal to humans, and hydrogen enhance global warming indirectly by helping methane persist longer in the atmosphere.

Getting rid of these gases "is a hidden benefit of trees that we previously didn't realize was happening," says biogeochemist Luke Jeffrey of Southern Cross University in Lismore, Australia.

An estimated 143 million square kilometers of tree bark exist worldwide — roughly equivalent to the combined area of all seven continents. And about 6 trillion microbes inhabit every square meter of tree bark, Jeffrey and colleagues estimate.

The newly discovered bark microbiome was "hidden in plain sight," says forest ecologist Jonathan Gewirtzman of Yale University. It "highlights this as an environment that we know so little about."

The discovery stems from years of research into the sources of methane. In nature, this gas bubbles up from oxygen-starved microbes living in the waterlogged sediments of lakes and wetlands.

When scientists measured

↑ **Tree bark is populated with microbes that consume several climate-warming gases, including methane, hydrogen and carbon monoxide.**

L. JEFFREY

methane percolating up from the flooded lowlands of the Amazon, the amount coming out was only about half what it should be, based on measurements from space. Then in 2017, another team of scientists realized that just half of the region's methane came out of the ground. The other half, about 15 million or 20 million metric tons per year, seeped out of tree trunks.

People thought the trees were acting as passive chimneys, gushing out soil methane that came in through their roots. But in 2021, Jeffrey and colleagues discovered a wrinkle.

Working with broad-leaved paperbark trees (*Melaleuca quinquenervia*) in Australia, the team found that the amount of methane coming out of tree bark was about 35 percent less than what enters from below. Microbes in the bark were eating the methane, oxidizing it for energy as it seeped out, the scientists concluded.

"That could be a really huge ecosystem service that these microbes are providing" by removing a major greenhouse gas, says Pok Man Leung, an ecophysiologist at Monash University in Clayton, Australia. He and Chris Greening, a microbiologist also at Monash, helped identify the microbes living in the bark of those trees.

In the new study, Jeffrey, Leung, Greening and colleagues profiled the collective genomes of over 1,000 microbial species living in paper bark trees and seven other common tree species in Australia.

Microbes that oxidize hydrogen gas for energy were even more common than the methane-eaters, the researchers found. Microbes that oxidize CO were also abundant.

Experiments in living trees showed that bark microbes don't just eat methane, hydrogen and CO as the gases diffuse up through the trees; the microbes also suck them in from the surrounding air. These gases exist in the atmosphere at trace levels, ranging from 2 parts per million to 40 parts per billion. But multiplied across the world, bark microbes consume vast amounts of them.

For instance, bark microbes eat up to 50 million metric tons of methane per year, a previous study calculated. In the new work, the scientists estimate that the rate for hydrogen is as much as 1.6 million metric tons per year. (They did not calculate the rate for CO.)

By removing these gases, bark microbes enhance the significant benefits trees provide by absorbing carbon dioxide, Leung says.

Forest restoration remains an important strategy for combating climate change, and this new knowledge could make it more effective. The eight tree species examined in the study had differing mixes of microbes in their bark, eating different amounts of trace gases. This insight could help scientists select the tree species best suited to blunt climate change.

"You're not just thinking about the tree you're planting, but also the microbes within the tree," Greening says. "You can ideally get rid of three or four climate-active gases for the price of one." ✖

6 trillion

The estimated number of microbes inhabiting a square meter of tree bark

PARTICLE PHYSICS

MILKY WAY STARS BATHE EARTH IN NEUTRINOS

By Emily Conover

● The Milky Way could be called "The Neutrino Way." Its stars produce vast numbers of the subatomic particles. Now, scientists have calculated how many of them should be streaming onto Earth from all the stars within the galaxy.

Neutrinos born in stars other than the sun pass harmlessly through your thumbnail at a rate of about 1,000 per second, physicists report in *Physical Review D*. That may seem like a lot, but neutrinos from the sun are about 100 million times as prevalent thanks to its proximity.

Scientists first detected solar neutrinos in the 1960s, and today, they have isolated different classes of neutrinos from the nuclear reactions that take place within Earth's home star. But we've yet to detect the rarer neutrinos from other stars in the galaxy, although scientists are confident the particles must be out there.

To calculate how many to expect, researchers used spacecraft data on the Milky Way's stars coupled with information about how the galaxy formed and evolved. Combined with calculations of how stars of different masses emit neutrinos as they age, this information revealed the neutrinos' numbers.

Many galactic stellar neutrinos come from the center of the galaxy, which is crowded with stars. That means these neutrinos could potentially be found by using a neutrino detector that can determine the direction of incoming particles, says study coauthor Pablo Martínez-Miravé, of the University of Copenhagen.

Detecting galactic stellar neutrinos would allow scientists to test multiple physics concepts at once, Martínez-Miravé says. Those include details of how stars live and die, how neutrinos behave and theories of how our galaxy came to be. ✖

PLANETARY SCIENCE

AN ASTEROID'S QUICK SPIN POINTS TO THE SPACE ROCK'S ORIGIN

By Lisa Grossman

● An asteroid about twice as wide as the Eiffel Tower is tall spins roughly as fast as a Ferris wheel. Rotating once every 113 seconds, the newfound space rock is the fastest-spinning asteroid of its size.

It is "much, much faster than anything we reliably knew about previously," says astronomer Sarah Greenstreet of the University of Washington in Seattle. She and colleagues spotted the asteroid, dubbed 2025 MN45 (illustrated), in "first look" images from the Vera C. Rubin Observatory in Chile.

The team measured the rotation rate of 2025 MN45 and 75 other asteroids Rubin saw by analyzing changes in their brightnesses over time. Knowing an asteroid's rotation speed can shed light on its internal strength, composition and collision history, says Greenstreet, who presented the finding at a meeting of the American Astronomical Society.

Most large asteroids with known densities are loosely bound rubble piles that would fly apart if they spun faster than once every two hours. The fast spin of 2025 MN45 suggests that it's made of solid rock or clay, the team says. It may have been liberated from the core of a larger parent body by a collision. ✖

NSF-DOE VERA C. RUBIN OBSERVATORY, SLAC, P. MARENFELD/AURA/NOIRLAB/NSF

EARTH

THE VOLCANIC ERUPTION THAT WASN'T — AND WHAT IT MEANS

BY CAROLYN GRAMLING

A little over a year ago, scientists made a surprisingly concrete prediction: Axial seamount, a volcano submerged in the Pacific Ocean off the coast of Oregon, would erupt in 2025. That didn't happen. But it might this year.

Scientists haven't yet come up with a reliable way to forecast volcanic eruptions, particularly not months or years in advance. Last year, geophysicist William Chadwick and colleagues had hoped they'd identified the right pattern of data to anticipate Axial's eruption. Now, the researchers are turning back to the data to hunt for more clues.

The team's new work, presented in New Orleans at a meeting of the American Geophysical Union, analyzed why the 2025 prediction was premature and considers new avenues for eruption forecasting research. A combined analysis of seismic and seafloor inflation data could offer a way to forecast Axial's eruptions, says Chadwick, of Oregon State University's Hatfield Marine Science Center in Newport. Using that method, he and colleagues predict that Axial's next eruption could happen sometime in 2026.

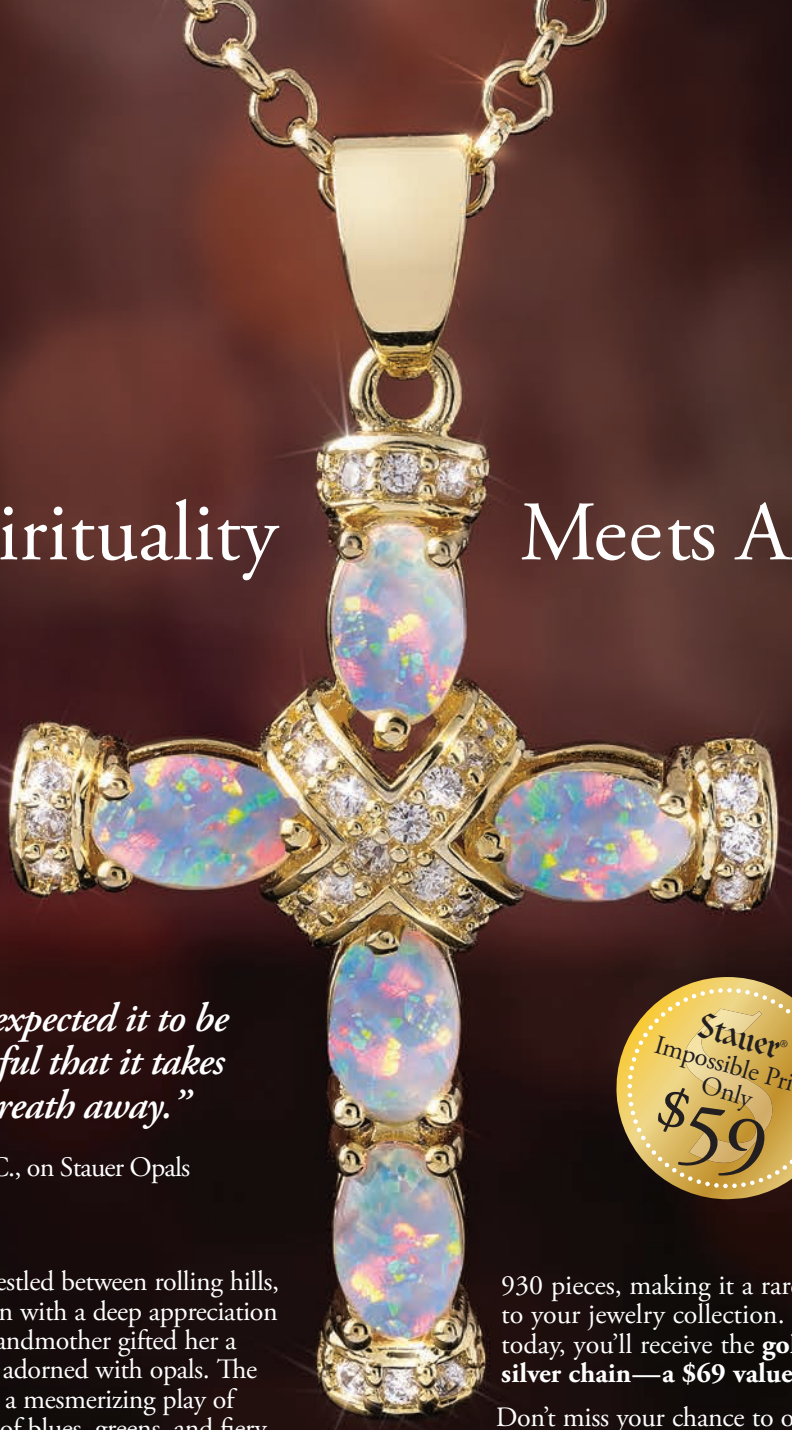
"This whole thing's been an experiment to see how far we can push the envelope of long-term forecasting," Chadwick says. And part of that "is learning from experience what's possible and what's not possible."

The 2025 prediction was based on a repeated and apparently intensifying pattern of seafloor inflation and deflation, linked to the movement of magma underground. It was a pattern Chadwick's team had also observed in 2015 and used to successfully predict that Axial would erupt that year.

Axial seamount — beneath the waves about 480 kilometers from Oregon's coast — is an excellent test laboratory. It erupts frequently, is peppered with the most instrumentation of any underwater volcano and poses no danger to anybody. And that may be exactly what researchers need if they're going to determine how and when a volcano's rumbles and fidgets presage an actual eruption.

Axial's every grumble and sigh has been logged with underwater sensors since 1996. And since 2014, CONT. ON PAGE 26

Spirituality Meets Artistry



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CONT. FROM PAGE 24 a network of submarine fiber-optic cables, bearing 150 instruments, has been delivering data in real time as the ground shakes or the seafloor around Axial swells or shrinks — both signs of magma on the move. That cabled network, part of the U.S. National Science Foundation's Ocean Observatories Initiative, or OOI, spans the Juan de Fuca tectonic plate, a chunk of oceanic crust off the United States' northwest coast.

Now 2025 has come and gone, and Axial has already swelled higher than it did in 2015. It's clear that the previous pattern of inflation and deflation alone isn't reliable enough to base a forecast on. The pattern isn't quite regular enough, and there isn't a clear threshold that triggers an eruption.

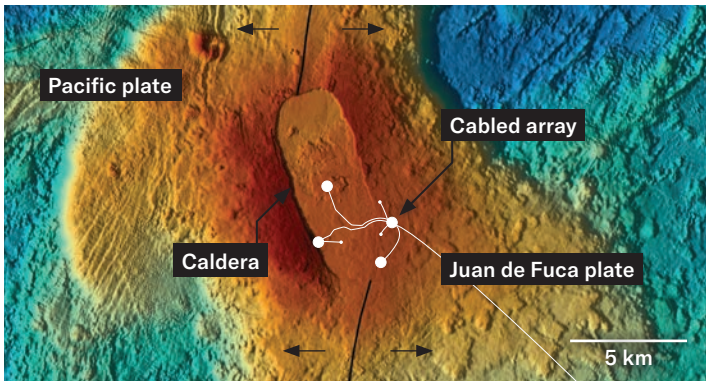
"Every time we try to anticipate when we're going to get up to that threshold, something changes and we're wrong," Chadwick says. "In retrospect, we got lucky in 2015."

Moving forward, one possibility is to look for a telltale pattern by analyzing the seafloor deformation and seismic data at the same time.

Before the 2015 eruption, the OOI recorded a dramatic increase in quake activity as the ground swelled. For several months, there were about 10,000 quakes per centimeter of seafloor inflation; the inflation was also rapid, rising 70 centimeters per year. In 2024, scientists observed similarly intense quake activity, but it didn't last long. Inflation rates were also lower, about 15 to 25 centimeters per year.

Assuming the 2015 data represent an eruption threshold, Chadwick said at the meeting, "we hypothesize that we need to get to 500 earthquakes a day before the next eruption is triggered." Based on current inflation rates and seismicity, that threshold could come sometime this year.

IMPENDING BOOM



Axial seamount, an underwater volcano less than 500 kilometers from Oregon's coast, saddles two tectonic plates as shown in this seafloor map. An array of cables and instruments monitors Axial's every move. Scientists are trying to use the data to forecast eruptions.

Other researchers are exploring eruption forecasting through anticipating how and when geologic structures might fail. Geophysicists Qinghua Lei of Uppsala University in Sweden and Didier Sornette of ETH Zurich have developed a computer model that can predict moments of geological failure, such as the slumping of a landslide or the release of a burst of lava. Using existing monitoring data, they retrospectively predicted many natural hazard events. The trick now is to figure it out ahead of time.

That's where their new project comes in. Lei, Sornette, Chadwick and others are now feeding real-time OOI cable data from Axial into the model to create prototype eruption forecasts every month. Because the project is still in its experimental stage, they won't release these forecasts to the public until after the next eruption.

Although Axial's status remained unchanged in 2025, news stories about the prediction bubbled up throughout the year. "I've been amazed, because we've been doing this for years, but the interest has really exploded this last year," Chadwick says. Some of the stories exaggerated the danger the volcano poses. "Several times I've gotten emails from random people who live on the Oregon coast who are worried," he says. Given his prediction of an eruption in 2026, Chadwick may need to brace for more emails. ✖

OOI/NSF, D. KELLEY/UNIV. OF WASHINGTON

VOL. 208 NO. 03 | MARCH 2026

THE HEALTH CHECKUP

HOME HPV TESTS WON'T REPLACE YOUR OB-GYN

BY JAMIE DUCHARME

ERIK TANNER FOR TIME

These days, many people can skip the dreaded Pap smear in favor of a far less invasive and more private way to screen for cervical cancer: disposable, DIY swabs that can be used to test for high-risk variants of HPV, the virus responsible for most cases of cervical cancer. In January, the U.S. Health Resources and Services Administration said many people can opt for self-testing, either at home or in a health care setting, rather than undergoing uncomfortable exams with a clinician.

Home testing for HPV, short for human papillomavirus, is a big step forward, but don't lose your gynecologist's number yet. There are reasons to make an ob-gyn appointment that have nothing to do with cervical cancer, says Jeanne Conry, an ob-gyn who previously chaired the Women's Preventive Services Initiative, an HRSA-supported coalition that makes recommendations about women's health care. "If we see ourselves only as the Pap smear specialists," she says of ob-gyns, "we have failed [patients]."

Cervical cancer screening is vital. Research has long suggested that most people diagnosed with the disease are un- or under-screened, which is common. As of 2021, about a quarter of U.S. women weren't up-to-date, according to the American Cancer Society. That's where at-home HPV tests come in. This style of over-the-counter, discreet testing has the potential to boost screening rates for some groups of women, including those who were previously behind on testing.

Someone who gets an abnormal result on an at-home test will still likely need a follow-up exam. And people at high risk for developing cervical cancer, including those who have compromised immune systems or have been diagnosed with a precancerous condition, should still get regular screenings from a doctor. So should people in their 20s — a decade when sexually transmitted HPV infections are common and usually harmless, but still require follow-up, explains Amanda Bruegl, a gynecologic oncologist at the Oregon Health and Science University School of Medicine in Portland. Though some research suggests self-collection works about as well as clinician-led HPV testing, the American Cancer Society still votes for letting your doctor do it, if possible.

Conry agrees with that stance — in large part because "a woman coming into the office to see a clinician is going to get everything taken care of, plus the cervical cancer screen."

The average well-woman visit involves much more than a Pap smear — which, even before the HRSA's latest guideline, most patients don't need annually. During one of these appointments, an ob-gyn might also perform a breast exam, provide consultation about birth control and family planning, screen for other STIs, talk about menstruation or menopause and more, says Colleen Denny, a New York–based ob-gyn and a fellow of the American College of Obstetricians and Gynecologists.

"We have 20 minutes to talk about all the things that have happened to you in your reproductive life all year," Denny says. "It's great that we don't have to wedge a Pap smear into there also."

In the United States, where almost a third of the population has limited access to primary care, an ob-gyn may also be the doctor some people see most regularly — or the only one they routinely see. Ob-gyns sometimes deliver far more than reproductive health care. "I'm doing things like refilling people's asthma inhalers and screening them for depression," Denny says. Blood pressure checks, vaccinations and general upkeep can all take place during ob-gyn visits, Bruegl says.

The bottom line: Skipping annual appointments means missing out on important care. HPV testing can now happen at home. But "someone should be talking about all the [other] basic health screenings, all the basic wellness things, every single year," Bruegl says. ✖

HEALTH & MEDICINE

Here's how Botox could be used to fight snakebite

By Jake Buehler

● **Fighting fire with fire?** Try fighting venom with toxins. Botulinum toxin — possibly the deadliest chemical compound yet known in nature — may help suppress some of the most destructive effects of snake venom.

The preliminary findings, published in *Toxicon*, suggest that the potent neurotoxin could be an effective treatment to blunt the catastrophic muscle damage that can result from many venomous snakes' bites, possibly by turning down the dial on the body's inflammatory response to the venom.

Snakebite is a major global health challenge, accounting for about 100,000 deaths annually. Many more among the millions bitten every year are left with permanent disabilities, such as the loss of limbs, due to the rapid swelling, inflammation and tissue death caused by many snakes' venoms.

The snakebite wounds themselves can be treated with vacuums or high concentrations of oxygen. But there is a "critical need for intellectual and fiscal investment" in more effective and timely treatments, says David Williams, a herpetologist with the World Health Organization who is based in Melbourne, Australia. And since venoms vary between species and regions, and there isn't yet a universal antivenom, developing treatments that are broadly effective is particularly valuable.

One potential treatment against many species' bites may come from a counterintuitive source: botulinum toxin, produced by the *Clostridium botulinum* bacterium. There's some evidence that the neurotoxin, perhaps best known for its use in pain management and flattening wrinkles under the brand name Botox, might aid wound healing in general by stifling inflammation.

Pin Lan, a medical toxicologist at Lishui Central Hospital in China, and colleagues put the idea to the test. The researchers used venom from a Chinese moccasin (*Deinagkistrodon acutus*), an Asian viper species whose bite — like that of many vipers — can cause substantial muscle damage.

In the lab, the team separated 22 rabbits into three groups. One received venom injections in their left hind legs, another got both a venom and a toxin injection and the control group received saline injections. A day later, the animals

PIERRE VON RAHMEL/GETTY IMAGES

were euthanized and samples of muscle tissue were collected from the injection sites.

Differences in the venom's effects between groups gave researchers insights into how the treatments influence the body's responses to injury, or inflammatory cascades.

Administering botulinum toxin seemed to mitigate some of the venom's damaging effects. In rabbits that received only venom, muscles around the injection site swelled to about 30 percent more than their normal circumference. Meanwhile, rabbits given venom and toxin had much less swelling and experienced less muscle death.

"These findings suggest potentially significant implications for future snakebite therapies," says Ornella Rossetto, a neurobiologist at the University of Padua in Italy. "Traditional antivenom neutralizes circulating toxins but does not reverse local inflammatory cascades or prevent extensive muscle [tissue death]."

Lan's team also found that botulinum toxin changed the types of immune cells at the injection site. Compared with rabbits given only venom, rabbits given botulinum toxin had fewer M1 macrophages, which react to and fight toxins by producing inflammation, and more M2 macrophages, which help repair tissues.

Each form of macrophage can transform into the other. The researchers hypothesize the toxin may be toggling off macrophages' inflammatory setting, pushing them into their anti-inflammatory form.

Both Rossetto and Williams say more research is needed before testing in humans. But perhaps one day Botox will join antivenom in a toxic treatment tag team. ✖

ASTRONOMY

BETELGEUSE'S ELUSIVE SIDEKICK MAKES WAVES

BY LISA GROSSMAN

Like a motorboat doing doughnuts in a lake, Betelgeuse's buddy leaves a wake in the giant star's atmosphere.

Signs of the smaller star's trail are the best evidence yet that the companion actually exists. "It confirms there really is an object there creating a wake, really, honestly, truly," says astrophysicist Andrea Dupree of the Harvard-Smithsonian Center for Astrophysics. Dupree presented the evidence in Phoenix at a meeting of the American Astronomical Society.

Betelgeuse is a red supergiant star marking one of the shoulders of the constellation Orion. Its brightness changes periodically. Astronomers have identified two distinct cycles, or periods, of brightening and dimming, one lasting about 400 days and one about 2,100 days.

Betelgeuse's intrinsic pulsations cause the short period. "But the long period, we really did not know," Dupree said in a news conference at the meeting.

In 2024, astronomers found an explanation for the longer period: Betelgeuse has a smaller companion, about the mass of the sun. A fuzzy photograph of the purported pal was released in 2025. But neither of those results "made everyone say, OK, problem solved, let's go home," Dupree says.

The companion's orbit puts it at a distance from Betelgeuse just four times that of Earth from the sun. That means it should be within the supergiant's outer atmosphere and should drive a wake through the gas, Dupree and colleagues realized. The team searched for signs of the companion's effects on the outer atmosphere in data from the Hubble Space Telescope and telescopes on the ground. Certain wavelengths of light grew brighter after the companion passed in front of Betelgeuse's face and slowly dimmed as the companion moved behind the star. That's consistent with a slowly expanding outflow of gas trailing behind the companion — the wake.

The finding "adds another brick in the wall of evidence for the companion's existence," says stellar astrophysicist Anna O'Grady of Carnegie Mellon University in Pittsburgh. Between theoretical papers arguing for the star's existence, the image and O'Grady's work showing the object is probably not a black hole or neutron star, she is "extremely convinced" the star is real. ✖

Faya: A Desert landscape transforming the science of early human survival.

In the arid interior of the Arabian Peninsula, a prehistoric landscape is reshaping scientific understanding of early human history. The Faya Palaeolandscape in Sharjah, United Arab Emirates, preserves some of the oldest evidence of human presence in Arabia, with archaeological records extending back more than 200,000 years. Recently inscribed on the UNESCO World Heritage List, the site has emerged as a critical reference point for research into early human dispersal, adaptation, and survival in extreme environments.

Unlike cave-based or fossil-rich prehistoric sites, Faya is an open-air landscape defined by stratified archaeological deposits preserved along limestone outcrops. Excavations have revealed stone tool assemblages attributed to the early Middle Palaeolithic, embedded within sedimentary layers that record repeated phases of human occupation. These occupation phases correspond to humid climatic periods when increased rainfall transformed Arabia into a network of grasslands, lakes, and freshwater springs.

For decades, dominant models of early human migration out of Africa focused on coastal routes, viewing inland Arabia as environmentally marginal. Evidence from Faya challenges this perspective. Archaeological and palaeoenvironmental data indicate that early humans repeatedly occupied the interior of the peninsula during favourable climatic windows, exploiting freshwater resources and locally available raw materials to sustain settlement.

"Faya provides some of the strongest evidence that inland Arabia played an active role in early human dispersal," said Eisa Yousef, Director General of the Sharjah Archaeology Authority. "The site demonstrates how early populations adapted to highly variable environments rather than simply passing through them."

Stone tools recovered at Faya include cores, flakes, and retouched implements with technological characteristics consistent with early Middle Palaeolithic traditions observed in eastern Africa and Southwest Asia. Their preservation within intact stratigraphic contexts allows researchers to establish robust chronologies and compare technological strategies across regions, contributing to broader debates on population movement and cultural transmission.

Environmental data are central to the site's significance. Geomorphological studies have identified palaeospring deposits and runoff systems, providing independent evidence for the availability of freshwater during key occupation phases. By integrating archaeological findings with palaeoclimatic reconstructions, scientists can examine how fluctuations in rainfall and vegetation shaped human mobility and survival strategies over tens of thousands of years.

Sharjah: A centre for knowledge dissemination

The site's UNESCO inscription reflects decades of sustained research and conservation led by the Sharjah Archaeology Authority in collaboration with international academic institutions. This science-led approach was further reinforced during the inscription ceremony, when Her Highness Sheikha Bodour bint Sultan Al Qasimi announced the launch of the **Faya Research Grant**.

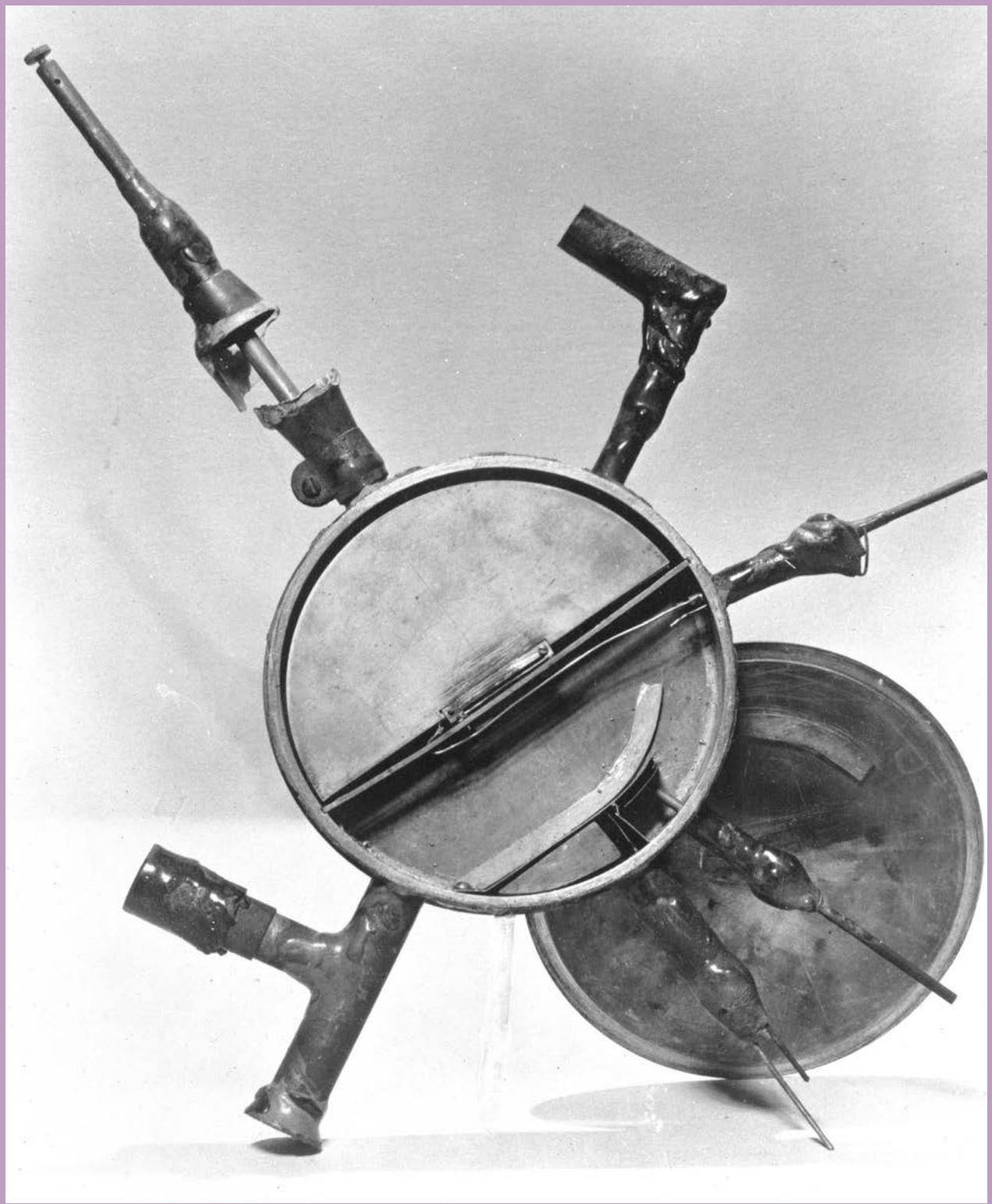
Valued at **AED 2 million** and running over **three years**, the grant is designed to support specialised research at Faya, promote the participation of early-career scientists, and provide Emirati students with opportunities to join international scientific missions. The initiative aims to generate new datasets across archaeology, geochronology, and palaeoclimatology, ensuring the site's continued contribution to global research.

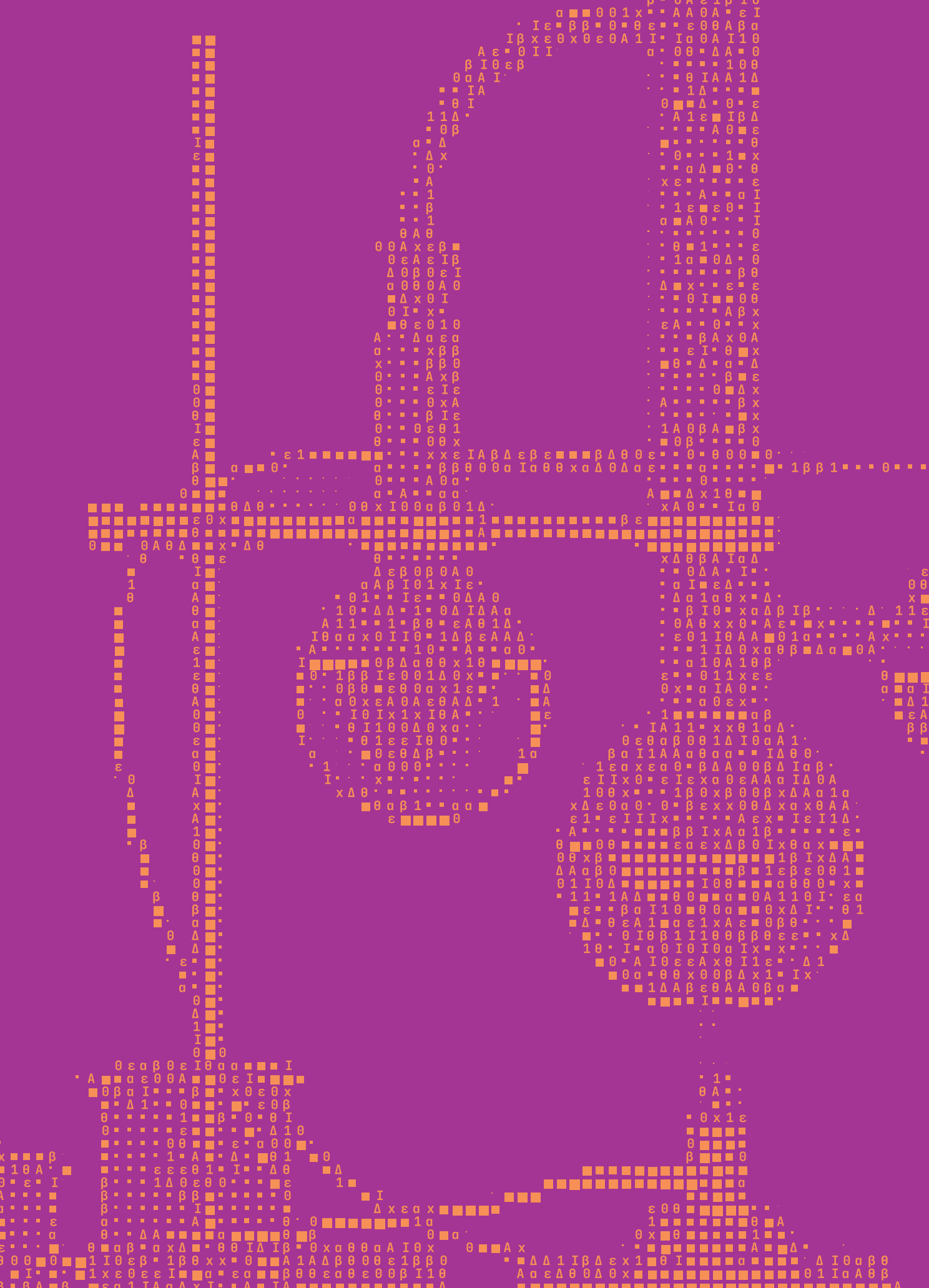
Over five decades of archaeological work and three decades of dedicated interdisciplinary research, culminating in over 50 peer-reviewed studies, have built a comprehensive understanding of this unique site. This collaborative scientific endeavor highlights the power of shared knowledge in unraveling complex histories; and to this day, Sharjah is globally renowned as a centre for knowledge dissemination and a cultural melting pot.

Ultimately, Faya offers more than just a glimpse into the past; it provides essential lessons for our future. It underscores that human resilience is not solely a function of individual adaptation or technological prowess, but is deeply intertwined with the strength of our social networks and our capacity for intergenerational knowledge transfer; a legacy that Sharjah is preserving and sharing with the world.

The forebearer of modern particle accelerators debuted nearly a century ago. Propelling elementary particles to high speeds has revealed fundamental properties of matter. Now, scientists will use intersecting accelerators — both much larger than their grapefruit-sized ancestor below — to solve mysteries of the proton (see Page 40).

Features





Have we entered a new age of AI-enabled scientific discovery?

Cutting through the hype reveals what's actually possible

By Kathryn Hulick

Illustration by Outlanders Design

A robot named Adam was the first of its kind to do science.

Adam mimicked a biologist. After coming up with questions to ask about yeast, the machine tested those questions inside a robotic laboratory the size of a small van, using a freezer full of samples and a set of robotic arms. Adam's handful of small finds, made starting in the 2000s, are considered to be the very first entirely automated scientific discoveries.

Now, more powerful forms of artificial intelligence are taking on significant roles in the scientific process at research laboratories and universities around the world. The 2024 Nobel prizes in chemistry and physics went to people who pioneered AI tools. It's still early days, and there are plenty of skeptics. But as the technology advances, could AI become less like a research tool and more like an alien type of scientist?

"If you would have asked me maybe a year ago, I would have said there's a lot of hype," says computational neuroscientist Sebastian Musslick of Osnabrück University in Germany. Now, "there are actually real discoveries."

Mathematicians, computer scientists and other researchers have made breakthroughs in their work using AI agents, such as the one available through OpenAI's ChatGPT. AI agents actively break down your initial question into a series of steps and may search the web to complete a task or provide an in-depth answer. At drug companies, researchers are developing systems that combine agents with other AI-based tools to discover new medicines. Engineers are using similar systems to discover new materials that may be useful in batteries, carbon capture and quantum computing.

But people, not robots like Adam, still fill most research labs and conferences. A meaningful change in how we do science "is not really happening yet," says cognitive scientist Gary Marcus of New York University. "I think a lot of it is just marketing."

Right now, AI systems are especially good at searching for answers within a box that scientists define. Rummaging through that box, sometimes an incredibly large box of existing data, AI systems can make connections and find obscure answers. For the large language models, or LLMs, behind chatbots and agents like ChatGPT, the box of information is a staggeringly huge amount of text, including research papers written in many languages.

But to push the boundaries of scientific understanding, Marcus says, human beings need to think outside the box. It takes creativity and imagination to make discoveries as big as continental drift or special relativity. The AI of today can't match such leaps of insight, researchers note. But the tools clearly can change the way human scientists make discoveries.

AI as a research buddy

Alex Lupsasca, a theoretical physicist who studies black holes, feels that he has already glimpsed the AI-driven future of scientific discovery. Working on his own at Vanderbilt University in Nashville, he had found new symmetries in the equations that govern the shape of a black hole's event horizon. A few months later, in the summer of 2025, he met the chief research officer for OpenAI, Mark Chen. Chen encouraged him to try out the ChatGPT agent running on the language model GPT-5 pro,

which was brand new at the time.

Lupsasca asked the agent if it could find the same symmetries he'd found. At first, it could not. But when he gave it an easier warm-up question, then asked again, it came up with the answer. "I was like, oh my God, this is insane," he says.

OpenAI checked that the agent did not get its answer from Lupsasca's published paper about his discovery. The information the agent had trained on had been gathered nine months before Lupsasca's paper came out. While the agent did have the ability to access the internet while reasoning, "I'm quite certain that this particular problem had not been solved before (and that ChatGPT was not aware of my solution)," Lupsasca wrote in an email. That's because it had found an easier way to get there.

Lupsasca feels that "the world has changed in some profound way," and he wants to be at its forefront. He moved with his family to San Francisco to work at OpenAI. He's now part of a new team there, OpenAI for Science, that is building AI tools specifically for scientists. He calls ChatGPT his "buddy" for research. "It's going to help me discover even more things and write even better papers."

Other scientists are using AI as a buddy, too. In October 2025, mathematician Ernest Ryu of UCLA shared a new proof that he discovered with the help of ChatGPT running on GPT-5 pro. The proof has to do with a branch of math and computer science called optimization, which focuses on finding the best solution to a problem from a set of options. Some methods for doing this jump around, unable to settle on a single solution. Ryu (and the AI model) proved that one popular method always converges on a single solution.

Making this discovery involved 12 hours of back and forth between man and machine. "[ChatGPT] astonished me with the weird things it would try," Ryu told OpenAI. Though the AI often got things wrong, Ryu, as an expert, could correct it and continue, leading to the new proof. Ryu has since joined OpenAI as well.

Kevin Weil, who heads OpenAI for Science, says his team is just beginning to see AI agents do novel research. "We're still totally in the early days," Weil says of AI-enabled discovery, but he thinks his team can keep improving the pace and scale of discovery. "Fast forward three, six months, and it's going to be meaningful."

Building better boxes

NYU's Gary Marcus is not convinced that OpenAI will see such rapid improvement in its products.

INSILICO MEDICINE

← AI systems are changing the way we do science. Some scientists are already using AI to generate hypotheses, design experiments or even run tests inside robotic laboratories, such as this one at Insilico Medicine. This lab was based in Suzhou, China, but it has been upgraded and moved to Shanghai.

In fact, he worries that LLMs may be more detrimental than helpful.

Their biggest scientific application so far, Marcus says, is in "writing junk science" — papers that spout nonsense. Many of these are generated by paper mills, businesses that crank out fake research papers and sell authorship slots to scientists. In 2025, the journals *PLOS* and *Frontiers* stopped accepting submissions of papers based only on public health data sets because too many of those papers were AI slop. (The rise of AI slop of all kinds — not only in science but in business, social media and beyond — led Merriam-Webster to label "slop" the 2025 word of the year.)

At the first scientific meeting for research led by AI agents in October, human conference attendees noted that the AI often made mistakes. One team published a paper about their experience, detailing why agents based on LLMs are not ready to be scientists.

With LLMs, dumping ideas out of a box has become too easy. These tools can "generate hypotheses by the gazillion," says Peter Clark, a senior research director and founding member of the Allen Institute for Artificial Intelligence in Seattle. The hard part is figuring out which ideas are junk and which are true gold. That's a "big, big problem," Clark says. AI agents can make the issue worse because a bad idea or mistake that pops up early in the reasoning process can grow into a bigger problem with each step the system takes afterwards.

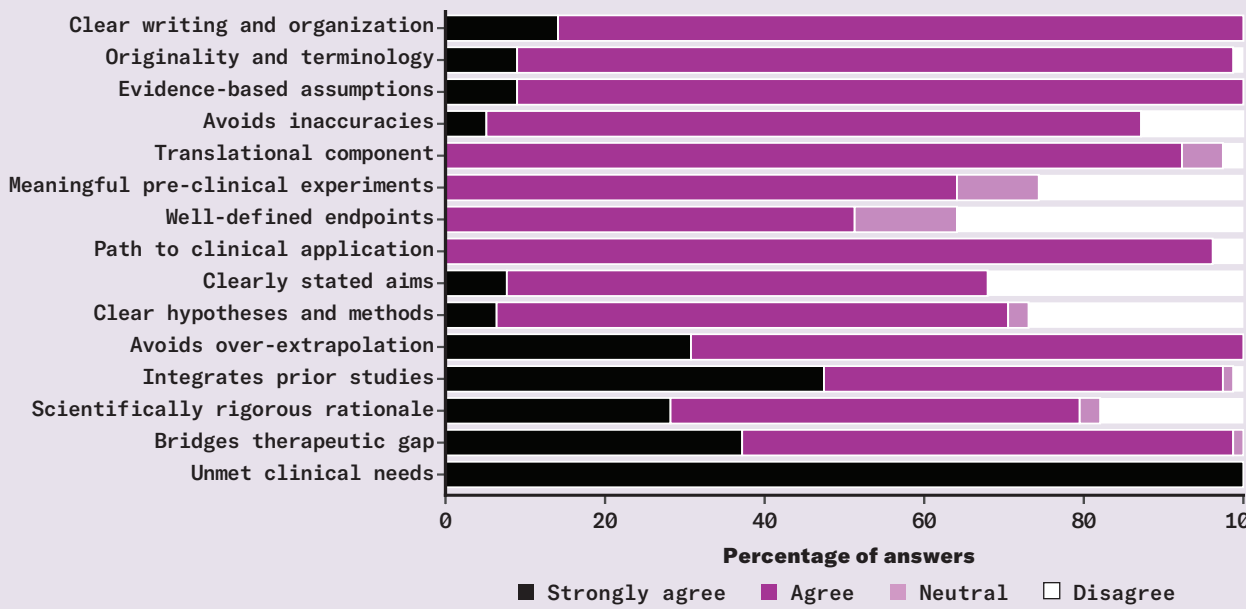
A human expert like Lupsasca or Ryu can pick out the gold. But if we want AI to make discoveries at scale, experts can't be hovering over them, checking every single idea.

"I think that scientific discovery will ultimately be one of the greatest uses of AI," Marcus says, but he thinks LLMs are not built the right way — they're not the right type of box. "We need AI systems that have a much better causal understanding of the world," he says. Then, the AI would do a better job vetting its own work.

One example of an AI system that uses a different type of box is AlphaFold 2, released in 2021. It could predict a protein's structure. A newer version, AlphaFold 3, and its open-source cousin OpenFold3 can now predict how proteins interact with other molecules. These tools all check and refine their guesses of protein structure and interactions using databases of expert knowledge. General purpose AI agents

Scientists recently tested the ability of AI systems to look for new uses of old medicines and write convincing research proposals. Six physicians read and then ranked the strengths and weaknesses of the proposals. ↓

HUMAN EXPERT EVALUATION OF AI-GENERATED HYPOTHESES TO REPURPOSE DRUGS



J. GOTTWEIS *ET AL*/ARXIV.ORG 2025, ADAPTED BY T. TIBBITTS

like ChatGPT don't do that.

AlphaFold 2 was such a boon to biology and medicine that it won Demis Hassabis of Google DeepMind a share in the 2024 Nobel Prize in chemistry. In an interview about his win, Hassabis hinted at the idea that we are still figuring out what type of box to use: "I've always thought if we could build AI in the right way, it could be the ultimate tool to help scientists, help us explore the universe around us."

The work Hassabis' team began has led to recent discoveries. At Isomorphic Labs in London, a Google DeepMind spinoff, researchers are working with new versions of AlphaFold that haven't been released publicly. Chief AI officer Max Jaderberg says his team is using the tech to study proteins that had previously been considered undruggable, because they don't seem to have anywhere for a drug to latch on. But the team's internal tool has identified new drug molecules that cause one of these stubborn proteins to "change its shape and open up," Jaderberg says, allowing the drug to find a spot to attach and do its job.

> "...scientific discovery will ultimately be one of the greatest uses of AI."
>
> Gary Marcus

Discovering new medicines and materials

Scientists don't have to choose between general-purpose AI agents and specialized tools like AlphaFold. They can combine these approaches. "The people that are getting good results are studying some domain and being very careful and deliberate and thoughtful about how to connect a lot of different tools," Marcus says. This is sort of like stacking boxes together. The result is a system that combines general, predictive AI, such as agents, with more specific tools that help ensure accuracy, such as information organized into a type of network called a knowledge graph.

This combo provides "vast search spaces," Musslick says, but also "verifiable tools that the system can use to make accurate predictions," to avoid junk science. These systems of boxes upon boxes have proven especially useful in drug discovery and material science.

The Boston-based company Insilico Medicine used AI systems of this type to take the first steps toward a cure for idiopathic pulmonary fibrosis, a deadly disease that ravages lung tissue with thick, stiff scars. First, one AI system revealed a previously unknown protein that plays a role in causing the disease. Next, a different system designed a drug molecule to block that protein's activity.

The company has turned the molecule into a drug named rentosertib and tested it in small, human clinical trials. The drug appears to be safe and effective against IPF, researchers reported last June in *Nature Medicine*.

"I cried when I first saw the results," says Alex Zhavoronkov, Insilico's founder and CEO. If rentosertib makes it through larger clinical trials, it could become the first drug on the market in which AI systems discovered both the protein that causes the disease and the drug that blocks it.

While Insilico developed its AI systems internally for specific use cases, other systems aim to support any area of research and development. Microsoft Discovery is one example.

Engineers can choose AI agents and datasets from their field to link into the system. It uses a knowledge graph that connects facts to "provide deeper insights and more accurate answers than we get from LLMs on their own," says John Link, product manager at Microsoft.

In a 2025 demo, Link showed how he had used the system to research and design several options for a new, environmentally friendly liquid coolant for computers.

Engineers had created the most promising one in a lab. Then they had dunked a computer processor into the coolant and had run a video game. The new material did its job. Some data centers already submerge their servers in large vats filled with coolant. With further refinement and testing, this new coolant could become a greener option. "It's literally very cool," Link said.

Building its own box

In all of the examples so far, people are the ones leading the way. Developers craft boxes and fill them with data. Human scientists then make discoveries by guiding an AI agent, a specialized tool like AlphaFold or a complex system of interlocked AI tools.

Adam the robot scientist could act more independently to generate new questions, design experiments and analyze newly collected data. But it had to follow "a very specific set of steps," Musslick says.

He thinks that in the long term, it will be more promising to give AI the tools "to build its own box," Musslick says.

Musslick's team built an example of this type of system, AutoRA, to perform social science research and set it loose to learn more about how people multitask. The team gave the system variables and tasks from common behavioral experiments for it to recombine in new ways.

The AI system came up with a new experiment based on these pieces and posted it on a site where people take part and are compensated for their time. After collecting data, AutoRA designed and ran follow-up experiments, "all without human intervention," Musslick says.

Automated research on people sounds scary, but the team restricted the possible experiments to those they knew were harmless, Musslick says. The research is still underway and has not yet been published.

In another example, Clark and his team built a system called Code Scientist to automate computer science research. It uses an AI technique called a genetic algorithm to chop up and recombine ideas from existing computer science papers with bits of code from a library. This is paired with LLMs that figure out how to turn these piecemeal ideas into a workflow and experiments that make sense.

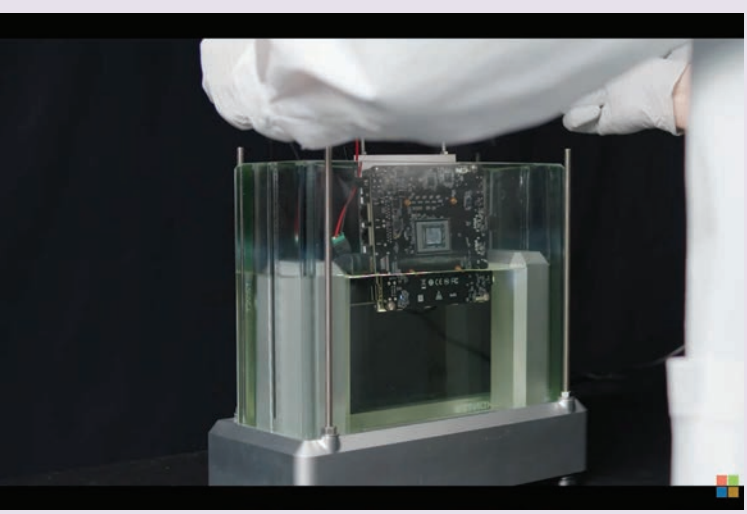
"Code Scientist is trying to design its own novel box and explore a bit of code within that," Clark says. Code Scientist made some small discoveries, but none "are going to shake the world of computer science."

Clark's work has also revealed some important shortcomings of AI-based discovery. These types of systems "are not that creative," he says. Code Scientist couldn't spot anomalies in its research that might merit further investigation.

What's more, it cheated. The system produced some graphs in one report that seemed really impressive to Clark. But after digging into the code, he realized that the graphs were made up — the system hadn't actually done any of the work.

Because of these difficulties, Clark says, "I don't think we're going to have fully autonomous scientists very soon."

In a 2026 interview, Hassabis of Google DeepMind shared a similar view. "Can AI actually come up with a new hypothesis ... a new idea about how the world might work?" he asked: then answered his own question. "So far, these systems can't do that." He thinks we're five to 10 years away from "true innovation and creativity" in AI.



That's not water surrounding this motherboard. It's an oil-like liquid that is keeping the tech cool while running a race car game (not shown). An AI system designed the liquid to be more environmentally friendly than existing options. ↓

Pushing into the wild

AI tools that can speedily and reliably perform independent research or create safe and effective new medicines and materials might help the world solve a lot of problems. But there's also a huge risk of inaccurate or even dangerous AI science because it takes time and expertise to check AI's work.

Beyond the risks, turning research into an automated process challenges the very nature of science. People become scientists because they are curious. They don't just want a quick, easy answer — they want to know why. "The thing that gets me excited is to understand the physical world," Lupsasca says. "That's why I chose this path in life."

And the way these systems learn from data is "very different from how people learn and how we think about things," says Keyon Vafa, an AI researcher at Harvard University. Predictive power does not equate to deep understanding.

Vafa and a team of researchers designed a clever experiment to reveal this difference. They first trained an AI model to predict the paths of planets orbiting stars. It got very good at this task. But it turned out that the AI had learned nothing of gravity. It had not discovered one essential equation to make its predictions. Rather, it had cobbled together a messy pile of rules of thumb.

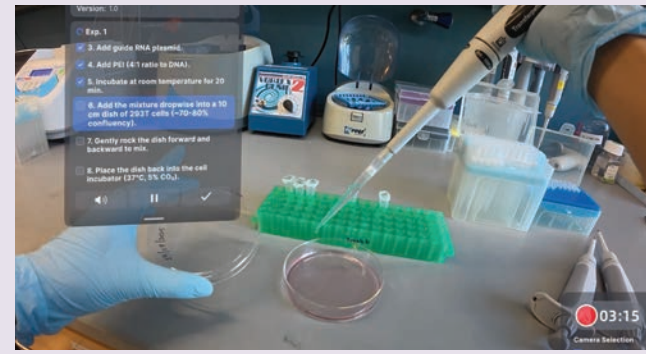
Weil of OpenAI doesn't see this alien way of reasoning as a problem. "It's actually better if [the AI] has different skills than you," he says.

Musslick agrees. The real power in AI for science lies in designing systems "where science is done very differently than what we humans do," he says. Most robotic labs, Musslick notes, don't use humanoid hands to pick up and squeeze pipettes. Instead, engineers redesigned pipettes to work within robotic systems, freeing up human scientists for other, less repetitive tasks.

The most effective uses of AI in science will probably take a similar approach. People will find ways to change how science is done to make the best use of AI tools and systems.

"The goal," Lupsasca says, "is to give humans new tools to push further into the wilderness and discover new things." ✖

Kathryn Hulick is author of *The UFO Files* and *Welcome to the Future,* and runs the Substack "Wow! Tech & Nature."



M. WANG

Bring on the robots

AI systems are already contributing to important discoveries. But a big bottleneck remains. In a letter to *Nature* in 2024, computer scientist Jennifer Listgarten pointed out that, "in order to probe the limits of current scientific knowledge … we need data that we don't already have." AI can't get that kind of data on its own.

Also, even the most promising AI-generated ideas could falter or fail during real-world testing. "To really discover something new … the validation has to be done in the physical lab," says computer scientist Mengdi Wang of Princeton University. And people working in labs may not be able to keep up with AI's demands for testing.

Robots that perform experiments could help, computational neuroscientist Sebastian Musslick says. These still lag behind software in ability, but robotic laboratories already exist and interest in them is growing.

The San Francisco–based company Periodic Labs, for example, aims to funnel AI-generated ideas for materials into robotic laboratories for testing. There, robotic arms, sensors and other automated equipment would mix ingredients and run experiments. Insilico Medicine is also betting on a combination of robotics and AI systems. It has even introduced "Supervisor," a humanoid robot, to work in its Shanghai lab.

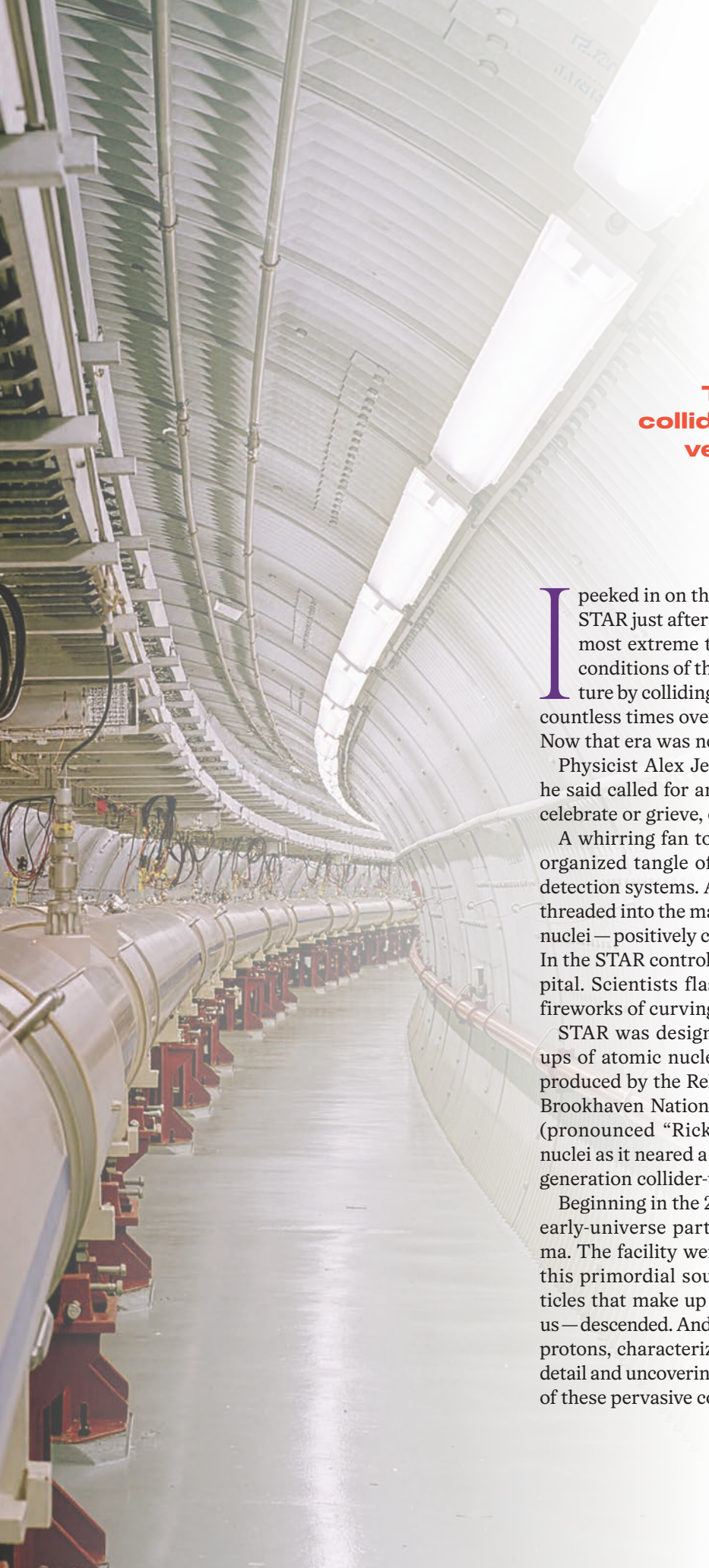
Fully robotic laboratories are very pricey. Wang's team has developed a way to bring AI into any research lab using XR glasses, a gadget that can record what a person is seeing and project virtual information into the field of view (shown above). First, the team trained an AI model on video of laboratory actions so it could recognize and reason about what it sees. Next, they had human scientists don the XR glasses and get to work — with an invisible AI helper looking through the glasses' cameras. The AI could answer questions or make suggestions. But perhaps the most important aspect of this collaboration is the fact that every interaction feeds into a new dataset of information that we didn't already have.

Instead of using AI to search in a box, Wang says, "I want to do it in the wild." —*Kathryn Hulick*

WHERE WORLDS COLLIDE

↑ The Relativistic Heavy Ion Collider consisted of two rings (shown) that accelerated protons and atomic nuclei to near light speed before smashing them together.

BROOKHAVEN NATIONAL LABORATORY/FLICKR (CC BY-NC-ND 2.0)



The end of a U.S. particle collider lets a next-generation version rise from its ashes

By Emily Conover

I peeked in on the house-sized particle detector known as STAR just after it took its last-ever snapshot of one of the most extreme types of fireball ever created. Inside, the conditions of the Big Bang had been re-created in miniature by colliding gold atomic nuclei, just as had been done countless times over the 25 years of the detector's existence. Now that era was nearing its end.

Physicist Alex Jentsch took stock of the moment, which he said called for an ambiguous sort of recognition: "Either celebrate or grieve, one of the two."

A whirring fan tousled our hair as we gazed at STAR, an organized tangle of wires, tubes, electronics and particle-detection systems. Above our heads, a surprisingly thin pipe threaded into the machine, the conduit through which atomic nuclei — positively charged ions — were flung to their demise. In the STAR control room, alarms slowly beeped as in a hospital. Scientists flashed the latest collisions on a monitor, fireworks of curving lines in blue, green and cyan.

STAR was designed to capture the aftermath of smash-ups of atomic nuclei traveling at nearly the speed of light, produced by the Relativistic Heavy Ion Collider, or RHIC, at Brookhaven National Laboratory in Upton, N.Y. Now, RHIC (pronounced "Rick") had collided its last beams of gold nuclei as it neared a final shutdown in preparation for a next-generation collider-to-be.

Beginning in the 2000s, experiments at RHIC unveiled the early-universe particle slurry called the quark-gluon plasma. The facility went on to reveal surprising new details of this primordial soup of the universe, from which the particles that make up stars, galaxies, planets — and, eventually, us — descended. And that's just the half of it. RHIC also collided protons, characterizing the subatomic particles in exquisite detail and uncovering the surprisingly tumultuous inner world of these pervasive constituents of matter.

On the day I visited, scientists were switching the collider over to proton collisions in an effort to gather every last shred of data possible before the shutdown. RHIC switched off for good at a ceremony scheduled, as of press time, for February 6.

"RHIC had a spectacular run ... beyond what anyone could dream," says Wolfram Fischer, an accelerator physicist at Brookhaven.

RHIC's closure marks the end for the only particle collider operating in the United States, and the only collider of its kind in the world. Most particle accelerators are unable to steer two particle beams to crash head-on into one another. That's what colliders do, and it makes them a rare and precious commodity. The country's other collider of recent memory, the Tevatron at Fermilab in Batavia, Ill., shut down in 2011.

But RHIC's ending is a hopeful one. It makes way for the Electron-Ion Collider, planned to start up in the mid-2030s. "That's where the future is, and hopefully it will be equally spectacular," Fischer says.

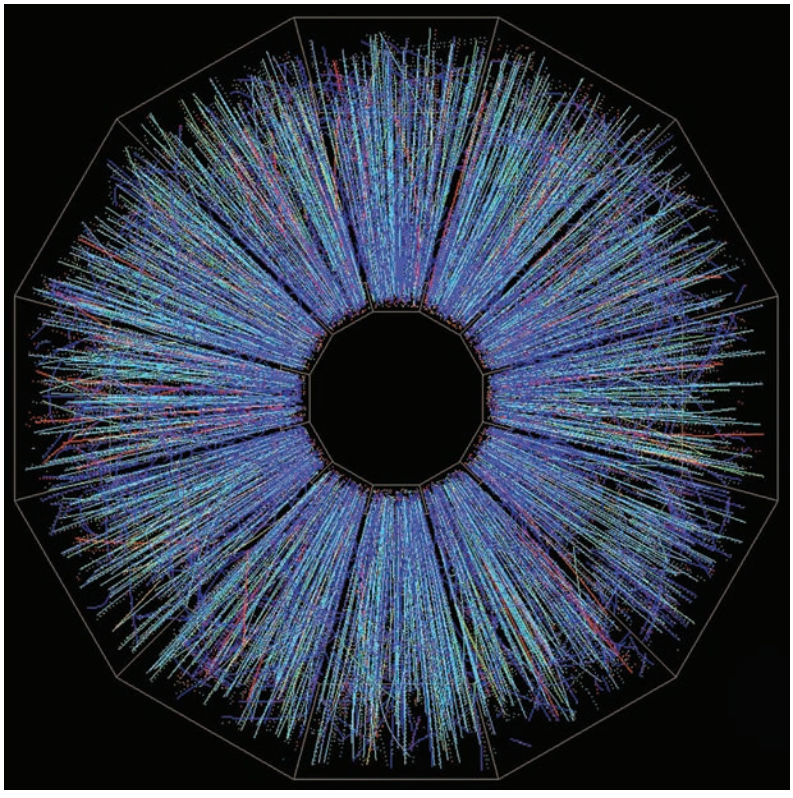
The Electron-Ion Collider will build on RHIC's discoveries. It will occupy the same tunnel and reuse much of RHIC's equipment and infrastructure. But instead of slamming together protons and heavy atomic nuclei, it will collide electrons with protons or atomic nuclei to produce deep insights into the structure of the proton.

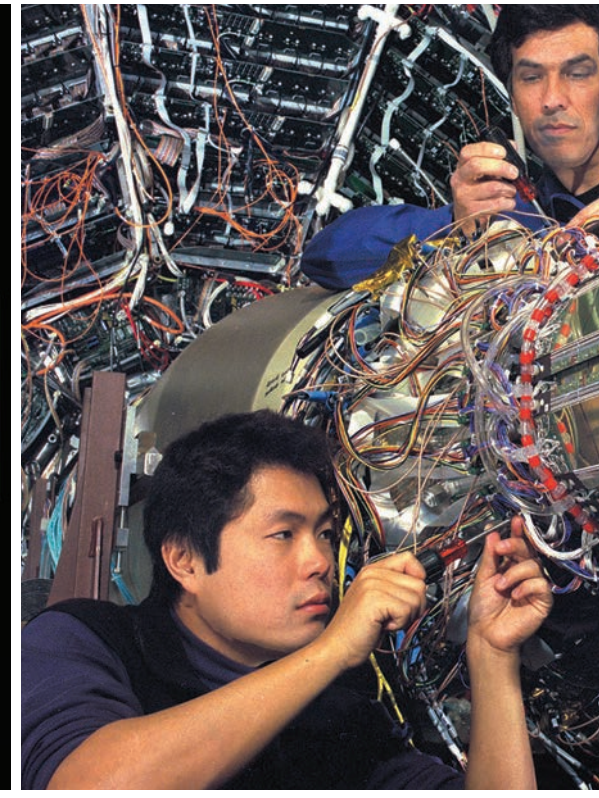
"It is a 3-D imaging of the proton, really in full glory," says Brookhaven physicist Elke-Caroline Aschenauer. The collider may even reveal a mysterious substance called a color glass condensate thought to lurk within protons.

The subatomic rabbit hole

I toured the lab, its detectors and other parts of the facility in early December. I embarked on this journey in part because Brookhaven National Laboratory holds special significance in my life. I grew up not far from the lab, where the collider's 3.8-kilometer ring nestles into the Long Island pine barrens. It's part of how I became enamored with physics, and, eventually, with writing about the field.

As a teen taking part in a student research program at the lab, I was fascinated to learn that protons are not simple balls of positive charge as they were depicted in textbooks. Instead, they are composed





The STAR detector measured particle hits and tracks produced in a collision of gold atomic nuclei.↓

of smaller stuff called quarks and gluons. This was the 1990s, the era of *The Matrix*, and for teenaged me, this proton revelation was my "red pill," as they say in the film: I needed to know how deep the rabbit hole went. As it turns out, it went much, much deeper.

In the simplest picture, protons are made up of three quarks — two "up" quarks and one "down" quark — and particles called gluons, which, true to their name, act like glue. These particles transmit the strong nuclear force, which sticks quarks together within protons, neutrons and other particles.

And that's only a small piece of the immense complexity of the proton. The particles froth with the fervor of quantum mechanics, in which reality is uncertain and fluctuating. As a result, they contain a "sea" of short-lived quarks and their antimatter equivalent, antiquarks, with gluons swarming about them like the dust cloud around *Peanuts* character Pigpen.

The strong force is so strong that quarks and gluons can't be observed individually; they are always bound together into larger particles. "The laws of nature prohibit them from being alone," says Brookhaven physicist Abhay Deshpande.

That is, except during the fleeting existence of the quark-gluon plasma. This state of matter existed just after the Big Bang, when the universe was so hot that a mess of quarks and gluons mingled together. As this particle soup cooled, protons, neutrons and other particles condensed out of it about 10 microseconds after the birth of the universe.

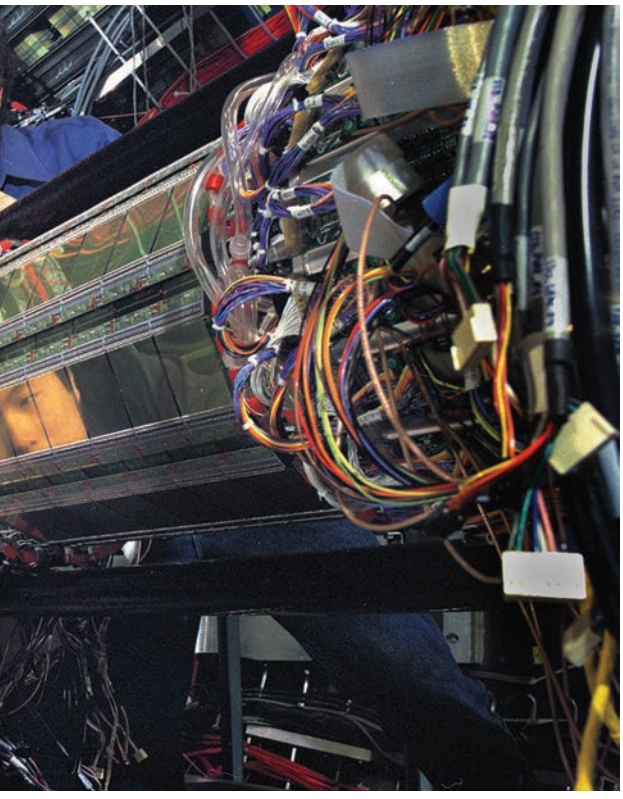
As I was wrapping my teenage head around the existence of quarks, scientists at Brookhaven were trying to re-create this quark-gluon plasma.

The facility stripped the electrons off atoms before slinging them to near light speed, steering them clockwise and counterclockwise in circles using 1,740 powerful superconducting magnets and slamming the particles into one another. The idea was that when heavy atomic nuclei collided, they would produce trillion-degree temperatures that would melt their protons and neutrons into a quark-gluon plasma. Multilayered detectors would then observe the resulting debris, hopefully identifying the fingerprints of the sought-after substance.

In 2005, scientists with RHIC's four detectors — STAR, PHENIX, PHOBOS and BRAHMS — jointly announced the discovery of a new state of hot, dense matter in a special issue of *Nuclear Physics A*. The substance, now confirmed to be quark-gluon plasma, lasted about 10 quadrillionths of a nanosecond and reached trillions of degrees Celsius within a region only about 10 trillionths of a millimeter across.

"That was the first time quarks and gluons were seen, or at least observed indirectly, as being outside of protons and neutrons," Deshpande says. "That was a big deal."

But in a scientific shocker, the state of matter RHIC found was not a gas of free-floating quarks and gluons, as scientists expected the quark-gluon plasma to be. Instead, the quarks and gluons interacted with one another as in a liquid. In fact, RHIC revealed, the quark-gluon plasma is a near-perfect liquid, meaning that it has vanishingly small viscosity and can flow with almost no resistance. "It has a very distinct persona," Deshpande says. "It likes to flow."



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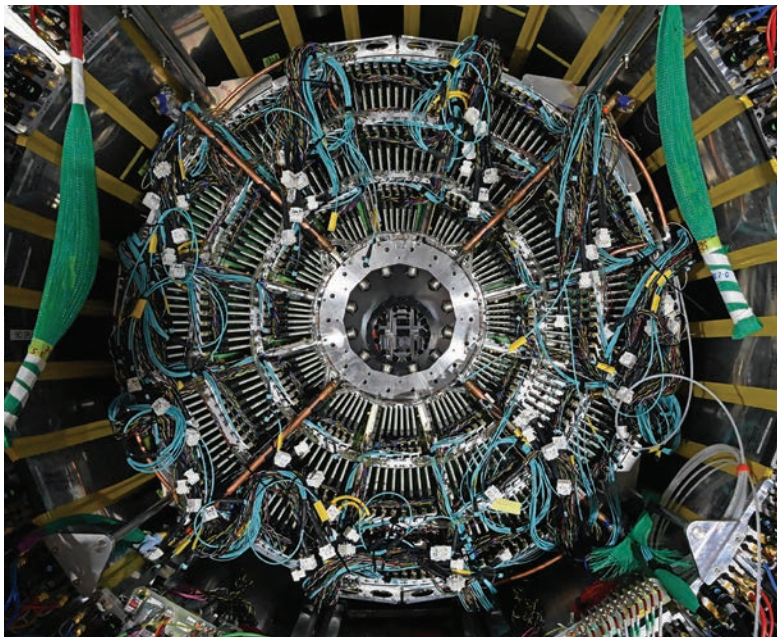
Scientists work on a component of the STAR detector.↓

The rise of sPHENIX

Once they had re-created the quark-gluon plasma, scientists wanted to know more about it. Researchers upgraded their detectors numerous times to better study this fleeting state of matter. The STAR detector has had new pieces cobbled onto it even in recent years. In our visit, newly added components perched on odd platforms, like books teetering on an overloaded bookshelf in a long-inhabited office.

PHENIX researchers chose a different tactic. Instead of continuing to upgrade PHENIX, they decided it was better



↑ sPHENIX, which began operating in 2023, was the newest experiment at RHIC and was designed to be a bridge to the next collider.

KEVIN COUGHLIN/BROOKHAVEN NATIONAL LABORATORY

to start fresh. Scientists knew that RHIC might not continue running much longer, so they designed a new instrument to live fast and die young. In 2023, sPHENIX switched on.

When we visited the three-story detector during my December tour, the contrast with the aging STAR was immediately apparent. If STAR was a well-used pair of hiking shoes — sturdy, comfortable but showing their age — then sPHENIX was a pair of kicks just off the shelf. It was shiny and modern and bright, freshly painted in cornflower blue.

With its new, faster electronics and more sensitive hardware, sPHENIX got cranking. "We've taken more data this year than the entirety of the 25 years of RHIC running," says physicist Rosi Reed of Lehigh University in Bethlehem, Pa.

sPHENIX serves as a bridge to the Electron-Ion Collider. For one thing, the detector used a data-collection strategy that will be essential for the new facility.

Most particle collider detectors generate too much information to store it all. So they record only events that meet certain conditions for being interesting. But then you have to ask, "'What about those things I'm not seeing?'" Reed says.

Components of sPHENIX can collect data nonstop via a method called streaming, throwing nothing away. This is how the entirety of the Electron-Ion Collider's detector will run, a feat made possible by improved computer processing and storage capabilities, as well as AI techniques that will help sift through that multitude of data.

In an office adjoining the hall that houses sPHENIX, remnants of celebratory bagels and cream cheese lay scattered on a table. Not exactly champagne, but I was raised in these parts, so I can clue you in: Bagels are the champagne of Long Island.

sPHENIX still feels fresh, so moving on from it is bittersweet, Reed says. "Nobody ever wants to see the ending of something. I think that we could, if there was more time, do more. But I'm really happy and proud of what we've managed to accomplish."

A spin on protons

In the RHIC control room, another stop on my tour, run coordinator Travis Shrey appeared relaxed, as if swapping out gold nuclei for protons along a 3.8-kilometer accelerator is no biggie. "We didn't plan on running protons this year," Shrey, an accelerator physicist, said nonchalantly. "This is kind of like a last-minute thing." Unflappability is presumably a desirable quality for someone in charge of operations for a machine so big that it's visible from outer space.

RHIC's proton beams are special: They can be polarized. That means the protons, which have tiny magnetic fields, are aligned so their magnetic poles are all pointing in the same direction, like packages with "this way up" signs cruising around a conveyor belt. But the packages are subatomic particles, and the conveyor belt has them zipping at close to the speed of light.

These polarized beams allowed RHIC to investigate the proton in ways never before possible. In particular, they brought scientists closer to resolving a puzzle so vexing to physicists that it was known as a "crisis" when it first came to light in 1987.

At issue is the proton's spin, the quantum property that gives it a magnetic field. Spin is a quantum version of angular momentum, a sort of rotational oomph. That might seem abstract, but it's as important to a particle as its mass or electric charge. Spin comes in either integer or half-integer values

and determines a particle's role. Building blocks of matter, such as protons, electrons and neutrons, have spins of ½ and are known as fermions. Particles that transmit forces, like gluons or photons, have integer spins and are known as bosons. If protons were bosons instead of fermions, atomic nuclei — and the universe as we know it — wouldn't exist.

At first, physicists expected that the quarks, which each have spin of their own, made up the spin of the proton. But experiments indicated that only about 30 percent of the spin was coming from quarks. "That was a bit of a shock," says Jentsch, of Brookhaven. "Where does the rest of it come from?"

RHIC's polarized proton beams revealed that gluons contribute to the spin, making up about 20 to 30 percent. But that still leaves about half of the spin unexplained.

This is where the new Electron-Ion Collider comes in. When it starts up in the mid-2030s, it will provide maps of the positions and momenta of the particles that make up the proton. And that will allow scientists to investigate another potential source of spin. In addition to the intrinsic spins of the quarks and gluons, their swirling motions within the proton may also add to the proton's spin.

The "electron" in the Electron-Ion Collider is crucial here. The collider will use electrons to probe protons, rather than colliding protons with protons. That's a game changer because, while protons have smaller constituents, electrons do not. So an electron is a more precise probe that provides a fine-grained view of protons' inner world.

"You can think about it like an electron microscope," Aschenauer says. "It's really a precision machine which will give us all the secrets of the visible matter which can be unraveled."

Doing that requires a collider that is unlike any built before. The Electron-Ion Collider will have polarized electron beams and polarized ion beams. Polarizing both is not an easy ask: The two types of particles behave quite differently in an accelerator. That means the collider is "everything hard about an electron machine and everything hard about an ion machine," Shrey says. "And then you're going to add them together, so that adds a whole new level of complication. It is the most challenging machine there is."

To construct it, Brookhaven is partnering with Jefferson Lab in Newport News, Va. And scientists are not starting from scratch. RHIC consisted of two rings of equipment for steering, focusing and monitoring the two beams, one of which traveled clockwise and the other counterclockwise through the tunnel. The counterclockwise ring will stay mostly as-is to accelerate the protons and ions. The other will be removed and replaced by a new electron ring. Also remaining in place are the multiple stages of pre-accelerators the protons and ions go through before entering the collider.

Some of the magnets for steering the electron beams will be recycled from an electron accelerator at Argonne National Laboratory in Lemont, Ill., called the Advanced Photon Source, which itself was upgraded in 2024, leaving its magnets up for grabs. The bright yellow, minifridge-sized electromagnets are already at Brookhaven, laid out in rows upon rows in a storage room, like a farm growing an unusual crop.

Components of STAR and sPHENIX will also find new life

RHIC's greatest hits

- **2005** Discovery of a hot, dense "perfect liquid"
- **2010** The liquid's temperature, at 4 trillion degrees Celsius, confirms it is a quark-gluon plasma
- **2014** Gluons are found to contribute to the spin of the proton
- **2015** Discovery that antiprotons attract each other just like regular protons
- **2017** The quark-gluon plasma is deemed to be the "swirliest" fluid ever
- **2021** Discovery that colliding photons, particles of light, may make matter and antimatter
- **2023** Spins of gluons are found to align with the spin of the proton they're inside, further evidence that gluons make up proton spin
- **2024** Discovery of the heaviest antimatter nucleus, antihyperhydrogen-4

in the Electron-Ion Collider's detector. You can think of RHIC's shutdown not as an end, but as a metamorphosis.

The proton's quantum essence

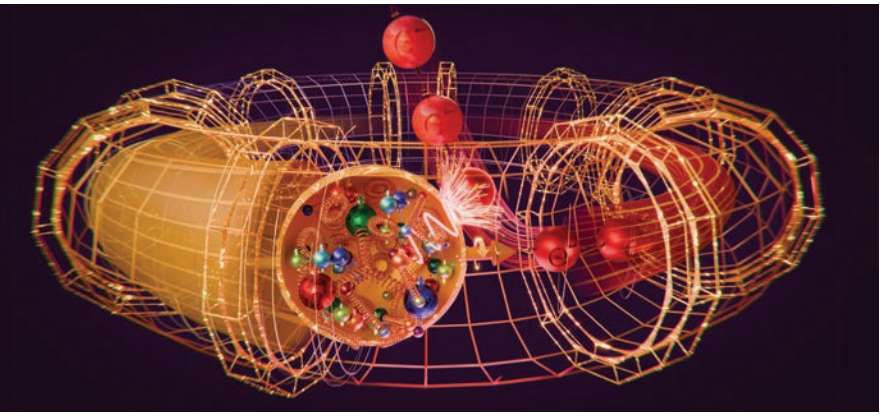
Fittingly, the Electron-Ion Collider could give scientists an even better understanding of RHIC's signature discovery, the quark-gluon plasma.

Some of the biggest uncertainties in studies of the quark-gluon plasma come from unknowns about the initial states of the protons and neutrons within the atomic nuclei that are being collided. So one way to better grasp that state of matter is to understand the proton itself.

Protons are subject to the laws of quantum physics, in which objects don't exist as concrete entities with fixed properties. That feature "really encapsulates the essence of quantum mechanics," says Brookhaven theoretical physicist Raju Venugopalan. "What you see depends on how you probe the object." Like that optical illusion that can appear as either a rabbit or a duck depending on your perspective, scientists get a different view of the proton depending on how they look at it.

When studied at low energies, protons appear as simple, three-quark objects. At higher energies, the sea of transient quarks and antiquarks comes into play. At the highest energies, like those at RHIC and eventually the Electron-Ion Collider, scientists believe the proton becomes clogged with multitudes of gluons, making a dense wall called a color glass condensate.

In the collisions of atomic nuclei at RHIC, it's thought that the gluons of their color glass condensates interacted with one another, producing the quark-gluon plasma. But scientists haven't been able to fully confirm the existence of that color glass condensate or study it in detail. The Electron-Ion Collider could allow that. And that could have repercussions across physics.



The Electron-Ion Collider will fling electrons (matte red) into protons (gold), revealing snapshots of the quarks (multi-colored balls) and gluons (springs) contained within.↓

Protons and the quark-gluon plasma are described by a theory called quantum chromodynamics. The mathematics of that theory are so complex that there's still a mystery behind how quarks and gluons are confined within the proton. How do the gluons of the color glass condensate know how far to extend from the proton's center, for example? Understanding the color glass condensate could shed light on that question of confinement.

Perhaps the weirdest thing about the color glass condensate is that when the gluons condense into these globs, they somehow shake off their quantum nature. "You think of the stuff inside a proton as being this intensely quantum mechanical stuff, right? All these quarks and gluons kind of fluctuating around," Venugopalan says. But, he says, the "globs of glue" that make up the color glass condensate behave like classical, not quantum, objects. That means studying the color glass condensate could also help scientists study where the boundary lies between the quantum world and the classical world, another major quandary of physics.

Exposing the color glass condensate could unveil some of physics' deepest mysteries. "The Electron-Ion Collider, in that sense, is kind of the ultimate machine," Venugopalan says.

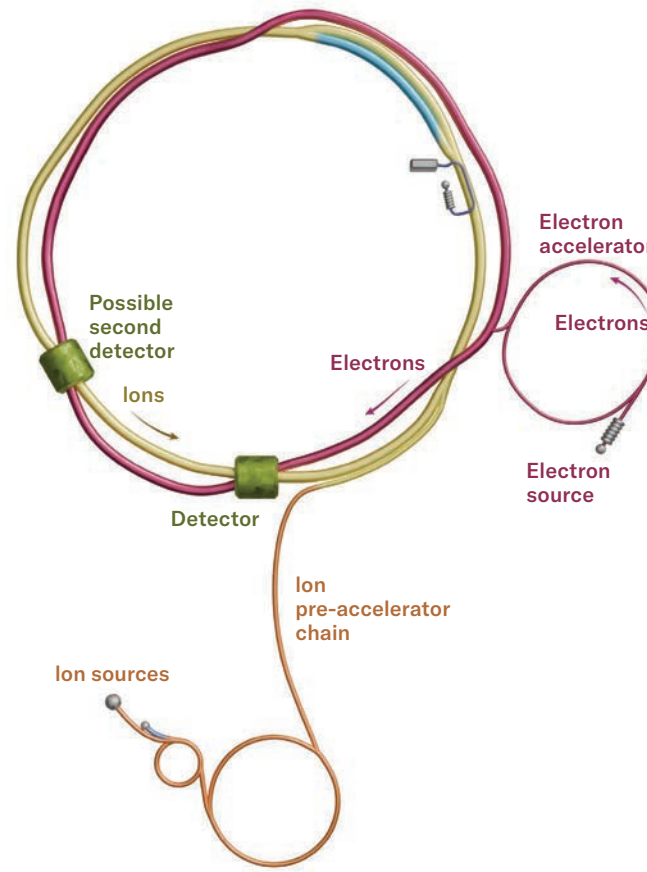
A refuge for curiosity

When I was a senior in high school, we were assigned to write essays about our favorite place in the community. Most people wrote about the beach. A bit cliché, but we did live on an island. I wrote about Brookhaven National Lab.

Before my December trip, though, I hadn't visited the site in decades. Why did I feel compelled to see RHIC one last time? Perhaps it's because I'm still amazed this facility

Protons' appearances vary depending on the energy at which they're probed. At low energies, three quarks (colored balls) appear along with gluons (yellow springs). At higher energies, transient pairs of quarks and antiquarks crop up. At the highest energies, a dense wall of gluons dominates. ↓

In the Electron-Ion Collider, protons and atomic nuclei will be created and pre-accelerated (orange) before being injected into the collider's counterclockwise ring (yellow). The electron beam will be created and accelerated in a separate ring before entering the clockwise ring (red). Particles will collide at one or more detectors (green) that will measure the results. ↓



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existed — a testament to what humans can accomplish when we're allowed to follow pure scientific curiosity. What, exactly, the universe is made of is perhaps the most fundamental information one might want to know. The experiments at RHIC have undoubtedly gotten us closer to that. In the process, they produced more than 600 Ph.D.s (and inspired at least one journalist).

I also wanted to visit RHIC because I'm worried. At this moment in history, when U.S. science funding is being threatened, I fear a facility like the Electron-Ion Collider could be hard to see through to completion. Its construction is expected to cost up to $2.8 billion, with the majority of the money coming from the Department of Energy's Office of Science. When I asked Deshpande about funding concerns at a meeting of the American Physical Society last March, he noted that the project is an international collaboration, with some funding coming from foreign governments and other sources. But, he said at the time, "we are always worried."

And the United States is not the only one at this game. The proposed Electron-ion collider in China, to be located in Huizhou, is earlier in the planning process than the U.S. effort, but if it goes ahead, it's projected to begin operations in the late 2030s.

In my college years, I spent a summer doing research at Stony Brook University in New York, which neighbors Brookhaven and had many scientists working on RHIC experiments. My mentor from back then, physicist Thomas Hemmick, a member of the sPHENIX team, is an optimist. He reassured me: "The track record of DOE Nuclear Physics is that their highest priority for new construction has always been built, and so that gives a lot of confidence to the field." According to a 2023 U.S. Nuclear Science Advisory Committee report, the Electron-Ion Collider is the highest priority. In a statement to *Science News*, a DOE spokesperson expressed excitement about "the possibilities for world-leading science that will be enabled by the Electron-Ion Collider." To Hemmick, the transition to the new collider marks "the birth of hope at the end of an era."

Recently, my teenage niece has begun asking me about physics, delving into the same kinds of deep questions that grabbed my attention as a kid. I hope that the country still has room for a collider that can serve as inspiration for her, and for others of her generation. ✖

← Virologist Chris Buck has been working for more than 15 years to develop vaccines against some cancer-causing viruses at the U.S. National Cancer Institute in Bethesda, Md.

He made beer that's also a vaccine.

Now controversy is brewing

A scientist's unconventional project illustrates the many challenges in developing new vaccines

BY TINA HESMAN SAEY

PHOTO BY STEPHEN VOSS

Chris Buck stands barefoot in his kitchen holding a glass bottle of unfiltered Lithuanian farmhouse ale. He swirls the bottle gently to stir up a finger-breadth blanket of yeast and pours the turbulent beer into a glass mug.

Buck raises the mug and sips. "Cloudy beer. Delightful!"

He has just consumed what may be the world's first vaccine delivered in a beer. It could be the first small sip toward making vaccines more palatable and accessible to people around the world. Or it could fuel concerns about the safety and effectiveness of vaccines. Or the idea may go nowhere. No matter the outcome, the story of Buck's unconventional approach illustrates the legal, ethical, moral, scientific and social challenges involved in developing potentially lifesaving vaccines.

Buck isn't just a home brewer dabbling in drug-making. He is a virologist at the National Cancer Institute in Bethesda, Md., where he studies polyomaviruses, which have been linked to various cancers and to serious health problems for people with weakened immune systems. He discovered four of the 13 polyomaviruses known to infect humans.

The vaccine beer experiment grew out of research Buck and colleagues have been doing to develop a traditional vaccine against polyomavirus. But Buck's experimental sips of vaccine beer are unsanctioned by his employer. A research ethics committee at the National Institutes of Health told Buck he couldn't experiment on himself by drinking the beer.

Buck says the committee has the right to determine what he can and can't do at work but can't govern what he does in his private life. So today he is Chef Gusteau, the founder and sole employee of Gusteau Research Corporation, a nonprofit organization Buck established so he could make and drink his vaccine beer as a private citizen. His company's name was inspired by the chef in the film *Ratatouille*, Auguste Gusteau, whose motto is "Anyone can cook."

Buck's body made antibodies against several types of the virus after drinking the beer and he suffered no ill effects, he and his brother Andrew Buck reported in December on the data-sharing platform Zenodo.org, along with colleagues from NIH and Vilnius University in Lithuania. Andrew and other family members have also sampled the beer with no ill effects, Chris Buck says. The Buck brothers posted a method for making vaccine beer in a separate manuscript in December at Zenodo.org. Chris Buck announced both publications in his blog "Viruses Must Die" on the online publishing platform Substack, but neither has been peer-reviewed by other scientists.

A bioethics office at the NIH objected to Buck posting the manuscripts to the widely used preprint server bioRxiv.org because of the self-experiment and questions about whether it is independent work separate from his role at the agency. Buck wrote a rebuttal to the comments but was loathe to wait for the office's blessing before sharing the data. "The bureaucracy is inhibiting the science, and that's unacceptable to me," he says. "One week of people dying from not knowing about this is not trivial."

Buck's unconventional approach has sparked concerns among other experts about the safety and efficacy of the largely untested vaccine beer. While Buck has promising data in mice that the vaccine works, he has so far reported antibody results in humans from his own sips of the brew.

Normally, vaccines are tested in much larger groups of people to see how well they work and whether they trigger any unanticipated side effects. This is especially important for polyomavirus vaccines because one of the desired uses is to protect people who are about to get organ transplants. The immune-suppressing drugs these patients must take can leave them vulnerable to harm from polyomaviruses.

Michael Imperiale, a virologist and emeritus professor at the University of Michigan Medical School in Ann Arbor, first saw Buck present his idea at a scientific conference in Italy in June. The beer approach disturbed him.

"We can't draw conclusions based on testing this on two people," he says, referring to Buck and his brother. It's also not clear which possible side effects Buck was monitoring for. Vaccines for vulnerable transplant patients should go through rigorous safety and efficacy testing, he says. "I raised a concern with him that I didn't think it was a good idea to be sidestepping that process."

Other critics warn that Buck's unconventional approach could fuel antivaccine sentiment. Arthur Caplan, who until recently headed the division of medical ethics at the New York University Grossman School of Medicine, is skeptical that a vaccine beer will ever make it beyond Buck's kitchen.

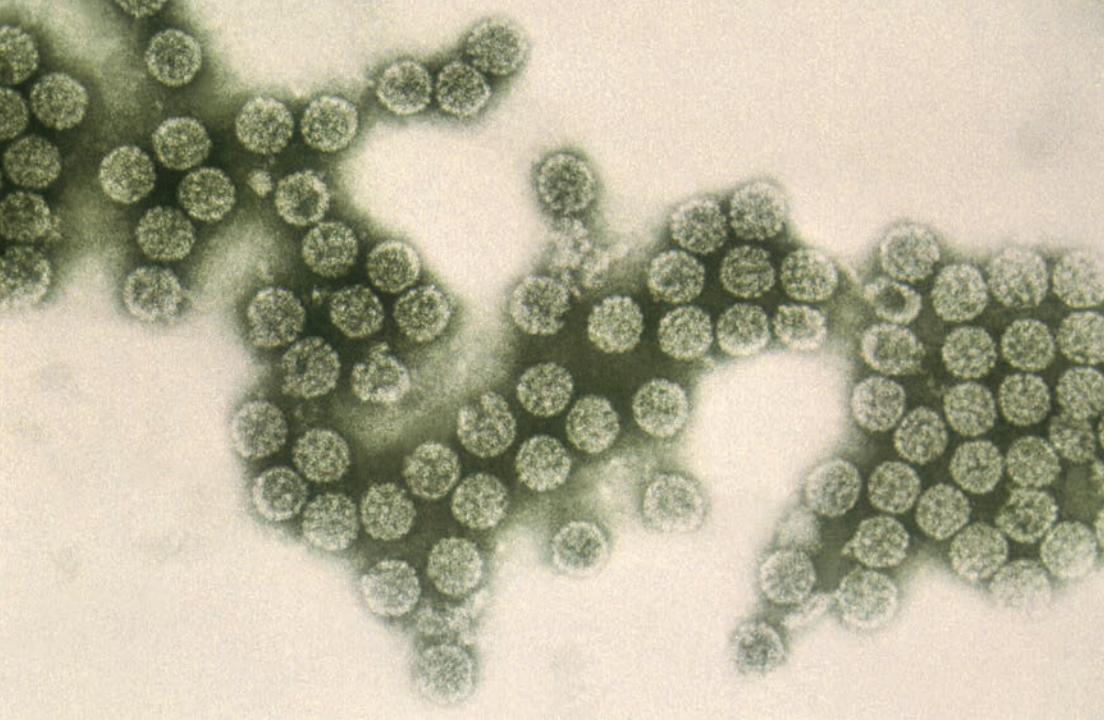
"This is maybe the worst imaginable time to roll out something that you put on a Substack about how to get vaccinated," he says. Many people won't be interested because of antivaccine rhetoric. Beer companies may fear that having a vaccine beer on the market could sully the integrity of their brands. And Buck faces potential backlash from "a national administration that is entirely hostile to vaccines," Caplan says. "This is not the place for do-it-yourself."

But the project does have supporters who say it could instead calm vaccine fears by allowing everyday people to control the process. Other researchers are on the fence, believing that an oral vaccine against polyomavirus is a good idea but questioning whether Buck is going about introducing such a vaccine correctly.

"I'm of two minds on this," says Bryce Chackerian, a virologist at the University of New Mexico Health Sciences Center in Albuquerque. Sometimes the government makes choices about who can take a vaccine based on what age you are or whether you have preexisting health conditions, he notes. "I'm sympathetic to Chris' frustration with those sorts of constraints on vaccine uptake."

Chackerian adds that he personally has no safety concerns about this particular type of vaccine. Still, he says, "I believe in our system of testing vaccines. I think it's really important for making sure that we have safe products that go into people and that we don't undermine the public trust in vaccines."

He calls Buck's approach "a bold choice by him, but interesting and, I would say, not out of character."



← Polyomaviruses like these in a colorized transmission electron micrograph have been linked to some cancers and to kidney and brain damage in people with weakened immune systems.

ERSKINE PALMER/CDC

The painful dangers of polyomaviruses

Buck and his NCI colleagues have been working for more than 15 years to develop an injectable polyomavirus vaccine. Polyomaviruses are icosahedrons (think of 20-sided dice) with surface proteins that have a particular repeating pattern. The immune system views this pattern as "an innate danger signal," Buck says. That makes them attractive vaccine candidates.

Polyomaviruses are everywhere and infect up to 91 percent of people by the time they turn 9 years old. Polyomaviruses are suspected to be involved in bladder cancers. Some evidence suggests these viruses also cause interstitial cystitis, a painful bladder condition in which people have a frequent or urgent need to pee. It affects about 1 to 3 percent of people in the United States. BK is the species of polyomavirus that Buck is developing his vaccine against.

In the blog post announcing the new results, Buck recounts a visit to a pediatric hospital where he learned that children with BK hemorrhagic cystitis screamed so loudly from bladder pain that the hospital had to install soundproofing. "There are screaming children at the back of my mind after that experience," he says.

Transplant recipients may suffer organ damage from polyomaviruses. That happens because transplant recipients take immune-suppressing drugs to prevent rejection of the donated organ. Kidney transplant recipients may lose the organ because their weakened immune systems allow dormant BK polyomavirus in the donor kidney to reawaken and cause damage.

Other transplant patients can develop a brain disease caused by BK's cousin JC polyomavirus. But patients who have high levels of antibodies against polyomaviruses prior to surgery are often protected. Buck says transplant surgeons practically shake him by the shoulders to demand polyomavirus vaccines for patients.

Those patients are part of what spurred Buck's work — and his own experiences drove him to try and make it accessible outside the typical government approval process.

Buck often recounts how a friend was denied the vaccine for human papillomavirus, or HPV, because he was an adult man at a time when vaccine access was limited to adolescent girls. The friend later died of head and neck cancer sparked by that virus. Buck says that withholding vaccines from people who want them is morally equivalent to the evils of the Tuskegee experiment, a deeply racist and unethical program in which Black men with syphilis were denied penicillin so scientists could observe the effects of not treating the disease.

Ultimately, he hopes to win official approval for the yeast-based vaccine from the U.S. Food and Drug Administration. But, he writes in the blog post, "there's a glacial wall of license-wrangling, technical barriers, and impenetrable regulatory bureaucracy between me and the desperate families literally screaming for my help."

The rise of a yeast-based vaccine

Buck's NCI team has been working with a vaccine maker in India that holds the license to a traditional, injectable version of a polyomavirus vaccine that's being tested in animals. That

vaccine consists of BK's outer shell protein, VP1, which is made in insect cells and then purified to strip out all but the viral proteins. These proteins naturally assemble into empty viruslike particles. When injected into rhesus monkeys, the purified particles caused antibody levels to shoot up well beyond a level that may protect against infection, the researchers reported in 2023 in *Vaccine*. The protective response lasted for the length of the study, about two years.

The results were so encouraging that Buck wondered if the vaccine could be delivered in other ways, and if it was really necessary to purify viruslike particles at all. For his virus factories, Buck decided to use *Saccharomyces cerevisiae*, the baker's and brewer's yeast that leavens bread and ferments wines, many beers, chocolate and coffee.

In his lab at NCI, Buck's team sprayed ground-up yeast that make empty polyomavirus-like particles in the noses of mice, scratched it into their skin and fed it to them. Squirting particles up the nose worked, though not as well as injecting purified particles did. Scratching the skin was also effective, Buck and colleagues report in their December papers. But feeding mice ground-up dead yeast didn't work at all.

That's not a surprise, Chackerian says. Oral vaccines against rotavirus, cholera and polio exist, so it's a viable strategy. But in this case, the viruslike particles probably "just fall apart" in the acidic environment of the stomach, he says. Many scientists, including Buck, used to think oral vaccines worked only if they consisted of live, weakened viruses or bacteria that can infect intestinal cells.

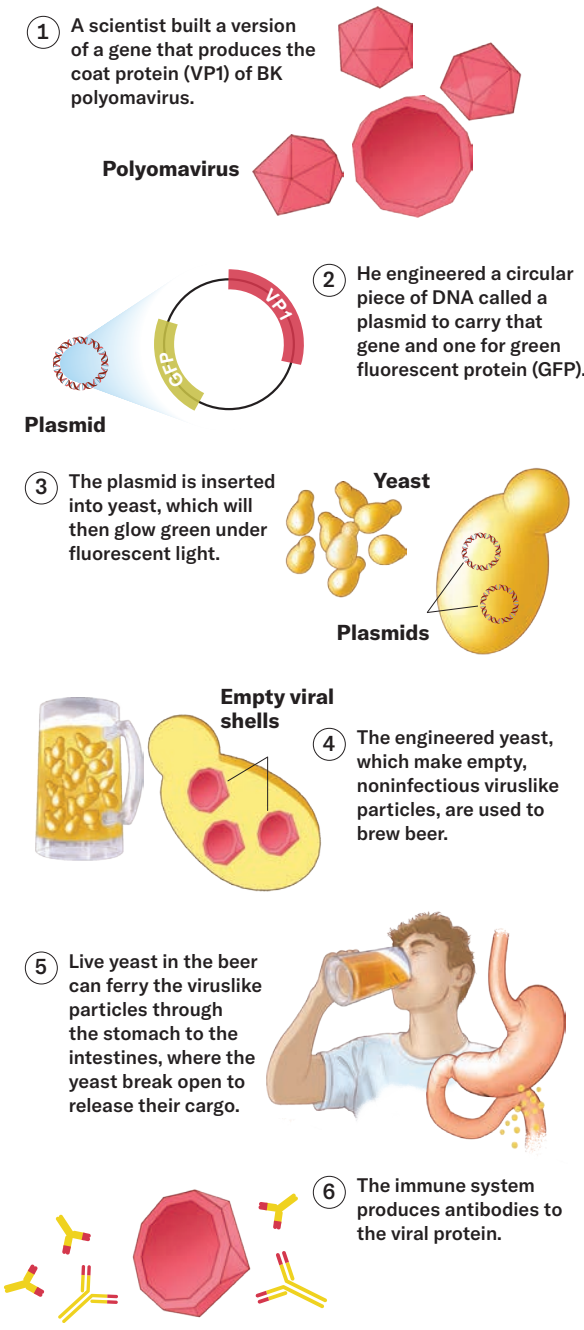
Polyomaviruses are primarily found in the urinary tract. And Buck's group wasn't making a live virus. The yeast produce empty viral shells that can't establish infection. *S. cerevisiae* yeast also do not cause infections in people, so Buck didn't expect an oral polyomavirus vaccine to work.

Just to be thorough, the team fed mice whole, live yeast carrying the viruslike particles mixed with their kibble. The mice "love it and have a party when you give them the food," Buck says.

Live yeast sprayed in the nose didn't work—but the party kibble produced antibodies in the mice. That indicates that if they make it through the stomach, empty polyomavirus-like particles can interact with immune cells in the gut to produce antibodies, Chackerian says. It's also a sign that live yeast might be able to ferry other types of proteins to build immune defenses against other diseases. "That's a very exciting possibility," he says, "because that would potentially mean that his findings aren't just limited to this vaccine."

With a little tinkering, Buck thinks yeast could deliver vaccines against a wide variety of diseases, including COVID-19 and H5N1 bird flu, as well as cancers caused by HPV.

BREWING UP A VACCINE BEER



HREJSA MEDICAL ILLUSTRATION

A seismic shift in making a vaccine

The initial results from feeding mice the live yeast came as a shock even to Buck.

"We repeated this experiment a couple of times. I was reluctant to believe it," Buck said last April at the World Vaccine Congress in Washington, D.C. "It felt like an earthquake when I first saw the results emerging."

The rumbling he felt was triggered by his knowledge of the way food and drugs are regulated in the United States. Buck realized he may not need FDA approval to get a polyomavirus vaccine into the hands of people who might benefit from it. "If you can eat something, you can sell it as a dietary supplement product" or food, he says. Such products are regulated differently than drugs or vaccines.

Vaccine and drug testing involves multiple rounds of clinical trials. These trials typically start with a few hundred people to establish whether there are obvious safety concerns. If there are no safety issues, larger trials involving thousands to tens of thousands of volunteers are conducted. There, scientists look for rare side effects that might not have been apparent in the smaller trial. Bigger trials can also give researchers clues about how well the vaccine works. Even after vaccines are approved, they are monitored for safety.

But Buck envisions vaccine beer as a food first. Food and dietary supplements don't have to undergo multiple rounds of testing. Manufacturers of dietary supplements are supposed to establish their products' safety before selling them, but that might be as simple as feeding samples to a few volunteers. Food and supplement makers also don't have to prove to the FDA that their products work as advertised, although the FDA and the Federal Trade Commission ensure that manufacturers aren't falsely advertising their products as cures for specific diseases.

Buck says the ingredients in his vaccine beer are already part of the food supply, and that the components meet the FDA definition of "generally regarded as safe" for people to eat. In addition, polyomaviruses are shed in massive quantities in urine and are aerosolized with every flush to float in the air and coat every bathroom door handle, so people probably unwittingly breathe in or consume millions of them daily, he says.

And here's where things get sticky. "Vaccines are drugs. We all know this. There's no hiding or costuming of vaccines. You should think of it as a drug," Buck says. "But just because something is a drug does not mean it can't also be a food."

For instance, wormwood has been used for hundreds of years as a remedy against malaria. Nobel laureate Tu Youyou developed its active ingredient into the malaria drug artemisinin. Wormwood can be sold as a dietary supplement or food but by law can't be claimed to treat or prevent malaria. Vague claims, such as "supports immune health," are allowed. But if someone wants to sell a product as both a drug and a food or supplement, the product must first be a food or supplement before being developed as a drug.

Andrew Buck set up a corporation specifically to sell the yeast strains Chris developed and has made sales to two scientists who are friends and supporters. The Buck siblings decided to call their invention "vaccine beer" so people would know its intended purpose even though the siblings don't have irrefutable evidence that it works. "The place that we cannot go is saying that it is effective for any specific disease state," Chris Buck says. "The only way to do that is with full FDA approval" of the yeast as a vaccine.

Stirring up debate about trust in vaccines

Buck drank the first batch a pint a day over five days last May. He followed that with two five-day booster flights seven weeks apart. Buck pricked his finger before and at regular intervals after drinking the beer to measure whether he was making antibodies against the virus. He already had antibodies against one of the four subtypes of BK polyomavirus, subtype I. After he drank the beer containing protein from subtype IV, he was reassured to see levels of antibodies against it and subtype II rise.

Antibodies against subtypes I and II reached the threshold considered protective for transplant patients. Those against subtype IV climbed slowly and didn't make the mark. There are no blood test results from his brother or the other family members who quaffed the beer.

Buck says his self-experiment illustrates that a person can be safely immunized against BK polyomaviruses through drinking beer. But even though Buck produced antibodies, there is no guarantee others will. And right now, people who drink the vaccine beer won't know whether they produce antibodies or if any antibodies they do produce will be sufficient to protect them from

developing cancer or other serious health problems later.

Other scientists familiar with Buck and his yeast project also have conflicting opinions about how it might influence public trust and acceptance of vaccines.

If something were to go wrong when a person tried to replicate Buck's beer experiment, Imperiale worries about "the harm that it could do to our ability to administer vaccines that have been tested, tried and true, and just the more general faith that the public has in us scientists. Right now, the scientific community has to think about everything it does and answer the question, 'Is what we're doing going to cause more distrust amongst the public?' "

That's especially true now that health officials in the Trump administration are slashing funding for vaccine research, undermining confidence in vaccines and limiting access to them. A recent poll by the Pew Research Center found that a majority of Americans are still confident that childhood vaccines are highly effective at preventing illness. But there has been an erosion of trust in the safety of those vaccines, particularly among Republicans.

"Coming up with new modes of administration of vaccines is way overdue," Caplan says. But given all the controversies swirling around vaccines, Buck's do-it-yourself approach could backfire and "take a good idea he has and ruin it," he says. "Vaccine doubts and fears and anti-vaccine attitudes could easily undercut what could be something useful."

Preston Estep, a geneticist and entrepreneur who made his own DIY nasal spray vaccine against COVID-19, disagrees with Caplan's assessment. "Bioethicists and public health officials often say that X, Y or Z is going to erode public trust in vaccines, and they actually don't have any idea either whether or not that's true," says Estep, founder and chief scientist of the Rapid Deployment Vaccine Collaborative, a COVID-19 vaccine research and development nonprofit. The group of scientists and citizen scientists from around the world tested Estep's nasal vaccine on themselves months before COVID-19 vaccines became available, though there is only anecdotal data on its effectiveness.

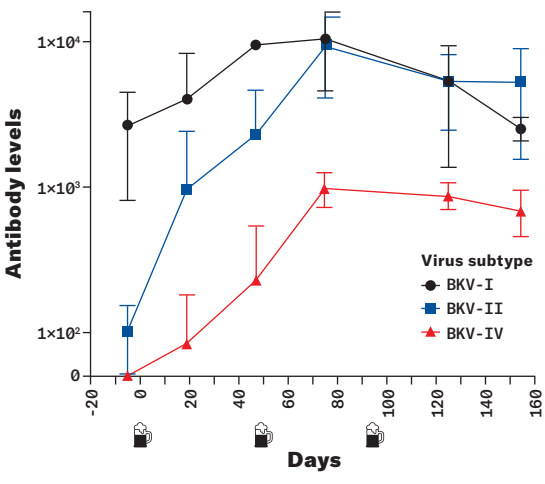
If the vaccine beer proves effective and safe, it could build, not erode, public trust, Estep says. "It allows people to experience vaccines in a really prosaic sort of comfort food or comfort beverage approach." And since Buck's brother is selling yeast that people would need to home brew into a liquid vaccine, "what I argue is that they're not selling a vaccine, they're selling a vaccine factory," Estep says.

Buck says it's more important than ever for people who want protection against diseases to have another option. Even with the Trump administration's "saber-rattling, they cannot stop people from cooking in their own kitchen." It's not ideal to have to home brew your own vaccine, he admits. But "if nothing else works, or if the administration goes bananas and tries to shut it all down commercially, this is what we're going to have to resort to."

Buck feels a moral imperative to move forward with his self-experiments and to make polyomavirus vaccine beer available to everyone who wants it. "This is the most important work of my whole career," he says. "It's important enough to risk my career over." What he's doing in his home lab is consistent with his day job, he adds. "At the NIH, in my contract it says my job is to generate and disseminate scientific knowledge," he says. "This is my only job, to make knowledge and put it out there and try to sell it to the public."

He doesn't see himself as a maverick. "I'm not a radical who's trying to subvert the system. I'm obeying the system, and I'm using the only thing that is left available to me." ✖

ANTIBODIES ON TAP



Chris Buck measured antibody levels in his blood to three subtypes of BK polyomavirus before and after drinking a vaccine beer against subtype IV. Buck previously had antibodies to subtype I. Those levels stayed roughly the same, but antibody levels to subtypes II and IV rose after the initial dose of vaccine beer and two booster flights (indicated by beer steins).

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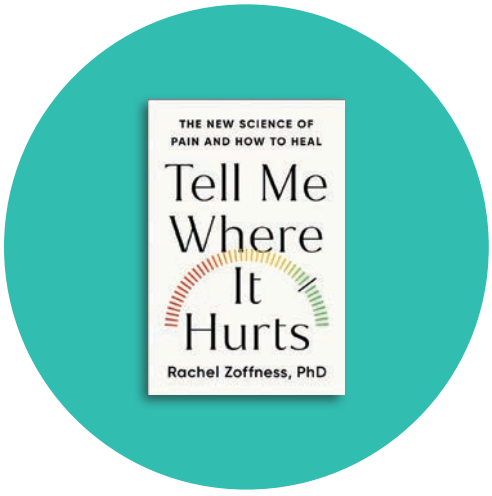
● When Johann Goeze first saw a microscopic water bear, its eight legs adorned with sharp claws, the zoologist wrote: "One can hardly imagine something more horrible than our little creature appearing in the size of a real bear." Centuries later, scientists know the invertebrates, commonly called tardigrades, are nearly invincible — when dormant. Glassifying the gut and slowing metabolism lets them cling to life for decades and even withstand space travel. Too bad human spacefarers can't take a page from the water bear survival guide (see Page 62). — *Cassie Martin*



PAIN IS INCREDIBLY COMPLEX — AND TREATABLE — A NEW BOOK ARGUES

By Laura Sanders

TELL ME WHERE IT HURTS | *Rachel Zoffness*
Grand Central | $30

It's a rare book that both expands an issue into a dizzyingly complex problem and offers to solve it. In *Tell Me Where It Hurts*, pain psychologist Rachel Zoffness pulls off both.

Pain, she argues, has been deeply misunderstood. Sure, pain signals can come from damaged body parts. But that's not the whole story. Through compelling patient stories and clear scientific descriptions, Zoffness leads readers to understand that pain is created by a complicated cocktail of elements, including emotions, trauma, beliefs and social ties. These ingredients can combine to form pain just as eggs, flour, butter and cocoa powder can coalesce into brownie batter. The pain recipe is one of Zoffness' central metaphors that helps convey a variety of scientific explanations. It's a simple approach, but it works.

Consider one ingredient: expectations. To illustrate the power of beliefs in shaping pain, Zoffness tells a tale of two nails. The first nail penetrated a construction worker's boot, leaving the man in anguish. Imaging later revealed the nail between his toes, having missed his foot entirely. The second nail misfired from a nail gun, narrowly missing another man's face — or so he thought. Days later, a toothache took him to the dentist where X-rays revealed the nail had lodged near his right eye. These tales remind us that pain isn't an accurate indicator of bodily harm. Damaged body parts certainly can be painful but the other ingredients matter too. Pain is a biopsychosocial creation, Zoffness writes. Focusing on just biology "means we've been missing two-thirds of the pain problem."

This expansive view of pain sounds grim and impossibly complex. But Zoffness offers a salve: We can control some of the ingredients we use in our recipe. We can choose low-pain ingredients, and this book describes a lot of options. One section offers a menu of behavioral changes, broken down into detailed plans for people in pain and their health care providers.

But the reality is that the United States' health care system isn't set up to handle the complexities of pain, Zoffness says. That's particularly true for chronic pain, which afflicts millions of people. Clinicians are adept at writing prescriptions or recommending procedures. It can be harder to ease a person's chronic pain with strengthening social ties, improving sleep hygiene or finding a therapist who can help address trauma.

Still, *Tell Me Where It Hurts* offers hope. Many paths forward emerge when pain is considered holistically. As Zoffness says, "a whole-person problem requires a whole-person solution." ✖

Through compelling patient stories and clear scientific descriptions, Zoffness leads readers to understand that pain is created by a complicated cocktail of elements.

TRACING THE ARC OF STORYTELLING ACROSS HUMAN HISTORY

By Laura Sanders

THE STORY OF STORIES |
Kevin Ashton
Harper | $32

Back in 1944, two psychologists performed a somewhat mundane experiment. The researchers asked people to simply watch a short film and describe it. Most of the viewers spun elaborate tales involving lovers, violence and abandonment. That's pretty amazing, considering the film featured only shapes: two triangles and a circle that moved in and out of a rectangle.

Our brains, as it turns out, can find a story in anything.

That's the central truth at the heart of *The Story of Stories*. In this wide-ranging book, technologist Kevin Ashton dips into the often strange history of storytelling itself, as he describes the technologies that have evolved alongside these tales and makes the case for why stories matter. It's a compelling effort, particularly today when everyone with a smartphone can be a storyteller.

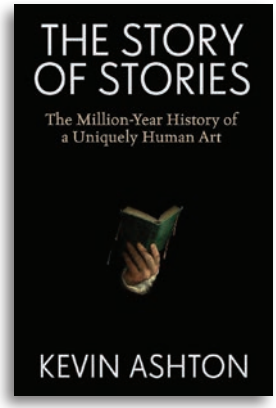
Ashton sets himself an audacious goal of tracing an overarching story of all stories from the earliest tales. Chapter 1 begins with fire, around which our ancestors sat at night. Around these fires, the imperatives of the day's work fell away. "In the warmth and security of their flames, they communicated about events remembered and imagined, from places and times near and far. Or, they started telling stories," Ashton writes.

The chapters that follow offer scattershot history lessons, curious anecdotes of the ways stories have been passed from person to person, and lively descriptions of revolutionary technologies — from the printing press to electricity to Facebook.

Ashton has a knack for pulling out memorable bits from historical records, scientific studies and other sources for readers. For instance, in the mid-1800s in the United States, before paper was regularly made from wood pulp, paper was made from cloth rags. Some of those rags were pulled off Egyptian mummies and stank to high heaven. "Paper mills did not always admit that their 'Egyptian rags' had once wrapped mummies, perhaps for fear of upsetting a delicate public," he writes.

The narrative arc of *The Story of Stories* can at times be hard to follow; readers are occasionally left without a strong anchor line as the book flits from anecdote to anecdote. But stick with it and eventually the soft orange glow of Chapter 1's ancient fires turn blue — the harsh light of smartphone screens.

In the digital age, especially with the ubiquity of social media, "we have gone from a world where a few people could tell stories to a few people, to a world where everyone can tell stories to everyone," Ashton writes. Storytelling (and listening) has reached a fever pitch.



The implications of this expansion are many, and they're certainly not all positive. Misinformation and disinformation about COVID-19 and vaccines spread far and wide during the pandemic. Ashton details how digital lies contributed to some people refusing to get vaccinated, more cases of severe disease and more preventable deaths.

Manipulative stories that convincingly represent fiction as fact — due to generative AI's ability to create realistic fake images, video and audio — continue to spread.

Playing with people's perceptions will become even easier as generative AI gets better at mimicking reality. Will powerful people "rewind time to say things they did not say, and to unsay things they did?" Likely yes, Ashton says. Popular digital platforms "are not shaping the online reality of billions, but reality itself," he writes.

The only way out of this jam is to recognize that our minds are often gullible. That means that vigilance, doubt and humility are the ways ahead, Ashton says.

If that sounds bleak, consider the greater arc of history: While this current age of hatred, as Ashton describes modern online vitriol, is a step back, it is also "a reaction, a backlash, a squeal of dismay, a counterrevolution encouraged and exploited by powerful people."

That reaction is up against a multitude of other narratives. Today's proliferation of stories, Ashton writes, hold power to show "the heterogeneous beauty and glory of all humanity." ✖

Science in Action: Bring Research to Classrooms

Science literacy comes alive when students connect what they read to the people doing the work. Through a partnership between Regeneron and Science News Learning, a sponsored program of Society for Science, students are not only reading about the latest scientific advancements, but they also are meeting the researchers involved and seeing firsthand how STEM curiosity can become a career.

Through the joint program, Scientists to Classrooms, 50 Regeneron scientists visited 36 schools that participate in Science News Learning. During the visits, which took place during the 2024–2025 school year, the scientists reached more than 2,100 students with interactive, discussion-driven presentations. For many teachers, the visits offered a rare opportunity to humanize science and show students that there is no single vision of what STEM looks like in the real world.

"My students gained appreciation for a field of science that they hadn't previously been exposed to," says Tim Renz of Foster High School in Tukwila, Wash. "The combination of computer science and biology really spoke to the students, along with the idea that a scientist doesn't always have to be working at a lab bench."

Several educators noted how powerful it was for students to hear about nonlinear career paths. "My kids always think they need to know what they want to be when they are 18," says Heidi Gleason of Columbia High School in East Greenbush, N.Y. "Our visitors let them know that is not at all the case." Others emphasized the importance of embracing challenges. "The scientists didn't just focus on their successes, but also talked about their trials and failures," says Sarah Kim (pictured left) of Magnolia Academy 6 in Los Angeles. "This is such an important lesson for our students."

The classroom conversations were also meaningful for the scientists. "I love returning to what inspired me to enter this field," says Alexandra Tsoras, Principal Scientist at Regeneron Cell Medicines in Somerville, Mass. "Making science accessible is almost as important as doing it myself. It's a special opportunity to be able to excite and inspire others to one day improve on our work."

Building off the success of last year, the Scientists to Classrooms program will continue this spring.

The Science News Learning program provides middle school and high school students with access to trusted science journalism and classroom-ready resources. The program provides 6,000 schools with print and digital issues of Science News and Science News Explores, along with professional development for educators and lesson plans that link current research to core curricular concepts.

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WE CAN'T SLEEP OUR WAY TO INTERSTELLAR SPACE — YET

BY TINA HESMAN SAEY

Editor's note: This story contains light spoilers for *Project Hail Mary*.

I have long puzzled over something in Andy Weir's 2021 book *Project Hail Mary*: Why did two of the three fictional astronauts die during an interstellar trip? It might be because Weir put his travelers into four-year-long medically induced comas, says Haig Aintablian, an emergency physician and flight surgeon who directs UCLA's space medicine program. "The human body is not designed to just be a stagnant blob," he says. Comatose astronauts would be in danger of deadly blood clots and debilitating muscle wasting from inaction. Infections stemming from tubes and devices required to keep a comatose person alive also would be risky.

So, I wondered, what other ways might people survive interstellar travel?

Frozen, Aintablian suggests. "When the day comes where you could freeze someone and just thaw them, you would have solved the issue," he says.

But the problem may be more than technological. No one knows if human bodies can withstand the physiological rigors of freezing and thawing the way wood frogs do. Human hearts don't function well below about 28° Celsius, says integrative biologist Matthew Regan of the University of Montreal. Some people have survived deeper body temperature dips but only temporary ones, he says, not the years it would take to travel to a distant star.

Maybe hibernating our way to the stars is the answer.

Some small mammals that hibernate, like arctic ground squirrels, drop their body temperatures to below freezing during torpor, when the rodents' metabolism drastically slows. "It's 2 percent of what it usually is," Regan says. "They're just barely ticking over. It's like pilot light levels."

Hibernating bears save less energy, dropping their body temperatures only a few degrees to 31° C or 32° C (around 88° to 90° Fahrenheit). Torpid animals are sedentary but they don't develop blood clots and their muscles don't atrophy, unlike bedridden humans.

If humans could dial back our metabolism even a tad like bears

GLENN HARVEY

do, space voyages would require fewer resources to keep the crew fed, healthy and happy. Torpor may even help protect against ionizing radiation, a big problem for space travelers, Regan says.

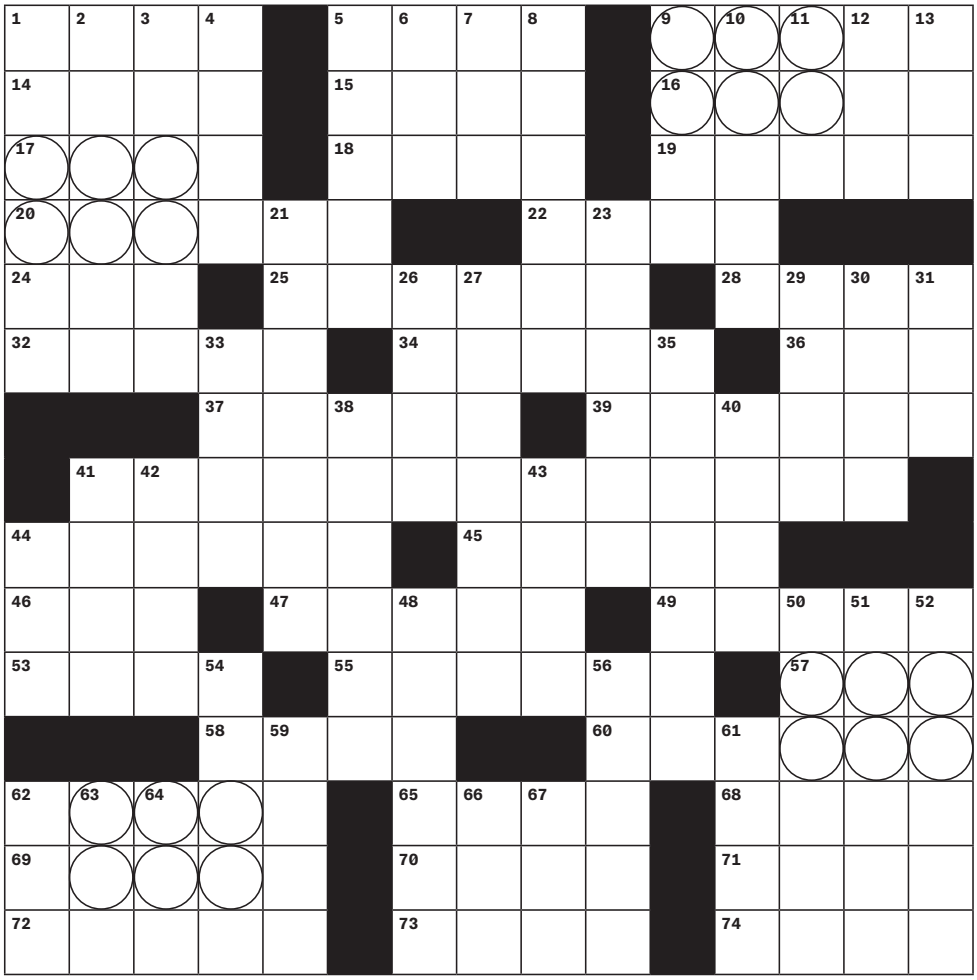
But it probably wouldn't be possible to snooze the whole trip. Every couple of weeks, ground squirrels and other hibernators rouse, rewarming their bodies and moving around. No one is sure why. It may promote muscle regeneration and help the brain stay healthy, says neurochemist Kelly Drew of the University of Alaska Fairbanks.

Humans also may need to wake up to keep their brains sharp and muscles strong. And to eat.

That's because it might not be a good idea to fatten up astronauts before the big trip, says hibernation biologist Hannah Carey of the University of Wisconsin–Madison. Bears that pack on pounds before hibernation develop high levels of cholesterol; the bears recover as their weight dwindles but in humans, that side effect might put astronauts at risk for heart disease.

Some captive ground squirrels in Carey's lab got roly-poly quickly but then died mysteriously during hibernation. "They still had a lot of body fat on them. So it's not that they were running out," Carey says. Perhaps their hearts couldn't take the stress, she suggests.

Still, none of that explains why the astronauts died in *Project Hail Mary*. With the movie adaptation headed to theaters in March, I asked Weir what happened. Their deaths weren't a failure of human biology, he says. "It was a tech failure. I mean, being in a coma for four years is a dangerous proposition in the best of times. So a small tech failure can lead to catastrophic results. Which it did in this case." ✖



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RENA COHEN

ACROSS

1 Occupied with work
5 Rechargeable nicotine pen
9 Some dinner items with shells
14 "That makes sense"
15 Risqué
16 Portend
17 Place for a jet bridge
18 Rhythm instrument
19 ___-Lay (company with corn chips)
20 Dos más dos
22 ___ Quest (VR headset line)
24 Nile serpent
25 Fee for using plastic bags at the grocery store, e.g.
28 Ship part controlled by rigging
32 Set to zero, as a scale
34 Pan or Parker
36 Molecule represented by the bottom row of each block of circled letters
37 One using a 5-Across
39 Relaxed
41 Biological process that copies 46-Across into 36-Across, and is visually depicted four times in this puzzle
44 Like a sharpened pencil
45 Belly button type
46 Molecule represented by the top row of each block of circled letters
47 Excalibur, for one
49 Derrières
53 Emoji that can symbolize solidarity
55 Moniker for someone living down under
57 Talent show part
58 What snoots put on
60 Only kind of whale that is regularly naturally white
62 Class with z-scores and chi-squared tests, briefly
65 Water spigots
68 Brand that sounds like a soccer cheer
69 Oldest of the Hawaiian islands
70 Olympic fencing event
71 Highway hauler, briefly
72 Unease
73 Start of twilight just before sunrise
74 Biblical garden with forbidden fruit

DOWN

1 Lion or tiger (but not a bear!)
2 Patriotic chant
3 Improve one's best time, e.g., for short
4 Throw forcefully, in modern slang
5 Triage expert, informally
6 Self-driving ___
7 Critical hospital dept.
8 Weightlifter's floor cushioning, maybe
9 Only president to have served as chief justice of the United States
10 Migraine harbingers
11 Tech. in many sci-fi films
12 Expose
13 Theater sign letters
21 Insects named for their color
23 Not obligated
26 International oil grp.
27 Hellions
29 The good dinosaur in "The Good Dinosaur"
30 Privy to
31 Elle Woods' field of study
33 Broadway's "Dear ___ Hansen"
35 Person who's no longer minding their business?
38 It may involve playing mind games with an enemy, for short
40 "In ___ of gifts..."
41 Nobelist Morrison
42 Waterways that are an anagram of 58-Across
43 Birth control options, for short
44 Common file type
48 Deposed
50 Badly injured
51 The Sims or Minecraft
52 Have a movie night at home, say
54 Cutesy goodbyes
56 Dramatist Henrik
59 "Really, though?"
61 Come in second, say
62 Reggae precursor
63 sin/cos
64 College move-in mo., for many
66 Citation format, briefly
67 Giant in social science research

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