Into the Unknome | Mulling Muon Magnetism

ScienceNews

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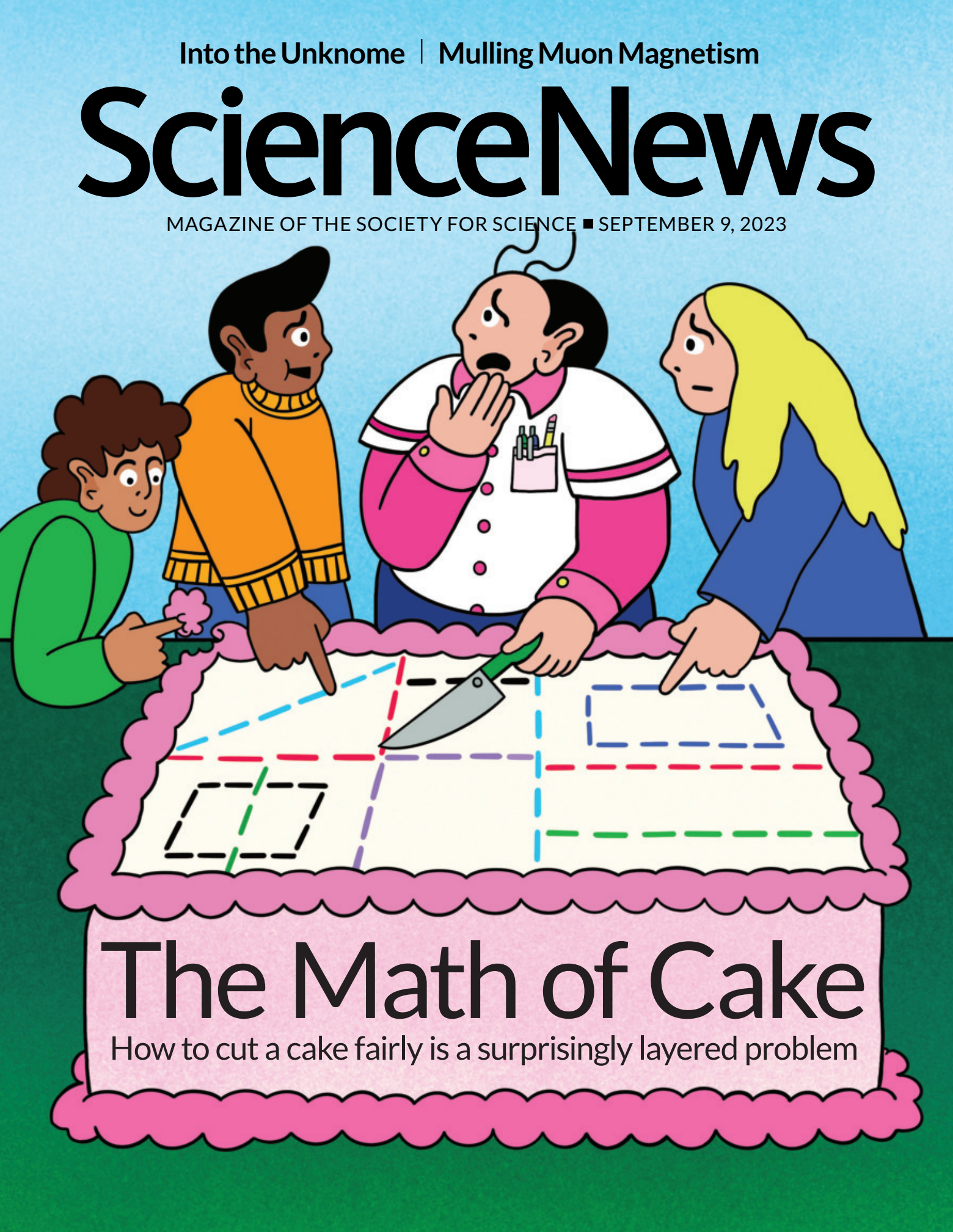

The Math of Cake

How to cut a cake fairly is a surprisingly layered problem

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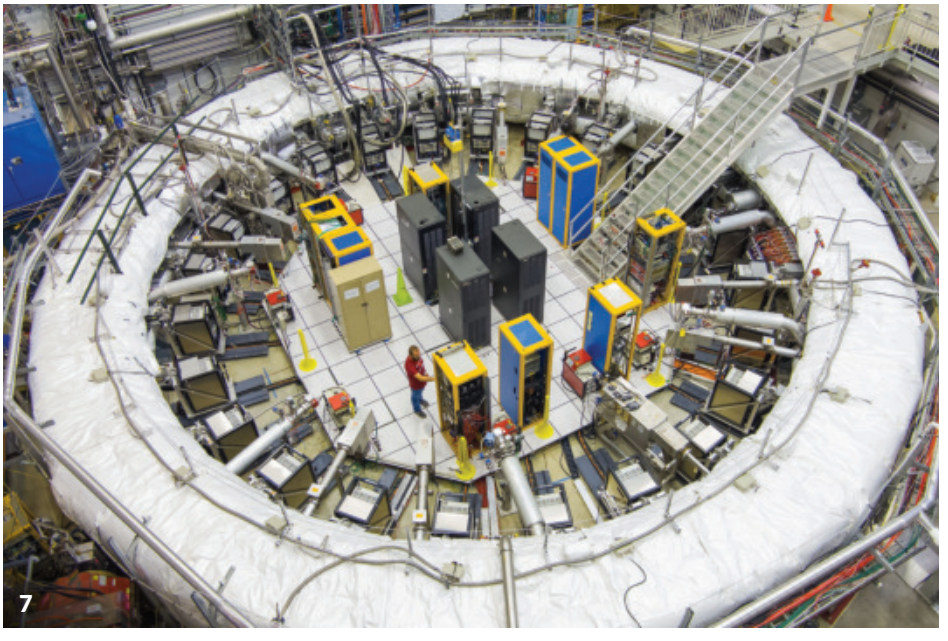
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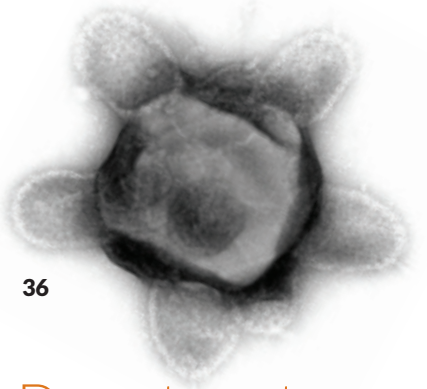
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Departments

COVER Solutions to the cake-cutting problem become more complex as the number of cake eaters grows. *Madeline McMahon*

Sewers provide solutions to public health data gaps

Tracking down the source of a disease outbreak is often challenging, requiring a laborious combination of in-person detective work, laboratory analyses and data crunching. The approach hasn't changed that much since 1854, when physician John Snow identified the source of a cholera outbreak in London by interviewing residents and mapping out where the infected people lived.

Surely there must be another way. There is, and it lies right beneath our feet. Researchers are increasingly turning to wastewater in municipal sewer systems as an efficient, effective way to monitor a community's health and spot outbreaks early on.

The coronavirus pandemic has vastly accelerated the use of wastewater testing for disease surveillance, freelance science writer Betsy Ladyzhets reports in this issue (Page 20). In the early days of the pandemic, scientists were desperately looking for a way to track the virus's movements. They knew that sewage testing was effective in identifying diseases spread through fecal matter but didn't know if SARS-CoV-2, the virus that causes COVID-19, would show up. Researchers in the San Francisco Bay area gathered sewage samples and compared the data with reported cases. They matched.

Since then, there's been an explosion of interest in the use of wastewater testing to track COVID-19, a data source that has become increasingly important as people rely more on at-home tests that aren't reported to public health agencies. Scientists have also tested wastewater to track the emergence of mpox in the United States (it worked) and are investigating whether sewage surveillance might be useful in guiding public health decisions on a host of other infectious diseases, from chicken pox to Lyme disease.

Fans of public health history will know that sewers have played a starring role in infectious disease management for centuries. The Romans, for example, started building sewers in the sixth century B.C., mainly to drain swamps and remove floodwaters. By the 19th century, urban areas in Europe and the United States had grown to the point where they were struggling to efficiently remove human waste without further contaminating the rivers and wells that provided drinking water. Civil engineering became a science, and London, Paris, Chicago and other cities invested vast sums in building sewer systems. Many of those systems remain in use today.

In a recent episode of *Ted Lasso*, the fish-out-of-water American coach takes his floundering English soccer team on a tour of London's Victorian-era sewers. A discussion ensues underground on the Great Stink of 1858, during which the scent of the sewage-clogged Thames became so rank that politicians in the new Parliament building allocated 3 million pounds to building a sewer system.

Coach Ted uses the sewers of London as a metaphor to help his players manage external criticism and internal self-doubt: Stink happens, you gotta let it flow and get on with your business. That metaphor may be a wee bit strained, but I relished seeing a great moment in municipal sanitation history get its due. And I'm glad that we can update you on the latest scientific efforts in using stinky sewers to fight disease. —*Nancy Shute, Editor in Chief*

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SOCIETY FOR SCIENCE

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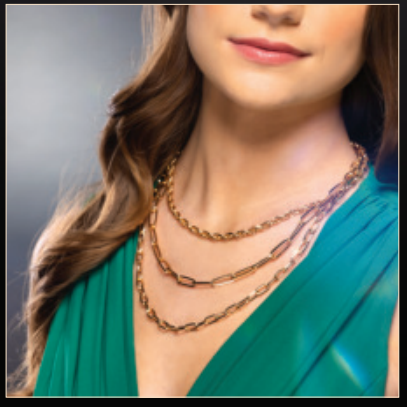

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Excerpt from the September 8, 1973 issue of *Science News*

50 YEARS AGO

Searching for superheavies

Physicists and chemists have been actively searching for superheavy elements, substances with atomic weights and numbers greater than the 105 [elements] now known. Results of two searches are reported… none were found…. Future searches will have to involve direct fusion of heavy nuclei by driving one against another in heavy-ion accelerators.

UPDATE: Particle accelerators have been crucial for creating superheavies beyond elements 104 and 105. Just a year later, element 106, seaborgium, emerged from collisions of oxygen ions and californium atoms — though its discovery wasn't officially confirmed until two decades later (*SN: 3/19/94, p. 180*). Elements 107 through 118 have since made their debut, with several joining the periodic table as recently as 2016. Scientists are now trying to create elements 119 and 120 (*SN: 3/2/19, p. 16*). Forming heavier elements and pushing known superheavy-weights to their limits could reveal insights into the forces that bind atoms together and the bizarre chemistry of the most extreme elements.

This bird nest, built by a Eurasian magpie, is one of five throughout Europe adorned with sharp spikes.

THE SCIENCE LIFE

Some birds fortify their nests with antibird spikes

It's the *Mad Max* dream of a bird's nest: a menacing composite of metal, clay, twig and plastic.

Spotted in a sugar maple tree in Antwerp, Belgium, the gnarly architecture brims with at least 1,500 long, sharp antibird spikes pointing outward. "That is really like a bunker for birds," says biologist Auke-Florian Hiemstra. "Like this fortress which cannot be taken."

The nest is one of five found in Europe, each one decorated with antibird spikes, Hiemstra and colleagues report July 11 in *Deinsea*. The pointy strips of bird-deterrent materials normally line eaves in cities around the

A-F. HIEMSTRA

SAY WHAT?

Unknome \un-nohm\ n.

A database that ranks proteins by how little is known about them

When it comes to vast, underexplored frontiers, space and Earth's oceans come to mind. But even in human bodies, there's still much to be discovered. Meet the "unknome," a new publicly available database that highlights how much we still don't know about human genes and proteins. By ranking groups of proteins by how little is known about them, the database could help scientists find proteins for future study, including for disease treatment and drug discovery, researchers report August 8 in *PLOS Biology*.

Cell biologist Sean Munro and colleagues compiled the unknome — a portmanteau of the words *unknown* and *genome* — to identify understudied but potentially important proteins and the genes that code for them. The database contains all protein families with at least one protein found in humans or 11 other commonly studied organisms. Over 13,000 groups and nearly 2 million proteins are included. Each group is assigned a "knownness" score based on how much is known about corresponding genes. Some 3,000 groups, including 805 that contain at least one human protein, have a score of zero.

Out of 260 low-scoring genes shared by fruit flies and humans that the team studied, 62 are essential for life in flies. Others are important for reproduction, growth, movement and resilience to stress, says Munro, of the Medical Research Council Laboratory of Molecular Biology in Cambridge, England. Whether those genes have similar effects in humans is unknown. — *Skyler Ware*

world. Now, they line the homes of some birds.

The study started when a hospital patient in Antwerp looked out his window and saw the nest in question. He contacted Hiemstra, who researches nests and plastic pollution at Naturalis Biodiversity Center in Leiden, Netherlands.

After breeding season, Hiemstra and colleagues traveled to collect the nest and take it back to the lab. As he wrote up his observations, other people tipped him off to four more similar nests in cities in the Netherlands and Scotland.

The nests belonged to carrion crows (*Corvus corone*) and Eurasian magpies (*Pica pica*). The crows used the spikes as part of the structure of their nests (*SN: 6/18/22, p. 5*). But Hiemstra suspects that the magpies employed the materials much as they were originally intended: to ward off other birds.

Since Eurasian magpies are relatively small, they create domed roofs over their nests to protect their eggs and hatchlings from avian predators. Magpies often adorn the roofs with thorny branches for extra protection. But in large cities, spiny vegetation is harder to come by, so the birds innovate with whatever materials are available, such as nails, screws or even knitting needles. Antibird spikes, the team says, serve as the ultimate Anthropocene replacement (*SN: 8/12/23, p. 16*).

Nests belonging to a carrion crow (left) and a Eurasian magpie (right) contain spikes typically used to deter birds from landing on buildings. The crow also used antibird netting in its nest.

The observations are "fascinating," says Zuzanna Jagiełło, an ecologist at the University of Warsaw who was not involved in the research. But the claim that the Eurasian magpies use the spikes to deter predatory birds needs to be verified with experiments and field observations, Jagiełło says. "It's a starting point to explore [the phenomenon] more deeply."

Already, Hiemstra has received reports of other nests made with the spiky material, leading him to believe that the construction may be relatively common. With enough nests, his team might be able to determine whether the spikes improve the survival of young birds that call the nests home.

Still, amid the scientific excitement, Hiemstra can't help but laugh. "I just love the irony of it all," he says. "It's just the perfect comeback of the birds."
—Luis Melecio-Zambrano

THE –EST

A colossal ancient whale might give the blue whale a run for its money

Move over, blue whales. There could be a new heavyweight champ in town. Fossilized vertebrae and ribs from a newfound ancient whale suggest that the creature could have outweighed modern blue whales, paleontologist Eli Amson and colleagues report August 2 in *Nature*. If so, the extinct whale would be the heaviest animal ever known.

The 39-million-year-old behemoth, *Perucetus colossus*, is a relative of modern whales, dolphins and porpoises. And its bones were massive. *P. colossus*' skeleton alone could have weighed about five to seven metric tons, two to three times as much as a blue whale's skeleton, the researchers estimate.

The extinct whale *Perucetus colossus* might have weighed up to 340 metric tons, edging out the blue whale for the title of heaviest known animal. But some scientists are skeptical it could have sustained that mass.

The fossils, found in southern Peru, were "clearly something exceptional," says Amson, of the State Museum of Natural History in Stuttgart, Germany. Scientists unearthed 13 vertebrae, each weighing more than 100 kilograms. Such heavy bones are consistent with a shallow-diving lifestyle, the team says. Deep-diving whales have lightweight skeletons so they can come up for air without working too hard. The massive bones of *P. colossus* might have helped it hover at shallow depths by balancing the buoyant force from air in its lungs.

Accounting for soft tissue, the team estimates that *P. colossus* could have weighed roughly 85 to 340 metric tons. For comparison, blue whales (*Balaenoptera musculus*) weigh about 100 to 190 metric tons.

Paleontologist Nicholas Pyenson of the Smithsonian National Museum of Natural History in Washington, D.C., is skeptical that *P. colossus* could have reached 340 metric tons. Without a skull, it's hard to know what the whale would have eaten to sustain such an enormous size, Pyenson says. Amson hopes to find a more complete specimen to answer that question. *—Skyler Ware*

CLOCKWISE FROM TOP: KEES MOELIKER; A.F. HIEMSTRA; ALBERTO GENNARI

PALEONTOLOGY

Fires may have doomed ancient beasts

A drying climate and humans transformed Southern California

Fossils from the La Brea tar pits, including of saber-toothed cats (left) and dire wolves (right), record an extinction event 13,000 years ago.

BY JAKE BUEHLER

By about 11,700 years ago, most large land mammals outside of Africa had gone extinct. Scientists have long debated whether these extinctions were primarily driven by human activities or a changing climate as the last ice age came to a close (SN: 3/22/14, *p.* 13).

A new study of the remains of animals trapped long ago in the La Brea tar pits, in what's now Los Angeles, suggests both factors worked in concert to bring about the demise of the region's megafauna. A warming, drying climate plus humans' hunting and burning of the landscape led to large fires that precipitated die-offs there around 13,000 years ago and forever changed the ecosystem, researchers report in the Aug. 18 *Science*.

The findings "reflect the reality of nature, which is that phenomena are rarely, if ever, driven by a single factor," says paleoecologist Danielle Fraser of the Canadian Museum of Nature in Ottawa.

The type of climate-human synergy implicated in the demise of some of California's biggest ancient mammals may warn of dramatic upheaval in modern ecosystems that are subjected to human-caused climate change, the scientists say. Over the last century, Southern California has warmed more than 2 degrees Celsius on average. That's a far more rapid change than the area faced during the end of the last ice age.

Paleontologist and evolutionary biologist F. Robin O'Keefe and colleagues had been studying the remains of ancient carnivores preserved in La Brea's asphalt seeps to see how the animals had physically changed over thousands of years. Then the researchers found evidence of an extinction event in the tar pit fossil record.

"We had lots and lots of megafauna, and then suddenly they were gone," says O'Keefe, of Marshall University in Huntington, W.Va.

The researchers dated the remains of 172 individuals representing eight megafauna species that lived from about 10,000 to 15,600 years ago. The sample included extinct species like saber-toothed cats (*Smilodon fatalis*), dire wolves (*Aenocyon dirus*) and ground sloths (*Paramylodon harlani*), and a single still-living species, the coyote (*Canis latrans*). Sure enough, about 13,000 years ago, seven of the eight species vanished from the tar pit fossil record, the team found.

To understand what was going on in the environment back then, the team turned to a sediment core from nearby Lake Elsinore. The core records regional vegetation, fire frequency and climate changes over tens of thousands of years. O'Keefe and colleagues also compared the extinction timing with a computer model of human population growth in North America.

Over the millennium preceding the extinction, the region warmed by nearly 6 degrees, the core revealed. The area dried out, with juniper and oak woodlands giving way to more drought- and fire-tolerant plants. Soon after this shift started, Southern California experienced a 300-year stretch of intense fires, evidenced by a spike in charcoal in the core.

Right before the burning started, human populations rapidly grew, according to the computer model, suggesting the two events are linked.

What's more, the changing climate and human activities transformed the region's woodlands into chaparral scrubland. It's a vicious feedback loop, O'Keefe says. Hunting herbivores makes the ecosystem more fire-prone as plants go uneaten. "You add more people and it gets hotter and drier, and you're killing more herbivores. So there's more fuel [to burn]," he says.

The seven extinct megafauna species vanished from Southern California about 1,000 years before they did elsewhere in North America. Those other populations may have met a similar end, the scientists say. "There is evidence for a continent-wide event, not just in Southern California but across the continent right about at the same time," O'Keefe says.

Paleoecologist Sandra Brügger of the University of Basel in Switzerland notes that similarly rapid ecological transformations have been documented in the Mediterranean and a broader swath of the U.S. West at the end of the last ice age.

The new findings, O'Keefe says, are a cautionary tale relevant to the survival of modern biodiversity. He points to recent intense fires in Hawaii, the U.S. West and Canada (SN: 8/12/23, *p.* 6). "The parallels are certainly there. The one thing that's different about today is that we know what happened before, and if we can learn something from that, maybe we can change our trajectory." ■

NATALIA KENT, COURTESY OF NHMLAC

PARTICLE PHYSICS

Data confirm muons' weird wobbles

Experiment highlights confusion over theoretical predictions

BY EMILY CONOVER

Muons might not behave as expected. But scientists can't agree on what to expect.

By taking stock of how the subatomic particles wobble in a magnetic field, physicists have pinned down a property of the muon's internal magnet to greater precision than ever before, researchers from the Muon g–2 experiment reported August 10 in a seminar hosted by Fermilab in Batavia, Ill.

Previous measurements of muon magnetism haven't aligned with predictions from the standard model of particle physics, which describes subatomic particles and the forces that bind them.

Many physicists have hoped that the muon discrepancy might be hinting at a flaw in the stalwart theory that could lead to a better understanding of the universe. But recent scientific surprises have muddled the theoretical prediction of the strength of the muon's magnet, making it harder to know how the new and old measurements, which agree with one another, compare with theory.

Muons are short-lived particles that behave like miniature magnets, each with their own magnetic field. The strength of that magnet is adjusted by a strange effect of quantum physics. Empty space is filled with a constant flurry of particles that appear temporarily before flitting out of existence. Known as "virtual" particles, they have very real effects. These transient particles alter the strength of the muon's magnet by an amount that can be calculated according to the standard model.

The precise value of this tweak — the anomalous magnetic moment, or "g–2" — is what has befuddled physicists. Tantalizingly, particles unknown to science could shift g–2's measured value. So hints of a disagreement with predictions have generated a hubbub. "The muons' behavior that we're measuring is affected by all of the forces and particles in the universe," says Muon g–2 researcher Brynn MacCoy of the University of Washington in Seattle. "It's basically giving us this direct window into how the universe works."

The first indication of a mismatch between prediction and measurements came from an experiment completed more than two decades ago. Then in 2021, the Muon g–2 experiment, based at Fermilab, reported results confirming the discrepancy.

Now, Muon g–2 has doubled its precision in an updated measurement. "To reach that level of precision is really unprecedented," says physicist Carlos Wagner of the University of Chicago. "I am simply in awe." The measurement incorporates four times as much data as the previous one, among other improvements.

Scientists aim to compare the measured value with the standard model prediction. But determining what, exactly, the standard model predicts is complicated.

In 2020, a group of theoretical physicists, the Muon g–2 Theory Initiative, came to a consensus prediction. But since then, contradictory information has come out from other experiments and theoretical calculations, leaving the prediction uncertain.

The confusion hinges on a bit of the g–2 calculation known as the hadronic vacuum polarization, which refers to the adjustment resulting from a virtual photon emitted by the muon that splits into a quark and its antimatter partner, an antiquark. Quarks make up particles called hadrons, including protons and neutrons. The quark and antiquark interact before annihilating back into a virtual photon.

The conventional way of calculating this hadronic vacuum polarization term involves using experimental data measuring how electrons and their antimatter particles, positrons, collide and produce hadrons. The results of such experiments are thought to be well understood.

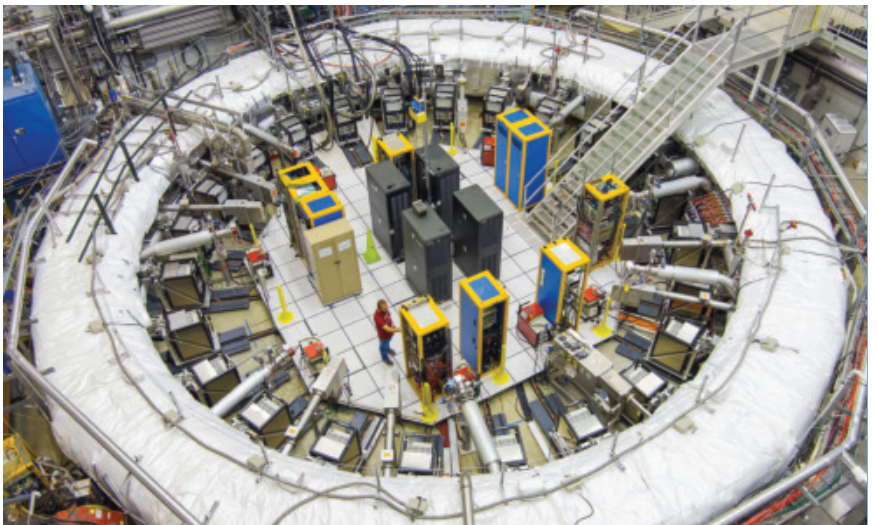
But an experiment at the VEPP-2000 particle collider in Russia disagrees with those other experiments, researchers reported in February at arXiv.org. If this outlier is correct, the hints of disagreement between muon measurements and prediction might be weaker than thought.

In 2021, a research group in Europe published in *Nature* an estimate of the hadronic vacuum polarization using a different method, called lattice quantum chromodynamics. That technique involves mathematically splitting up spacetime into a grid to make calculations more tractable. The estimate pointed to a closer harmony between the prediction and measurements of g–2.

So the focus has now shifted from scrutinizing the experimental measurements to analyzing the disagreement among theoretical techniques.

"The experiment has delivered," says theoretical physicist Thomas Teubner of the University of Liverpool in England, a member of the Muon g–2 collaboration. To figure out if muons are keeping with the standard model or cracking it, it's up to the theoretical physicists, he says. "We have to get our house in order." ■

Physicists have made the most precise measurement of a magnetic property of muons by studying how the particles wobbled as they circled within this doughnut-shaped magnet at Fermilab.



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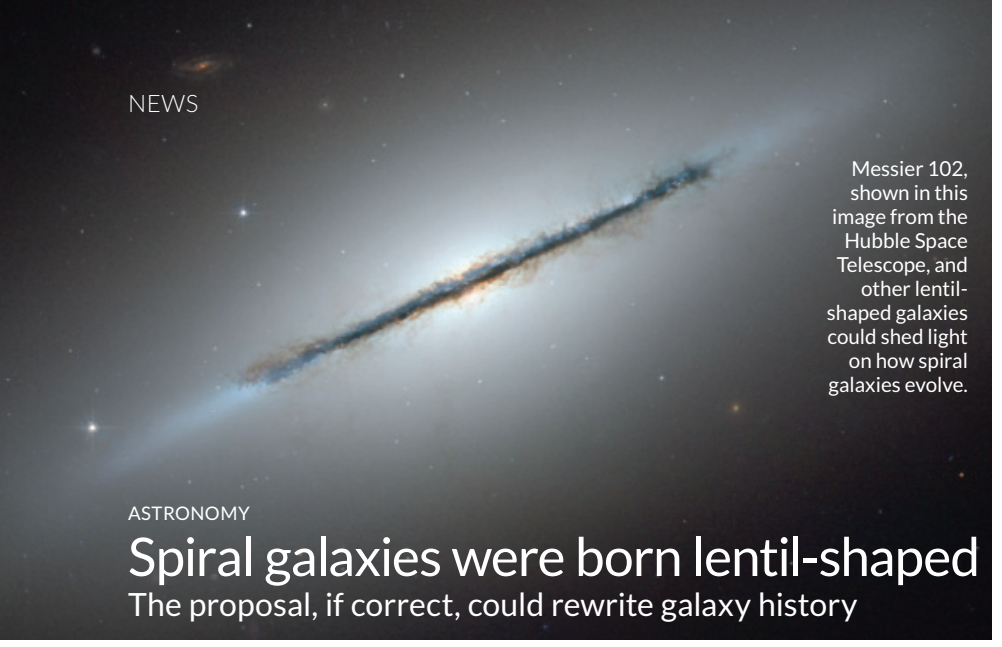


Messier 102, shown in this image from the Hubble Space Telescope, and other lentil-shaped galaxies could shed light on how spiral galaxies evolve.

ASTRONOMY

Spiral galaxies were born lentil-shaped

The proposal, if correct, could rewrite galaxy history

BY ELISE CUTTS

The Milky Way might have once looked more like a legume than a starry whirlpool.

Over their unfathomably long lifetimes, spiral galaxies like the Milky Way are generally thought to morph into lentil-shaped "lenticular" galaxies and then into elliptical blobs. But an analysis of nearby galaxies suggests that our galaxy, and others like it, was once lenticular, astronomer Alister Graham reports in the July *Monthly Notices of the Royal Astronomical Society*. If correct, Graham's proposed update to the evolutionary sequence of galaxies would rewrite the history of the Milky Way.

"Lenticulars have always been sort of the abandoned stepchild of [galaxy] morphology," says astronomer Christopher Conselice of the University of Manchester in England. But this paper puts them into focus, he says, as being a major aspect of how galaxies change.

Lenticulars get their name from the way their entire halo of stars, when viewed edge on, bulges in the middle and thins out toward the sides, much like a double-convex lens — or a lentil. These galaxies exhibit a confusing mix of properties that has made their presumed place in the middle of galaxy evolution sequences rather suspect. "We've known for a while that that's almost certainly not correct," Conselice says.

Particularly puzzling is that lenticular galaxies have a lot less star-forming gas than spiral galaxies do, despite both types having starry disks. What exactly is responsible for the difference isn't well understood. Graham, of Swinburne University of Technology in Hawthorn, Australia, found new clues to this mystery of galaxy evolution by considering black holes.

Most galaxies harbor a supermassive black hole in their center, and when galaxies merge, so do those black holes. This makes the mass of a galaxy's black hole a kind of record of its past collisions. If a galaxy got big by gobbling up its neighbors rather than by sucking up surrounding gas, Conselice says, then its black hole should be hefty relative to the swarm of stars that surrounds it.

Using images from the Hubble and Spitzer space telescopes, Graham compared the black hole masses and stellar masses of about 100 nearby galaxies. For galaxies of the same shape, black hole mass and stellar mass tend to be linked in a predictable way — except for the lenticular galaxies.

When Graham took a closer look at the lenticulars, he realized they are actually two distinct groups that had been lumped together: those that have a lot of interstellar dust and those that do not. This division, which he previously reported in the May *Monthly Notices of the Royal Astronomical Society*, could have been a superficial aesthetic difference. But the galaxies' black hole masses suggest otherwise.

Dust-poor and dust-rich lenticulars have entirely different relationships between their black hole masses and stellar masses. That suggests different histories and explains the apparently scattered behavior of lenticular galaxies.

Dust-rich lenticular galaxies tend to have heftier supermassive black holes than the ones found in both spirals and dust-poor lenticulars. Dust-poor lenticulars are usually on the small side in terms of both black hole mass and stellar mass.

From the finding, Graham concluded that spiral galaxies are actually in between the two types of lenticulars, evolutionarily speaking. Dust-poor lenticulars become spirals after capturing small "satellite galaxies" and other minor mergers, bumping up their black hole masses and scooping up nearby gas, his analysis suggests.

When spirals collide with other substantial galaxies, they become dust-rich lenticulars, Graham proposes. And indeed, every dust-rich lenticular in his dataset was previously recognized as the remnant of a spiral galaxy merger, he adds. Collisions between these dust-rich lenticulars are then enough to finally erode the galaxies' disks of stars and destroy their dust, producing blobby elliptical galaxies.

Black holes are good tracers of galaxy evolution, Conselice says, but the new sequence could be controversial. One issue is that lenticular galaxies in the nearby universe are usually such lightweights that they would need to merge tens or even hundreds of times to form a large spiral galaxy, he says. That's far more than the expected average of around five mergers over 10 billion years.

But things might have been different in the early universe, Conselice says. Long ago, there could have been more massive lenticulars. Figuring that out might be possible with the James Webb Space Telescope, which is allowing scientists to peer farther away and further back in time than ever before (SN: 8/12/23, p. 18).

"If you could look in the more distant universe, you could potentially see some of these galaxies when they're first forming, or when they're evolving," Conselice says. "We could potentially really test this idea." ■

NASA, ESA, THE HUBBLE HERITAGE TEAM/STSCI/AURA, WILLIAM C. KEEL/UNIV. OF ALABAMA, TUSCALOOSA

CHEMISTRY

Magnetic rust filters water of estrogen

Hormone-trapping nanoparticles might limit harm to aquatic life

BY SKYLER WARE

A new "smart rust" might one day help pull pollutants out of waterways, leaving cleaner water behind.

Researchers adorned tiny particles of iron oxide, or rust, with molecules that grabbed on to estrogen and similar hormones in water samples. A magnet then removed both the particles and the trapped pollutants from the water, materials scientist Lukas Müller reported August 16 in San Francisco at a meeting of the American Chemical Society.

The new technology could potentially limit excess estrogen's harmful effects on wild animals, especially those that live in waterways. With the nanoparticles, "we are able … to clean very different kinds of environmental pollutants," Müller says.

Estrogen typically enters waterways through human and animal waste (SN: 1/5/02, *p.* 10). Chronic exposure to low concentrations can have harmful effects on aquatic life, including higher instances of cancer or reproductive issues, says Konrad Wojnarowski, a biologist at Ludwig-Maximilians-Universität München in Germany.

Wastewater treatment plants can remove some of the estrogen, but the process isn't cheap or energy efficient, Wojnarowski says. For now, "we still don't have an ideal way of dealing with estrogen pollution in the environment," but nanoparticles could help, he says.

To build nanoparticles that catch estrogen, Müller and chemist Marcus Halik, both of Friedrich-Alexander-Universität Erlangen-Nürnberg in Germany, drew on previous designs for rusty nanoparticles that bind other pollutants, including oil and herbicides. The iron oxide cores are each about 10 nanometers in diameter and covered in phosphonic acid. These surface molecules act like sticky hairs that scoop up contaminants.

The estrogen-trapping nanoparticles use two types of phosphonic acid. One kind repels water and interacts with the neutrally charged part of the hormone molecule. The other kind is positively charged, which attracts parts of estrogen that carry a slight negative charge.

The nanoparticles successfully removed estrogen from water samples prepared in the lab, the researchers found, though they have yet to report just how well the particles performed. The duo's next step is to test the nanoparticles on samples from waterways. If the technology is eventually commercialized, it would probably be confined to sewage treatment plants rather than released directly into the environment, Müller and Halik say.

The researchers are now investigating exactly how phosphonic acid grabs and holds on to estrogen at the atomic scale in an effort to improve binding. ■

ANIMALS

Macaques get social to beat the heat

After Hurricane Maria, monkeys adapted by sharing shade

BY ERIN GARCIA DE JESÚS

After Hurricane Maria battered Puerto Rico in 2017, monkeys living there forged new bonds to share a suddenly scarce resource: shade.

Rhesus macaques (*Macaca mulatta*) willing to hang out with others boosted their chance of survival in the storm's aftermath, researchers report in a preprint posted July 24 at bioRxiv.org. That newfound sociability may have allowed multiple animals to escape the scorching heat of the day beneath any trees left standing and other sources of shade they could find.

Hurricane Maria destroyed nearly two-thirds of the vegetation on Cayo Santiago, a once lush key located off Puerto Rico's coast. More than five years later, Cayo Santiago's flora hasn't recovered, says Camille Testard, a behavioral ecologist at the University of Pennsylvania.

That's a problem for the island's colony of about 1,600 macaques, managed by the Caribbean Primate Research Center. Today, shade often comes in smaller forms than trees: from boulders, water basins or even human shadows.

Rhesus macaques on Cayo Santiago line up in the shade of a bare tree trunk in July 2019.

"If you're collecting data on the island, you're going to have monkeys that are sitting in your shade and following you around," Testard says.

In 2021, Testard and colleagues reported that the macaques — typically hierarchical animals that fight over food, mates and other resources — formed new relationships immediately after the storm. Fights still occurred but were less common.

To see how expanded social networks affected behavior, the researchers examined interactions recorded within groups of monkeys over a 10-year span, five years before the storm and five years afterward, though 2020 was excluded because of the pandemic.

After Hurricane Maria, monkeys spent more time in close company in the hot afternoon compared with relatively cooler mornings. The recorded interactions don't specify whether the monkeys were sitting in shade, says coauthor Lauren Brent, a behavioral ecologist at the University of Exeter in England. But more-social monkeys were less likely to die in the five years after the storm, which suggests that afternoon gatherings took place in the shade, so the animals might cool down.

It's a "wonderful" example showing how behavior can be an important factor for survival as environments change, says Richard Buchholz, a behavioral ecologist at the University of Mississippi in Oxford. Because researchers on Cayo Santiago ensure macaques have food and water, it's unclear whether the same might happen in wild monkeys, he says.

It's possible that the boost in sociality comes not from a benefit of being tolerant of their peers, but because there's a cost to being intolerant, Buchholz says. "We tend to get lethargic when things get super hot." The animals may be calmly sitting together in the shade so as not to raise their metabolisms, "avoiding the metabolic cost of chasing after somebody and building up more heat that you'll have to get rid of somehow." ■

ANIMALS

Many frogs glow in blue light

During twilight, fluorescence might aid communication

BY JAKE BUEHLER

In the dim twilight hours, many frogs may emit a faint green or orange glow.

A large survey in South America shows that far more frogs are biofluorescent than previously thought, researchers report July 28 in a preprint posted at bioRxiv.org. The ghostly colors may play a role in frog communication, the scientists say.

The findings "are a reminder to check our own perception as humans," says Jennifer Lamb, a herpetologist at St. Cloud State University in Minnesota who was not involved with the research. "We are very visually dominant in terms of our senses. And other animals are too, but they might be experiencing that visual world differently than we are."

Biofluorescence happens when an organism absorbs light at one wavelength and reemits it at a wavelength with lower energy. Over the last several years, researchers have recognized the trait in a growing diversity of species, from the fur of flying squirrels and platypuses to the nests of certain wasps (SN: 12/5/20, p. 12).

Fluorescence in frogs was first discovered in 2017. Investigations of frog biofluorescence since then have used just one or two light sources, usually violet or ultraviolet light, says Courtney Whitcher, an evolutionary biologist at Florida State University in Tallahassee.

To get a more cohesive picture, she and colleagues tested frogs using five different light sources covering a range of wavelengths, from green to UV light. From March to May 2022, the team shined lights on 528 frogs captured in Brazil, Colombia, Ecuador and Peru and measured any reemitted light.

All 151 species tested had some degree of fluorescence. Before this study, less than two dozen frog species were known to fluoresce out of 42 species tested.

Green and orange fluorescence was

SÉBASTIAN TREMBLAY

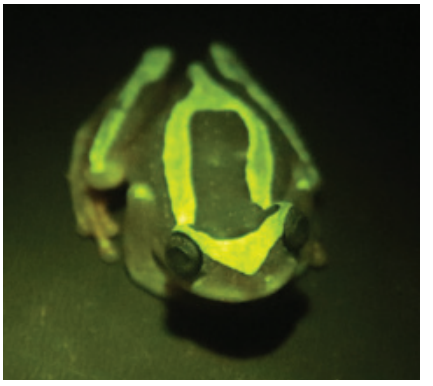
most intense under the blue light that dominates at twilight, similar to how many salamander species fluoresce under blue light (*SN*: 3/8/20, *p.* 4).

Much of the fluorescence seemed centered on the throat and underside, which are commonly used in courtship rituals. "While they're calling, that vocal sac region is expanding and contracting," Whitcher says. Fluorescence may make for a more noticeable display.

The green glow is probably something other frogs can see, the researchers say. In twilight hours, when frogs tend to court and mate, frog eyes are quite sensitive to the particular green light that's emitted from the frogs' skin, previous studies of frog vision suggest. Orange fluorescence, though, may be intended for a different receiver, such as a predator, serving as a warning signal, Whitcher says.

It's "astonishing" how widespread this fluorescence is, says evolutionary biologist Mark Scherz of the Natural History Museum of Denmark in Copenhagen. But he is skeptical that the fluorescence is strong enough for communication. Twilight is much dimmer than daylight, he says, so there may not be much light available for conversion to an emerald glow.

Whitcher is now investigating whether fluorescence in male frogs influences females' mating choices. "Maybe there's a threshold of fluorescence intensity that is needed in order to elicit some kind of behavioral response," she says. ■



Under blue hues, this elegant tree frog fluoresces green (visible in the banding).

C. WHITCHER

PLANTS

Climate change threatens oldest moss

Fast-evolving *Takakia* is losing ground in the warming Himalayas

BY BETHANY BROOKSHIRE

The world's oldest type of moss has seen four mass extinctions — but may not survive climate change.

The genus *Takakia* has the highest number of fast-evolving genes of any moss, researchers report August 9 in *Cell*. A decade-long study of *Takakia* in the Himalayas shows that it's well-adapted to its high-altitude home, with resistance to extreme cold and intense ultraviolet light. But no matter how fast its genes can change, rapidly rising temperatures in the region were associated with a decrease in the moss's range — a faster decrease than any of the mosses around it.

The two species of *Takakia* are unlike any other plant in the world. "The evolutionary position of *Takakia* in plants is like that of platypus in mammals," says Yikun He, a plant geneticist at the Capital Normal University in Beijing. *Takakia* branched off from the other mosses about 390 million years ago.

Just as the platypus has a lot of not-quite-mammal traits, such as egg-laying, *Takakia* has features that make it not quite like other plants, including featherlike leaves and a lack of pores for controlling the flow of oxygen and carbon dioxide.

To learn more about *Takakia*, He and colleagues set up a study on the Tibetan Plateau, more than 4,000 meters above sea level. Over 11 years, the team collected samples, analyzed genomes, collected data on the surrounding ecosystem and compared modern specimens with fossils from 165 million years ago.

Takakia has an average-sized moss genome of 27,000 genes, but 31 different categories of its genes are evolving faster than any other moss, including genes important for photosynthesis and desiccation, the researchers found.

Takakia needed that speed when the Himalayas began to rise 65 million years ago. As the mountains stretched skyward, the moss was exposed to lower temperatures and higher amounts of UV light. It had to adapt. And adapt *Takakia* did.

When the team exposed *Takakia* to a high amount of UV light, it was unharmed. Comparison mosses began to die within 72 hours. The hardy moss makes "high amounts of metabolites like flavonoids and polyunsaturated fatty acids to protect against radiation," coauthor Ralf Reski, a plant biotechnologist at the University of Freiburg in Germany. It also has genes that enable more efficient DNA repair, essential protection against harmful solar rays.

Takakia is also adapted to the extreme cold. It can go dormant for eight months of the year while under snow and gets all of its growth and reproduction done in a three- to four-month period, He says.

All of these features evolved from about 50 million years ago to the present, the study shows, without the moss ever changing its physical appearance compared with fossils.

But this relatively speedy evolution doesn't seem to be fast enough to help the moss adapt to climate change.

During the study, Reski, He and colleagues documented an average increase in temperature of about 0.4 degrees Celsius in the region. Meanwhile, the coverage of *Takakia* in their sample population decreased by about 1.6 percent per year — faster than four other local mosses.

The researchers predict that by the end of the century, the moss could go extinct.

Others are more optimistic. There are populations in other places, including Japan and the United States, says evolutionary biologist S. Blair Hedges of Temple University in Philadelphia. Even if the Tibetan Plateau becomes *Takakia*-free, he hopes the moss can make it elsewhere.

In the meantime, He, Reski and their colleagues are cultivating *Takakia* populations and transplanting them to other regions in Tibet in the hopes of giving an old moss a new lease on life. ■

NEUROSCIENCE

Scientists extract music from the mind

A computer model used brain data to re-create a Pink Floyd song

BY CLAUDIA LÓPEZ LLOREDA

In what seems like something out of a sci-fi movie, scientists have plucked the famous Pink Floyd song "Another Brick in the Wall" from individuals' brains.

Previously, researchers have used electrodes, computer models and brain scans to decode and reconstruct individual words and entire thoughts from people's brain activity (SN: 6/3/23, p. 14).

The new study, published August 15 in *PLOS Biology*, adds music into the mix, showing that songs can also be decoded from brain activity and revealing how different brain areas pick up an array of acoustic elements. The finding may eventually help improve communication devices used by people with paralysis or other conditions that limit the ability to speak.

Neuroscientist Ludovic Bellier of the University of California, Berkeley and colleagues decoded the song from data captured by electrodes on the brains of 29 people with epilepsy. While in the hospital being monitored for the disorder, the individuals listened to the 1979 rock song.

People's nerve cells, particularly those in auditory areas, responded to hearing the song. The electrodes detected not only neural signals associated with words, but also rhythm, harmony and other musical aspects. With that information, the researchers developed a computer model to reconstruct sounds from the brain activity data, and found that the model could produce sounds that resemble the song.

"It's a real tour de force," says neuroscientist Robert Zatorre of McGill University in Montreal. "Because you're recording the activity of neurons directly from the brain, you get very direct information about exactly what the patterns of activity are."

The study highlights which parts of the brain respond to different elements of music. Take the superior temporal gyri, or STGs, which are located in the lower middle of each side of the brain. Activity in one area within the STGs intensified at the onset of specific sounds, such as when a guitar note played. When vocals were used, activity in another area increased and stayed elevated.

The STG on the right side of the brain, but not the left, seemed to be crucial in decoding music. Removing information from the right STG in the computer model decreased the accuracy of the song reconstruction, the researchers found.

"Music is a core part of human experience," says Bellier, who has been playing musical instruments since he was 6 years old. "Understanding how the brain processes music can really tell us about human nature. You can go to a country and not understand the language, but be able to enjoy the music."

Further probing musical perception will probably be difficult because the brain areas that process it are hard to access without invasive methods. And Zatorre wonders about the broader application of the computer model, which was trained on just the Pink Floyd song. In addition to other songs, "does [it] work on other kinds of sounds, like a dog barking or phone ringing?" he asks.

The goal, Bellier says, is to eventually be able to decode and generate natural sounds in addition to music. In the shorter term, incorporating the more musical elements of speech, including pitch and timbre, into brain–computer devices might help individuals with brain lesions, paralysis or other conditions communicate better. ■

ARCHAEOLOGY

Ancient jewelry hints at village life

A necklace buried with a child about 9,000 years ago in Jordan is providing a window into an early farming community. Over 2,500 imported stone and shell beads linked a stone pendant and a mother-of-pearl ring to form the intricate necklace, researchers report August 2 in *PLOS ONE*.

The necklace had come apart by the time the grave was excavated in 2018, and no strings were preserved. To reconstruct the ornament (right), the team analyzed the distribution of beads on the remains of the approximately 8-year-old child. Microscopic differences in the intensity of wear helped to determine each bead's position in strung rows. Comparing the ring with similar objects found at the site, called Ba`ja, revealed how many strings the ring could have held.

Mourners probably gathered to bury the child, says coauthor Hala Alarashi of the Spanish National Research Council in Barcelona. Public rituals at graves in the Middle East occurred as early as 12,000 years ago (*SN: 9/25/10, p. 14*). *— Bruce Bower*

H. ALARASHI *ET AL*/*PLOS ONE* 2023

Listen to sounds reconstructed from people's brain activity at **bit.ly/SN_PinkFloyd**

Urgent: Special Summer Driving Notice

To some, sunglasses are a fashion accessory…

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

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

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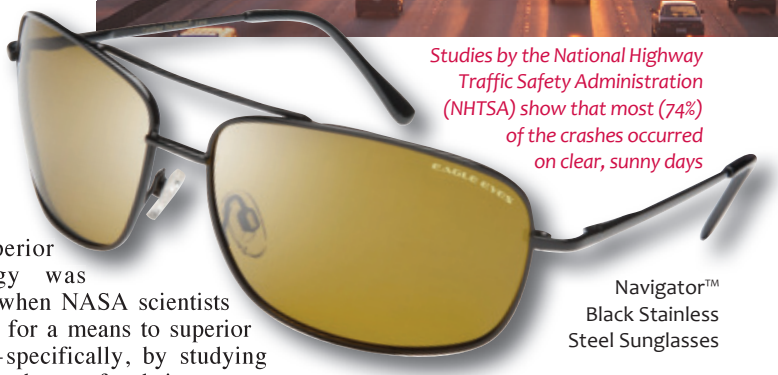
Studies by the National Highway Traffic Safety Administration (NHTSA) show that most (74%) of the crashes occurred on clear, sunny days



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MADELINE MCMAHON

A Fair Slice?

Why mathematicians are still interested in the cake-cutting problem

By Stephen Ornes

Ariel Procaccia has thought a lot about how to cut cake over the last 15 years. That's partly because the Harvard computer scientist has three children who among them have celebrated more than two dozen birthdays. He knows what it's like to stand with a knife before a layered masterpiece, frosted with buttercream and chocolate curls, while pressed on all sides by small partygoers who instinctively recognize when someone else gets a better slice.

But it's also because much of Procaccia's work focuses on exploring the mathematical rules for dividing stuff up. One way to do that is to think abstractly about dessert. For more than 75 years, he and other researchers trying to formalize fairness have been asking the deceptively simple question: What methods for cutting a cake guarantee that everyone who shows up to the party is happy with what they get?

The answers reach far beyond birthday parties. Cake-cutting contemplation is part of a sprawling mathematical subfield focused on the fair division of resources. It has spurred a raft of algorithms informing how to allocate food among hungry

communities, how to split rent or chores among roommates, how to draw boundaries for fair voting districts and more. A mathematical problem at its heart, cake cutting connects rigorous reasoning to questions of human preferences and real-world issues, and so attracts not only mathematicians, but also computer scientists, economists, social scientists and legal experts. Questions of fairness (and unfairness) are decidedly universal. Of course, so is dessert. "It's this very elegant model in which you can really distill what fairness is, and reason about it," Procaccia says.

The cake, says Steven Brams, a game theorist and political scientist at New York University, is a metaphor for any divisible good, like land or time or limited resources. When cake-cutting insights are applied to settling international disputes, he says, "we are potentially helping the world find solutions."

Experts have come up with cake-cutting algorithms — the mathematical rules for describing how to cut a cake fairly — many times and in many guises. (The approaches almost always focus on rectangular cakes. The related but more recent "pie-cutting" problem addresses circular desserts or pizza.) The easiest rules reveal how to fairly share a cake between two people: One person cuts the cake into two pieces that they believe to be equal in value, and the other person picks first. Each eater receives a piece that they feel is at least as valuable as the other's, if not better. Reports of this fair division strategy date back to ancient Greece.

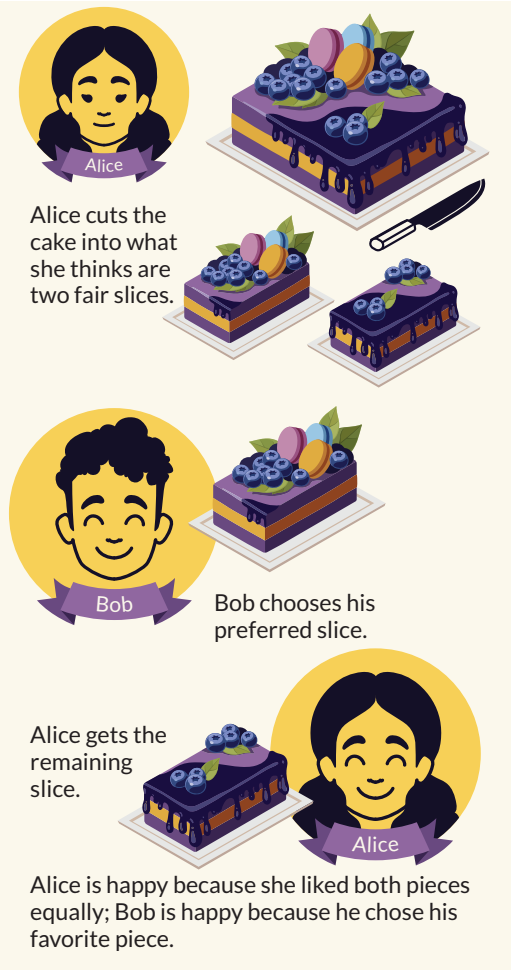
In the 1940s, mathematicians began taking serious interest in a mathematical approach to fairness, using cake cutting as an access point. They started exploring how to fairly share among three people, since I-cut-you-choose is a two-player game. That led to looking for ways to extend those algorithms to arbitrarily large numbers of people, and to asking more nuanced questions, like what is fairness exactly, and how do you prove it?

Cake cutting is easy to formulate and easy to relate to, says game theorist Bettina Klaus of the University of Lausanne in Switzerland, who studies fairness in real-world situations like school choice allocation and equal access to housing. "But at the same time, the problem is mathematically interesting and challenging because of its complexity once the number of agents to share the cake grows."

Recent years have brought progress in identifying the fewest number of cuts needed for a given number of people, as well as the maximum number of cuts, which can get ridiculously high but at least shows that cake cutting is finite. And new variations on the question keep emerging. What if you divide a cake for multiple groups of people instead of individuals? Or, as explored in a paper published last year, what if cake eaters lie about their preferences? And what if you're divvying up something that comes in discrete, indivisible pieces, like unopened Halloween candies, instead? By focusing on precise definitions and new scenarios, mathematicians have found new applications and kept cake cutting at the forefront of investigations into fairness.

"You can argue that fairness, or the lack thereof, is one of the most important problems in the world today," says Brams, who over four decades has published hundreds of works on cake cutting or fairness more generally. "And we're looking at the theoretical foundations of fairness."

Cut and choose The simplest approach to fairly cutting cake, often called the "divider-chooser" method, works for just two people.



Recipes for fairness

Documented experiments in finding fair ways to split stuff up go way back, at least to Hesiod's poem *Theogony*, written some 2,700 years ago. In

"You can argue that fairness, or the lack thereof, is one of the most important problems in the world today."

STEVEN BRAMS

OLENA SHMAHALO

Trim away Sharing among two is easy. But when you have to share a cake among three people, things get harder. In the "last-diminisher" method, three people — Alice, Bob and Carla — each believe they are getting a piece that they value at ⅓ of the total. Mathematicians call that "proportionality," but whoever exits the game first could still be envious of someone else's piece.

Round 1

Alice cuts a piece that she thinks represents ⅓ the value of the cake and passes it to Bob.

Bob and Carla each have a chance to trim the piece, if they think it is worth more than ⅓ the value, or pass. In this case, Bob passes and Carla trims.

The piece goes to whoever trimmed it last. (If both Bob and Carla had passed, Alice takes the piece.)

Round 2

The trim gets added back to the remaining cake, which Alice then cuts into what she thinks are two fair slices.

Bob chooses his preferred slice.

Alice gets the remaining slice.

Everyone appears to be happy with their piece. But Carla, who exited the game early, could still think that Alice's or Bob's piece is better than hers.

one story in the poem, gods and mortals clashed in Mecone, a mythical Greek city. As a sacrifice to appease the gods, Prometheus, who was both a god and humankind's greatest benefactor, divided a recently slaughtered ox into two piles, one containing unappealing bare bones covered with a layer of fat and the other containing the desirable meat concealed beneath an unappealing section of stomach. Prometheus invited Zeus to take his pick. Zeus, seduced by the shiny fat, chose the unappetizing bones.

In this ancient story, Prometheus infuses the classic I-cut-you-choose strategy — the simplest version of cake cutting — with deception. But when I-cut-you-choose is executed in pursuit of fairness, it should guarantee the satisfaction of everyone involved.

The outcome is proportional, meaning that each player feels like their slice represents a fair share of the total. So for two players, a player would value their own slice at ½; for three, a fair share would be ⅓. (And for some arbitrary n number of cake eaters, a fair share would be 1/n.) If the cake is the same throughout, proportionality is equivalent to all the slices being the same size.

But cake cutting isn't an interesting mathematical problem if the cake is all the same. Ordinary division and a kitchen scale could readily separate a slab of uniform chocolate sponge into any number of proportional pieces. The problem becomes more complicated if you assume that the cake is heterogeneous — if it's unevenly frosted, for example, or includes sections of varying flavors and toppings.

A maraschino cherry–lover might choose the smallest slice and feel satisfied if they get the cake's only cherry. In this case, what mathematicians call the "serendipity of disagreement" gives rise to rich math. The most interesting math arises when there are differing opinions.

A two-person I-cut-you-choose scenario still works here. The divider divides the cake into two pieces of equal value in their view and will be happy with either; the chooser chooses their preferred piece. But increase the number of cake eaters, each with particular preferences, and there's no easy solution.

Hugo Steinhaus of the University of Warsaw was one of the first mathematicians to dive into this complexity. During World War II, as questions of fair division of land were playing out on a large and violent scale, Steinhaus developed a modified I-cut-you-choose strategy for three players. It came to be called the lone-divider method.

In this approach, one person, let's call her Alice,

OLENA SHMAHALO

cuts the cake into three pieces that she values equally (each at ⅓ of the total). Then a second person, Bob, indicates which of the pieces would be acceptable to him. If he approves at least two pieces, then the third person, Carla, can take any piece she wants, followed by Bob (who has at least one acceptable piece available). Alice gets the one that's left.

But if either Bob or Carla disapprove of the same piece, then that piece goes to Alice (who valued all pieces equally). The remaining two pieces (which Bob and Carla must value at ⅔ or more of the total) are recombined and shared between Bob and Carla using I-cut-you-choose.

Steinhaus described this algorithm in a short paper published in 1948 in *Econometrica*. It represented one of the first rigorous investigations in the field of cake cutting. "The rule for the first partner," Steinhaus wrote, "allows him to cut the object—it may be a cake—as he pleases."

Steinhaus' method worked for only three eaters, but in the same paper, he reported that two colleagues had developed an algorithm that could achieve proportionality for any number of cake eaters. The method is known as the last-diminisher method, and it goes like this: One person cuts off a piece of cake they deem to represent a fair share and passes that piece along to the next person. Each remaining player has a chance to either trim the cake (if they think it represents more than a proportional share) or pass (if they think it's proportionally fair or less than fair). Once everyone has had a chance to trim, or "diminish" the slice, the last person who trimmed gets the piece and exits the game.

The trim is then recombined with the remaining cake, and the process begins again with the remaining players. When only two players are left, they use I-cut-you-choose.

Brams has called the last-diminisher method an elegant solution, and it guarantees that everyone judges their own piece to be at least as valuable as a fair share. But it's not perfect because it doesn't take envy into account. In both the lone-divider and last-diminisher approaches, a person who exits the game early may end up coveting a piece that is cut later in the game—even though they thought their piece was proportional. These algorithms are not what mathematicians call "envy-free," which is another way to think about fairness.

There is another practical limitation to the last-diminisher method: With enough players, the cake that remains in later rounds might end up broken apart by a lot of slicing—or even reduced to crumbs. It's easy to see how a partygoer might not value that as highly as a whole piece.

Refining ideas of fairness

Since the debut of the last-diminisher method, cake cutting has fueled a small but mighty body of serious mathematics.

The 1960s brought a major step forward when mathematicians John Conway and John Selfridge, independently of each other, came up with a new cutting algorithm for three people. Unlike the work by Steinhaus and colleagues, the new recipe achieved both perceived proportionality and avoided any envy among the recipients.

An envy-free solution, in which no one covets another person's piece, is easy to achieve, points out computer scientist Haris Aziz of the University of New South Wales in Sydney. Just throw the entire cake away. "If you don't give anything to anybody, that's envy-free," he says.

But if the cake lands in the rubbish bin, no one is happy. In Conway's and Selfridge's more pleasing scheme, Alice first divides the cake into three pieces she believes are of equal value. Then, Bob can trim one piece—at most—to create a two-way tie for the most valuable. (The trimmings are set aside.) Carla is left to choose among the three. Then the order reverses, and if Carla didn't choose the trimmed piece, Bob takes it. Alice gets the one that remains. The eaters then turn to the trimmings, following a similar iterative protocol of cutting, trimming and choosing.

> What mathematicians call the "serendipity of disagreement" gives rise to rich math.

Yet for decades more, an envy-free cake-cutting solution for any arbitrary number of eaters remained elusive. In the late 1980s, on his PBS television show *For All Practical Purposes: Introduction to Contemporary Mathematics*, mathematician Sol Garfunkel featured the unsolved cake-cutting problem and related questions of fair division.

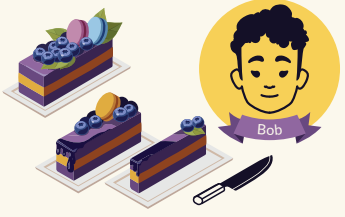
But the problem wouldn't go unsolved for much longer. In 1995, Brams at NYU and Alan D. Taylor of Union College in Schenectady, N.Y., devised a new procedure that cuts cake for four people with no one envying anyone else. "That was considered a breakthrough of sorts," Brams says. It built on the "trimming" approach of Conway and Selfridge, running a similar procedure on all possible pairs of cake eaters. Brams and Taylor described how the procedure could be extended to any number of people.

The approach still had limitations. There was no guarantee of how many cuts it might take. "We

No envy This version of cake cutting for three people, named for John Selfridge and John Conway, ensures that each person — Alice, Bob and Carla — feel that their piece represents ⅓ the total value of the cake. It also ensures that none of the cake eaters will be envious of another person's piece. The Selfridge-Conway procedure has been extended for any number people, but the cutting can last a very long time.

Round 1

Alice cuts the cake into three pieces that she considers equal.



Bob can either pass or trim one — and only one — of the pieces to make two that are tied for the best.

The trimmings are set aside.

Preferred slices are picked in this order: Carla first, getting her favorite piece.

Bob goes next. If Carla doesn't pick the trimmed piece, Bob has to take it (this ensures he gets one of the pieces he thought were tied for best).

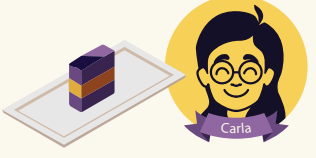
Alice gets the remaining piece, one of her original pieces.

Round 2

In dividing the trimmings, whoever between Bob and Carla got the untrimmed piece (in this case Carla) cuts the trim into three equally valuable pieces.

Pieces are picked in this order: Bob chooses first, getting his favorite piece.

Alice, who thought her piece was preferable to the trimmed piece in the previous round, goes next.



Carla ends up with one of the pieces she trimmed.

This approach is free of envy because Bob got to pick first, Carla valued all the trims equally and Alice feels like any trim is a bonus, since she would have been happy with her original piece alone.

showed in general that you could require three cuts or 3 million cuts," Brams says. Or many, many more.

A few years later, mathematicians Jack Robertson and William Webb of Washington State University in Pullman described a useful computation model that could be used to analyze how many steps, including cuts and evaluations, are required by an algorithm. Its calculations confirmed, for example, that no maximum number of cuts could be predicted for any algorithm known at that time that divided cake proportionally and without envy for any arbitrary number of players.

Over the next few decades, many mathematicians came to wonder whether an upper bound for envy-free cake cutting even existed. If not, in theory, cake cutting could go on forever. What's more, Procaccia says, no one had figured out the minimum, either.

Unreasonable cake cutting

Procaccia never actually set out to study cake cutting. In 2008, he was teaching a course on the mathematical foundations of artificial intelligence. One day, walking home after delivering a lecture on resource allocation and the Robertson-Webb model, he realized how he could find a lower bound — a minimum number of steps, including cuts — for envy-free cake cutting for any number of people. The lower bound he found was somewhere around n^2 steps, where n is the number of cake eaters.

That would lead to his first paper on cake. Procaccia has a knack for giving mathematical papers catchy titles. The lower-bound paper, published in 2009, was titled "Thou shalt covet thy neighbor's cake." In 2010, he coauthored one called "Truth, justice, and cake cutting," which introduced the question of truthfulness — in addition to guaranteeing proportionality and removing envy. If a person hides their preferences during the cutting, someone may end up with an unequal share. It's "mathematically fascinating," Procaccia says.

As Procaccia continued in the field, he began thinking more about useful algorithms that could put insights from cake cutting — and the theory of fair division in general — to good use. One example: dividing rent.

The easiest way, of course, is to divide the total due by the number of inhabitants. But that ignores the "serendipity of disagreement." One person might want a window, another might prefer the bigger closet. In 2014, Procaccia and colleagues designed a web-based tool called Spliddit that collected users' preferences and produced mathematically fair ways to divide anything, from rent among roommates to possessions among divorcees.

OLENA SHMAHALO

The biggest recent breakthrough in cake cutting, Procaccia says, came from Aziz and computer scientist Simon Mackenzie, based in Sydney, who determined an upper bound on envy-free, proportional cake cutting. First, in 2015, the pair tackled the problem of how to share cake among four people. By borrowing ideas from Conway and Selfridge and from Brams and Taylor, the team devised an algorithm that produced an upper bound of 203 steps, which could include almost as many cuts. That's a lot but not too unreasonable.

A year later, the team extended the approach to an arbitrary number of people, reporting an algorithm with a finite number of cuts for envy-free, proportional cake cutting. It was a potentially astronomical number of cuts, but it was finite — answering a long-standing question in the field.

Cake cutting for n people, Aziz and Mackenzie reported, could require as many as n^n^n^n^n^n operations. That's a totally unreasonable number. The maximum number of steps for five people would be around $2 \times 10^{2,180}$. That means five people cutting the cake billions of times per second for 100 trillion years might barely be getting started.

However, Aziz says the algorithm can be adapted to a more reasonable, though still really big upper bound if the partygoers, for example, allow for a little cake to be left over. And it's still possible that mathematicians could bring that upper bound lower in the future.

What's next

Explorations into the question of how to fairly cut a cake aren't over. Inspired by Procaccia's 2010 paper on truthfulness, computer scientist Biaoshuai Tao of Shanghai Jiao Tong University investigated what happens when you try to account for dishonest cake eaters. "If everyone knows how the cake is allocated, then I should get more if I tell the truth," he says.

But in some cases, dishonesty can yield an advantage. If Alice and Bob were to divide a cake, and Alice knew that Bob always preferred chocolate, she might knowingly divide the cake unequally so the smaller piece contained more chocolate. Then Bob would choose according to his preference, and Alice would get the larger piece.

In his work, presented in July 2022 at the Association for Computing Machinery Conference on Economics and Computation, in Boulder, Colo., Tao found that truthfulness and proportionality are incompatible, making it impossible to construct a cake-cutting algorithm that strictly guarantees truthfulness, proportionality and no envy.

Practical applications for cake cutting also continue to abound. Klaus, in Lausanne, points to school choice as an example.

A district with limited seats in certain schools has to balance the school board priorities — scores on entrance exams or geographic distribution, for example — with the preferences of parents to try to find a proportional solution with a fair value. "In the past, schools were just assigned ... without asking people what they want," Klaus says. "The school choice comes from the fact that the preferences of the parents or the kids would be taken into account."

And there are plenty of other real-world applications for questions of fair division. Brams has used ideas from cake cutting to study fair voting procedures. (To elect their leaders, at least four scientific societies, including the Mathematical Association of America, adopted an algorithm developed by him.)

Procaccia has applied fair division algorithms to model food allocation. Aziz is exploring applications ranging from how to divvy up chores or other tasks that can't be divided to how to best schedule doctors' shifts in hospitals.

Others are studying fair allocation of goods that can't be cleanly divided. After a divorce, for instance, former partners might come to agreement on a fair split only if some items are taken out of consideration. These investigations include approaches that are close to envy-free if not mathematically perfect.

Even after decades of investigation, cake cutting isn't like a simple jigsaw puzzle with a well-defined solution. Instead, over time, it has evolved into a kind of mathematical sandbox, a constructive playground that brings together abstract proofs and intuitive applications. The more researchers explore it, the more there is to explore.

"I'm interested in it now not only because it's beautiful in math," Tao says, "but I still believe there's a lot to be done." ■

Over time, cake cutting has evolved into a kind of mathematical sandbox, a constructive playground that brings together abstract proofs and intuitive applications.

Explore more

- Steven J. Brams and Alan D. Taylor. *Fair Division: From Cake Cutting to Dispute Resolution.* Cambridge University Press, 1996.
- Jack Robertson and William Webb. *Cake-Cutting Algorithms: Be Fair if You Can.* AK Peters/CRC Press, 1998.

Stephen Ornes is a freelance science writer based in Nashville.

Testing wastewater at treatment plants can reveal the spread of a disease in a community.

The Future of Disease Tracking

A rapidly growing list of pathogens are detectable in wastewater

By Betsy Ladyzhets

The future of disease tracking is going down the drain — literally. Flushed with success over detecting coronavirus in wastewater, and even specific variants of SARS-CoV-2, the virus that causes COVID-19, researchers are now eyeing our collective poop to monitor a wide variety of health threats.

Before the pandemic, wastewater surveillance was a smaller field, primarily focused on testing for drugs or mapping microbial ecosystems. But these researchers were tracking specific health threats in specific places — opioids in parts of Arizona, polio in Israel — and hadn't quite realized the potential for national or global public health.

Then COVID-19 hit.

The pandemic triggered an "incredible acceleration" of wastewater science, says Adam Gushgari, an environmental engineer who before 2020 worked on testing wastewater for opioids. He now develops a range of wastewater surveillance projects for Eurofins Scientific, a global laboratory testing and research company headquartered in Luxembourg.

A subfield that was once a few handfuls of specialists has grown into more than enough scientists to pack a stadium, he says. And they come from a wide variety of fields — environmental science, analytical chemistry, microbiology, epidemiology and more — all collaborating to track the coronavirus, interpret the data and communicate results to the public. With other methods of monitoring COVID-19 on the decline, wastewater surveillance has become one of health experts' primary sources for spotting new surges.

Hundreds of wastewater treatment plants across the United States are now part of COVID-19 testing programs, sending their data to the National Wastewater Surveillance System, or NWSS, a monitoring program launched in fall 2020 by the U.S. Centers for Disease Control and Prevention. Hundreds more such testing programs have launched globally, as tracked by the COVIDPoops19 dashboard run by researchers at the University of California, Merced.

In the last year, wastewater scientists have started to consider what else could be tracked through this new infrastructure. They're looking at seasonal diseases like the flu, recently emerging diseases like bird flu and mpox, formerly called monkeypox, as well as drug-resistant pathogens like the fungus *Candida auris*. The scientists are even considering how to identify entirely new threats.

Wastewater surveillance will have health impacts "far broader than COVID," predicts Amy Kirby, a health scientist at the CDC who leads NWSS.

But there are challenges getting from promise to possible. So far, such sewage surveillance has been mostly a proof of concept, confirming data from other tracking systems. Experts are still determining how data from our poop can actually inform policy; that's true even for COVID-19, now the poster child for this monitoring. And they face public officials wary of its value and questions over whether, now that COVID-19 health emergencies have ended, the pipeline of funding will be cut off.

This monitoring will hopefully become "one of the technologies that really evolves post-pandemic to be here to stay," says Mariana Matus, cofounder of Biobot Analytics, a company based in Cambridge, Mass., that has tested sewage for the CDC and many other health agencies. But for that to happen, the technology needs continued buy-in from governments, research institutions and the public, Matus and other scientists say.

How wastewater testing works

Wastewater-based epidemiology has a long history, tracing back at least to physician John Snow's 1850s observations that cholera outbreaks in London were connected to contaminated water.

In the 1920s and '30s, scientists began to take samples from sewage and study them in the lab, learning to isolate specific pathogens that cause disease. These early researchers focused on diseases that spread through contaminated water, such as polio and typhoid.

Today, automated machines typically retrieve sewage samples. The machines used to collect waste beneath maintenance hole covers are "like R2-D2 in terms of size" or smaller, says Erin Driver, an environmental engineer at Arizona State University in Tempe who works on collection methods.

Driver can plug this machine, or a larger version used for sampling at wastewater treatment plants, into a water pipe and program it to pull a small amount of sewage into an empty bottle at regular intervals, say, once an hour for 24 hours. She and colleagues are developing smaller versions of the automated sampler that could be better suited for more targeted sampling.

What happens in the lab to that bottle of waste depends on what scientists are testing for. To test for opioids and other chemicals, scientists might filter large particles out of the sample with a vacuum system, extract the specific chemicals that they want to test, then run the results through a spectrometer, an instrument that measures chemical concentrations by analyzing the light the chemicals give off.

To determine levels of SARS-CoV-2 or another virus, a scientist might separate liquid waste from solid waste with a centrifuge, isolate viral genetic material, and then test the results with a PCR machine, similar to testing someone's nose swab. Or, if scientists want to know which SARS-CoV-2 variants are present, they can put the material through a machine that identifies a variety of genetic sequences.

Would the coronavirus even show up in waste?

In the panicked early days of the pandemic, an urgent basic question loomed. "Will this even work?" remembers Marlene Wolfe, an environmental microbiologist at Emory University in Atlanta. While polio is spread through fecal matter, there were early hints that the coronavirus mostly spreads through the air; scientists initially weren't even sure that it would show up in sewage.

On the same day in 2020 that the San Francisco Bay Area went on lockdown, Wolfe and colleagues at Stanford University, where she was based at the time, got a grant to find out. The team was soon spending hours driving around the Bay Area to collect

OPPOSITE PAGE: BILANOL/ISTOCK/GETTY IMAGES PLUS

A small automated machine perches at the edge of a maintenance hole, ready to retrieve wastewater samples (like the one in the gray container) from the Tempe, Ariz., sewage system.

sewage samples, "navigating lockdown rules" and negotiating special permissions to use lab space, she says.

"We were anxiously waiting to see if our first samples would show a positive result for SARS-CoV-2," Wolfe says.

Not only did the sewage samples test positive, Wolfe and her colleagues found that coronavirus levels in the Bay Area's wastewater followed the same trends as reported cases, the team reported in December 2020 in *Environmental Science & Technology*. When case counts went up, more virus appeared in the sewage, and vice versa. Early projects in other parts of the country showed similar results.

More than three years later, data on reported cases have become much less reliable. Fewer people are seeking out lab-based PCR tests in favor of easier-to-access at-home tests—with results often not reported. Wastewater trends have become the best proxy to provide early warnings of potential new COVID-19 surges, such as the increased spread this summer, to health officials and the public alike.

Opening the tracking floodgates

In summer 2022, wastewater tracking got a new chance to prove itself. Mpox was rapidly spreading globally, including in the United States. But tests were limited, and the disease, which was spreading primarily through intimate contact between men, quickly drew social stigma, leading some people to hesitate in seeking medical care.

Within a few weeks of the start of the U.S. outbreak, Wolfe and her colleagues, as well as research teams at Biobot and other companies, had developed tests to identify mpox in sewage.

Just as scientists had seen with COVID-19, mpox trends in wastewater matched trends in official case numbers. In California, wastewater results even suggested that the disease may have spread farther than data from doctors' offices suggested, Wolfe and collaborators reported in February in the *New England Journal of Medicine*.

Like COVID-19, mpox doesn't transmit through the water, but sewage testing still picked up the virus. The early results from that summer outbreak convinced some health officials that wastewater technology could be used for many diseases, no matter how they spread, Matus says.

Scientists are starting to find more and more infectious diseases that can be tracked in sewage. "Honestly, everything that we've tried so far has worked," says Wolfe, who is now a principal investigator of WastewaterSCAN, a national sewage testing project led by researchers at Stanford and Emory. The project team currently tests samples for six different viruses and is working on other tests that it can send out to the more than 150 sites in its monitoring network.

Through an informal literature review of pathogens important for public health, scientists at Biobot found that previous research had identified 76 out of 80 of them in wastewater, stool or urine, suggesting that those pathogens could be monitored through sewage. The list ranges from the chicken pox virus to the microbes that cause sexually transmitted diseases like chlamydia to the tickborne bacteria that cause Lyme disease.

Finding focus

With this much opportunity, the question on many researchers' minds is not, "What *can* we test for?" but "What *should* we test for?"

In January, a report put out by the National Academies of Sciences, Engineering and Medicine came up with three criteria. The pathogen should threaten public health. It should be detectable in wastewater. And it should generate data that public health agencies can use to protect their communities.

Given all the threats and hints of what can be found in wastewater, the first two criteria don't narrow the field too much. So for now, researchers are taking cues from state and local public health officials on which pathogens to prioritize.

Biobot is working on tests for common diseases like the flu, RSV, hepatitis C and gonorrhea. And the CDC has its eye on some of the same common pathogens, as well as strategies for tracking antimicrobial resistance, a threat that has increased during the pandemic as health systems have been under strain.

Even if they choose the perfect targets, though, researchers also have to figure out how to generate useful data. For now, that's a sticking point.

How to use the data

Tracking pathogens is one thing. But determining how the results correspond to actual numbers of sick people is another, even in the case of COVID-19, where researchers now have years of detailed data. As a result, many public health officials aren't yet ready to make policy decisions based on poop data.

E. DRIVER/ARIZONA STATE UNIV.

In New York City over the last three years, for example, the local government has poured more than $1 million into testing for COVID-19, mpox and polio in sewage from the city's water treatment plants. But the city's health department hasn't been using the resulting data to inform local COVID-19 safety measures, so it's unclear what's being done with the data.

Health officials are used to one swab per person, says Rachel Poretsky, a microbiologist at the University of Illinois Chicago. She also heads wastewater monitoring for the city of Chicago and the state of Illinois.

Public health training relies on identifying individual sick people and tracing how they became ill. But in wastewater surveillance, one data point could represent thousands of sick people — and the data come from the environment, rather than from hospitals and health clinics. What to do next when positive results turn up isn't as obvious.

Numbers collected from the health care system always represent patients, so a spike indicates a surge in cases. In the case of sewage data, however, environmental factors like weather, local industries and the coming and going of tourists also can create "weird outliers" that resist easy interpretation, Poretsky says. For instance, a massive rainstorm might dilute samples, or chemical runoff from a factory might interfere with a research team's analytical methods.

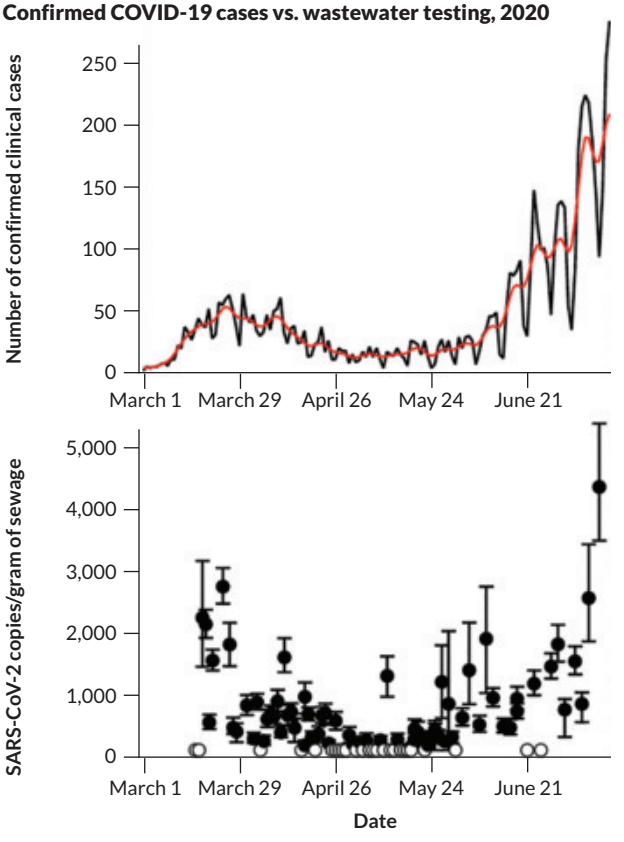
Data interpretation only gets more complicated when scientists begin testing wastewater for an increasing number of health threats. Every pathogen's data need to be interpreted differently.

With coronavirus data, for example, wastewater tests consistently come back positive, so interpreting the data is all about looking for trends: Are viral concentrations going up or down? How does the amount of virus present compare with the past? A spike in a particular location might signal a surge in the community that hasn't yet been picked up by the health care system. The community might respond by boosting health resources, such as opening vaccine clinics, handing out free masks and at-home tests, or adding staff to local hospital emergency departments.

Expanding network Hundreds of wastewater sites (blue dots), including some airports, monitor for SARS-CoV-2 in North America. With COVID-19 test reporting waning, this sewage surveillance is helping monitor surges in infections.

GRAPHS: K.E. GRAHAM *ET AL/ENVIRON. SCI. TECHNOL.* 2020; MAP: C.C. NAUGHTON, 2021. COVIDPOOPS19: SUMMARY OF GLOBAL SARS-COV-2 WASTEWATER MONITORING EFFORTS BY UC MERCED RESEARCHERS. ESRI ARCGIS ONLINE DASHBOARD. HTTPS://ARCG.IS/1AUMMW

Confirmed COVID-19 cases vs. wastewater testing, 2020



Proof of concept Results from early efforts in 2020 showed that wastewater tests (bottom) to detect COVID-19 mirrored new reported cases (top) in San Jose, Calif. Scientists estimate the virus can be detected in concentrations as low as 40 copies of virus per gram of dried sewage.

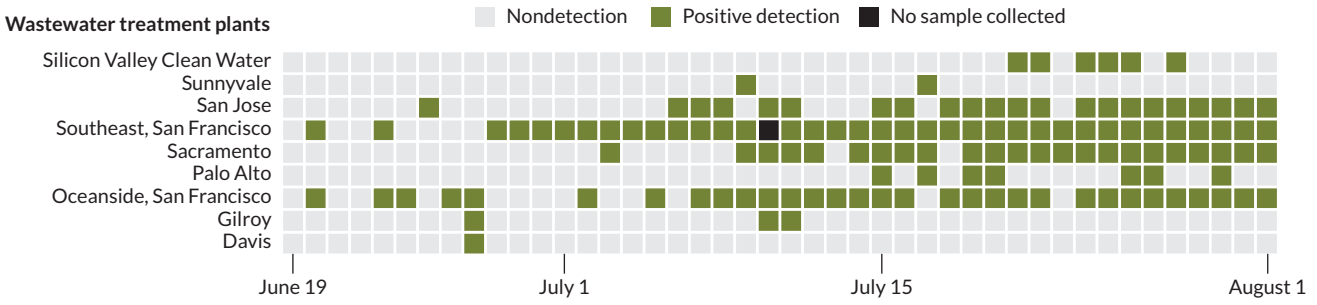
Mpox, on the other hand, has infected far fewer people, and positive tests have been rare after last summer's outbreaks ended. Now, researchers are simply watching to see whether the virus is present or absent in a given sewershed.

"It's more about having an early warning," Matus says. If a sewershed suddenly tests positive for mpox after negative results for the last few months, health officials might alert local doctors and community organizations to look out for anyone with symptoms, aiming to identify any cases and prevent a potential outbreak.

Another complicated pathogen is *C. auris*, a fungus that has developed resistance to common drugs. It can spread rapidly in health care settings — and be detected in sewage. Researchers from Utah and Nevada reported in February in *Emerging Infectious Diseases* that it was possible to track *C. auris* in the sewage from areas experiencing outbreaks.

If hospitals or health officials could identify the presence of this fungus early, that information could guide public health

Mpox DNA detection in wastewater solids, 2022



Viral verification As mpox spread in the United States in 2022, scientists tested wastewater samples at nine sites in California for the virus. At five of those sites, the virus was detected before or within a day of the first case being confirmed in that sewershed.

actions to curb outbreaks, says Alessandro Rossi, a microbiologist at the Utah Public Health Laboratory in Salt Lake City. But interpreting the warnings isn't as clear-cut for *C. auris* as for viruses.

The fungus can grow in sewage after it leaves health care facilities, Rossi says. The pathogen has "the potential to replicate, form biofilms and colonize a sewershed." In other words, *C. auris* can create its own data interference, potentially making wastewater results seem worse than they really are.

Moving wastewater into the future

Most current testing programs are reactive. By looking at health threats one at a time using specific PCR tests, the programs mostly confirm that pathogens we already are worrying about are getting people sick.

But some scientists, like Wim Meijer, envision a future in which wastewater monitoring wades into the unknown and alerts us to unusual disease outbreaks. The microbiologist, of the University College Dublin, heads Ireland's wastewater surveillance program. Ideally, in this ahead-of-the-curve future, after detecting something alarming in sewage, his team could closely collaborate with health officials to study the pathogen and, if necessary, start combating the threat.

One idea for turning the tech proactive is to prepare for new health threats that we can see coming. For example, Meijer and his colleagues are interested in screening Ireland's sewage for the H5N1 bird flu, but they are not yet doing this testing.

Another approach takes advantage of genetic testing technology to look at *everything* in our waste. Kartik Chandran, an environmental engineer at Columbia University who has mapped sewers' microbial ecosystems with this technique, describes it as "trying to shine the light more broadly" rather than looking where the light is already shining brightest.

Such an approach might identify new pathogens before sick people start going to the doctor's office, potentially leading to an earlier public health response. But with health officials still unsure of how best to use wastewater data, much more basic research is needed first.

"People think wastewater surveillance is the answer to everything, and clearly that's not true," says Kirby, of the CDC, reflecting concerns from the state and local officials that she collaborates with at NWSS. Before diving ahead into proactive surveillance, Kirby and her colleagues are working to set up basic wastewater standards and protocols for health agencies. Priorities include evaluating how sewage trends correlate to cases for different pathogens and developing standards for how to use the data.

The wastewater surveillance field also needs to keep growing if the goal is to monitor and contribute to global health, with more sites contributing data and more scientists to analyze it. All of this work requires sustained funding.

The CDC's program so far has been funded by COVID-era legislation and will run out of money in 2025. While wastewater surveillance is more cost-effective than other types of testing, it still requires a lot of resources. Washington's state health department, for example, paid Biobot more than $500,000 for a one-year sewage testing contract, while the CDC has paid the company more than $23 million since 2020 for its work with NWSS.

For the last few years, wastewater surveillance has been a giant, messy group project. Scientists have collaborated across fields and locations, across private and public institutions, through Zoom calls and through poop samples shipped on ice. They've shown that waste might hold the key to a new way of tracking our collective health.

A lot of unanswered questions remain, and it could be some time before your local sewer can tell you exactly what disease risks you might be facing. But COVID-19 pushed thousands of experts to look into their toilets and start asking those questions. "Now, everyone's a believer," says Driver, of ASU. "Everyone's doing the work." ■

Explore more

■ National Academies of Sciences, Engineering of Medicine. "Wastewater-based disease surveillance for public health action." 2023.

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M.K. WOLFE *ET AL*/*NEJM* 2023

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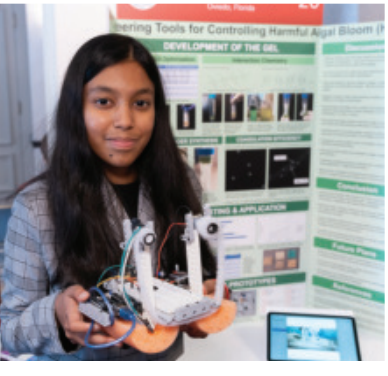

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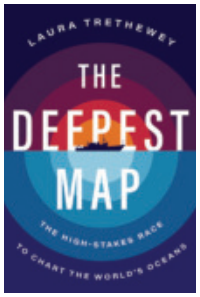
Thermo Fisher Scientific is the new title sponsor of the Society for Science's middle school STEM competition, now called the Thermo Fisher Scientific Junior Innovators Challenge (JIC). Across the United States, students compete in the nearly 275 middle school science fairs that are affiliated with the Society. The top 10 percent of projects submitted by sixth, seventh and eighth grade students earn the opportunity to apply for the Thermo Fisher JIC, hosted in Washington, D.C.

Previously known as the Broadcom MASTERS, the competition supports and celebrates students at a critical time in their emotional and educational development, encouraging them to continue on their STEM journey through college and career.



The Deepest Map
Laura Trethewey
HARPER WAVE, $32

BOOKSHELF

The thrills and dangers of mapping the deep sea

In 2019, the multimillionaire and explorer Victor Vescovo made headlines when he became the first person to visit the deepest parts of all five of Earth's oceans. But arguably the real star of the expedition was marine geologist Cassie Bongiovanni, the lead ocean mapper who ensured Vescovo piloted his submersible to the actual deepest depths.

Today, only 25 percent of the seafloor is well mapped. When Vescovo set out to score his record, the exact deepest location in each ocean was unknown. Bongiovanni, Vescovo and their crew had to chart these regions in detail before each dive.

"Traditionally, captains never cared about the seafloor as long as it stayed far enough away from the hulls of their ships," journalist Laura Trethewey writes in *The Deepest Map*. The book explores humankind's quest to map the seafloor, framed around Bongiovanni's adventures.

Seafloor topography has been a big concern for militaries patrolling Neptunian frontiers with nuclear submarines and companies facilitating intercontinental communication via subsea cables (SN: 4/10/21, p. 28). In recent decades, seafloor data have become crucial to the deep-sea mining industries searching for metals needed to produce green technology.

Satellites have revealed many of the knobs and crevices visible in the deep blue of Google Maps. But with that relatively coarse information, entire mountains can be missed. To see the seafloor in high resolution requires a sophisticated sonar system aboard a big ship that sends sound signals from the sea surface into the abyss. Mappers like Bongiovanni calculate depth from the time it takes for the signal to travel down and bounce back to the surface. These state-of-the-art sonar systems transform "the satellite-predicted blur into a sharp three-dimensional terrain of ripples, cracks and tears in the seafloor," Trethewey writes. "The seafloor is 'heard,' rather than seen."

The seafloor is well mapped in some places, but for the majority of the ocean, scientists have only a basic sketch of deep-sea topography.

MICHAEL SCHMELING/ALAMY STOCK PHOTO

Through Trethewey's tale, she twines stories of tagging along with scientists and ocean mappers. That includes her inaugural adventure at sea, which a crew member noted was "pretty rough for a first-timer," as he and Trethewey clung to a doorframe in near gale force winds. On this cruise aboard research vessel E/V *Nautilus*, which was surveying a poorly mapped stretch of California's coast, Trethewey (and readers) are introduced to the art and science of seafloor mapping. On this day, Trethewey learned that mapping is especially difficult — and sometimes impossible — when the ocean is angry.

Trethewey's insightful writing helps readers understand just why mapping the ocean — even in shallow coastal waters — is crucial to so many endeavors. She visits a remote Inuit village on the western bank of Canada's Hudson Bay, where she joins hunters who map ever-changing coastlines for their own safety. Later, she scuba dives with archaeologists in Florida who use underwater maps to explore remnants of early human history that have been submerged for thousands of years.

A distant, possibly unreachable goal envisions creating a complete map of the entire seafloor by the end of this decade, an effort known as Seabed 2030. Because the oceans are vast and replete with remote and dangerous places that people simply can't or shouldn't go, this effort will almost certainly require autonomous surface vehicles armed with sonar. Such devices are already probing the depths and sending back data. Staring at computer screens in a sun-filled conference room, Trethewey watches as a drone outfitted with cameras, environmental sensors and a sonar system maps a bit of seafloor off California as she sips her coffee. "The future of ocean mapping weirdly felt a lot like checking social media or doing anything else on your phone these days," she wryly observes.

Trethewey's book is about more than just mapping the oceans. It's also about what can go wrong when explorers explore. It's hard to read *The Deepest Map* without being reminded of the recent implosion of the Titan submersible in the North Atlantic that killed everyone on board in June. Indeed, Trethewey describes how, during Vescovo's first solo dive, his colleagues endured 25 minutes of apprehension-turned-alarm when they didn't hear from him.

She also reminds us how easily exploration can turn into exploitation. In the not-so-distant past, Europeans "discovered" the so-called New World and mapped it, Trethewey writes. Exploitation followed. Scientists and environmentalists alike are now concerned that a full, detailed map of the ocean floor might lead to the destruction of delicate, mostly unknown habitats if deep-sea miners are allowed to extract metals.

Trethewey envisions a different outcome. Seabed 2030's mapping effort may help people see that "the weird, wonderful deep-sea world is not a blank space, another frontier to use up and throw away," and should be safeguarded for scientists "to uncover our past and protect our future." — *Alka Tripathy-Lang*

JULY 15, 2023 & JULY 29, 2023

Feline fecundity

*One shot of an experimental gene therapy kept female cats kitten-free for at least two years, **Erin Garcia de Jesús** reported in "Gene therapy prevents cat pregnancy" (SN: 7/15/23 & 7/29/23, p. 10).*

Reader **Christie Borem** asked why the researchers focused on female cats.

It only takes one "pesky" male cat to impregnate multiple females, says reproductive biologist **David Pépin** of Massachusetts General Hospital and Harvard Medical School. If male contraceptives alone were used, nearly every male cat would need to receive treatment to prevent pregnancies in females. But each female cat that receives contraception is one less female giving birth to litters, regardless of the male population, **Pépin** says. What's more, surgical sterilization is a more invasive procedure for female cats than it is for males, which makes females an ideal target for quick and easy birth control, he says.

With that said, contraception for both male and female cats would be helpful for controlling populations of feral cats, **Pépin** says. Researchers are developing new birth control methods for male cats, but none have proved permanent.

Spinning out

*The North Pole drifted about 1.6 meters toward the east coast of Greenland between 1993 and 2010. About 78 centimeters, or about 4.4 cm per year, of that shift was due to irrigation alone, **Sid Perkins** reported in "Irrigation nudges the North Pole" (SN: 7/15/23 & 7/29/23, p. 12).*

Reader **Hugh Black** wondered if factors such as population growth and climate change also contribute to polar drift.

Any relatively permanent redistribution of mass would contribute to drift, but water probably has the biggest influence, says **Clark Wilson**, a geophysicist at the University of Texas at Austin.

Glacier and ice sheet melting, which has accelerated over the last several decades, contributed about 4.1 cm/yr to the North Pole's drift during the study period, **Wilson** and colleagues estimated. The team hasn't looked at the effect of population growth, but **Wilson** speculates that its contribution to polar drift would likely be smaller than that of water impounded in reservoirs behind dams, which the team estimated to be about 1.5 cm/yr during the study period.

What's the big G?

*Physicists have spent centuries trying to pin down the value of Newton's gravitational constant, or "big G," **James R. Riordon** reported in "What is big G?" (SN: 7/15/23 & 7/29/23, p. 28).*

Labs around the world attempting to measure G, which reflects the strength of gravity between things with mass, have turned up values that disagree. Reader **Richard Bisk** wondered whether dark matter could be influencing the measurements.

"Scientists have been trying to detect dark matter on Earth for decades without much success. We are still in the dark," says physicist **Stephan Schlamminger** of the National Institute of Standards and Technology in Gaithersburg, Md. Some efforts to detect dark matter have used torsion balances, a tool that experimentalists measuring G also use. Since dark matter has yet to be detected with those efforts, it's relatively safe to assume that the mysterious stuff does not influence measurements of G in a significant way, **Schlamminger** says. Still, dismissing the idea completely "would be foolish because detecting dark matter with a G experiment could easily lead to a [Nobel Prize]," he says.

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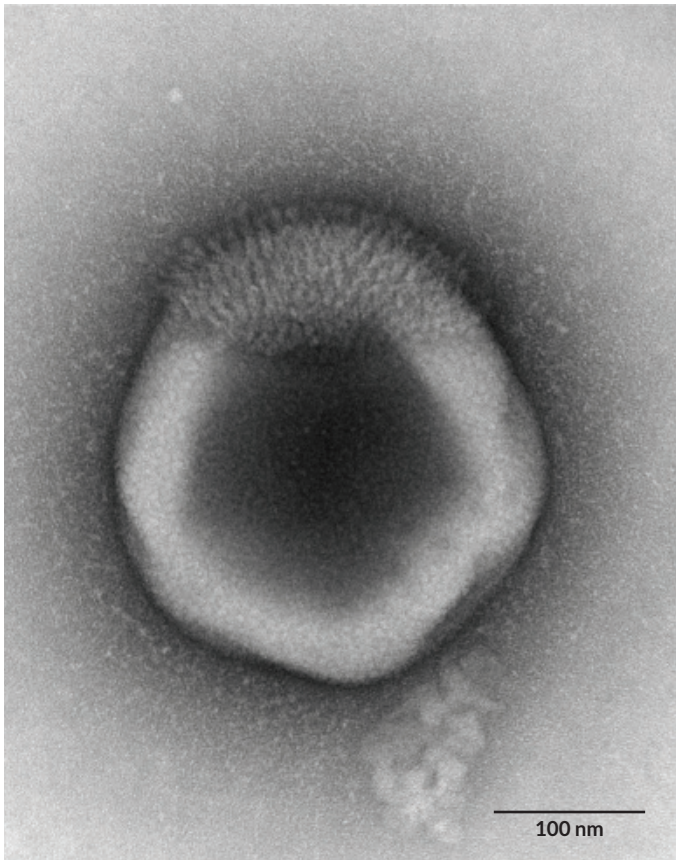

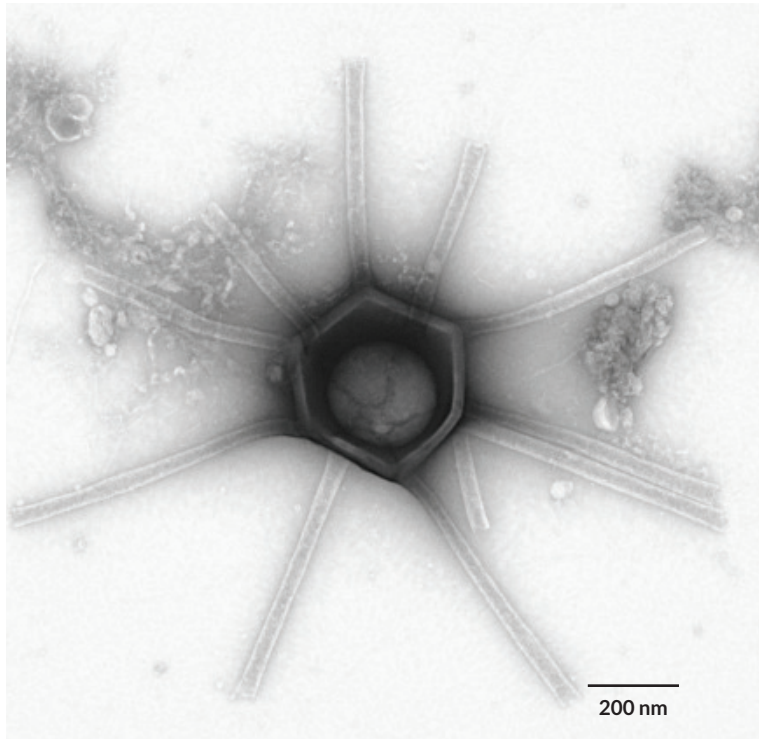

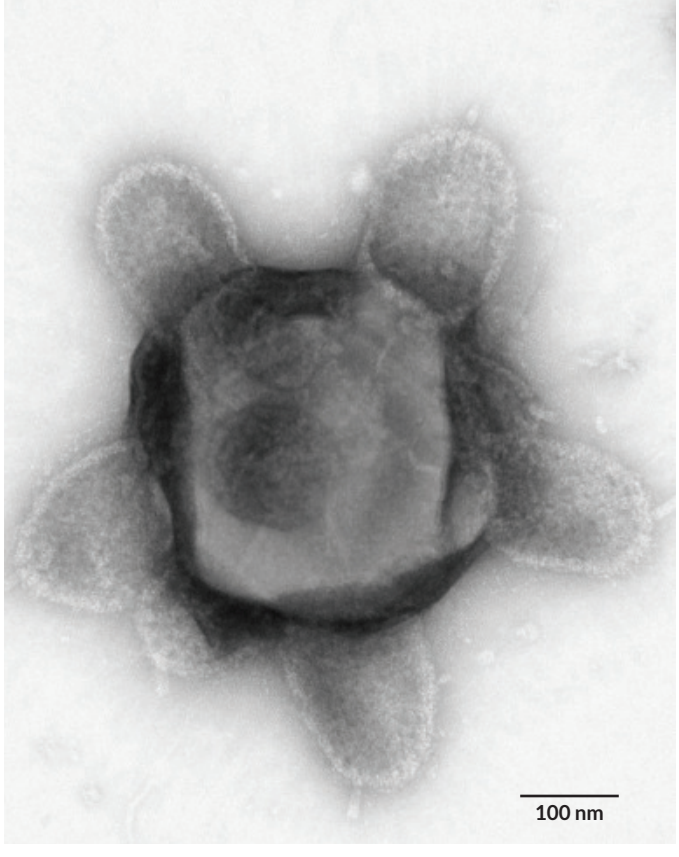

A fantastical world of potential viruses lurks under the soil

Giant viruses may try out all sorts of funky styles.

New images reveal the varied — and sometimes whimsical — shapes of hundreds of potential viruses, each one a soil-dwelling giant. One shape is dubbed "haircut" for its fibers that bristle like freshly buzzed hair (top left). "Gorgon" has tubelike appendages snaking from its shell (top right). And flaps poking out of "turtle" resemble the reptile's head, limbs and tail (left), virologist Matthias Fischer and colleagues report June 30 at bioRxiv.org.

Giant viruses are about 10 to 50 times as wide as those that cause the common cold. The newly revealed shapes "tell us that we've underestimated how structurally diverse these viruses are," says Fischer, of the Max Planck Institute for Medical Research in Heidelberg, Germany.

Using transmission electron microscopy, Fischer and colleagues analyzed about half a kilogram of soil from Harvard Forest in Petersham, Mass., to produce an image gallery of giant virus diversity — potentially. Fischer is careful not to call the finds "viruses" just yet. It's possible they are some other type of microorganisms or fragments of viruses.

Scientists can only speculate why a giant virus might form various appendages. They may help the virus infect a host or move through the environment, Fischer says. Regardless, he thinks more peculiar shapes remain to be discovered. "If a handful of forest soil already contains so many different virus particles," he says, "this is clearly just the very tip of the viral Mount Everest." — *Meghan Rosen*

ALL: M.G. FISCHER, U. MERSDORF AND J.L. BLANCHARD/BIORXIV.ORG 2023

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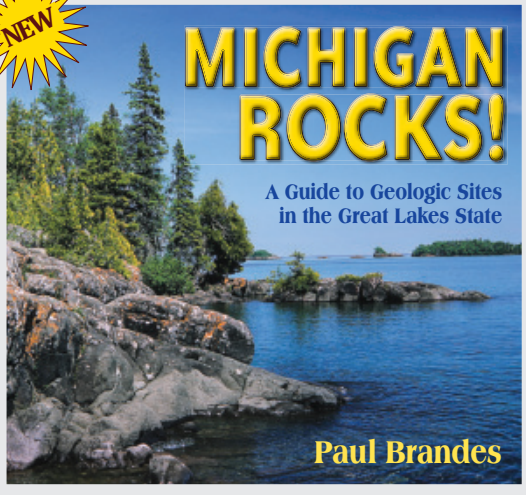

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PAUL BRANDES

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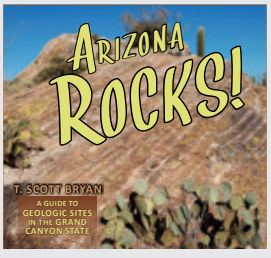

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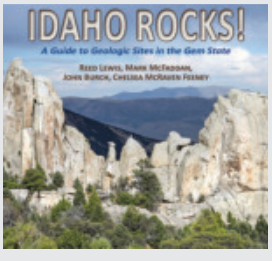

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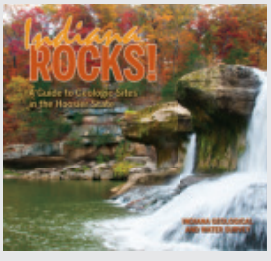

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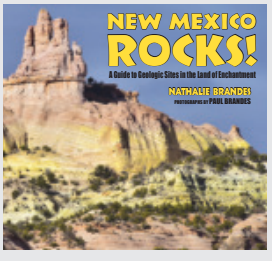

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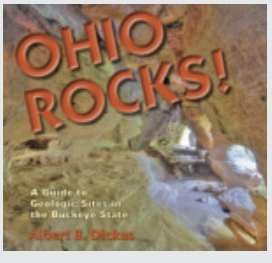

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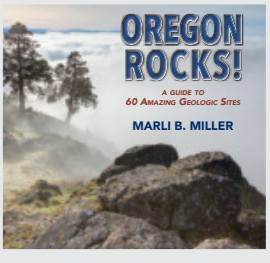

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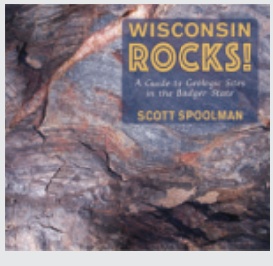

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