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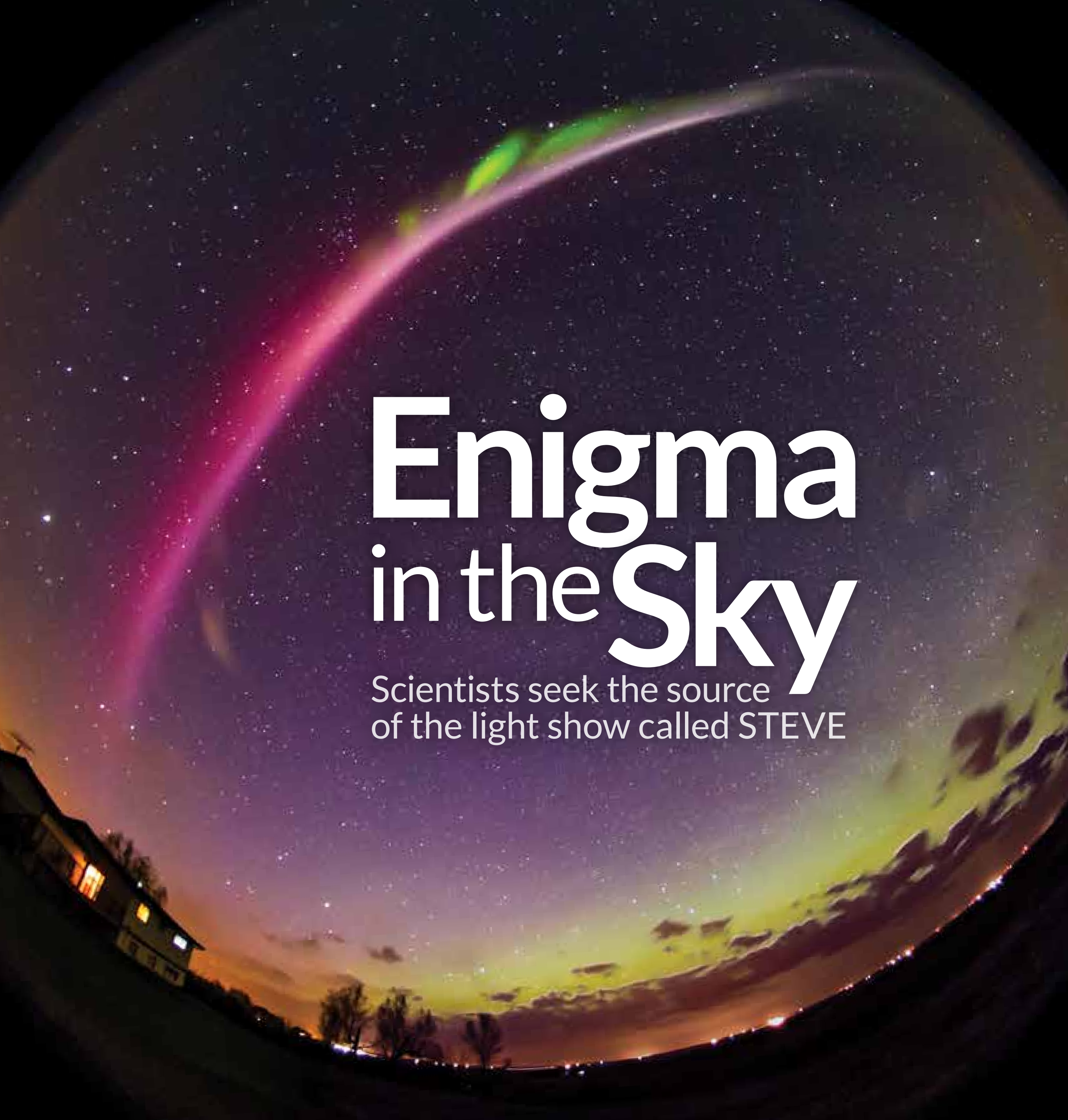
ScienceNews

MAGAZINE OF THE SOCIETY FOR SCIENCE ■ FEBRUARY 24, 2024



Enigma in the Sky

Scientists seek the source of the light show called STEVE

CONGRATULATIONS

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Regeneron and Society for Science salute the amazing young scientists selected as finalists from more than 2,100 entrants in the 2024 Regeneron Science Talent Search.


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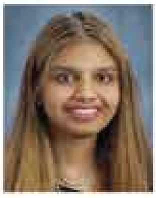
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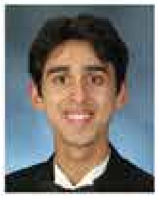
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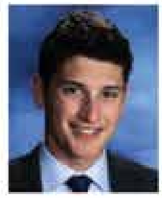
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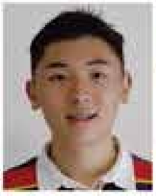
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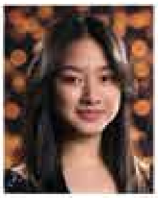
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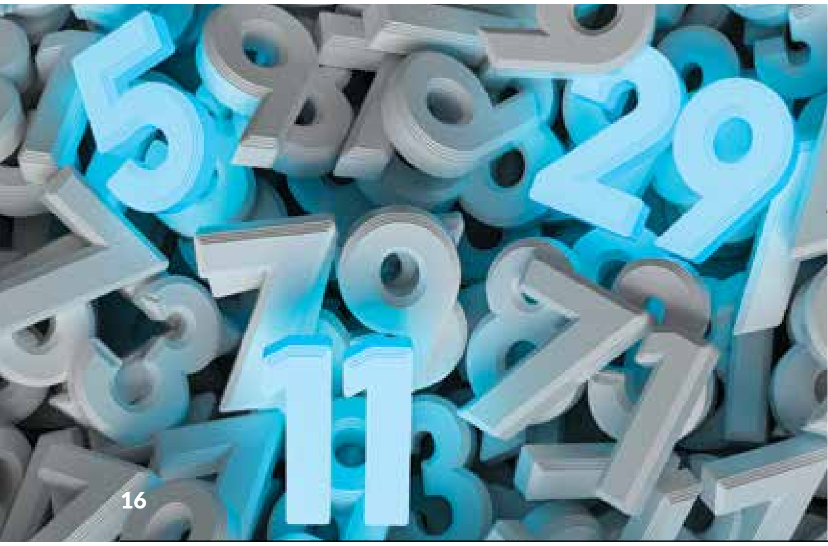

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FROM TOP: LISA SHEEHAN; FREDRIK PLEJEL; VICTORIA ZERO

COVER In this photo taken with a fish-eye lens, the purplish STEVE and its green picket fence light up the sky over rural Canada. *Alan Dyer/AmazingSky.com*

Come along with us on a mathematical mystery tour

Many if not most of the articles in *Science News* involve some math, whether as an essential tool in conducting research or a way to solve real-world problems, such as how to calculate a safer crowd size during the pandemic, detect gerrymandering in voter districts or cook the perfect steak.

But sometimes we dig into pure mathematics—math that doesn't address an immediate practical need but is worthy of pursuit for its own sake. That includes last year's discovery of an "einstein" tile, a long-sought two-dimensional shape that can cover an infinite surface but only with a pattern that never repeats (SN: 4/22/23, *p.* 7).

In this issue, we report on a big advance in combinatorics, which is about as pure mathy as a topic can be (we also revisit the einstein tile, see Page 8). The tale centers on two computer scientists. While trying to solve a seemingly unrelated problem in a distant field, the pair made a breakthrough in a puzzle that mathematicians have been wrestling with for a century (Page 16).

Combinatorics is a branch of mathematics that involves the counting and arrangement of numbers or other things. An enduring question in combinatorics is whether it's possible to predict whether an infinitely long list of numbers must include an arithmetic progression: a sequence of equally spaced numbers such as 2, 5, 8, 11, 14, 17.

On first glance, this doesn't sound like the kind of challenge that brilliant people would devote decades of their lives to figuring out. But as freelance writer Evelyn Lamb, a mathematician herself, explains, people seem hardwired to seek out puzzles and driven to find the answers. "We humans just love going down these rabbit holes, having natural curiosity and building theories about things we see around us," Lamb told me. "We all have things we're super-interested in and then start diving deep."

Arithmetic progressions have fascinated people since antiquity. Today, these sequences and other repeating patterns are part of many areas of math and computer science, providing both challenges and potential solutions. Such patterns can also provide a bit of fun. You don't have to be a mathematician to get hooked on the plethora of sequence puzzles, whether based on numbers, letters or symbols, that are all over the internet.

I confess that I'm not someone who would put "learn more about combinatorics" at the top of my to-do list. But I was quickly drawn into the tale Lamb tells. Part of the appeal, she says, is that most everyone was introduced to numbers at a very young age, and many of us have played around with arithmetic progressions in school or in games, even if we've never heard the term. It's not hard to become intrigued with something that seems so simple but can quickly become so complicated.

But if numbers can feel almost innate, they can also be intimidating. "If you feel bad at math, you feel like you're not smart," Lamb says. Her goal in telling the story of people's long-held fascination with arithmetic progressions is to help us enjoy math for math's sake. Read her article, and I think you will.
—Nancy Shute, Editor in Chief

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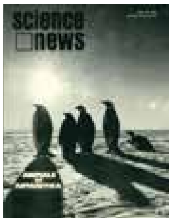


Excerpt from the February 23, 1974 issue of *Science News*

50 YEARS AGO

Cancer drugs by computer

Chemists often need to sort a large number of compounds according to whether or not they possess a given property.... [Researchers] have been working on a technique of getting computers to teach themselves how to solve such problems. The most recent experiments indicate that the technique [based on pattern recognition] may be useful in finding cancer drugs.

UPDATE: Modern computers can do more than sift through known compounds. With advanced artificial intelligence, computers are helping scientists design novel molecules and predict how those compounds will react with proteins in the body, possibly leading to new cancer treatments. The technology is promising but still in its early days. Ultimately, most drug candidates will still falter in people, some scientists caution. In 2021, the international biotech company Exscientia launched the first trial of an AI-developed cancer drug. But the company shelved the drug in 2023 after it proved to be ineffective. Other AI cancer drugs are in various stages of testing.

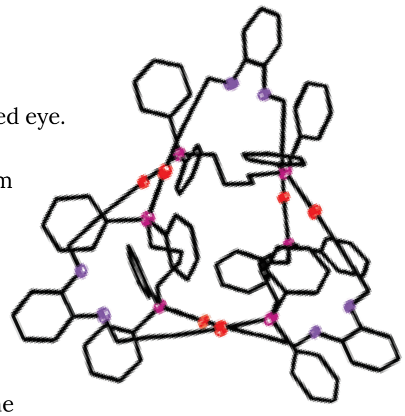
IT'S ALIVE

Snails that give live birth seem to leave labor up to the babies

The rough periwinkle snail's brood pouch contains embryos at various stages of maturity (shown). When young hatch, they may have to crawl out of mom's body on their own.

THE –EST

The smallest molecular knot yet



Imagine a knot so small that it can't be seen with the naked eye. Then think even smaller.

Chemists have tied together a chain of 54 atoms to form the smallest molecular knot yet. Described January 2 in *Nature Communications*, the pretzel-shaped knot (illustrated), called a trefoil, has a backbone made of gold (red), phosphorus (purple), oxygen (magenta) and carbon atoms (black nodes). The previous smallest molecular knot, reported in 2020, contained 69 atoms.

Chemist Richard Puddephatt and colleagues created the new knot while attempting to build complex structures of interlocked ring molecules, or catenanes. Someday catenanes could be used in molecular machines — think switches and motors at the molecular scale — but for now scientists are still figuring out how to build them. In this case, that effort resulted in something else by mistake.

"It was just serendipity really, one of those lucky moments in research that balances out all the hard knocks that you take," says Puddephatt, of the University of Western Ontario in London, Canada.

The new knot is also the tightest molecular trefoil knot. Researchers calculate a molecular knot's tightness by dividing the number of atoms in the chain by the number of chain crossings to get what's called the backbone crossing ratio, or BCR. The smaller the BCR, the tighter the knot. The new knot has a BCR of 18. The previous smallest molecular knot was also the previous tightest, with a BCR of 23.

Studying small molecular knots could someday lead to new materials (SN: 9/15/18, p. 32). But for now, the team is still trying to determine why this combination of atoms results in a knot at all. — *Anna Gibbs*

FROM TOP: FREDRIK PLEIJEL; Z. LI *ET AL*/*NATURE COMMUNICATIONS* 2024

The oddball minority of animals that don't lay eggs includes a tough little snail called a rough periwinkle (*Littorina saxatilis*).

This tidal-zone snail switched to live birth relatively recently in its evolutionary history, and its newcomer version of birthing offspring is ... different. Mom gives birth multiple times a day, and it's probably not her but the babies who do the hard labor.

Egg-laying periwinkle relatives have a jelly gland that creates a goo-protected mass of eggs. But in *L. saxatilis*, the gland has evolved into a make-do womb, or brood pouch. Eggs still form there but stay inside mom until after hatching, says Kerstin Johannesson, an evolutionary ecologist at the University of Gothenburg in Sweden.

Mom can have a few hundred embryos at various stages of maturation in the gland. When birthing the mature ones, if she starts to push, "the ones that are not ready [would] probably come out," Johannesson says. So it's likely that periwinkle babes crawl out of their mother's body on their own. To do so, each baby snail seems to scrape a hole in its own embryo, "like a hatching bird," Johannesson says. Then babies somehow find an exit.

The live birth of these snails intrigues Johannesson because the species probably gained the ability in the last 100,000 years or so. That's an evolutionary eyeblink.

When comparing rough periwinkles with two close sister species, the only reliable visible difference is the quirk of live birth. To clarify just how distinct the species have become, Johannesson and colleagues turned glass ornaments into snail passion chambers, pairing one snail from a live bearer species with one from an egg layer in each bauble. Some couples mated but produced no viable offspring — a sign the partners are separate species (*SN: 11/11/17, p. 16*).

> The species probably gained live birth in the last 100,000 years or so. That's an evolutionary eyeblink.

Genetic studies of how live birth arose found differences in some 50 regions in the snail's genes. None of the changes seems more influential than the others, the team reports in the Jan. 5 *Science*.

The brood pouch's protection might explain the species' success, even though babies emerge looking small and vulnerable, Johannesson says. Between the fingers, they feel "like grains of sand."

Mom may not help her offspring emerge, but she can serve up their first meal: diatoms and bacteria ready to be scraped off her shell. Nom nom! *— Susan Milius*

HOW BIZARRE

Fern revives dead leaves

To get by in western Panama's Quebrada Chorro forest, one tree fern repurposes its dead fronds, turning them into roots.

In 2019, tropical forest ecologist James Dalling of the University of Illinois Urbana-Champaign came across a thicket of *Cyathea rojasiana* tree ferns in Quebrada Chorro. Moving dead fronds out of the way wasn't easy: The leaves, still attached to the plants, extended into the ground. Digging them up revealed rootlets sprouting from vein tips. In the lab, rootlets planted in pots with a stable form of nitrogen pulled the nutrient into the ferns, confirming that the structures act as roots, Dalling and colleagues report January 18 in *Ecology*. The fern may use dead leaves to seek out nutrients instead of investing in new roots.

"I've never heard of any other fern doing this, or for that matter, any other land plant," says botanist Erin Sigel of the University of New Hampshire in Durham.

Robbin Moran, a neotropical fern expert based in St. Louis, is similarly stunned. "It's weird." *— Darren Incorvaia*

SAY WHAT?

Beakiation \bē-kē-'ā-shən\ n.

In parrots, a swinging gait that employs the beak and feet

Parrots don't just hang out for fun. To move along narrow branches, some parrots can hang from a branch with their beak, swing their body sideways and grab hold farther along with their feet. The newly described gait, dubbed beakiation, expands the birds' locomotive repertoire, researchers report January 31 in *Royal Society Open Science*.

Parrots "are specialized for climbing and moving around in the trees," says biomechanist Michael Granatosky of the New York Institute of Technology in Old Westbury. But, he wondered, "what would happen if you flip a bird upside down or make them go onto the tiniest [branch] possible?"

So he and colleagues lifted four rosy-faced lovebirds (*Agapornis roseicollis*) to a suspended bar just 2.5 millimeters in diameter. The birds overwhelmingly shuffled along it using their beak and feet in a cyclical side-swinging motion, moving an average of 10 centimeters per second.

Using force measurements and other data collected across 129 strides, the team calculated how energy efficient beakiation is. Birds recovered about 24 percent of the energy they expended in a stride during the swinging part of the motion. For comparison, gibbons that swing between branches recover nearly 80 percent. This movement, called brachiation, is fast and fluid, while beakiation is not. *— McKenzie Prillaman*

STEVEN GAINES

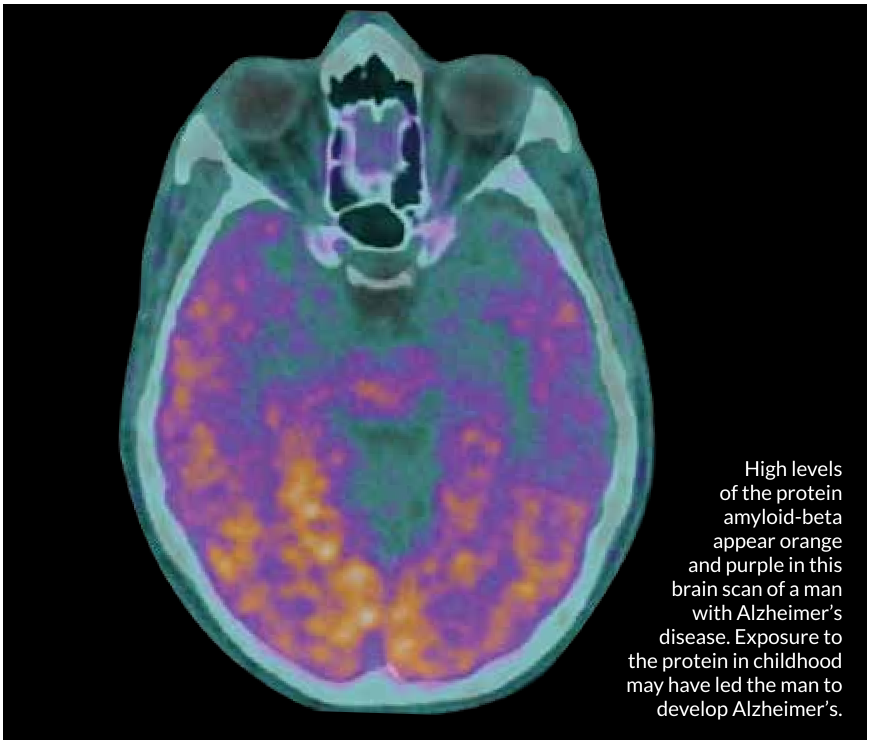
The rosy-faced lovebird can travel along thin branches using beakiation, a side-swinging motion that involves the beak and feet.

Watch a video of a lovebird move using its beak at **bit.ly/SN_Beakiation**

HEALTH & MEDICINE

Rarely, Alzheimer's may be transmitted

Scientists link five cases with a discontinued medical treatment



High levels of the protein amyloid-beta appear orange and purple in this brain scan of a man with Alzheimer's disease. Exposure to the protein in childhood may have led the man to develop Alzheimer's.

BY LAURA SANDERS

Under extremely rare circumstances, it appears that Alzheimer's disease can be transmitted between people. Five people who received contaminated injections of a growth hormone as children went on to develop Alzheimer's unusually early, scientists report January 29 in *Nature Medicine*.

The findings represent "the first time iatrogenic Alzheimer's disease has been described," neurologist John Collinge said January 25 in a news briefing, referring to a disease caused by a medical procedure.

That sounds alarming, but scientists emphasize that Alzheimer's disease is not contagious in everyday life, including caretaking and most medical settings. "We are not suggesting for a moment that you can catch Alzheimer's disease," said Collinge, of the University College London's Institute of Prion Diseases. "This is not transmissible in the sense of a viral or bacterial infection."

The reassurance is echoed by neurobiologist Carlo Condello of the University of California, San Francisco, who wasn't involved in the study. "Only under incredibly artificial, now out-of-date medical practices is this appearing."

Most cases of Alzheimer's disease arise spontaneously in older people. That's part of what makes these newly described cases so unusual. Symptoms started early for these five people, between ages 38 and 55. In three for whom genetic data were available, researchers ruled out mutations linked to early-onset forms of the disease.

The five people had all received growth hormone injections early in life. Used to treat various growth disorders, the hormone was extracted from cadavers and combined into batches. Some of these mixtures were later found to contain prions — infectious, misshapen proteins — that caused Creutzfeldt-Jakob disease, or CJD. More than 200 people were affected worldwide. This type of growth hormone treatment stopped in 1985; doctors now use synthetic versions.

It turns out that those batches held another problem. In an earlier study, Collinge and colleagues found higher-than-expected levels of amyloid-beta in the brains of four people with CJD who had died. Accumulation of the protein is a hallmark of Alzheimer's and, in these cases, a worrisome signal that perhaps some of these proteins had been transferred, along with prions, from donors. A-beta from some of the batches spread in the brains of mice by converting normal proteins to misfolded ones, suggesting that A-beta behaves in some ways like a prion, the researchers reported in 2018.

Now, the team reports on eight more people who had received contaminated growth hormone. None of these people had CJD, but three had been diagnosed with Alzheimer's. Further exams found that two more people had the disease and two had signs of cognitive trouble. One person didn't have symptoms.

The most likely cause of these five Alzheimer's cases seems to be the introduction of A-beta early in life, the team concludes. "Taken as a whole, the only real explanation is the shared exposure" to contaminated growth hormone, neurologist Gargi Banerjee of University College London said during the news briefing.

The team's interpretation is plausible, Condello says. "What's in those extracts could have done what they claim it did."

But scientists can't be certain that contaminated growth hormone caused these people's Alzheimer's disease. It's possible that the underlying conditions that necessitated the injections, or other medical procedures such as radiation, contributed to early Alzheimer's. And several of the people had had seizures, which may influence cognitive problems. "The definitive answer may never come," Condello says.

Still, the results may hold clues about how Alzheimer's takes hold, and whether A-beta, like a prion, incites other proteins to misfold under certain conditions. Untangling how various forms of A-beta spread lies ahead, Collinge said. ■

G. BANERJEE *ET AL*/*NATURE MEDICINE* 2024

ENVIRONMENT

Many regions are losing groundwater

But better management practices can help replenish aquifers

BY CAROLYN GRAMLING

The world's precious stash of subterranean freshwater is shrinking — and in nearly a third of aquifers, that loss has been speeding up in the last several decades, researchers report in the Jan. 25 *Nature*.

A one-two punch of unsustainable groundwater withdrawals and changing climate has caused global water levels to fall on average, leading to water shortages, slumping land surfaces and seawater intrusion into aquifers. The new study suggests that groundwater decline has accelerated in many places since 2000, but the researchers say that these losses can be reversed with better water management.

It's the first effort to synthesize global-scale groundwater data collected on-site, rather than by satellite. Previous studies have quantified the scope of global groundwater loss by analyzing data collected by a pair of NASA satellites known as GRACE (*SN: 7/25/15, p. 13*). Though satellites can scan the entire globe, some of the nuance of water loss — and recovery — in regional aquifers can be hard to detect from space, the researchers say.

Hydrologist Scott Jasechko of the University of California, Santa Barbara and colleagues analyzed water level data collected in about 170,000 monitoring wells around the world since 1980. Those wells offer glimpses into the state of almost 1,700 of the largest aquifer systems.

Groundwater levels are now dropping by more than half a meter per year in 12 percent of these aquifers and by a tenth of a meter per year in 36 percent of them. The fastest declines are happening in some of the world's most arid regions, including central Chile, Iran and parts of the western United States.

But there are signs of hope. Groundwater levels in some areas have begun to climb in the last two decades, even after shrinking at the end of the 20th century. Those recoveries are probably due to changes in regional water management, the team says. Groundwater losses from an aquifer in Thailand's Bangkok basin, for example, reversed this century thanks to regulatory measures such as charging fees on groundwater pumping and licensing wells. Iran's Abbas-e Sharghi basin, meanwhile, is recovering after water was diverted to the basin from a large dam between 2005 and 2014.

The reversals suggest that "long-term groundwater losses are neither universal nor inevitable," the team wrote in the study.

By identifying hot spots that need the most urgent attention, this work helps highlight which parts of the world are most at risk of involuntary human migration due to water shortages, says Li Xu, an environmental scientist at the University of Saskatchewan's Global Institute for Water Security in Saskatoon, Canada.

"Water is the key trigger for human migration or displacement worldwide, and those populations in low- and middle-income countries and in dry regions are most vulnerable," Xu says. Identifying the regions most at risk could lead to timely policy interventions, he says, especially for cross-border aquifers that could further increase the risk of armed conflicts. ■

Decades of drought and excessive water pumping are causing land to sink in many parts of Iran, such as in Malard (shown in 2019), just west of Tehran.

ASSOCIATED PRESS

PHYSICS

Einstein tile inspires a weird material

The theoretical quasicrystal shares properties with graphene

BY EMILY CONOVER

"The hat" wowed mathematicians. Now the shape is shaking up physics.

In 2023, mathematicians reported that the 13-sided tile was the first known "einstein" (SN: 4/22/23, p. 7). That's a shape that can perfectly cover an infinite plane — no gaps or overlaps — but only without forming a repeating pattern.

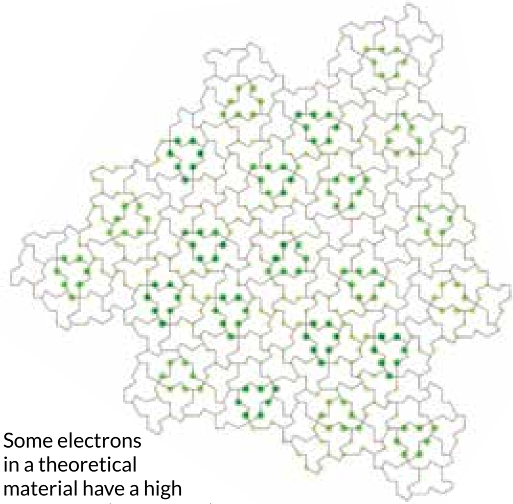
Scientists have now predicted the properties for a two-dimensional material based on the hat. It's a quasicrystal, a material that is orderly like a crystal but the arrangements of atoms don't repeat. Intriguingly, this hat-based material shares properties with graphene, a crystalline material, the researchers report in a study to appear in *Physical Review Letters*.

"It's got lots of properties that we associate with quasicrystals, but then it acts strangely like crystals," says physicist Sinéad Griffin of Lawrence Berkeley National Laboratory in California. "It's a really fun study."

Previously, mathematicians needed more than one shape to cover an infinite plane with an aperiodic tiling, the mathematical term for this type of nonrepeating pattern. Some earlier aperiodic tilings have connections to real-world materials. Penrose tilings, based on sets of two tiles discovered in the 1970s by mathematician Roger Penrose, look like a 2-D slice through a quasicrystal. Such quasicrystals have been found in meteorites and atomic bomb test debris, in addition to being made in the lab (SN: 6/19/21, p. 12).

Scientists wanted to know what a material based on the hat tiling might be like. Physicist Adolfo Grushin of Institut Néel of CNRS in Grenoble, France and colleagues calculated the properties of electrons in a 2-D material in which atoms sit at vertices of the hat tiles.

To characterize a material, scientists can look at the relationship between the energies of its electrons and their wavelengths. (According to quantum physics, electrons travel through materials as waves; the wavelength denotes the size of those waves.) In this energy–wavelength relationship, the team found striking similarities between the hat quasicrystal and graphene, a 2-D crystal of carbon.



Some electrons in a theoretical material have a high probability (dark green) of encircling mirrored tiles.

That's because many of the vertices of the hat tiling fall along a hexagonal grid like that of graphene, Grushin says.

The fact that the hat tiling is made up of a single tile shape, rather than multiple shapes, also helps explain how it straddles the worlds of crystals and quasicrystals.

At a particle accelerator in Germany, scientists used highly charged uranium ions to test the theory of quantum electrodynamics.

QUANTUM PHYSICS

In an extreme test, QED still stands

Pivotal quantum theory works even in strong electric fields

BY EMILY CONOVER

To put one of physics' most important theories to the test, scientists go to extremes. Extremely strong electromagnetic fields, that is.

The theory of quantum electrodynamics, which describes interactions of electrically charged particles and light, has been checked to painstaking precision (SN: 3/11/23, p. 10). The theory correctly predicts properties of simple atoms, like hydrogen or helium. But it has been less carefully tested in strong electromagnetic fields, like those of large atomic nuclei.

The theory's predictions hold up even in those conditions, physicist Robert Lötzsch of Friedrich Schiller University Jena in Germany and colleagues report in the Jan. 25 *Nature*.

Quantum electrodynamics, or QED, is an integral part of the standard model of particle physics, the theory of fundamental particles and their interactions. So testing it in all possible scenarios is key.

To probe QED's prowess, the scientists turned to uranium, which has a whopping 92 protons in its nucleus and a mighty electric field. The tests used uranium that had been stripped of all but two electrons to form an ion, or electrically charged atom. This type of uranium ion is called helium-like uranium because helium atoms normally have just two electrons.

Field strengths around such ions are much stronger than any field produced by humankind, Lötzsch says.

At the GSI Helmholtz Centre for Heavy Ion Research in Darmstadt, Germany, the team accelerated slightly charged uranium and sent it through copper foil, peeling all but one electron from each ion. When sent through nitrogen gas, the ions grabbed an electron to make helium-like uranium. The process left each ion with one of its two electrons in a high-energy state.

Those electrons quickly jumped to lower energy levels. By measuring X-rays released from a given jump, the team determined the energy of that transition.

FROM TOP: A. GRUSHIN/INSTITUT NÉEL/CNRS; J. MAI/GSI HELMHOLTZ CENTRE FOR HEAVY ION RESEARCH GMBH

The use of a single tile means it's closer to being periodic than other aperiodic tilings, without actually repeating.

Unlike graphene, however, the hat material is chiral, which means that the electrons would behave differently if you were to flip the material as if reflected in a mirror. In a real material, that chiral property might affect how light interacts with the substance, for example, by rotating the light's polarization, the orientation of its electromagnetic waves.

More interesting features popped up when the team investigated what would happen if the material were placed in a magnetic field. In the hat tiling, a fraction of the hat tiles are mirror images of the others. Electrons with zero energy became trapped around the flipped hats at certain magnetic field strengths. "We found it quite beautiful that this happens," Grushin says.

Although the material is entirely theoretical for now, the researchers proposed some ways that it could be brought to reality. For example, scientists could manually place molecules on a surface in a pattern matching the hat tiling. That would be the ultimate hat trick. ■

The result matched predictions. QED held up.

In strong electromagnetic fields, "how QED has to be calculated completely changes from how it's done in low fields," Lötzsch says. In general, QED calculations must consider interactions between electrons and virtual particles, which flit into and out of existence. In the strong electromagnetic fields of atomic nuclei, calculating the effect of many interactions becomes more complex. For helium-like uranium, scientists must also calculate the effect of interactions between electrons.

Many physicists expect that another theory will supplant the standard model. A flaw in QED's predictions could point the way. The study is a "unique and stringent test" of QED, says Fabian Heiße, a physicist at the Max Planck Institute for Nuclear Physics in Heidelberg, Germany. "Such tests are very important for the search [for] physics beyond the standard model." ■

Mars' Jezero crater looks hostile to life in this photo taken by a NASA rover, but pathogens may be able to grow there.

JPL-CALTECH/NASA, ARIZONA STATE UNIV., MALIN SPACE SCIENCE SYSTEMS

ASTRONOMY

Stowaway bacteria may thrive on Mars

Potential pathogens can grow in a fake Martian environment

BY ADAM MANN

Future interplanetary explorers beware: Potentially harmful bacteria hitchhiking to Mars on human bodies might survive the harsh conditions on the Red Planet's surface and even flourish.

Recent experiments exposed four disease-causing microbes to a simulated Mars-like environment, with its lack of water, scant atmospheric pressure, deadly ultraviolet radiation and toxic salts. The bacteria remained alive for various periods of time and, in some cases, even reproduced in imitation Martian soil, scientists report in the January *Astrobiology*.

The findings have implications for astronaut health and efforts to prevent the contamination of other worlds (SN: 1/20/18, p. 22). "Bacteria are really resilient little creatures that survive a lot of things, which is why they've existed for billions of years on Earth," says microbiologist Samantha Waters of Mercer University in Macon, Ga.

Previous research into the survivability of microbes on Mars has mostly focused on Earth's extremophiles — organisms that live in places with lots of radiation, salt, temperature swings or aridity. Then, lab experiments showed that several bacterial species that can live on or inside humans could grow in a medium resembling the nutrient-poor conditions of meteorites, scientists reported in 2020 in *Astrobiology*.

That made those researchers wonder how such microbes would hold up in Mars' unforgiving environment. So several members of that team, as well as microbiologist Tommaso Zaccaria, exposed *Burkholderia cepacia*, *Klebsiella pneumoniae*, *Serratia marcescens* and *Pseudomonas aeruginosa* to simulated Martian conditions including surface soil, or regolith. Usually, these species live harmlessly with us, but they can become pathogenic when stressed or for immunocompromised people.

"At the beginning, we thought that the regolith would have a toxic effect on the cells so it would limit their growth," says Zaccaria, of the German Aerospace Center in Cologne. "But instead, we saw that it was the opposite."

Three species survived the experiment. Notably, *P. aeruginosa* grew steadily for up to 21 days. Zaccaria and colleagues are now trying to figure out just how the microbes held on. Perhaps in the crannies of the simulated soil, bacteria found oases with enough water, nutrients and protection from UV radiation, Zaccaria says.

The results suggest that crewed missions to Mars should pack plenty of antibiotics in case such bacteria survive, mutate and infect human explorers. And since searches for life on Mars want to avoid mistaking an earthly microbe for a native Martian one, Zaccaria also recommends that areas of the Red Planet be set aside like national parks, with only sterilized robotic vehicles allowed in.

Human ingenuity will hopefully find ways to mitigate such problems, Waters says. "At the end of the day, we want to move forward and explore our solar system more," she says. "We try our best and that ultimately will lead to some really beautiful discoveries and some really cool history." ■

At the Ol Pejeta Conservancy in Kenya, lions switched from hunting zebra to buffalo when tree cover declined — the result of invasive ants messing up an ecological relationship.

ECOSYSTEMS

Lions alter hunting tactics due to ants

The insects indirectly made the big cats more conspicuous

BY BETHANY BROOKSHIRE

How did the ant steal the lion's dinner? This isn't the beginning of one of Aesop's fables. It's the question at the heart of a new study showing how the disruption of one tiny mutual relationship on the African savanna has big impacts on the food web — all the way to the lion's den.

When big-headed ants (*Pheidole megacephala*) invade the savanna, they kill native acacia ants (*Crematogaster* spp.) that defend whistling thorn trees against hungry elephants. Without acacia ants around to bite them, elephants rip up the trees, which increases visibility and makes it difficult for lions to catch their preferred zebra meals. Lions end up hunting buffalo instead.

The findings, published in the Jan. 26 *Science*, show that invasive species' effects can be very indirect and suggest that changes in low-level mutualisms — partnerships between species — might also echo up food webs in other ecosystems.

Over the last 15 years or so, wildlife ecologist Jake Goheen and colleagues at the University of Wyoming in Laramie and the Ol Pejeta Conservancy in Kenya, have been studying how acacia ants protect whistling thorn trees. When an elephant tries to eat the tree, "ants swarm up inside its nostrils and bite from the inside out," Goheen says.

The scientists were also examining what the lions in the conservancy eat as part of a separate study. "One of the things that we found … was that lions are much more effective, they're more successful with their hunts, in areas where tree cover is high," Goheen says.

But what happens when tree cover is suddenly low? To find out, Goheen's team collared six lionesses from the local prides to track their activity and kills. The researchers also set up experimental plots where big-headed ants had invaded,

Big-headed ants encircle and tear apart two larger acacia ants. The demise of acacia ants leaves their tree home in Africa undefended and vulnerable to elephants.

and where the native ants still held sway.

The big-headed ant arrived in the conservancy between 2002 and 2005, Goheen says. "We think it probably was imported on produce," brought into the houses or tourist camps in the area. The invading insects kill local acacia ants wherever they find them. And another study has shown that without defending ants, elephants tear down the thorn trees five to seven times as often.

In the new study, the scientists could have used drones or satellite images to study tree cover, but "we don't have that kind of money," Goheen says. Instead, the researchers tracked the collared lions, and then got down on hands and knees near the lions' recent kills, using a range finder to measure the openness of the area. Areas with big-headed ants had visibility that was nearly 2.7 times as high as areas without ants — meaning that lions could see farther, but so could their prey.

Lions relied on the cover of trees to pounce on hapless zebras nearby: Where visibility was low, the lion's chance of taking down a zebra was 62 percent. But when visibility was high, the probability dropped to 22 percent.

Between 2003 and 2020, zebra dinners decreased from 67 percent of lion kills to 42 percent. But the lions didn't go hungry. Instead, they went for bison. Buffalo kills increased from zero to 42 percent of kills over the same period. It's a risky diet. Lions are more likely to be injured by "big and feisty" buffalo than zebras, Goheen says.

The findings show that "the disruption of a mutualism can have cascading effects on other species in the community," says plant ecologist Emilio Bruna of the University of Florida in Gainesville. "Those effects can be unexpected and indirect."

It's a clue, Bruna says, that ecologists should be looking out for other pairs like the acacia ant and the thorn tree, where a single special relationship is a foundation for an ecosystem and a single anthill could cause a savanna-wide shift in who is eating who. ■

FROM TOP: VICTORIA ZERO; PATRICK MILLIGAN

ANIMALS

Artificial light disorients flying insects

Moths, flies and others seem to lose their sense of direction

BY ERIN GARCIA DE JESÚS

Moths and other insects flying in circles around porch lights aren't captivated by the glow. Instead, they may have lost track of which way is up, high-speed infrared camera data suggest.

Flying insects naturally turn their back toward light. But when insects turn their back on artificial light sources, their sense of direction goes topsy-turvy, scientists report January 30 in *Nature Communications*. The insects may lose track of where the ground is, leaving them flying in circles or toward the ground.

The finding is the first "satisfying answer to a long-standing phenomenon" of why certain insects flock to streetlamps, says Florian Altermatt, an evolutionary biologist at the University of Zurich. "It was an actually rather simple explanation, defying the previous, more complex ones."

Those hypotheses included flying insects becoming blinded by light, interpreting light sources as safe havens from predators and mistaking human-made lights for the moonlight they use to navigate.

Just as pilots flying planes have tools to work out which way is up when they're gaining speed, flying insects may turn their back on the sky's light to keep their feet pointing toward the ground. "It's a really good idea until somebody invents the LED," says entomologist Samuel Fabian of Imperial College London.

At a field station in Costa Rica, Fabian and colleagues watched as insects from 10 orders circled endlessly around hanging or standing lights. Others flew upward in a steep climb, losing speed until they couldn't fly any higher. When the light source pointed up, some individuals flipped over and headed for the ground.

Aloft insects kept lights at their back, even if they ended up crashing. The same was true of moths and dragonflies in lab tests. Had the insects flown toward the light or in smooth spirals, that would have suggested the light acted as a beacon or compass. Instead, Fabian says, "it's a bit like somebody's grabbed a joystick and is pulling it in the wrong direction."

Normal flight resumed when the team shined light on a white sheet stretched above the ground, creating a diffuse, sky-like glow.

In the lab, there were some exceptions. Oleander hawk moths (*Daphnis nerii*), for instance, flew over artificial lights just fine. But in the wild, hawk moths still crashed. Perhaps over time, individuals learn to ignore the lights, the team suggests.

It's clear that artificial light can put insects on a crash course, says ecologist Brett Seymoure of the University of Texas at El Paso. But more research is needed to confirm if it happens because insects use the sky's light for navigation, irrespective of the presence of artificial light. ■

ARCHAEOLOGY

How Stone Age people made rope

A mammoth ivory tool unearthed in central Europe has offered a peek at how teamwork enabled Stone Age folks to make thick, sturdy ropes.

Researchers assembled 15 mammoth ivory pieces, recovered from Hohle Fels Cave in southwestern Germany in 2015, into a nearly complete rope-making implement (shown above). The final product, about 20 centimeters long, features four circular holes containing carved spiral grooves, archaeologists report in the Feb. 2 *Science Advances*.

The ivory lay among stone tools and other artifacts from *Homo sapiens* of Eurasia's ancient Aurignacian culture. Radiocarbon dating places the finds at between 35,000 and 40,000 years old. Researchers had previously suggested that four similar mammoth ivory artifacts from other German Aurignacian sites were ritual objects or tools for straightening wooden shafts or working leather. But Nicholas Conard of the University of Tübingen in Germany and Veerle Rots of the University of Liège in Belgium were unconvinced.

Microscopic wear and plant residue on the Hohle Fels artifact and an earlier find indicated that plant fibers had been pulled through the holes, guided by clockwise grooves, suggesting the tool was used for making rope. The earliest evidence of string-making dates to between 52,000 and 41,000 years ago among European Neandertals (*SN: 5/9/20 & 5/23/20, p. 5*).

The researchers conducted experiments with replicas of the finds, running animal sinews and six types of plant fibers through tool openings. Thin, hand-twisted strands, each held by one person, were fed through the holes. Another person held the tool while someone pulled and twisted the exiting fiber strands into a single piece. Four or five people could make five meters of strong rope in 10 minutes.

These findings do not tie up all the loose ends regarding ancient rope production. "But for the first time," Conard says, "we have documented artifacts likely used to make rope and demonstrated how they worked." *— Bruce Bower*

N.J. CONARD AND V. ROTS/*SCIENCE ADVANCES* 2024

Watch a video of insects flying near an artificial light at **bit.ly/SN_InsectFlight**

NEUROSCIENCE

Handwriting boosts brain connectivity

For learning and memory, pens may be mightier than keyboards

BY CLAUDIA LÓPEZ LLOREDA

Writing out the same word again and again in cursive may bring back bad memories for some people, but handwriting can boost connectivity across brain regions that are implicated in learning and memory, a new study shows.

When college students wrote words by hand, connectivity across the brain — particularly in brain waves associated with memory formation — increased compared with when students typed the words, researchers report January 26 in *Frontiers in Psychology*.

The finding shows that "there is a fundamental difference in brain organization for handwriting as opposed to typing," says neuroscientist Ramesh Balasubramaniam of the University of California, Merced, who was not involved in the research.

It also adds to growing evidence of handwriting's benefits. Previous research has shown that handwriting improves spelling accuracy, memory recall and conceptual understanding. Scientists think that the slow process of tracing out letters and words gives individuals more time to process the material and that the intricate movement itself aids learning.

In the new study, psychologists Audrey van der Meer and Ruud van der Weel, both of the Norwegian University of Science and Technology in Trondheim, recruited 36 students from the university and stuck a cap of electrodes on their heads. The researchers asked the students to type or handwrite in cursive with a digital pen a word that appeared on a computer screen. The cap recorded electrical brain activity while participants carried out each task.

In the data, the researchers looked for coherence: two brain areas active with the same frequency of electrical waves at the same time. Scientists use brain activity to calculate coherence between brain areas, which can indicate how strongly those areas are connected.

Handwriting but not typing showed coherence. Relative to typing, handwriting increased activity in low-frequency alpha and theta waves in brain areas associated with learning, the team found. Handwriting also increased connectivity across central brain regions, many of which are implicated in memory, and across parietal regions, which are involved in sensory and motor processing.

In an experiment, college students in Norway typed and handwrote words they saw on a screen while electrodes monitored their brain activity. Compared with typing, handwriting boosted connectivity across brain regions implicated in learning and memory, researchers found.

NORWEGIAN UNIV. OF SCIENCE AND TECHNOLOGY

The findings suggest that distinct processes of brain activation happen while a person types or writes. Even with very similar movements, "the activation seems much, much higher in handwriting," Balasubramaniam says. "There's more involvement of these brain regions when you're handwriting."

Van der Meer and van der Weel think this boost may facilitate learning because these particular waves between these specific brain regions are implicated in memory formation. But since the study did not test whether participants remembered the words, it's unclear how the increased activity impacts learning, says psychologist Kathleen Arnold of Radford University in Virginia. The study "warrants some follow up to see what exactly is causing those connectivity differences and whether or not they reflect learning outcomes."

The unique movement required to type or write could explain the differences, Balasubramaniam says. But "we've got to start somewhere, and these are the first results to actually show that these two things have different brain activation patterns."

Handwriting may help with learning processes, but typing is often faster and more practical. Students and teachers should therefore consider the task at hand when deciding to handwrite or type, van der Meer says. For example, taking notes by hand may help retain information better while typing an essay may be easier.

Despite the need for more studies to determine optimal learning strategies, experts say that handwriting shouldn't be left behind in the digital age. Schools "need to bring in more writing into curriculum design," Balasubramaniam says.

In California, a recently enacted law requires students in first through sixth grade to learn cursive writing. The new study and others like it could give fodder for similar legislation elsewhere.

Writing is also part of our cultural heritage, van der Meer notes. The ability to write a grocery list or a love letter, she says, "is important for us humans." ■

ANTHROPOLOGY

Did climate drive ancient plagues?

Cold snaps coincided with three Roman Empire outbreaks

BY BRUCE BOWER

For those who enjoy pondering the Roman Empire's rise and fall, consider the close link between ancient climate change and infectious disease outbreaks.

Periods of increasingly lower temperatures and rainfall declines coincided with three pandemics that struck the Roman Empire, researchers report in the Jan. 26 *Science Advances*. Reasons for strong associations between cold, dry phases and those disease outbreaks are poorly understood. But the findings, based on climate reconstructions from about 200 B.C. to A.D. 600, help "us see that climate stress probably contributed to the spread and severity of [disease] mortality," says study coauthor Kyle Harper, a historian at the University of Oklahoma in Norman.

Harper has previously argued that the First Plague Pandemic, also known as the Justinianic Plague, combined with declining global temperatures to weaken the Roman Empire (*SN: 6/20/20, p. 24*).

The new findings reinforce the idea that climate shifts can influence the spread of infectious diseases, says historian John Haldon of Princeton University. But it's unclear whether other factors, including long-distance trade networks and densely populated settlements in the ancient Roman realm, heightened people's vulnerability to outbreaks, he says.

To reconstruct the ancient climate, Harper and colleagues turned to fossilized dinoflagellates. These single-celled algae had been preserved in a sediment core from the Gulf of Taranto in southern Italy. Dinoflagellates live in the sunlit upper part of the sea, and different species assume signature shapes in the late summer and autumn before sinking to the ocean floor. Some species live only in cold waters, others only in warm waters.

In late summer and autumn, water temperature in the Gulf of Taranto closely aligns with southern Italy's air temperature, says marine palynologist Karin Zonneveld of the University of Bremen in Germany. Her group tracked changes in the composition of dinoflagellate species in radiocarbon-dated core slices to estimate late summer and autumn temperatures in southern Italy during the Roman Empire.

In "The Plague of Rome" by painter Jules-Élie Delaunay, the angel of death directs fatalities during the Antonine Plague. Climate shifts may have contributed to mortality during this and two other disease outbreaks in the Roman Empire, researchers say.

The team also used the algae to gauge changes in ancient rainfall. Plentiful rainfall in central and northern Italy causes rivers to discharge nutrient-rich water into the Gulf of Taranto. Dinoflagellates that rely on plentiful nutrients thrive under those conditions and end up on the seafloor. Thus, these species' appearance in the sediment core reflect stretches of ample rainfall. The preservation of species that prefer nutrient-poor waters, on the other hand, represent periods of scant rainfall.

The analysis revealed that warm, stable temperatures and regular rainfall occurred from about 200 B.C. to A.D. 100. During this Roman Warm Period, the empire experienced political and social stability. Then, phases of increasingly cold and dry conditions occurred shortly before or during three pandemics: the Antonine Plague, which spread from Egypt to Europe in the late 160s; the Plague of Cyprian, which struck during a time of political turmoil in the mid-200s; and the Justinianic Plague, which reached Italy by 543. By the late 500s, average temperatures were about 3 degrees Celsius lower than the highest averages during the Roman Warm Period.

It's unclear how high death rates climbed during the outbreaks and how they factored into the fall of the Roman Empire. By the time of the Justinianic Plague, the empire's power and influence had waned.

Despite providing valuable new information about ancient Rome's climate, the researchers can't say how temperature and rainfall shifts may have aided the spread of infectious diseases, says archaeologist Brandon McDonald of the University of Basel in Switzerland. The bacterium *Yersinia pestis* caused the Justinianic Plague, but pathogens of the other two pandemics remain unknown, he says, further muddying attempts to explain how climate may have influenced those events.

Many infectious microbes flourish in cold, dry conditions, says Colin Elliott, an economic and social historian at Indiana University Bloomington. Grain production in Italy and other parts of the Roman Empire suffered during cold years, he says. Hungry people in Italy's countryside may have migrated to cities where imported grain was available. "Diseases moved with migrants, but surges of malnourished and immunologically [vulnerable] populations into cities almost certainly increased pandemic virulence," he says. ■

Blue-footed boobies are popular with visitors to North Seymour Island in the Galápagos. Monogamous pairs like the one shown rear chicks in poop-covered ground nests.

E. GARCIA DE JESÚS

ANIMALS

Bird flu reaches the Galápagos Islands

Global outbreak has spared the archipelago's animals — for now

BY ERIN GARCIA DE JESÚS

As I step among poop-covered rocks heading toward the plateau of a small island in the Galápagos, a part of me rejoices. I'm on my way to see the archipelago's famed blue-footed boobies for the first time. And the sight of fresh guano everywhere serves as a reminder: The ongoing avian influenza outbreak has not yet ravaged this paradise.

Ghostly, leafless palo santo trees and saltbushes that sprinkle North Seymour Island are surrounded by boulders in varying shades of reddish-tinged black and brown. White splotches of guano splattered on rocks are hard to miss against this arid landscape in November, the tail end of the dry season. The poop's sources are similarly difficult to overlook.

The island hosts a large colony of frigate birds, some of which hang suspended in the air above as my companions and I disembark from a dinghy and scramble up the rocky path. As I admire the birds' red throat sacs — which males inflate like balloons to attract females — I hope that the birds don't deposit excrement on my head.

A short walk along a dusty trail brings us to, in my opinion, the stars of the show, blue-footed boobies. The dopey-looking birds show no sign of fear even as we cluster around their nests eagerly snapping photos.

That I had the chance to visit North Seymour's birds at all was a relief after traveling more than 5,000 kilometers for a vacation in Galápagos National Park. Just two months before, at the end of September, news broke that deadly avian influenza had reached the archipelago.

This flu virus poses a grave threat to the islands' birds, some of which are found nowhere else on Earth. Government officials closed some islands to tourists to protect the birds — an understandable tactic that left me selfishly thinking about the possibility of not getting to see iconic species up close.

To track this virus, "we have eyes watching the whole archipelago," Gustavo Jiménez-Uzcátegui, a wildlife veterinarian at the Charles Darwin Foundation in Puerto Ayora, Santa Cruz Island, told *Science* in September.

The concern is warranted. Outside the Galápagos, the bird flu panzootic — the animal version of a pandemic — has been widely destructive. It's unclear why the archipelago has so far escaped the worst of avian influenza, Jiménez-Uzcátegui told me when we met in Puerto Ayora. Also unknown is how the outbreak might permanently affect bird populations and the ecosystems that they're a part of.

"Most people have no idea that we are in the middle of a wildlife emergency, an animal pandemic, and that this may be the nail in the coffin for some species," says Michelle Wille, a viral ecologist at the Peter Doherty Institute for Infection and Immunity in Melbourne, Australia, who studies avian influenza. "It's very concerning."

Bird flu's staggering toll

While the variant of the flu virus behind the ongoing panzootic emerged in Europe in 2020, the outbreak itself didn't take off until late 2021. Since then, avian flu has probably killed millions of wild birds (*SN: 4/8/23, p. 6*). In Peru, at least 100,000 wild birds have died. Places including Russia and Canada have documented tens of thousands of deaths. In the United States, roughly 9,000 wild birds have tested positive for avian flu.

In October, bird flu made its first appearance in the Antarctic region, killing brown skuas on Bird Island, a British territory. In January, gentoo penguins found dead in the Falkland Islands also tested positive for the virus.

But birds aren't this flu's sole targets. "If you can imagine thousands of dead birds, you can imagine how this is an all-day buffet for scavengers," Wille says. Avian predators all over the world, including bears and foxes, have tested positive. Marine mammals such as seals and sea lions that swim with or eat infected birds have experienced mass die-offs. In the Arctic, a polar bear died in October after contracting the virus. And on January 11, researchers confirmed that elephant and fur seals in South Georgia, a subantarctic island, had been infected.

By the time of my November trip, fears of Galápagos birds dying en masse hadn't come to fruition. To date, just 34 birds in the archipelago — including red- and blue-footed boobies, Nazca boobies, frigate birds and tropic birds — have tested positive for avian flu.

That the global outbreak is happening at all is a chapter in a predictable story, says Nichola Hill, a disease ecologist at the University of Massachusetts Boston. And the virus's incursion into some mammals is "absolutely on track with being the worst-case scenario you could have imagined for this."

Long-term effects remain unclear

Researchers have long understood that avian influenza viruses, which normally cause mild disease in waterfowl like ducks, can turn deadly after spreading and evolving on poultry farms (*SN: 9/10/05, p. 171*). Close relatives of the virus responsible for the ongoing panzootic have been "simmering away" in Eurasia's poultry and wild bird populations for more than a decade, Hill says. "In the last three years, it's had major consequences for wildlife."

For now, researchers are focused on documenting the sheer scale of avian and mammalian deaths. "We will probably not know the true extent of this for years to come," Wille says. The ripple effects on ecosystems will likewise take years to unravel.

Death rates vary among bird species. Waterfowl are key spreaders of bird flu and have at least some built-in protection from the virus. Because their immune systems have coevolved with influenza viruses, waterfowl have a head start on immunity compared with other birds, Hill says. Meanwhile, birds like bald eagles and red-tailed hawks that don't have such a long history with influenza are "just getting hit really hard," she says.

That disparity has Hill wondering how long it might take for infections to become less deadly, as wild birds of various species develop immunity against the virus. Her lab aims to explore how bird immune systems have coevolved with avian flu, including which parts of the immune response are crucial for preventing the virus from running rampant and causing death in some species.

As of now, Wille says, there are no signs that the panzootic is slowing down. But there are glimmers of hope for reducing the damage it could cause.

E. GARCIA DE JESÚS

In frigate birds, bright red throats distinguish adult males from females and juveniles. Several frigate birds on North Seymour Island tested positive for avian influenza in late 2023.

In October, researchers announced some early results from a bird flu vaccine trial in California condors. Six out of 10 birds that received two doses of the vaccine had antibody levels that were high enough to provide at least partial protection against death if infected. If the vaccine does indeed work, then "it demonstrates that we may be able to limit the impact on highly endangered species," Wille says.

What's kept Galápagos birds safe?

Why avian flu has been less aggressive in the Galápagos compared with most everywhere else — and whether it will stay that way — remains a big question, Jiménez-Uzcátegui says. But he has one intriguing hypothesis.

"The unique difference from the other parts [of South America], like Peru, Ecuador," he says, "is the habitat."

Flu in both people and birds tends to be a cold-season disease (*SN: 1/28/23, p. 8*). Last year, El Niño arrived in the Galápagos, bringing warmer than average waters to the part of the Pacific Ocean that surrounds the islands. The more moderate temperatures may have made it harder for avian flu to spread, Jiménez-Uzcátegui says.

In the future, piecing together the relationship between the local climate and influenza infections could help determine if Jiménez-Uzcátegui's hunch is correct. He and his team also hope to examine the immune systems and genetics of birds that call the Galápagos home. For now, though, researchers and officials there continue to keep an eye out for influenza on the islands.

On the heels of the coronavirus pandemic, it's easy to wonder what effect this might have on humans, especially because influenza outbreaks can be devastating (*SN: 11/6/21, p. 18*). But, for now, it's Earth's wild birds that are enduring their worst flu outbreak yet.

My visit to Galápagos National Park, a truly special place for nature lovers, showed me that there are small signs of hope in these iconic islands. Still, the virus's impacts could reverberate for years to come. ■

WHERE ORDER EXISTS

How two outsiders tackled the mystery of arithmetic progressions

By Evelyn Lamb

Consider this sequence of numbers: 5, 7, 9. Can you spot the pattern? Here's another with the same pattern: 15, 19, 23. One more: 232, 235, 238.

"Three equally spaced things," says Raghu Meka, a computer scientist at UCLA. "That's probably the simplest pattern you can imagine."

Yet for almost a century, mathematicians in the field of combinatorics have been puzzling out how to know whether an endless list of numbers contains such a sequence, called an arithmetic progression. In other words, is there a way to be mathematically certain that a set contains a sequence of three or more evenly spaced numbers, even if you don't know much about how the numbers in the set were selected or what the progression might be?

Progress on the question has been slow, even plodding. But last year, Meka and Zander Kelley, a Ph.D. computer science student at the University of Illinois Urbana-Champaign, surprised mathematicians by making an exponential leap. The researchers are outsiders in combinatorics, which is concerned with counting configurations of numbers, points or other mathematical objects. And the duo didn't set out to tackle the mystery of arithmetic progressions.

Kelley and Meka were instead investigating abstract games in computer science. The pair sought a mathematical tool that might help them understand the best way to win a particular type of game over and over again. "I'm super-interested in a collection of techniques that fall under this umbrella called structure versus randomness," Kelley says. Some of the earliest progress on arithmetic progressions relied on such techniques, which is what led Kelley and Meka to dive into the topic.

The mystery of whether arithmetic progressions will show up is just one of many mathematical questions related to order versus disorder in sets of objects. Understanding order — and when and where patterns must emerge — is a recurring theme in many branches of math and computer science.

Another example of order in objects says that any group of six people must contain either a group of at least three mutual acquaintances (all three know each other) or a group of at least three complete strangers (no one knows another). Research has shown that it doesn't matter who they are, where they are from or how they were selected (*SN: 7/17/93, p. 46*). There's something powerful, maybe almost spooky, about the fact that we can say this — and make other similar claims about structure in sets — with mathematical certainty.

Solving the mystery of arithmetic progressions might open doors to investigating more complex relationships among numbers in a set — gaps that change in more elaborate ways, for instance. "These are more sophisticated versions of the same theorems," says Bryna Kra, a mathematician at Northwestern University in Evanston, Ill. "Typically, once you see arithmetic progressions … you see other patterns."

After publishing their work on arithmetic progressions, Kelley and Meka, with Shachar Lovett of the University of California, San Diego, imported techniques from their investigations of arithmetic progressions into a different context. The researchers solved a question in communication complexity, a subfield of theoretical computer science concerned with transmitting data efficiently between parties who have only partial information.

What's more, knowing that certain mathematical structures have to appear in certain situations can be useful in real-world communication networks and for image compression.

Potential applications aside, researchers who study arithmetic progressions — or other facets of purely theoretical mathematics — are often motivated more by sheer curiosity than any practical payoff. The fact that questions about such simple patterns and when they appear remain largely unanswered is, for many, reason enough to pursue them.

What are arithmetic progressions?

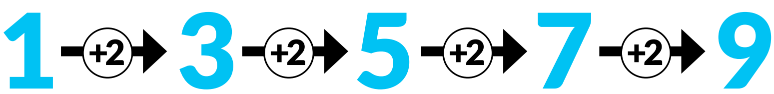
Let's take a moment to get our hands on some sets of numbers and the arithmetic progressions those sets contain, starting with the prime numbers, perennial favorites of math enthusiasts. A prime number is any whole number divisible only by itself and by 1; the first 10 primes are 2, 3, 5, 7, 11, 13, 17, 19, 23 and 29. Within those numbers, we can find a few arithmetic progressions. The numbers 3, 5 and 7 form a three-term arithmetic progression with a gap of two. But the numbers in a progression don't have to follow each other immediately within the larger set: The numbers 5, 11, 17, 23 and 29 form a five-term arithmetic progression with a gap of six.

Within a finite set of numbers, it's straightforward to determine whether there are any arithmetic progressions. It might be tedious depending on the set, but it's not mysterious. For infinite sets of numbers, though, the question gets interesting.

The primes go on forever, and mathematicians have asked many — and answered some — questions about arithmetic progressions within them. Is there a longest possible arithmetic progression, a cap on the number of terms, in the primes? Or, can you find a progression of any finite length if you look long

OPPOSITE PAGE: LISA SHEEHAN

A simple arithmetic progression



Just add 2 It's easy to create an arithmetic progression, a sequence of numbers that are equally spaced. Just start with any number and add the same number repeatedly (the number 2, in this example). Creating a set of numbers that avoids arithmetic progressions can be harder though.

C. CHANG

enough? In 2004, mathematicians proved that the latter is true (*SN: 4/24/04, p. 260*). But questions including how far along the number line you have to look to find an arithmetic progression with a given number of terms or a given gap size remain active areas of research, for the primes and for other sets.

The primes contain infinitely many arithmetic progressions, but some infinite sets contain none. Consider the powers of 10: 1, 10, 100, 1,000…. The gaps between consecutive terms get bigger fast — 9, 90, 900…. And none of them are the same. Playing around with the numbers a bit, you can convince yourself that no two powers of 10, whether consecutive or not, have the same gap as any other pair.

With that context, we now approach a question at the heart of this research: Why do some sets have arithmetic progressions while others don't? One big difference between the primes and powers of 10 is that there are a lot more primes than powers of 10. Sort of. Both sets are infinite, but if you pick any arbitrary number as a cutoff and look at how many primes or powers of 10 there are below that number, the primes win every time. There are four primes from 1 to 10, versus only two powers of 10. There are 25 primes from 1 to 100 and only three powers of 10. The primes don't just win every time, they win by a lot, and the amount they win by keeps increasing. In this way, the primes are "denser" — in an intuitive and technical sense — than the powers of 10.

A sparse enough set of numbers can have gaps arranged in ways that manage to avoid arithmetic progressions. Too dense, though, and the set can't avoid having gaps that match up. In the 20th century, mathematicians settled on a way to measure that density. They are now looking for the density above which arithmetic progressions must appear.

Progress on progressions

The study of arithmetic progressions in sets of whole numbers began in earnest in 1936, when Hungarian mathematicians Paul Erdős and Pál Turán posited that any set of whole numbers that is dense enough must contain arithmetic progressions of any desired length.

For finite sets, it's easy to understand what density is. In the set of whole numbers between 1 and 10, the primes have a density of 4/10, or 0.4. But if we want to understand the density of the entire unending collection of prime numbers within the entire unending collection of the whole numbers, we need to find a way to make sense of infinity divided by infinity, or ∞/∞.

Mathematicians use a concept called asymptotic density to wrangle with the density of an infinite set of whole numbers. The basic idea is to choose some number as a cutoff point, N, and see what happens as N increases. If the density tends toward some fixed number, that is the set's asymptotic density.

Let's return to the powers of 10, whose density decreases across the number line. As you go out farther and farther, the proportion of whole numbers that are powers of 10 approaches zero — so the set has an asymptotic density of zero. Other sets have a positive asymptotic density, and some never settle down into an asymptotic density at all.

What Erdős and Turán proposed is that any set of numbers with positive, rather than zero, asymptotic density must contain at least one arithmetic progression. For some sets, it's obvious (the even numbers have an asymptotic density of 0.5 and definitely contain arithmetic progressions). But proving it for any arbitrary set of numbers turned out to be a challenge.

It wasn't until 1953 that German-British mathematician Klaus Roth proved the conjecture, opening the door to a more nuanced understanding of the role density plays in arithmetic progressions. He showed that any set with positive asymptotic density must contain at least one three-term arithmetic progression, or 3-AP. His argument relied on proving that dense enough pseudorandom sets — those that might not truly be chosen randomly but have the general properties of random sets — must contain arithmetic progressions. Then he developed a way to zoom in on parts of non-pseudorandom sets and show that, if the initial set is dense enough, these zoomed-in areas must be structured in ways that guarantee the presence of an arithmetic progression.

In early 2021, Kelley and Meka were investigating a problem in complexity theory called parallel repetition of games. Don't think Monopoly or chess; the "games" the researchers were thinking about won't be making Hasbro money any time soon. "We have a tendency to call anything a game if it has turns," says Kelley. In the typical games Kelley and Meka were looking at, the players have access to different information and have to work together to find an answer to a question. But they can't communicate during the game, so they must decide on a strategy beforehand. Kelley and Meka sought to determine how to maximize the chances that the players win many games in a row.

It's not quite a hop, skip and a jump from parallel repetition of games to arithmetic progressions, but Kelley and Meka got there fairly quickly. "Maybe in a month we were at the 3-AP problem," Meka says. Previous research on parallel repetition of games had used structure versus randomness arguments. Because Roth's work on arithmetic progressions was the first to use such a technique, Kelley and Meka were interested in that work in its original habitat.

"In theoretical computer science, people are looking outward to math for some tools that they could use, and unless you're ready to get yourself into some serious trouble, usually you see if you can use the tools, and then if you can't, you move on," Kelley says. "You don't try to go open them up and see what they're like." But he and Meka did just that, knowing that they might go down a deep rabbit hole and end up with nothing to show for their time and effort. They dug into Roth's arguments — as well as more recent research on the same subject — to see if they could push the work further. And so they found themselves staring down arithmetic progressions.

Refining the state of the art

Roth's contribution was more powerful than just showing that any set with positive asymptotic density must contain a 3-AP. He also proved that some sets with asymptotic density of zero, if the density tends toward zero slowly enough as you go out along the number line, must also contain at least one 3-AP.

Think of the density as having to pass beneath a limbo bar. If a set gets sparse too slowly, it can't make it under and it must contain an arithmetic progression. But a set that approaches a density of zero quickly enough ducks under. For that set, anything goes: It may or may not have such a progression.

Roth's initial proof found an upper limit to where the limbo bar must be. He showed that any set whose density approaches zero at a rate similar to or slower than the expression 1/log(log(N)) must contain at least one arithmetic progression. Log means to take the logarithm, and remember that N is the number chosen as the arbitrary cutoff in an infinite set. We're considering what happens as N increases.

Logarithms grow slowly, roughly akin to the number of digits a number has. The logarithm of 1 is zero, of 10 is 1, of 100 is 2, of 1,000 is 3, and so on. But taking the logarithms of those logarithms gives much more sluggish growth. To nudge log(log(N)) from zero to 1, we have to move N from 10 to 10 billion. Dividing 1 by this double log, as appears in Roth's work, we get a density that just plods toward zero.

Several years earlier, in 1946, mathematician Felix Behrend had investigated the lower limit of the limbo bar. He developed a recipe for cooking up sets without 3-APs, showing that any such set must be extremely sparse indeed. His limit was a density that goes to zero at approximately the same rate as $1/e^{(\log(N))^{1/2}}$. That expression might not look familiar, but there's an exponential function in the denominator. The log and ½ power slow things down a bit, but the whole expression goes to zero much faster than the double log Roth later found.

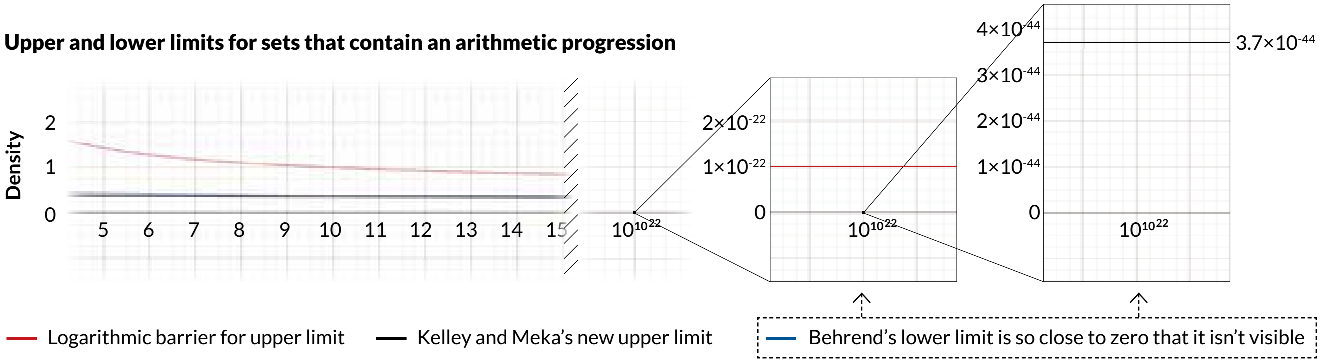
In the last few decades, researchers have been attempting to close the gap between Roth-style estimates of the sparsest sets that must contain a 3-AP and Behrend-style estimates of the densest sets that do not contain one. In 2020, mathematicians Thomas Bloom of the University of Oxford and Olof Sisask of Stockholm University broke what had come to be known as the logarithmic barrier for the Roth-style upper limit of the limbo bar, showing that any set with a density that goes to zero more slowly than 1/log(N) must contain at least one 3-AP. The work was seen as a breakthrough in the field, though the upper limit was still closer to the previous best-known upper limit than to Behrend's lower limit.

Kelley and Meka pushed the upper limit down dramatically. Their result was a rate that goes to zero at approximately the same rate as $1/e^{(\log(N))^{1/11}}$. That formula looks eerily similar to Behrend's lower limit. For the first time ever, the upper and lower limits are within shooting distance of each other. Closing that gap would reveal the specific location of the limbo bar and thus give a clear answer to which sets must contain at least one 3-AP.

The audacity of hope

When Kelley and Meka started on the 3-AP problem, they thought they would probably just poke around to identify the barriers to moving the upper

In the 1930s, Hungarian mathematicians Pál Turán (below left) and Paul Erdős (below right) proposed that any set of numbers that is dense enough must contain an arithmetic progression. The conjecture was proved in the 1950s, but related questions about order in sets of numbers persist.



Headed to zero How quickly a set's density approaches zero as you move far out along the number line (insets) can reveal whether that set must contain an arithmetic progression. In 2023, computer scientists Zander Kelley and Raghu Meka showed that if the density approaches zero at a rate roughly similar to or slower than the black line above, the set must contain a progression. This upper limit is dramatically lower than "the logarithmic barrier" (broken in 2020 and shown in red), but it is still a long way from the lower limit (identified by Felix Behrend decades ago).

limit down. A year later, the two were writing a paper about their breakthrough. "I think one thing that kept us going was it never felt like we were completely hitting a wall," Meka says. "It always felt like we were either learning something useful, or we were actually making progress."

Meka describes their overall approach, based on Roth's early techniques, as exploiting a "wishful dichotomy" between randomness and structure. They developed a definition of pseudorandomness for their work and showed that for this definition, any dense enough pseudorandom set must contain at least one arithmetic progression.

After handling the pseudorandom case, the team considered more structured sets of numbers and showed that those sets too had to exhibit the desired patterns. Finally, Kelley and Meka expanded from these types of sets to all large enough sets of numbers, proving that those sets must have the properties of either the pseudorandom or the structured sets.

The most remarkable thing about Kelley and Meka's work is that they were able to make such dramatic progress without developing a new approach to arithmetic progressions. Though they brought new insights and established new connections to previous work, they did not create new machinery.

"It just seemed completely intractable to push those techniques through," Sisask says, "until this paper by Kelley and Meka landed in my inbox." He and Bloom, who had previously broken the logarithmic barrier, "spent a while digesting the paper and talking about it until we understood it in our own language," he says.

Mathematicians and computer scientists tend to use some different notation and terminology, but Sisask, Bloom and other experts in the field quickly recognized the work as solid. After digesting the arguments, Sisask and Bloom wrote an explanation of the work, with some subtle technical improvements, geared toward other researchers in combinatorics. Several months later, the team coaxed the upper limit down a tiny bit more, getting a new bound of 1/e^(log(N))^⅑.

Combinatorics researchers are still trying to figure out how low they can go. Will they be able to push the upper limit all the way down to the best known lower limit, or will there always be a little gap where our knowledge is incomplete? Kelley and Meka are using the tools they honed on arithmetic progressions to continue work on problems in complexity theory and other areas of theoretical computer science.

When I asked Meka how two computer scientists made such a big advance on a mathematics problem that had stumped combinatorics experts for years, he said he isn't sure. He thinks maybe their edge came from being fresh to the challenge.

"The problem has been around for a long time and progress seemed pretty stuck," he says. In fact, after he and Kelley were well on their way to publishing, Kelley says he ran across a blog post from 2011 that outlined exactly why mathematicians were pessimistic about the very approach that the two had eventually used.

"People thought that these techniques couldn't push beyond existing barriers," Meka says, "but maybe we didn't know that the barriers existed." ■

Explore more

- For more on finding order among objects, check out this Numberphile video about friends and strangers: bit.ly/SN_FriendsStrangers

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Evelyn Lamb is a freelance writer based in Salt Lake City.

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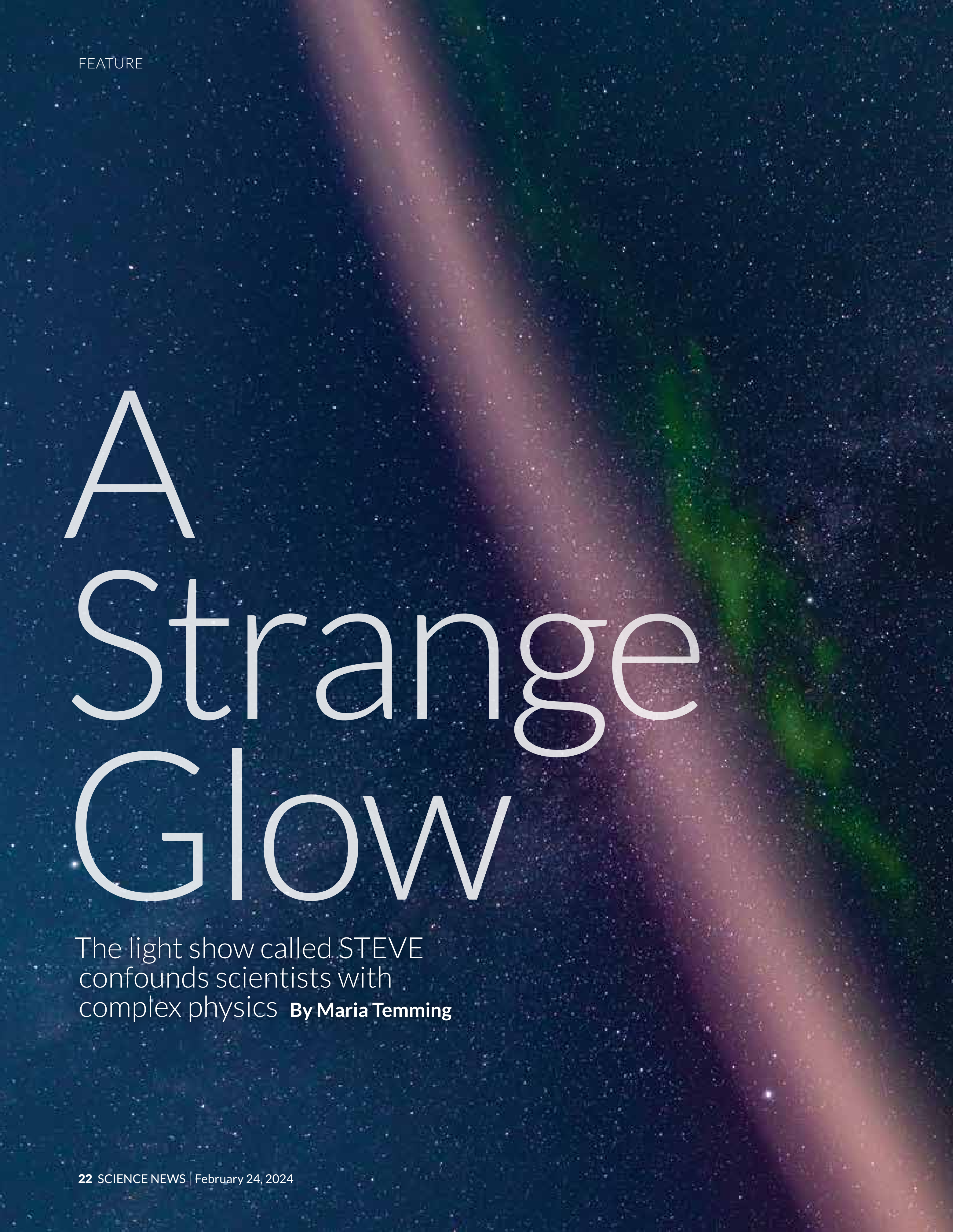

A Strange Glow

The light show called STEVE confounds scientists with complex physics **By Maria Temming**

Scientists are trying to decipher the atmospheric conditions that create the mauve light show known as STEVE and its green sidekick, dubbed the picket fence, both visible in this 2022 photo.

From the pristine dark of his backyard in rural Alberta, Canada, Alan Dyer has taken stunning photos of a rare sky glow called STEVE. To capture this ribbon of mauve, he and other citizen scientists who photograph the sky typically let their cameras collect light for seconds at a time. Long exposures smear out STEVE's finer details in favor of making its color pop. But when STEVE stretched over his house one August night in 2022, Dyer tried a different approach.

He zoomed in on the sky glow with his camera and took a video of STEVE's nitty-gritty details at a rate of 24 shots per second. Instead of the largely smooth drift of purple seen in past images, Dyer's footage exposed STEVE as a frenetically flickering torrent of purplish-white fuzz.

"It didn't look that beautiful," Dyer says. But on the off chance it might be scientifically useful, he sent the video to Toshi Nishimura, a space physicist at Boston University.

"I said, 'Oh my God, no one has ever seen this before,'" says Nishimura, who was eager to analyze such a high-resolution view of STEVE. But upon inspection, STEVE's fine details didn't jibe with scientists' tentative understanding of the atmospheric chemistry behind the airglow. "This fine-scale structure gave us a huge headache, actually," Nishimura says.

That confusion is par for the course when it comes to the science of STEVE, short for strong thermal emission velocity enhancement. Ever since citizen scientists first showed researchers images of STEVE in 2016, the images have raised more questions than they've answered. "Every time we find something new [about STEVE], the number of physics questions that it opens up is triple what we expected," says space physicist Bea Gallardo-Lacourt of NASA's Goddard Space Flight Center in Greenbelt, Md.

"STEVE and the picket fence are arguably the biggest mystery in space physics right now."
CLAIRE GASQUE

Nishimura and colleagues presented the new high-resolution view of STEVE in San Francisco at a December meeting of the American Geophysical Union. Other researchers at the meeting described a similarly perplexing observation, that another non-aurora sky glow can morph into STEVE. But there was a glimmer of clarity: A computer simulation shared by another group of sky detectives may explain what causes the "picket fence" of green stripes that can appear with STEVE.

"STEVE and the picket fence are arguably the biggest mystery in space physics right now," says space physicist Claire Gasque of the University of California, Berkeley. Because satellite signals can be affected by the conditions in Earth's atmosphere where STEVE appears, explaining what gives rise to this airglow could have uses beyond understanding a pretty light show.

Multiplying mysteries

When aurora chasers in Canada first introduced STEVE to the scientific community, researchers knew it was no aurora (*SN: 4/14/18, p. 5*). Auroras form when charged particles from the magnetic bubble, or magnetosphere, around Earth rain down into the atmosphere. Those particles crash into oxygen and nitrogen near Earth's poles, painting the sky with brushes of red, green and blue. But STEVE was an unusual shade of purple. And it appeared closer to the equator than the northern and southern lights do.

"For us here in southern western Canada," Dyer says, "the aurora is typically to the north." STEVE, meanwhile, can come right overhead.

STEVE was later linked to a river of charged particles surging through the atmosphere (*SN: 6/8/19, p. 5*). That plasma stream, moving at several kilometers per second, is thought to heat the air about 200 kilometers off the ground to the point of glowing purple — but what molecules give STEVE its signature color remains unclear, especially in light of Dyer's new footage.

Dyer's video zoomed in to capture details of STEVE that spanned just 90 meters — fairly small for an airglow that can span thousands of kilometers.

In New Zealand in 2015, a citizen scientist captured images of a red airglow called a SAR arc (top) morphing into a purple STEVE streak (middle) and a green picket fence (bottom).

The footage showed a clumpy, speckled stream of purple rushing westward at about 9 kilometers per second, sporting variations in brightness as small as a few kilometers across, some of which popped in and out of view within seconds, Nishimura and colleagues reported in the December *JGR Space Physics*.

"The leading theory of the STEVE emission is that there's nitric oxide that is excited by the fast plasma stream," Nishimura says. That nitric oxide is thought to give off the purple light. Excited nitric oxide can glow for an hour, Nishimura notes; that's about how long STEVE lasts overall. But the granular bursts of brightness that last mere seconds add a wrinkle to that idea.

Firing a sensor-strapped rocket through STEVE could identify the molecules responsible, Nishimura says. "But the challenge is that we need to know when and where STEVE is going to happen, and that's extremely difficult."

STEVE can appear just after the peaks of substorms, which are disturbances in Earth's magnetic field that can stir up spectacular auroras. "STEVE generally appears after the main aurora show has kind of faded," Dyer says. But not every substorm comes with a STEVE encore, and research presented by Gallardo-Lacourt and her colleagues at the meeting in December suggests not all STEVEs need a substorm to appear.

One thing that might help researchers refine their STEVE predictions, Nishimura says, is a better understanding of the light show's relationship to another non-auroral airglow called a stable auroral red, or SAR, arc — which citizen science photos now suggest can morph into STEVE.

Interacting light shows

In March 2015, citizen scientist Ian Griffin set out to photograph a particularly dazzling auroral display near Dunedin, New Zealand. But just north of the southern lights, he spotted something strange — a wide, red sky glow that morphed into the mauve strand of STEVE. Griffin's time-lapse footage offered researchers their first glimpse of STEVE blooming out of a SAR arc. Space physicist Carlos Martinis of Boston University and colleagues reported the observation in 2022 in *Geophysical Research Letters*.

Scientists have studied SAR arcs for decades. Like STEVE, these airglows stretch east-to-west across the sky closer to the equator than the northern and southern lights. But unlike STEVE's roughly hour-long set, SAR arcs can stain the sky for hours to days at a time — visible with cameras, though usually too dim to see with the naked eye.

SAR arcs form when disturbances in Earth's magnetosphere cause charged particles thousands of kilometers out in space to collide, creating heat that seeps down into the ionosphere — the layer of the atmosphere home to STEVE. That heat energizes electrons, which then excite oxygen atoms. The process generates red light that's typically about one-tenth as bright as auroras. But the SAR arc that Griffin saw was radiant enough to rival red southern lights.

"It was just stunning," says Megan Gillies, who studies auroras at the University of Calgary in Canada. Griffin's footage inspired her to search for other cases of STEVEs emerging from SAR arcs. She and colleagues found one spotted by the Transition Region Explorer, or TREx, Spectrograph in April 2022 in Lucky Lake, Saskatchewan. STEVE's bright purple streak emerged from a SAR arc's red glow, hung around for about half an hour, then gave way to more red, the group reported last year in *Geophysical Research Letters*.

"It's like watching a fire smoldering, and then you throw more wood on it and then it blazes up. Whoosh, there it goes! And then it kind of dies back down," Gillies says. "There's something that happens that triggers a STEVE," she says, but because not all SAR arcs mutate into STEVEs, it's not clear what causes this transition.

It might have something to do with the plasma torrent that powers STEVE. SAR arcs have similarly been linked to westward plasma flows in the atmosphere, though not as fast as the plasma flows that power STEVEs, Martinis notes. As the SAR arc seen in 2015 evolved into STEVE, satellite data did show a wide stream of plasma in the atmosphere narrow and quicken

PREVIOUS SPREAD: © A. DYER/AMAZINGSKY.COM; THIS PAGE: I. GRIFFIN, C. MARTINIS *ET AL*/*GEOPHYSICAL RESEARCH LETTERS* 2022

See a high-res video of STEVE at **bit.ly/SN_STEVE_Video** into the kind of intense filament typical of STEVE. But what triggered this switch is an open question, Martinis says. Further complicating matters: Citizen scientists and imagers have also spotted STEVEs and SAR arcs existing alongside but seemingly independent of each other.

With researchers left scratching their heads over these observations, "this is where modeling comes in," Gillies says. Theorists can use computers to test hypotheses about the physics that produces light patterns resembling STEVE, she explains. Computer models are already helping piece together another STEVE-related puzzle — the source of the picket fence.

Building STEVE's picket fence

At first, researchers thought STEVE's sometimes sidekick of green stripes was a plain old aurora. After all, the picket fence's bright green glow is similar to some normal northern lights. But the specific wavelengths of light emanating from the picket fence hint that it might not be an aurora after all (*SN: 12/5/20, p. 10*).

Showers of charged particles from way out in the magnetosphere light up normal auroras. "When they collide with the atmosphere, they're going to create a pretty wide spectrum of colors," Gasque says. That includes green from oxygen, and red and blue from nitrogen. "That blue is kind of the smoking gun that we didn't see with the picket fence," Gasque says. Its absence hints that the picket fence's green spires don't arise from the same process as auroras.

An alternative explanation for the picket fence might be electric fields embedded within Earth's atmosphere that run parallel to the planet's magnetic field, Gasque says. Those fields could energize local electrons to excite oxygen into glowing green and give nitrogen enough energy to glow red but not blue. Gasque and colleagues ran a computer simulation of Earth's atmosphere with electrons energized by electric fields. The team compared the light produced inside the simulated atmosphere with light from a picket fence seen by the TREx Spectrograph in Lucky Lake in 2018.

The simulation did indeed reproduce the ratio of red to green light seen in the real-life picket fence without a tinge of blue, bolstering the idea that atmospheric electric fields could construct the picket fence, the researchers reported in the Nov. 16 *Geophysical Research Letters* and at the American Geophysical Union meeting.

VINCENT LEDVINA/THEAURORAGUY.COM

Normal auroras (left) are gentle ripples of red, green and blue light. Enhanced auroras (right) contain sharp slices of brighter light, which may be produced through a similar process as STEVE's green picket fence. So studying enhanced auroras could help demystify this feature of STEVE.

But scientists need to confirm that such electric fields actually exist at the altitudes where picket fences appear.

"The plan now is to try and fly a rocket through one of these structures," says Gallardo-Lacourt. Gasque and colleagues have just proposed a similar mission to NASA. The rocket wouldn't fly through the picket fence — which, like STEVE, is too hard to predict. Instead, it would target phenomena with similar coloring that are far more common: enhanced auroras.

"With enhanced aurorae, you have kind of these sharp, bright layers within the aurora," Gasque says. The sharpness of those variations in auroral light and their picket fence–like color scheme hints that they might be powered by electric fields as well, Gasque says. If a future rocket mission detects electric fields threaded through enhanced auroras, that would help confirm that similar fields build the picket fence.

NASA's Geospace Dynamics Constellation mission aims to launch a fleet of spacecraft as early as 2027 that will probe Earth's magnetosphere and ionosphere. That might yield more data that explain aspects of STEVE, Gallardo-Lacourt notes. In the meantime, STEVE's dedicated paparazzi of citizen scientists will continue snapping photos of the phenomenon from the ground.

"We're out specifically looking for STEVE and knowing that there's scientific interest in it," Dyer says. "Prior to the era of STEVE ... you might have thought, 'Well, there's nothing amateurs can contribute now to aurora research; it's all done with rockets and satellites and the like.' But nope! There's a lot we can contribute," even if that contribution often presents researchers with new puzzles to solve. ■

Explore more

- Toshi Nishimura *et al*. "Fine-scale structures of STEVE revealed by 4K imaging." *JGR Space Physics*. December 2023.

Editor's note: Claire Gasque is the daughter of Science News' *news director, Macon Morehouse, who was not involved in assigning or editing this article.*

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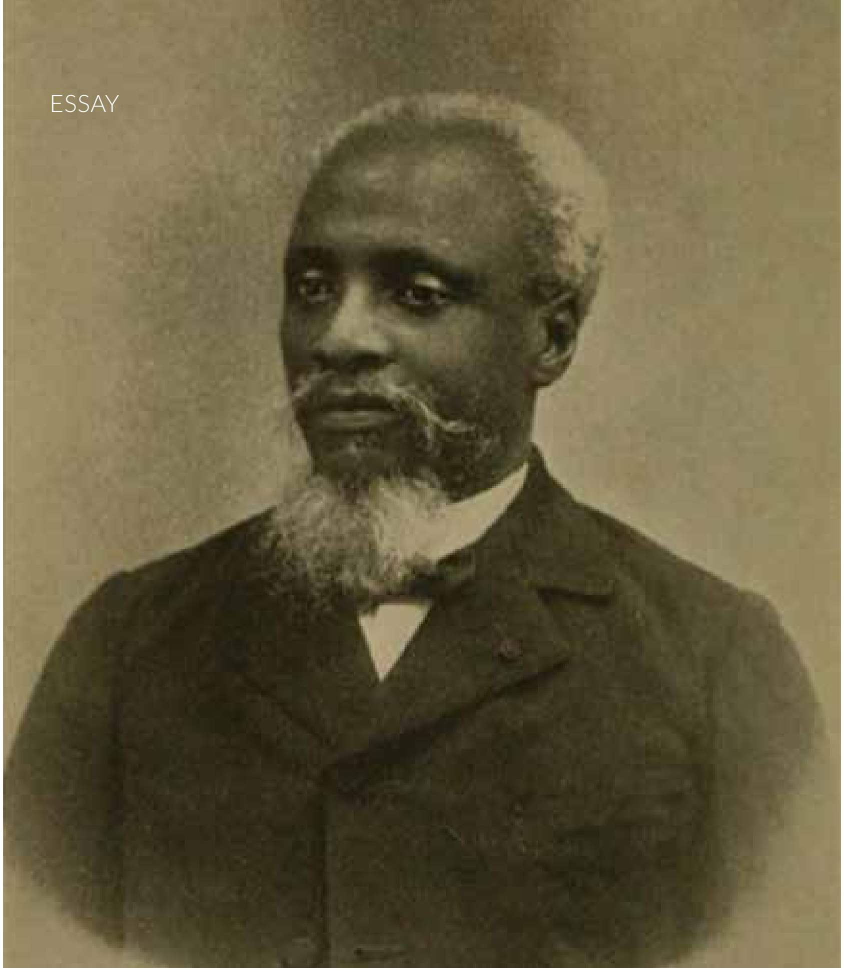


HISTORY AND ART COLLECTION/ALAMY

A Rebuttal to Racial Hierarchies

Anthropologist Anténor Firmin wrote a critical race theory book in 1885 **By Sujata Gupta**

UNSUNG CHARACTERS

This article is part of a *Science News* series highlighting people of science — past and present — who we believe should be better known. Watch for more of these stories, and send your ideas to editors@sciencenews.org

At the end of the 19th century, one of the hottest debates among anthropologists was whether human beings originated from a single ancestor or many (the answer: just one). Members of both camps, though, largely agreed that whatever their origins, some races were superior to others. Haitian anthropologist Anténor Firmin knew that premise to be false.

"Human beings everywhere are endowed with the same qualities and defects, without distinctions based on color or anatomical shape," Firmin wrote in French in his 1885 book, *The Equality of the Human Races*. "The races are equal."

Firmin was ahead of his time. Today, genetic research confirms that human populations cannot be divided into distinct racial groups.

But few scholars in the nascent field of anthropology, or any other contemporaries, read his treatise. Instead, leaders in the field were deeply influenced by the French white supremacist Arthur de Gobineau's four-volume *Essay on the Inequality of the Human Races*, published in the 1850s.

Against that backdrop, in 1859, Paul Broca, a French physician and brain researcher interested in the study of human origins, founded the Société d'Anthropologie de Paris, one of the first anthropological societies in Europe. Broca believed he could use skull measurements to identify human populations, which could then be categorized into a racial hierarchy. When Firmin joined that society in the 1880s, the belief that data supported white supremacy had become foundational to anthropology.

Anthropologist Carolyn Fluehr-Lobban of Rhode Island College in Providence wrote in *American Anthropologist* in 2000 that few anthropologists outside of Firmin's native Haiti had heard of *The Equality of the Human Races*. "This is hardly surprising since most of the early [Black] pioneers of anthropology have only recently been brought to light," she wrote.

Those leaders include other Haitians, such as doctor and writer Louis-Joseph Janvier, who wrote *The Equality of Races* in 1884, and politician Hannibal Price, who wrote *On the Rehabilitation of the Black Race by the Republic of Haiti* in 1900. American abolitionist Martin Delany wrote *Principia of Ethnology: The Origin of Races and Color* in 1879.

Firmin remains underappreciated today, notes Fluehr-Lobban. And he would probably still be languishing in near-total obscurity if not for an English translation of his book that came out in 2000. Following that publication, a small number of anthropologists and other social scientists began calling for Firmin to be recognized as a founding father of anthropology. His arguments, after all, predated by several decades similar arguments by the German-American scholar Franz Boas, often considered the father of modern anthropology. Like Firmin, Boas argued that race was a cultural construct.

Firmin was among the first to view anthropology as the study of all humankind, rather than the more exclusionary approach common in his day, says Fluehr-Lobban, who wrote the introduction to the English translation of his book.

Firmin also brought to the book a deep scientific rigor that was not yet common in the field. His highest priority was that "the case be made on the facts," Fluehr-Lobban says.

No scientific evidence

Firmin was born in the northern town of Cap-Haitien in 1850 to a working-class family. He grew up at a time of tremendous national pride. Haiti achieved independence from France in 1804, making it the first free Black republic in the world and the first independent nation in the Caribbean.

As a young adult, Firmin studied law, which led to a career in politics. He served as the inspector of schools in Cap-Haitien and as a Haitian government official in Caracas, Venezuela. He married his neighbor, Rosa Salnave, in 1881. In 1883, Firmin became Haiti's diplomat for France and moved to Paris.

Firmin, like many scholars of his day, read across fields, Fluehr-Lobban says. That led him to become interested in the study of humankind. While in Paris, Firmin spoke of this interest with French physician Ernest Auburtin, who invited him to join the Société d'Anthropologie de Paris.

It did not take long for Firmin to question his membership in a group openly hostile to people who looked like him. Faced with such a tough environment, Firmin remained silent at meetings. He acknowledges this reluctance to strike up a debate with other society members in his book's preface: "I risked being perceived as an intruder and, being ill-disposed against me, my colleagues might have rejected my request without further thought."

Instead, Firmin penned his 451-page rebuttal, using a title that clearly contradicted de Gobineau's influential work.

On a general level, Firmin takes aim at the nonscientific tenor of many society members' arguments. "On the one hand, there is a dearth of solid principles in anthropological science at this point; on the other hand, and precisely for this reason, its practitioners, with their methodical minds, are able to construct the most extravagant theories, from which they can draw the most absurd and pretentious conclusions," Firmin writes in a chapter devoted to dismantling the then-popular classification of races using cranial measurements.

Firmin uses the bulk of the book to flesh out his argument in precise detail. For instance, Firmin conducts a thorough analysis of the physical factors that were purported to separate the races, such as height, size, muscularity and cranium shape. He then painstakingly combs through the data to debunk prevalent theories of racial hierarchies.

"What can we conclude here from these observations? Can we find here any indication of hierarchy at all?" he queries at one point in reference to a chart on brain volume. The question is rhetorical. The measurements of supposedly distinct racial groups instead often overlap. Nor do the measurements conform to established racial hierarchies. "It is all so very anarchic," he concludes.

The power of Firmin's writings stems from his deep commitment to following the evidence, says anthropologist Niccolo Caldararo of San Francisco State University. "His criticism of European, especially French, scientists was so careful, was so precise, was so perfectly defined that he undermined their practice as bias rather than empiricism."

Modern-day relevance

The translation of Firmin's text came out of a chance encounter between Fluehr-Lobban and a Haitian student in her Race and Racism class in 1988. That student approached Fluehr-Lobban and asked if she had ever heard of Firmin. She had not but was intrigued.

> The power of Firmin's writings stems from his deep commitment to following the evidence.

In collaboration with Asselin Charles, a Haitian-born literary scholar then at neighboring Brown University, the duo set out to find a copy of the book. That turned out to be no easy feat. "There were three copies in the United States," says Fluehr-Lobban. "One of them was in the Library of Congress."

To Fluehr-Lobban's delight, upon receiving her request, library staffers sent her the book. Charles served as translator.

"As a result of this book coming out in English, it had a whole new life," Fluehr-Lobban says. Still, she adds, the book has yet to get its due: "It has not gotten into the canon of anthropology."

Fluehr-Lobban hopes that will change, especially given the book's modern-day relevance. Despite clear evidence that race has no biological basis, some scientists still use the concept as an organizing principle. And racism remains prevalent.

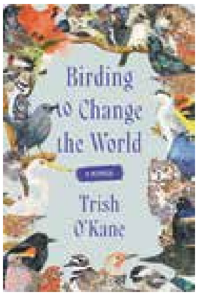
"This was a critical race theory book [written] in 1885," says Fluehr-Lobban.

Firmin, however, remained optimistic that science would eventually get the last word.

"Truth is like light: one may hide it for as long as human intelligence can conceive, it will still shine in the cellar where it has been relegated; at the least opportunity, its rays will pierce the darkness and, as it shines for all, it will compel the most rebellious minds to bend before its laws," he wrote. "Science owes all its prestige only to this power, to this intransigence of the truth." ■

Explore more

- Anténor Firmin. *The Equality of the Human Races*. Translated by Asselin Charles. University of Illinois Press, 2000.



Birding to Change the World
Trish O'Kane
ECCO, $29.99

BOOKSHELF

The transformative power of bird-watching

A "spark bird" is the species that inspires someone to start bird-watching. For Trish O'Kane, that bird was the northern cardinal. The backyard regular caught her eye while she was living with a friend in New Orleans, five months after Hurricane Katrina ravaged the region and her house in August 2005. Hearing cardinals' chipping calls was an initial step toward over 1,960 hours of birding, 33 field notebooks filled with avian antics and a career change.

In her memoir, *Birding to Change the World*, O'Kane charts her pivot from human rights journalist to environmentalist. She worked as a hate crime researcher, an investigative reporter and a writing instructor for incarcerated mothers before starting work as a journalism instructor at Loyola University New Orleans the week before Hurricane Katrina hit. "How to stop war, how to end economic injustice, how to fight racism and white supremacy — these global problems were the focus of my life and work," O'Kane writes. "I never paid any attention to environmental issues."

Her fledgling interest in birds actually began a few days before the monster storm arrived. O'Kane notes how, despite the gorgeous weather, flocks of alarmed gulls shrieked over one of the levees near Lake Pontchartrain. "This was the first time I began to think of them as more than pretty flying objects and instead as creatures with their own agendas," she writes. "But they can't watch CNN, so how could they possibly know that a massive hurricane is going to hit us in less than forty-eight hours?" It's one of many moments where O'Kane makes sense of the bizarre abilities of birds — bizarre by human standards, anyway — by weaving established research with interviews with scientists. The gulls were reacting to sharp drops in barometric pressure from the encroaching storm.


JOSHUA BROWN

Environmentalist Trish O'Kane (far left), now a lecturer at the University of Vermont, takes students birding on Derway Island in Burlington.

Post-Katrina, O'Kane must navigate between working at Loyola and coping with the loss of her home. She finds relief in watching the birds that flit about in New Orleans' Audubon Park. She starts bringing her class along for writing sessions. House sparrows, often scorned by bird enthusiasts for killing native birds, transform into a symbol of resourcefulness by building nests and foraging among the wreckage.

"My students stare at me in disbelief when I tell them that until I was forty-five years old, I never cared about birds," O'Kane writes. She strived to make the world a better place for people. Now she was considering the welfare of wildlife. "I suddenly wondered how many creatures had died simply because of the way I lived." She decides to pursue an eco-oriented career. In 2007, she enrolls in a doctorate program at the University of Wisconsin–Madison to study environmental science.

Most of the book focuses on O'Kane's efforts to preserve Warner Park, along Madison's Lake Mendota. It's a convenient location for O'Kane to satisfy birding requirements for an ornithology class. But soon she successfully campaigns to stop the construction of a parking lot in one of the park's meadows. Her activism snowballs into Wild Warner, a local crew of wildlife watchers flocking together to defend the park from further development. The organization eventually becomes part of O'Kane's dissertation research, along with a birding class that pairs middle school students with college-student mentors.

It's here that the memoir shows readers that an expertise in nature doesn't require a degree. Take Jan, a retired feed mill worker plagued by chronic obstructive pulmonary disease. O'Kane calls Jan an "ecology gold mine" of animal stories, thanks to his walks through Warner Park prescribed by his doctor. Then there's Jeremy, a seemingly disinterested boy enrolled in O'Kane's birding class. When reporters join an outing, the normally quiet Jeremy gushes about indigo buntings. O'Kane soon learns that Jeremy had taken to secretly studying the field guide gifted to him by his mentor.

O'Kane's love for common birds fuels much of her work, a refreshing reminder of the incredible feats of nature happening in our own neighborhoods. A birder chasing the next exotic species to cross off their "bird life list" might dismiss the sighting of a shy gray catbird, readily found "meowling" under the cover of a nearby hedge. O'Kane, though, studies catbird migration. By strapping the birds with radar backpacks, her team confirms that the Warner Park's catbirds migrate every fall as far as Mexico and Guatemala before returning each spring.

At its core, *Birding to Change the World* is about how people and birds today depend on one another. For birds, that dependence is tangible — for instance, the preservation of marsh habitat for wetland species. For people, the connection can be less concrete. "For millennia, our species has seen birds as symbols of liberation," O'Kane writes. In her case, it was liberation from the grief and depression that Katrina brought. "Bird by bird, every chickadee, nuthatch, catbird, wren, and owl forged a new neural pathway in my brain, a joyful pathway." — *Aaron Tremper*

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SOCIETY FOR SCIENCE

JANUARY 13, 2024

Words matter

*An ancient grave with a sword, shield and mirror belonged to a woman who about 2,000 years ago may have fought in raids and helped fend off enemy attacks in what's now southwestern England, **Bruce Bower** reported in "Iron Age warrior grave belonged to a woman" (*SN: 1/13/24, p. 5*).*

Reader **Cathryn Brenner** expressed disappointment in a phrase in the story. "The woman warrior was described as potentially having a 'violent streak.' The connotation of violent streak, if not the actual meaning, is negative and used to describe a personality trait that is evidenced in the frequent use of violence or physical harm to others across many contexts," **Brenner** wrote. "I see no evidence in this article that, if she was a warrior, she acted in any way other than a male warrior — raiding and defending. And I have never ever ever seen a male warrior described with this term! I am shocked that at this time, this phrase got past everyone involved with the article."

Shifting spins

*Enormous polygonal rock patterns lie near Mars' equator deep below the surface, radar data suggest. The finding hints that the Red Planet's equator was once much icier than it is now, perhaps because of differences in the tilt of the planet's axis, **Elise Cutts** reported in "Buried polygons hint at Mars' tipsy past" (*SN: 1/13/24, p. 12*).*

Reader **Robert Walty** wondered if some sort of cosmic collision could have caused the tilt of Mars' axis to change. "It has often been suggested that the reason Uranus' spin axis is on its side could be due to a collision with another large body in the past. This collision hypothesis was not mentioned in the article," **Walty** wrote.

It likely was not an event, such as an asteroid impact, that caused a change in Mars' tilt, but rather the natural evolution of the planet's spin over time, says geoscientist **Ross Mitchell**, who along with colleagues discovered the patterns.

Earth's axis is tilted at an average of 23.3 degrees. Stabilized by our moon, the planet's tilt wobbles by a little more than a degree from that average, says **Mitchell,** of the Chinese Academy of Sciences' Institute of Geology and Geophysics in Beijing. But Mars' two small moons provide no such stabilizing effect. So even though the Red Planet's tilt is currently quite similar to Earth's at an average of 25 degrees, it might have varied drastically in the past — between around 15 and 40 degrees, he says.

What's more, simulations of the solar system's history suggest that the Red Planet's average tilt may have been greater than 40 degrees for most of its existence, **Mitchell** adds. If true, that "would mean that most of the climate history recorded in the Martian geologic record might be very different from the current cold, dry climate we know today."

The new finding supports such a prediction, **Mitchell** says. The radar images of the ancient polygonal rock patterns buried under Mars' surface suggest that the planet's equator, which currently is "dry as a bone," experienced freeze-thaw cycles of water a few billion years ago.

Questioning quantum gravity

*Random fluctuations in gravitational fields might allow physicists to seal the rift between the general theory of relativity, which describes gravity, and quantum physics, without the need for a theory of quantum gravity, **Emily Conover** reported in "What if gravity isn't quantum?" (*SN: 1/13/24, p. 15*).*

Reader **John Rippingale** wondered what could cause random fluctuations in a gravitational field.

In this theory of gravity that some researchers propose, there is intrinsic randomness in the way that spacetime bends in response to a massive quantum particle, **Conover** says. As a result, the gravitational field of an object would appear to fluctuate slightly. "So if this theory is correct, there's no need for a cause for that randomness — it's just a fact of nature," she says.

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What happens when a sprinkler sucks in water

Physicists are fascinated with heady puzzles, from the nature of space and time to how the universe came to be. But spinning lawn sprinklers? Yes, that too.

A new experiment provides an answer to a quirky physics quandary popularized by physicist Richard Feynman in the 1980s. The puzzle centers on a style of sprinkler that works by squirting water out the ends of an S-shaped tube. The sprinkler spins away from the escaping water due to conservation of angular momentum. That much is straightforward.

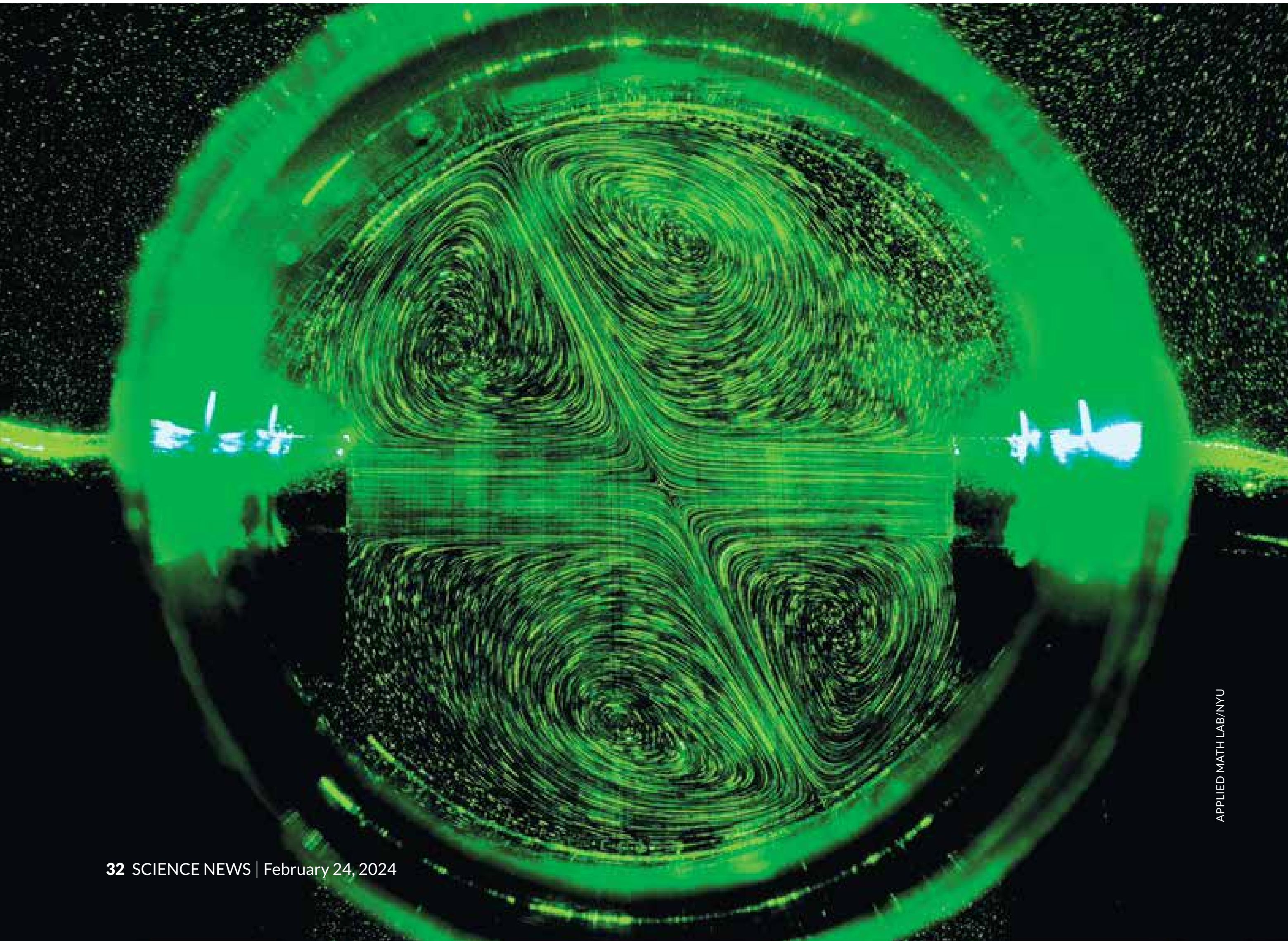
But what happens if you stick the sprinkler in a tank of water and have it suck the water in? The question seems simple. But complex fluid flows and subtleties of momentum conservation have led different physicists to argue that it should either spin in the opposite direction as it does when operated normally, or not move at all. Different experiments likewise clashed.

So applied mathematician Leif Ristroph of New York University and colleagues gave it a whirl. "It ended up being one of the hardest problems our lab has ever worked on," he says. The team performed experiments with a painstakingly crafted transparent sprinkler in a tank of water. To reduce friction, which confounded earlier experiments, the device itself floats. When run in reverse, the sprinkler indeed spins in the opposite direction, the researchers report in the Jan. 26 *Physical Review Letters*. A peek inside, alongside calculations that backed up the measurements, revealed why.

The image below shows how fluid moves in the sprinkler as it sucks in water, made visible with lasers that illuminate added microparticles. As water enters the sprinkler from the sides, two jets form across the middle and stir up vortices.

Importantly, the jets and vortices aren't symmetrical. When the jets collide in the sprinkler's middle, they continue on at an angle, suggesting they make a glancing collision, rather than hit head on. That's because even though the arms of the sprinkler are perfectly aligned, the internal jets aren't. The trip through the curved arms (partly seen below at the far left and right) displaces the flow of water in each jet. That asymmetry sets the sprinkler rotating backward to conserve angular momentum.

The sprinkler puzzle's solution just demanded a spritz of insight. —*Emily Conover*



APPLIED MATH LAB/NYU

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