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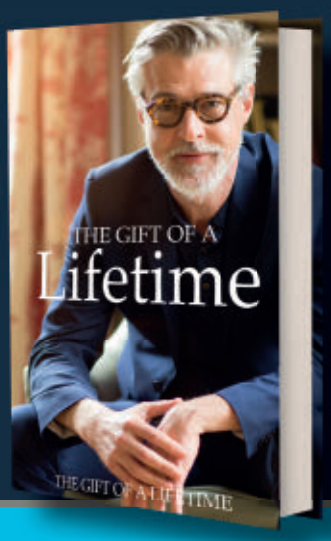

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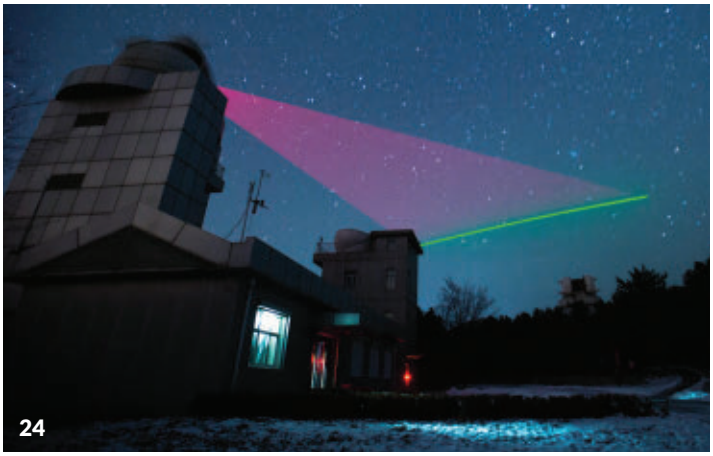
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Future quantum computers could break the codes that keep all of our private information secret. But solutions are coming in the form of new algorithms — and a quantum internet. *By Emily Conover*

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COVER In Mato Grosso, Brazil, sections of the Amazon have been cut down for agriculture. *Lucas Ninno/Moment/Getty Images*

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Quantum computing may break the internet

We entrust our lives to the internet: bank accounts, medical records, dating profiles, family history—even our shopping lists and pet photos. Digital security systems use mathematical formulas to encrypt information and keep the snoops and crooks at bay. But quantum computing could bust through many online security protections.

Blame the weirdness of the quantum world. There, tiny particles do things that seem to defy logic, such as existing in two contradictory states at once.

Quantum computers have been used for scientific experiments for decades, but only recently have they become useful for practical purposes. Scientists and companies have been racing to build machines that can perform certain calculations much faster than existing computers.

Just one small problem: A quantum computer could soon crack the cryptography systems that protect the internet as we know it.

Cryptography currently relies on a simple assumption—that it's virtually impossible to guess the "key" that will unlock our secrets. In the roughly 50 years since the invention of public-key encryption, that has been a safe bet, because today's standard computers are limited in their ability to perform certain tasks, such as factoring large numbers.

Quantum computers, which use bits called qubits that can represent 0, 1 or both simultaneously, are not so limited. It is possible—some scientists say likely—that a quantum computer powerful enough to crack public-key cryptography could come online in the next 15 years.

Fortunately, scientists are on the case. In this issue, physics and senior writer Emily Conover explores the efforts already under way to develop new quantum-proof encryption methods (Page 24). This includes new standards from the U.S. National Institute of Standards and Technology due next year, which will help ensure that cybersecurity experts, businesses and government entities develop coordinated strategies.

Things are moving fast. Conover reports that last November, Google revealed that it is using post-quantum cryptography for internal communications. Others are looking ahead to a quantum internet that would be immune to hacking, even from quantum computers. A few quantum networks have already been built in the United States, Europe and Asia. Although the networks have a limited reach, Chinese banks are using quantum networks to transmit data.

The threat of cybercrime has become part of everyday life. Last week my bank texted to let me know that my credit card had been hacked. (Evidently the bank's algorithms realized that I didn't take a bus from Washington, D.C., to New York to get my nails done.) This was a minor inconvenience for me, but others are not so lucky. More than 1.1 million people in the United States reported identity theft in 2022, according to the Federal Trade Commission. Businesses, governments and financial institutions suffer billions in losses each year due to cybercrime.

As we conduct even more of our lives online, we will all have a stake in ensuring that our private data is kept secret, even in the quantum realm.

—*Nancy Shute, Editor in Chief*

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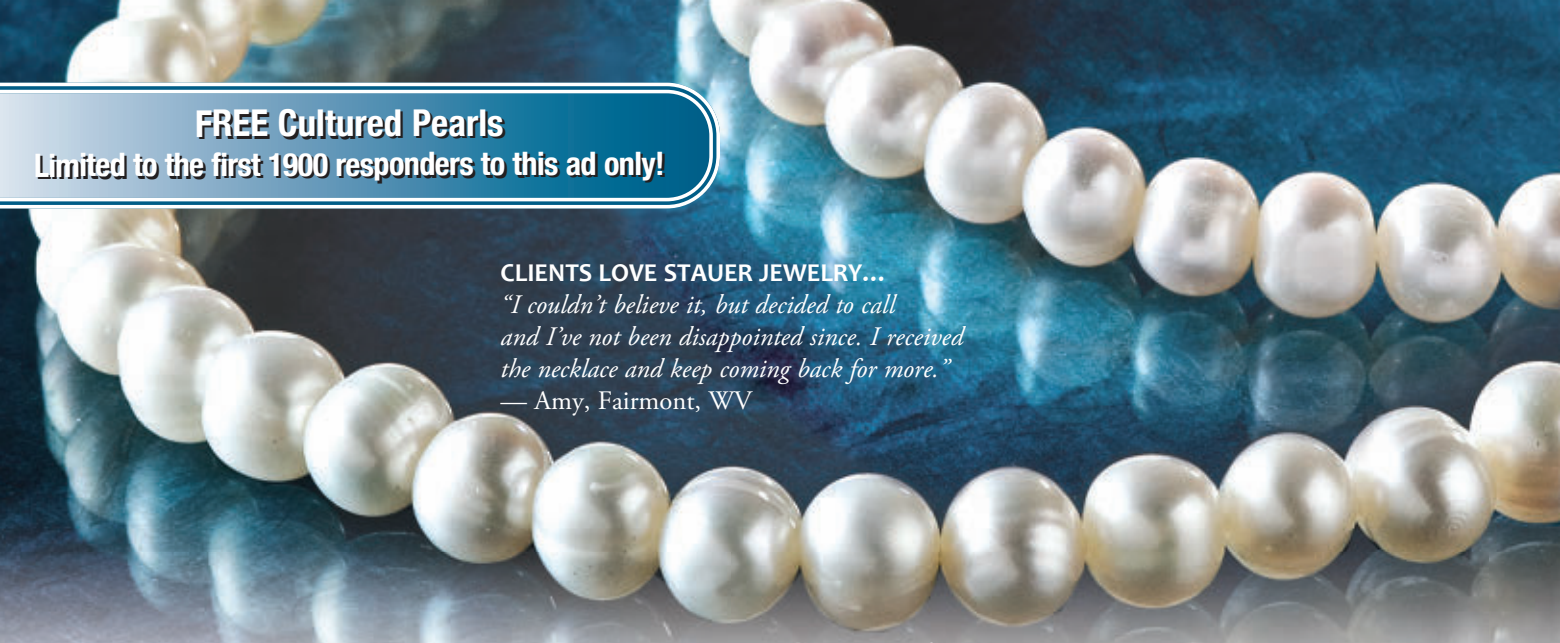

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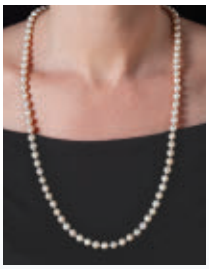

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50 YEARS AGO

Comets, novas and the Mayans

Did the Mayans record novas and comets? … Comparing dates of known historic novas and comets with [20] Mayan dates, [a researcher] found no acceptable correlation. Nevertheless, [the researcher] believes that the Mayans probably did record such events and that a record will eventually be found.

UPDATE: Solid evidence that ancient Maya people marked dying stars or passing comets continues to elude archaeologists. Several early codices and stones may have recorded hieroglyphs that together mean "comet." But Spanish conquistadores destroyed many of the originals, and only copies made well after the Maya empire's collapse clearly depict comets. In 2017, an analysis of Maya records and astronomical data hinted that the Maya indirectly marked at least one comet by predicting when meteor showers would dazzle the sky. Between the years 250 and 909, six royal coronations happened within days of the annual Eta Aquariid meteor shower, researchers found, which occurs when Earth passes through the tail of Halley's comet.

Insecticide resistance is growing among *Anopheles* mosquitoes. Now, scientists may have found a solution: the microwave.

THE SCIENCE LIFE

Restoring an insecticide's mosquito-killing power

Heating an insecticide can give it new life.

Microwaving deltamethrin rearranges its crystal structure but doesn't change its chemical composition. The rearrangement renews deltamethrin's ability to kill mosquitoes that have become resistant to the insecticide, researchers report April 21 in *Malaria Journal*.

The researchers didn't set out to revive insecticides. Crystallographer Bart Kahr of New York University and colleagues had been working on crystal growth

THE EVERYDAY EXPLAINED

Here's why shouting into the wind seems futile

Shouting into the wind isn't so ineffective after all. The idiom describes an unsuccessful attempt to communicate. But it's not actually more difficult to shout upwind, says acoustics researcher Ville Pulkki of Aalto University in Espoo, Finland. Sending a sound against the flow of air makes the sound louder due to an acoustic effect called convective amplification. Sound sent downwind is quieter. So, if you're yelling upwind, a listener standing in front of you should have no problem hearing you — contrary to popular belief.

The misperception has a simple explanation, Pulkki says. "When you yell against the wind, you hear yourself worse." Because your ears are downwind of your mouth, your own voice sounds quieter to you. Pulkki attempted to test the effect by yelling from a moving vehicle as microphones recorded the amplitude of his voice (shown below). The results were inconclusive, so he and colleagues replaced the human element with a speaker playing tones and a cylinder. Microphones measured sound amplitude where the mouth and ears would be on the cylinder when the speaker faced upwind and downwind. Pairing the data with computer simulations confirmed the source of the misperception, the team reports March 31 in *Scientific Reports*.

A similar effect occurs when an ambulance goes by. The siren is louder when moving toward a stationary observer than it is when moving away. When you're bellowing upwind, it's not the source of sound that's moving, but the medium in which the sound travels.

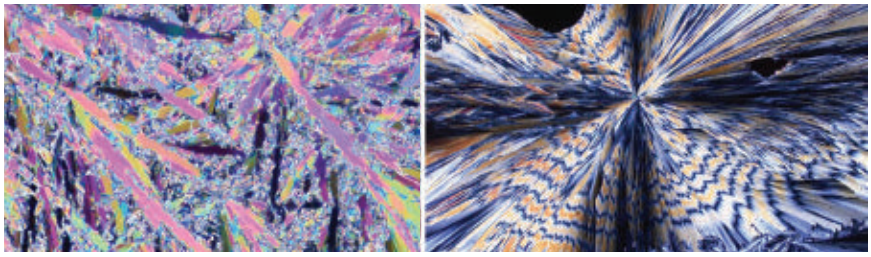
Whichever way the wind blows, acoustics can explain it. — *Emily Conover*

FROM TOP: EPHOTOCORP/ISTOCK/GETTY IMAGES PLUS; ILKKA HUHTAKALLIO

experiments with DDT, "the very old, notorious insecticide from the last century," Kahr says. The researchers realized that DDT has two crystal forms, one of which works better than the other.

They soon started experimenting with deltamethrin, which is an insecticide commonly used against mosquitoes that can carry malaria. Mosquitoes absorb the insecticide when they come in contact with treated surfaces. The team previously discovered that heating deltamethrin changed its crystal structure, letting it work faster (SN: 11/21/20, p. 8).

Altering the arrangement of crystals is a tried-and-true way of giving drugs new and different properties, Kahr says. His team heated a chalk formulation of deltamethrin called D-Fense Dust in an oven with precise temperature control. "But just for kicks, we said because this deltamethrin is a consumer product, what if you just pop it in the microwave for five minutes?" he says. "Does that achieve the same thing?" The answer: yes. But Kahr warns that insecticides should not be heated in appliances used to cook food.



In lab tests, five strains of mosquitoes that were resistant to the insecticide deltamethrin (typical crystal form, left) died when exposed to deltamethrin crystals that had been microwaved (right).

The microwaved crystals worked on mosquitoes that were sensitive to deltamethrin. For the new study, the team tested the crystals on five strains of deltamethrin-resistant *Anopheles* mosquitoes from West Africa. In all cases, the rearranged crystals killed the pests.

The finding is encouraging, says Janet Hemingway, director of the Infection Innovation Consortium, a public-private effort in the United Kingdom to find new ways to combat infectious diseases.

Rising insecticide resistance is impairing the ability to tamp down malaria, Hemingway says. But it's unclear whether heated deltamethrin infused into bed nets would retain its potency. And popping existing nets in the microwave isn't practical. "You'd need some pretty big microwaves given these things come in shipping containers," she says.

Kahr's team is working to get heated deltamethrin into bed nets and find other application methods that appeal to consumers. —*Tina Hesman Saey*

SCIENCE STATS

Marsquake reveals a thick crust

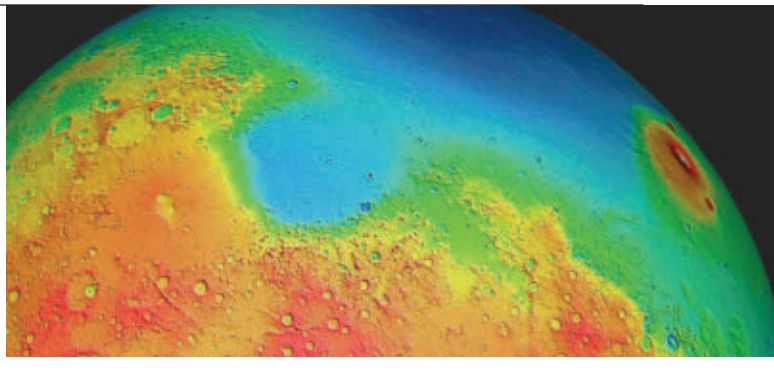
Planetary scientists now know how thick the Martian crust is, thanks to the strongest Marsquake ever observed.

On average, the crust is between 42 and 56 kilometers thick, researchers report in a paper posted March 6 to the preprint server ESS Open Archive. That's roughly 70 percent thicker than the average continental crust on Earth.

The measurement was based on data from NASA's InSight lander, a stationary seismometer that recorded waves rippling through Mars' interior for four Earth years. In May 2022, the entire planet shook with a magnitude 4.7 quake that lasted for about 10 hours (SN: 6/18/22, p. 5).

InSight recorded seismic waves from the quake that circled Mars up to three times. That let seismologist Doyeon Kim of ETH Zurich and colleagues infer the crust thickness over the whole planet. Not only is the crust thicker than that of the Earth and the moon, but it's also inconsistent across the Red Planet, the team found. And that might explain a known north-south elevation difference on Mars.

Topological and gravity data from Mars orbiters have shown that the planet's northern hemisphere is substantially lower than the southern one. Researchers had suspected that perhaps the rocks in the north have a different density than those in the south.



The northern hemisphere of Mars, shown in false-color, is mostly lowlands (blue) while the southern hemisphere is more mountainous. Knowing the thickness of Mars' crust is helping scientists study why.

~70 percent

How much thicker Mars' crust is than Earth's

But the crust is thinner in the northern hemisphere, the team found, so the rocks in both hemispheres probably have the same average densities. That finding helps scientists narrow down the explanations for why the difference exists in the first place.

The team's analysis also suggests that much of Mars' internal heat—generated by radioactive potassium, uranium and thorium—originates in the crust. Using crust thickness data, computer simulations estimated that 50 to 70 percent of those elements are probably in the crust rather than the underlying mantle. The finding supports the idea that parts of Mars still are volcanically active (SN: 12/3/22, p. 12). —*Lisa Grossman*

FROM TOP: JINGXIANG YANG; MARS ORBITER LASER ALTIMETER SCIENCE TEAM

HEALTH & MEDICINE

A rare mutation held off Alzheimer's

The case could offer clues to developing new treatments

BY SIMON MAKIN

A genetic mutation never seen before protected a man with an inherited form of Alzheimer's from developing the disease for decades.

He is the second known person to have such protection, following a report in 2019 of a woman with a different mutation (SN: 2/1/20, p. 20). Both mutations may have staved off the disease by acting in similar ways in the brain, an insight that could lead to new treatments for all forms of Alzheimer's, scientists report in the May *Nature Medicine*.

But some researchers are cautious about concluding too much from just two cases. "The results look very promising, but it would be useful to see replication in more samples," says neurologist Rudolph Tanzi of Harvard Medical School. Still, he says, the work "can serve as a useful guide for drug discovery."

Both the man and woman came from the same Colombian family with a mutation in the *PSEN1* gene that causes the rare inherited variety of Alzheimer's. People with "familial" Alzheimer's usually start showing signs in their 40s. The more common "sporadic" form typically doesn't cause symptoms until people are in their 70s or 80s.

The woman stayed sharp into her 70s, while the man remained mentally healthy until 67. "That means they were protected, because they should have gotten the disease 30 years earlier, and they didn't," says Diego Sepulveda-Falla, a neurologist at the University Medical Center Hamburg-Eppendorf in Germany.

The woman had a protective mutation in a gene closely linked to Alzheimer's, *APOE*. This mutation is known as the Christchurch variant, after the city in New Zealand where it was first found. The mutation identified in the new study was in a gene called *RELN*. Sepulveda-Falla and colleagues named this new mutation RELN-COLBOS, after a joint Colombia-Boston study that the man who had it participated in. He died three years ago, at age 74, from other causes, and his family donated his brain for study.

The researchers compared the two cases, finding striking similarities and differences. Amyloid plaques, thought by many researchers to be deeply involved in Alzheimer's, were abundant in both patients' brains. But the woman had low levels of another possible contributor to Alzheimer's, clusters of proteins called tau tangles. The researchers think this is what spared her from dementia for decades, as tau is thought to be more tightly linked to symptoms than amyloid.

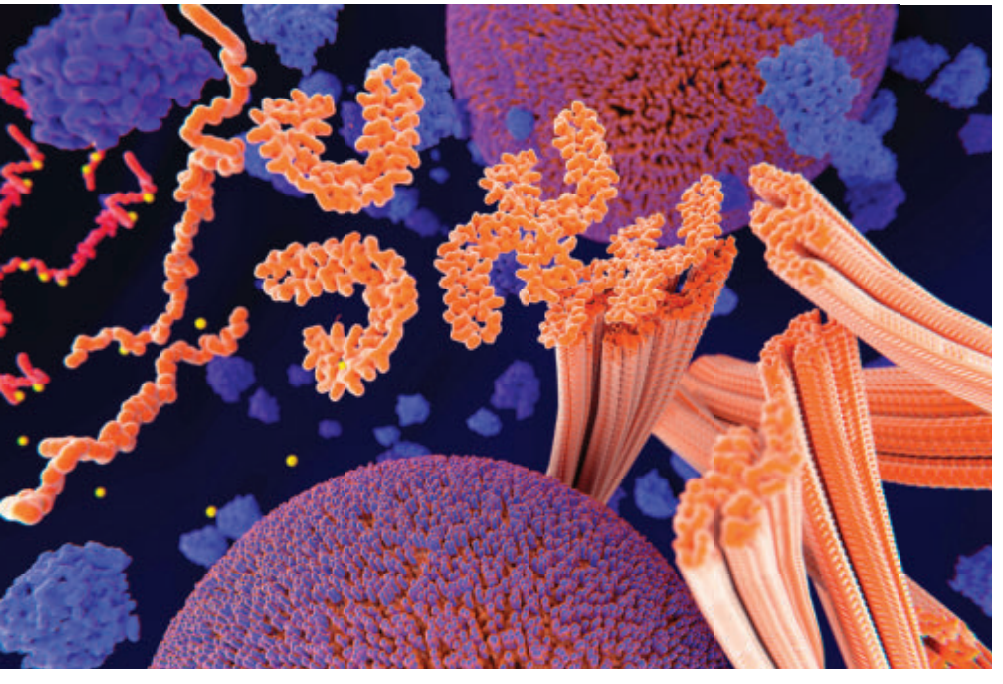
In the Colombian man's brain, the researchers found a different picture. He had a lot more tau tangles than the woman did. "This shocked us initially, then we figured out we needed to roll our sleeves up and dig deeper," Sepulveda-Falla says.

Some brain regions, notably the entorhinal cortex, which is important for memory and one of the earliest areas affected in Alzheimer's, had been spared from tau tangles, the team found.

The difference in tau between the two cases is due to where the two protective genes are active in the brain. In adults, *RELN* is active in only a few places, including the entorhinal cortex. *APOE* is active everywhere. "Since *APOE* is ubiquitous, in one patient you get protection all around," Sepulveda-Falla says. "In this other, the protection is localized to [certain] neurons, and by chance they happen to be the neurons that are key for preserving cognition."

Despite affecting different genes, both mutations produce proteins that attach to the same molecules on cells and appear to reduce the formation of tau tangles. The researchers confirmed this for the new mutation using mice genetically engineered to produce tau. Introducing the RELN-COLBOS mutation into these mice prevented tau buildup. This mechanism, common to both mutations, could be targeted by new treatments aiming to stave off all types of Alzheimer's, the team says. ■

Aggregations of proteins called tau tangles (orange clumps in this illustration of a brain cell) are a major sign of Alzheimer's disease. Certain mutations may protect against the formation of tangles.



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NEUROSCIENCE

A paralyzed man can walk easily

Brain and spine implants turn thoughts into fluid movements

BY SIMON MAKIN

A system that restores communication between the brain and spine has enabled a man paralyzed by a spinal cord injury to regain near natural walking ability.

Once the patient's brain activity was decoded, the brain-spine interface took mere minutes to calibrate, after which the man reported natural-feeling control over movements. He still needs crutches but can easily navigate ramps and steps, surpassing gains from previous treatments, researchers report May 24 in *Nature*.

"The results are consistent with what I'd hope would happen, which is encouraging," says V. Reggie Edgerton, a physiologist at Rancho Los Amigos National Rehabilitation Center in Downey, Calif., who was not involved in the study. In terms of treating spinal cord paralysis, he says, "we're at the stage of the Wright brothers and flight."

Spinal cord injuries can interrupt communication between the brain and spine, causing paralysis. Previous research showed that stimulating spinal cord nerves can produce movement (SN: 7/16/22 & 7/30/22, *p.* 18). This is the first time that a patient's own brain activity has been used to reestablish voluntary control of leg movements.

A biking accident 12 years ago left 40-year-old Gert-Jan, who requested using only his first name, paralyzed from an incomplete spinal cord injury. Six years later, he enrolled in a clinical trial of a spinal cord implant that stimulates nerves that control leg movements. Gert-Jan regained the ability to step with a walker, but it involved making unnatural heel movements so that motion sensors could trigger preprogrammed nerve stimulation patterns. He had difficulty starting and stopping, and could walk only over flat surfaces.

The new study aimed to hand control over to Gert-Jan's brain. After three years of using the spinal cord implant, "he hit a plateau in his recovery and became interested in using the new brain-controlled stimulation," says neuroscientist Grégoire Courtine of the École Polytechnique Fédérale de Lausanne in Switzerland. "He became our first test pilot."

Courtine and colleagues implanted electrodes onto the surface of Gert-Jan's brain to create a system that translates thought into movement. Two arrays record activity from the sensorimotor cortex, a region of the brain that helps direct muscle movements. The signals are sent wirelessly to a processing unit that converts them into stimulation patterns, which are then transmitted to the spinal cord implant.

The team asked Gert-Jan to attempt leg joint movements while they analyzed his brain activity. Hip, knee and ankle movements each had their own unique pattern, the researchers found, enabling them to map brain signals to intended movements. The team created stimulation patterns targeting muscles that control putting weight down, pushing forward and leg swings to reproduce walking motions. During use, an artificial intelligence algorithm translates incoming brain signals into appropriate command signals for the spinal implant.

Researchers calibrated the system so that Gert-Jan could control the amount of movement. "This brings a more fluid walking pattern," Courtine says, helping Gert-Jan adapt his foot placement and even climb stairs.

"The stimulation before was controlling me, and now I'm controlling the stimulation," Gert-Jan said May 23 during a news conference.

Using the device during a neurorehabilitation training program led to mobility improvements even when the brain-spine interface was turned off, the team found. "This suggests new nerve connections developed," Courtine says.

Researchers need to understand more about how this recovery works. "The question is: Where in the brain is getting connected to where in the spinal cord? And we don't really know that," Edgerton says. "We need to figure out how the two are working together."

The extent of Gert-Jan's recovery delivered quality of life boosts, such as moving around the house independently and standing at a bar drinking with friends. While many paralyzed people prioritize other problems, such as bathroom function and blood pressure, this study aimed only to restore mobility.

GILLES WEBER/CHUV

Gert-Jan was paralyzed by a spinal cord injury 12 years ago. He and a scientist test a brain-spine interface that has restored some of Gert-Jan's ability to walk.

Gert-Jan has been using the system for nearly two years, Courtine says, and the brain implant has remained stable and reliable. Courtine and colleagues think the approach will work for other patients, but caution that the extent of recovery may depend on the severity of injury.

The team plans to apply the approach to the upper limbs too, neuroscientist Henri Lorach, also of the École Polytechnique Fédérale de Lausanne, said at the news conference. "We are initiating a clinical trial in three participants that will target these circuits."

Courtine and colleagues developed a version of the system that Gert-Jan could operate himself at home, but further improvements are needed. The processing unit is bulky and the brain implant involves two 5-centimeter-wide cylinders that sit in holes cut in the skull.

Onward Medical, a Lausanne-based company cofounded by Courtine, is working on miniaturizing the brain implant and processing unit. The goal, Courtine says, is to develop a commercial version that is "easy for patients to use in daily life." ■

HEALTH & MEDICINE

RSV vaccine earns landmark approval

The U.S. Food and Drug Administration may soon approve others

BY TINA HESMAN SAEY

Respiratory syncytial virus hospitalizes tens of thousands of people each year in the United States. Now there's a powerful new tool against it: the first RSV vaccine.

The U.S. Food and Drug Administration announced May 3 that it had approved an RSV vaccine made by GSK for use in people ages 60 and older. GSK expects that the vaccine will be available later this year, before RSV season starts.

The virus causes coldlike symptoms for many people, but can cause severe illness, hospitalization and death for infants and older people. An estimated 60,000 to 160,000 older adults are hospitalized each year with RSV infections, according to the U.S. Centers for Disease Control and Prevention. And about 6,000 to 10,000 of them die. Individuals with chronic heart or lung disease and those with weakened immune systems are especially vulnerable.

The newly approved vaccine reduced the risk of developing lung infections by about 83 percent compared with a placebo. In a trial of about 25,000 people 60 and over, only seven people who got the vaccine developed RSV lung infections, compared with 40 people who got a placebo. The vaccine's efficacy against severe lung infection was even better at about 94 percent: Just one person in the vaccine group versus 17 people in the placebo group developed that complication.

A number of other companies also have RSV vaccines in the works, including for infants and children. At least one of these candidates could be ready for deployment this fall, potentially reducing the number of doctor visits, hospitalizations and deaths from the infections.

Designing vaccines

Since vaccines for RSV are so new, it is uncertain what approach might provide the most protection. Companies are therefore targeting the virus in a variety of ways.

GSK, Pfizer and Moderna have developed vaccines based on one of RSV's proteins. The F protein sits on the virus's outer membrane and helps it fuse to human cells. This protein is a shape-shifter. Before fusion, it looks like a rounded knob. After fusion, it resembles a needle or pointy tower.

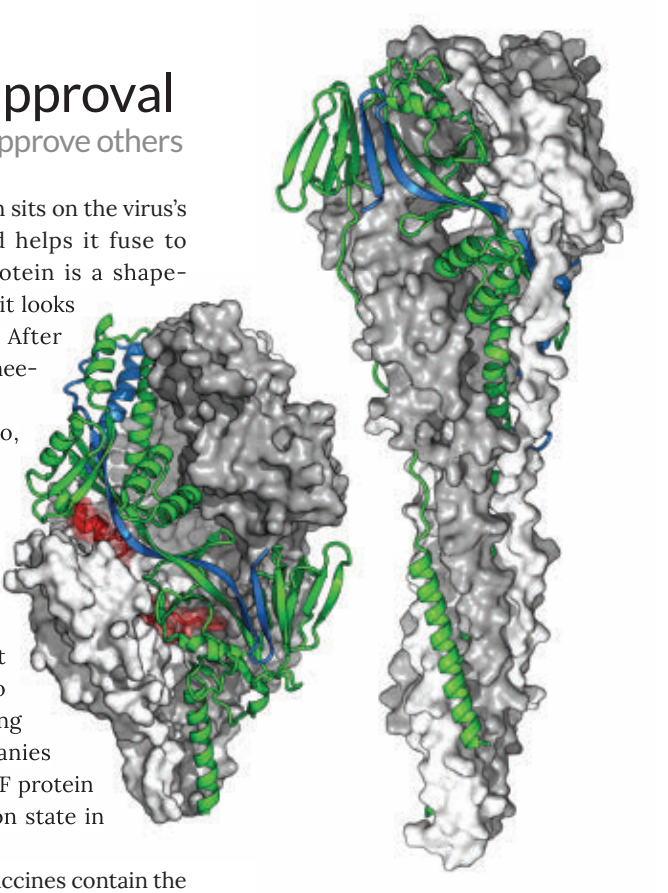
About 10 years ago, researchers at the U.S. National Institutes of Health figured out that locking the protein into its knob state causes the immune system to react more strongly than to the virus' shape-shifting form. All three companies use some version the F protein locked in the prefusion state in their vaccines.

Pfizer's and GSK's vaccines contain the protein itself. Moderna's candidate, like its COVID-19 vaccine, is an mRNA vaccine that tells the body to produce the protein.

Bavarian Nordic, headquartered near Copenhagen, is taking a different approach. For its RSV vaccine, the company engineered the vaccinia virus to make five RSV proteins, including the F protein. The vaccinia virus is used to make smallpox and mpox vaccines. The company hopes the engineered virus, which can't replicate well in the body or cause disease, will trigger antibodies against all the RSV proteins.

Another company, Codagenix, is tinkering with RSV's genetic instruction book to make the virus unable to cause disease but stimulate an immune reaction when given as a vaccine. Scientists introduced over 1,000 mutations in one gene to slow down production of its protein, limiting viral replication, says Jeffrey Fu, the company's chief business officer. Those mutations change the virus's RNA but don't alter the amino acids in its proteins.

"We're able to design viruses ... that look identical or nearly identical to the real virus," Fu says. Data from lab animal studies suggest the vaccine can trigger production of protective antibodies that prevent RSV from entering cells.



RSV uses its F protein (illustrated) to enter cells. Locking the protein into the knoblike shape it has before it fuses to cells (left) produces stronger immune system reactions than its pointier postfusion shape does (right).

JASON MCLELLAN

Most children get infected with RSV by the time they are 2 years old. Codagenix, based in Farmingdale, N.Y., has just begun testing the safety of its vaccine, which will be given as nose drops rather than as shots, at a low dose in healthy 5-year-olds. If safe, the company wants to gradually increase the dose, as well as begin testing the vaccine candidate in younger children, working down to 6-month-olds.

Infant protection

Only Pfizer is testing the ability of its vaccine to protect newborns. But instead of giving the vaccine candidate to babies, the company gave it to over 7,300 healthy

pregnant women. The idea is that the mother will produce antibodies against RSV that will transfer through the placenta and breast milk to the baby. Those antibodies would give babies protection against the virus in the especially vulnerable first six months of life.

The strategy seems to work. In the 90 days after birth, six infants born to moms who got the vaccine had severe RSV lung infections requiring medical attention. In a placebo group, 33 babies had severe lung infections. That's a vaccine efficacy of about 82 percent, researchers reported in the April 20 *New England Journal of Medicine*. Within six months after birth, vaccine efficacy stood at about 69 percent.

The vaccine didn't meet statistical criteria for preventing less-severe lung infections, but there were about half as many of these infections in babies whose mothers got the vaccine compared with babies whose mothers got a placebo.

The vaccine also kept babies out of the hospital, with an efficacy of almost 68 percent in the first 90 days of life and 57 percent within 180 days.

Like the COVID-19 vaccines and most vaccines for respiratory illnesses, the vaccine wasn't great at outright preventing infection (*SN Online*: 4/29/22). Its efficacy against any RSV illness requiring medical attention was around 39 percent up to six months after birth.

On May 18, an advisory committee to the FDA recommended the vaccine for approval in a split vote. All 14 committee members agreed the vaccine was effective, but four members had concerns about its safety. There were slightly more preterm births among mothers who got the vaccine than in the placebo group. Though the increase did not rise to statistical importance, the committee members who raised the safety concerns said the clinical trial wasn't properly designed to detect that potential complication.

The FDA generally follows the recommendations of its advisory committee. A decision is expected later this summer and may come in time for mothers to get vaccinated ahead of RSV season.

More protection for older adults

Babies, toddlers and preschoolers are perhaps the population that people worry most about when it comes to RSV, but the virus hits older people hard too.

"This is a relatively unrecognized infection in adult populations," Edward Walsh, an infectious diseases doctor at the University of Rochester Medical Center in New York, said April 5 at the World Vaccine Congress held in Washington, D.C.

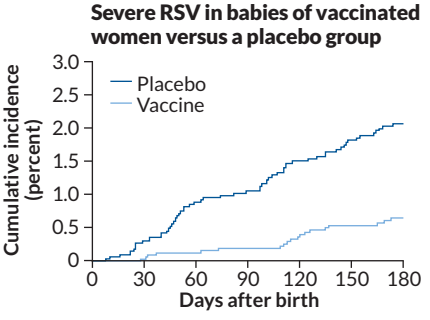
Walsh and colleagues conducted a trial of Pfizer's vaccine in more than 34,000 people ages 60 and older in Argentina, Canada, Finland, Japan, the Netherlands, South Africa and the United States. Half got the company's vaccine candidate and half got a placebo.

The trial started in August 2021. That's roughly when RSV hit its zenith in the United States that year, after having almost vanished in the winter of 2020–21 thanks mostly to COVID-19 pandemic precautions, including social distancing and mask wearing.

Though RSV returned to infect a lot of children in the 2021–22 season, it didn't come back in prepandemic numbers in older adults, especially not in the over-60 crowd, Walsh said. "They continued to stay away from grandchildren, stay away from crowds and wear masks."

The team found only 16 percent of prepandemic numbers of infections in older adults in the Rochester area during the study period. With such low numbers of infections, Walsh said, "we were very nervous that [the trial] wasn't going to show us anything."

Protecting babies In a clinical trial, the antibodies of pregnant women given an RSV vaccine protected their babies from severe lung infections for months after birth.



Rochester was just one of 240 sites in the study. Data collected from each site allowed the researchers to calculate the vaccine's efficacy. The researchers considered different levels of severity based on whether the virus infected the lungs and how many symptoms, such as cough, wheezing or shortness of breath, that participants reported.

In the placebo group, 14 participants developed lung infections with three or more symptoms while just two participants in the vaccine group developed that level of illness, for an efficacy of about 86 percent, Walsh and colleagues reported in a second study in the April 20 *New England Journal of Medicine*. Against RSV lung infections with two or more symptoms, the vaccine had an efficacy of about 67 percent. Those efficacy numbers are lower but similar to those of the newly approved GSK vaccine.

Moderna hasn't yet published results from its vaccine trial in a scientific or medical journal, but preliminary data issued in a press release in January suggest a vaccine efficacy of about 84 percent for preventing lung infections with two or more symptoms.

In a human challenge trial conducted by Bavarian Nordic, healthy volunteers were given the company's vaccine and then exposed to RSV. The vaccine prevented symptomatic infections with 79 percent efficacy, the company reported in a press release in 2021. But that was among healthy adults ages 18 to 50 who have less risk of severe complications than elderly people do.

Bavarian Nordic conducted a clinical trial in the United States and Germany of 20,000 people ages 60 and older. Results should be available later this year.

The efficacies of the different vaccines aren't directly comparable because the studies were done in different countries with different people and disease definitions that don't completely line up.

Without masking and social distancing, RSV probably won't disappear again. And the new vaccines probably won't stop RSV's spread. But they may at least protect the most vulnerable among us against the virus's worst effects. ■

B. KAMPMANN *ET AL*/*NEJM* 2023

NEUROSCIENCE

Implants track chronic pain in the brain

Neural signals point to a marker of the debilitating condition

BY LAURA SANDERS

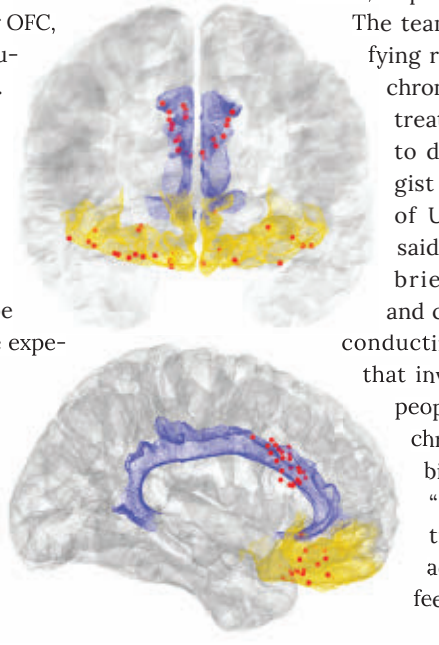
Scientists can see chronic pain in the brain with new clarity.

Over months, electrodes implanted in the brains of four people picked up specific signs of their persistent pain. This detailed view of chronic pain, described May 22 in *Nature Neuroscience*, suggests new ways to curtail the devastating condition.

The approach "provides a way into the brain to track pain," says neuroscientist Katherine Martucci of Duke University School of Medicine.

In the United States from 2019 to 2020, more adults were diagnosed with chronic pain than with diabetes, depression or high blood pressure, another group reported in the May *JAMA Network Open*. Because chronic pain is an amalgam influenced by the body, brain, context, emotions and expectations, it can be invisible to an outsider and difficult to treat, Martucci says.

One treatment approach is to stimulate the brain with electricity. In the new clinical trial, researchers at the University of California, San Francisco and colleagues implanted electrodes into the brains of four volunteers with chronic pain. These electrodes can both monitor and stimulate nerve cells in two brain areas: the orbitofrontal cortex, or OFC, and the anterior cingulate cortex, or ACC. The OFC isn't known as a key influencer of pain, but it has many neural connections to pain-related areas, including the ACC, which is thought to be involved in how people experience pain.



In a study of four people with chronic pain, implanted electrodes (red dots) listened to activity in two brain regions: the ACC (purple) and the OFC (yellow).

Before researchers stimulated the brain, they needed to know how chronic pain was affecting it. For about three to six months, the electrodes monitored brain signals of the participants as they went about their lives. During that time, they rated their pain on standard scales two to eight times a day. Machine learning linked pain ratings to brain activity patterns, creating a signature of each person's chronic pain.

Though the signatures were mostly unique to each person, there was overlap: Brain activity in the OFC tracked with people's chronic pain levels. Some unexpected pain patterns cropped up along the way too. Two volunteers' pain fluctuated on a roughly three-day cycle, for instance.

Brain activity in the OFC could represent a biomarker of chronic pain, a signal that could help doctors track treatment responses and serve as new targets for treatment, says neuroscientist Chelsea Kaplan of the Chronic Pain and Fatigue Research Center at the University of Michigan in Ann Arbor. Study volunteers had stroke-related pain and phantom limb pain after a leg amputation. "We would need to know if these findings can generalize to other patients and pain conditions," Kaplan says.

The team's goal of identifying reliable markers of chronic pain is to guide treatment rather than to diagnose, neurologist Prasad Shirvalkar of UC San Francisco said May 18 in a news briefing. Shirvalkar and colleagues are now conducting a clinical trial that involves stimulating peoples' brains to treat chronic pain. He views biomarkers as a tool "to actually help treat a patient, to actually make them feel more seen." ■

ANIMALS

Diving sharks may hold their breath

Some hammerheads seem to close their gills to stay warm

BY FREDA KREIER

Even fish sometimes hold their breath in cold, dark, deep water.

Scalloped hammerhead sharks living near Hawaii spend their days basking in warm surface waters. At night, these fish hunt for squid and other prey hundreds of meters below the surface, where the temperature is much colder. The sharks may hold on to body heat in the frigid waters by suppressing the use of their gills while diving, essentially holding their breath for around an hour at a time, researchers report in the May 12 *Science*.

Whales and other deep-diving mammals hold their breath (*SN: 11/7/20, p. 5*). But this is the first time the behavior has been spotted in diving fish, says Mark Royer, a shark physiology and behavior researcher at the University of Hawaii at Manoa in Honolulu.

The body temperature of sharks is largely controlled by the warmth of the water around them. These fish lose and gain a lot of body heat while breathing through their gills, which snag oxygen from water passing through the organ.

"Gills are like giant radiators strapped to your head," Royer says. Because gills leak heat, many shark species tend to stick to roughly the first 100 meters of sun-heated water near the ocean surface. In the tropics, home to scalloped hammerhead sharks (*Sphyrna lewini*), temperatures near the ocean surface hover around 26° Celsius on average.

But tags attached to scalloped hammerheads revealed that the sharks take nightly, hour-long dives up to 1,000 meters below the surface. At these depths, water temperatures can get as low as 5° C, which is far too cold for a tropical shark.

To find out how the sharks endure such frigid temperatures, Royer and colleagues attached specially designed instruments

P. SHIRVALKAR

Scalloped hammerhead sharks may close their gills to stay warm on deep dives near Hawaii.

DERON VERBECK

to the backs of sharks that had gathered in a shallow bay off Oahu to mate. For the next 23 days, the sensors tracked how the sharks moved, how deep they swam and how their internal temperature changed.

"It was kind of like attaching a Fitbit to a shark," Royer says. "It allowed me to get precise details on what the shark was doing."

Sharks went on V-shaped dives, the data showed, plunging hundreds of meters before firing straight back up "like a missile," Royer says. But strangely, the body temperature of diving sharks barely budged for the bulk of the dive. It was only when the sharks slowed their ascent at a depth of around 290 meters, where the water is a little cooler than at the surface, that their body temperature dropped by an average of 2.8 degrees C.

The fish must have shut off their gills for most of the dive to hold on to heat, the team concludes. It was only when the sharks had returned to a safer depth temperature-wise that they may have reactivated their gills—taking in oxygen for the first time in around an hour and sucking in cold water in the process.

Holding on to heat while diving could help sharks move quickly in the deep ocean, says Julia Spaet, a shark ecologist at the University of Cambridge. Though it is absolutely possible that these hammerheads do this by suppressing gill activity, Spaet says, scientists will need to gather direct evidence using cameras or other means to prove that it is true.

At least one video from a deep-sea dive hints that this is the case. The gills of a scalloped hammerhead roaming at a depth of 1,000 meters near Tanzania appeared to be closed in footage captured several years ago, Royer and colleagues note.

That evidence along with the new finding makes Royer "very confident" that the sharks do in fact hold their breath. "It just goes to highlight how extraordinary this species is," he says. ■

ENVIRONMENT

A push for EVs made inequities worse

California's electric vehicle rebates left vulnerable people behind

BY CAROLYN GRAMLING

A worldwide gearshift from fossil fuel–powered cars to electric vehicles, or EVs, could significantly reduce the amount of carbon dioxide that humans emit to the atmosphere. But current strategies for vehicle electrification can also shift some pollution to communities already suffering under higher economic, health and environmental burdens, researchers warn.

California leads the United States in EV adoption and thus offers a window into this evolving problem. In an effort to reduce its carbon footprint, the state in 2010 instituted the California Clean Vehicle Rebate Project, or CVRP, a program that offers consumers money back for purchasing or leasing new EVs.

Now, an analysis of the CVRP's impact on the state's air quality from 2010 to 2021 reveals both good and bad news, researchers report May 3 in *PLOS Climate*. Though more EVs on the road reduced California's overall CO_2 footprint, the state's EV rebate program didn't make purchasing the cars more accessible for everyone. And an increase in electricity generation may even have worsened air quality for the most disadvantaged communities.

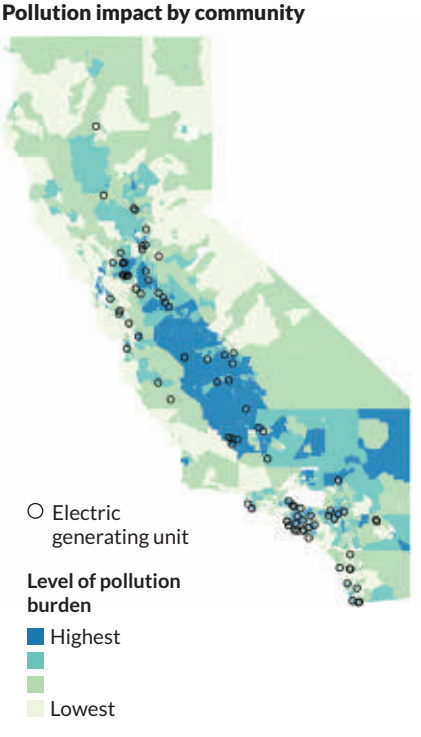
Environmental scientist Jaye Mejía-Duwan of the University of California, Berkeley and colleagues assessed the CVRP's impact on a community and statewide level. The team developed a computer model that incorporates data on where the rebates went, how much additional electricity would be required to power those EVs, which of the state's electric generating units, or EGUs, would provide that electricity and how much pollution they might produce.

The team then overlapped these data with the mapping tool CalEnviroScreen. It identifies which of the state's more than 8,000 census tracts — county subdivisions used in population assessments — are the most vulnerable to pollution. That vulnerability measure is based not only on exposure to pollutants such as power plant emissions but also on factors such as income, education level, access to health care and linguistic isolation.

The CVRP reduced the state's overall CO_2 emissions by an average of about 280,000 metric tons per year, Mejía-Duwan says. In 2020, transportation in California produced about 140 million tons of CO_2 — about 40 percent of the total 370 million tons of CO_2 emitted in the state that year. The program has also reduced the state's overall emissions of sulfur dioxide and a group of nitrogen oxides known as NOx, two other types of air pollution.

But California's most disadvantaged communities didn't see the same overall improvement in air quality, Mejía-Duwan and colleagues found. Those communities didn't have the same decreases in sulfur dioxide and NOx gases, and some even saw an increase in fine particulate matter known as $PM_{2.5}$ (SN: 8/29/20, p. 7). "These particles are small enough to penetrate deep into the lungs and cross over into the bloodstream," increasing the risk of cancer, cardiovascular problems and cognitive decline, Mejía-Duwan says.

Where the power is California's electric generating units (circles) are disproportionately located in communities that bear the highest burden from pollution (dark blue), based on exposure and socioeconomic factors.



J. MEJÍA-DUWAN, M. HINO AND K.J. MACH/*PLOS CLIMATE* 2023

That increase may be indirectly related to putting more EVs on the road. Although electric vehicles themselves don't produce $PM_{2.5}$, increased electricity generation, if from fossil fuels, can. Renewable resources supplied about half of the electricity that California generated in 2022. But natural gas–fired power plants still provide a hefty chunk of the state's power.

"Electric vehicles are often incorrectly referred to as 'zero-emissions vehicles,' but they're only as clean as the electric grid from which the energy is sourced," Mejía-Duwan says. The most disadvantaged 25 percent of the state's communities contain 50 percent of the natural gas–fired power plants, the team found.

EVs also tend to be relatively heavy due to their hefty batteries. "Heavier vehicles can produce as much if not more particulate matter" than equivalently sized conventional cars due to brake, tire or road wear, Mejía-Duwan says.

Increasing the cleanliness of the electric grid would help reduce inequities in air quality and cut down on air pollution generally, as would changes to the management of the state's generated power, the researchers say. California's solar, wind and hydroelectric energy production has grown rapidly. But the battery technology to store and use that energy later lags behind. Most renewable energy is generated during the day, so some researchers have suggested plugging in EVs while it's light out to take advantage of the daytime glut of electricity — and then using the vehicles to help power houses at night.

Even if the electric grid were cleaned up, that wouldn't address the underlying factors behind inequities in EV adoption. Since 2010, the CVRP has provided more than 400,000 rebates of up to $7,500, depending on income. Yet those rebates have disproportionately gone to the least disadvantaged communities. Several

attempts by the state to address the issue, such as by imposing an income cap on eligibility, have had little effect.

One roadblock is that prospective EV buyers must have enough money for a down payment and be able to wait several months for the rebate money. Another is that car manufacturers are trending toward producing larger, more expensive EVs. In April, Chevrolet announced that it will discontinue its most affordable EV, the Bolt, as the company pivots to producing electric SUVs and trucks.

There's also a lack of equitable access to vehicle charging infrastructure. And then there are subtler but no less insidious issues, such as "a lack of sufficient multicultural and multilingual outreach about EVs, plus the fact that people of color and minoritized communities report facing discrimination at dealerships," Mejía-Duwan says.

These findings echo and support researchers' longtime concerns about how current programs to encourage vehicle electrification will disproportionately impact different people. "It's not a surprise," says Román Partida-López, senior legal counsel for transportation equity at the Greenlining Institute, a nonprofit organization based in Oakland, Calif. "What [California] is doing is a move in the right direction, but it's not enough."

California and other states pursuing aggressive zero-emissions policies need to be more intentional about targeting their efforts toward disadvantaged communities, Partida-López says. Instead of offering rebates, a better strategy to reduce the barriers to EV adoption would be to provide other types of incentives, he says, such as vouchers that low-income households could use at the time of purchase, as well as financing programs.

Making EVs accessible to everyone will be essential to transitioning to zero emissions (SN: 1/28/23, p. 22). "We're not going to meet any of those goals unless we center equity" in program designs, Partida-López says. "The focus has always been, 'How do we transform the market?' We need to change the narrative to 'How are we going to focus on the people most impacted, to help with this transition?'" ■

ANIMALS

The human shield effect can be lethal

Apex predators push smaller ones into deadly run-ins with people

BY FREDA KREIER

Moving toward humans when large predators approach can be risky for bobcats and other midsize carnivores, radio collar data suggest.

ZACHARY WARDLE

When wild animals take refuge from predators by straying near people, the illusion of safety can be deadly.

In the wilderness, midsize predators like coyotes fear larger carnivores like wolves and cougars, which will violently attack and kill them. A new study finds that when the larger predators are around, the smaller ones will try to evade attack by moving into spaces shaped by people. But that ends up putting them at a much higher risk of getting killed — by people, scientists report in the May 19 *Science*.

The study is among the first to show that large cats and wolves shape the behavior of other predators outside of wilderness areas, says Laura Prugh, a wildlife ecologist at the University of Washington in Seattle.

When populations of large carnivores plummeted from being hunted in vast stretches of North America, predators less threatening to humans flourished. Then, as large predators were reintroduced into the wild — including wolves in Yellowstone National Park — scientists started to notice deadly (and mostly one-sided) violence erupting between old and new meat-eating residents.

Understandably, smaller predators try to stay clear of their murderous kin. Yet how this works outside of wilderness areas is unclear. Herbivores tend to hide from danger in spaces shaped by people — be it farms or suburbs. The phenomenon is called the human shield effect. Other research on midsize predators suggests that they avoid people when given the chance.

"Animals are really, really scared of humans," says Taal Levi, a wildlife ecologist at Oregon State University in Corvallis who was not involved in the work. In experiments where scientists played recordings of either growling or human voices, smaller meat eaters like coyotes were more likely to "avoid areas where you play recordings of Rush Limbaugh or people talking in general," he says.

To see how smaller predators actually behave near human territory, Prugh and colleagues put radio collars on 37 bobcats, 35 coyotes, 19 wolves and 60 cougars in two rural areas of Washington. These collars tracked the animals' locations every four to six hours for up to two years.

When large carnivores were nearby, coyotes and bobcats, the midsize predators, were twice as likely to move toward ranches, roads, fields and towns. But the animals traded one threat for another: People shot, trapped or otherwise killed 25 bobcats and coyotes during the study period. That's three times as many coyotes and bobcats as the large predators killed.

Perhaps animals aren't good at reading danger signs from people, Prugh says. A coyote is unlikely to make the connection that a person is behind a gun. But the smell and sound of wolves are hard to forget if you've been attacked.

As large carnivores such as wolves and cougars started to venture outside of wilderness areas, scientists were unsure whether the animals could fulfill their ecological role of controlling populations of smaller carnivores, Levi says. This study shows that they can — and will — indirectly shape how smaller meat eaters live and die near people. ■

PLANETARY SCIENCE

Saturn's rings may be relatively young

The halos have been gathering dust for up to 400 million years

BY NIKK OGASA

Saturn's rings might have formed while trilobites scuttled about on Earth. Space dust has been accumulating on the icy halos for no more than 400 million years, researchers report in the May 12 *Science Advances*.

The 4.5-billion-year-old planet appears to have acquired its iconic ornamentation relatively recently, says physicist Sascha Kempf of the University of Colorado Boulder. "We're quite lucky to see a ring in the first place."

Saturn's rings are made of countless icy particles that become covered with dust when tiny meteoroids strike them. These dustings darken the rings' complexion, like mud sullies snow on roads in winter.

This cosmic staining was key to the new analysis, as was the now-defunct Cassini spacecraft's Cosmic Dust Analyzer. From 2004 to 2017, the instrument measured the velocities, masses, charges and compositions of roughly dust-sized micrometeoroids moving around Saturn.

Out of millions of dust particles floating among the rings, Kempf and colleagues identified about 160 micrometeoroids that could have hailed from beyond the Saturn system. Using the estimated rate at which the incoming dust accumulates on the planet's rings, the researchers calculated how long it would have taken to darken the rings to their observed color. Saturn's hoops might have materialized up to 400 million years ago, the team found. For reference, that's more than 100 million years after mysterious, now-extinct invertebrates called trilobites appeared on Earth.

The age of the rings has been debated for decades (SN: 11/12/16, p. 10). Even after the new study, there's still disagreement.

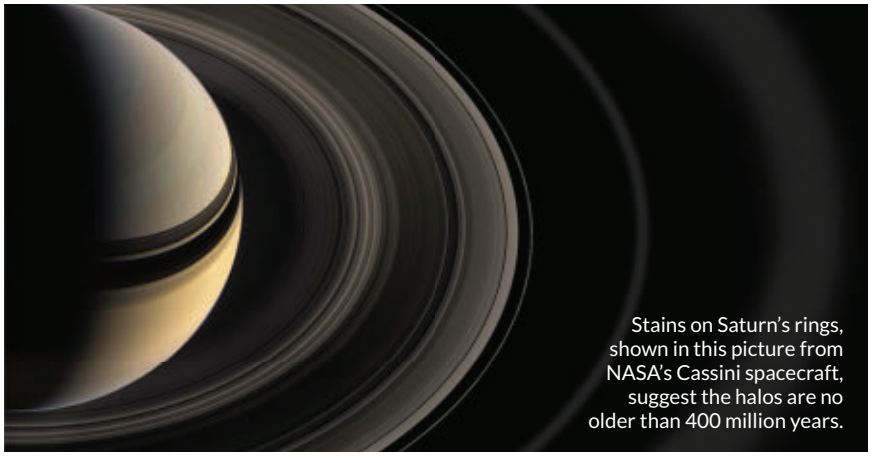
If the rings lose dust over time, they could be even more ancient than the new analysis suggests, says planetary scientist Aurélien Crida of Université Côte d'Azur in Nice, France. "Possibly as old as Saturn."

It seems clear that the rings have been exposed to micrometeoroid impacts for at least 100 million years, Crida says. But simulations of the rings' formation from the gravitational shredding of an early moon suggest their size is consistent with an age of billions of years, he says.

Researchers have previously reported silicate grains falling from the rings into Saturn's atmosphere. Some unidentified process might be cleaning the rings of the micrometeoroid dust, making them appear younger than they are, Crida says.

Alternatively, those falling dust grains might have come from meteoroid impacts that shattered ring ice, Kempf says.

Experiments that smash micrometeoroids into ice particles could help resolve the discrepancy, Crida says. For now, the debate over the age of the rings lives on. ■



Stains on Saturn's rings, shown in this picture from NASA's Cassini spacecraft, suggest the halos are no older than 400 million years.

PLANETARY SCIENCE

Jupiter's lightning is a lot like Earth's

Bolts on both planets form and travel in similar ways

BY NIKK OGASA

On Jupiter, lightning jerks and jolts a lot like it does on Earth.

Jovian lightning emits radio wave pulses that are typically separated by about one millisecond, researchers report May 23 in *Nature Communications*. The energetic prestissimo, the scientists say, is a sign that Jupiter's lightning propagates in steps, at a pace comparable to that of the bolts that cavort through Earth's thunderclouds. The similarities between the two world's electric phenomena could have implications for the search for alien life.

Arcs of lightning on both planets appear to move somewhat like a winded hiker going up a mountain, pausing after each step to catch their breath, says atmospheric physicist Ivana Kolmašová of the Czech Academy of Sciences in Prague. "One step, another step, then another step … and so on," she says.

On Earth, lightning forms as turbulent winds within thunderclouds cause ice crystals and water droplets to rub together. The particles become charged and move to opposite sides of the clouds, progressively building up charge differences across the clouds. When those differences grow big enough, air's ability to insulate charge breaks down, electrons are released and lightning takes its first step. From there, the surging electrons repeatedly ionize the air, lurching the bolt forward at an average of hundreds of thousands of meters per second.

Scientists have suggested that high-energy bolts observed in Jovian clouds might also form through collisions between ice crystals and water droplets (SN: 8/29/20, p. 20). But it was uncertain whether the alien bolts extended and branched in increments, as they do on Earth, or if they took some other form.

Kolmašová and colleagues analyzed

JPL-CALTECH/NASA, SPACE SCIENCE INSTITUTE

Lightning cavorts through Jupiter's clouds (illustrated) at a rhythm akin to bolts in Earth's skies, data from the Juno spacecraft suggest.

hundreds of thousands of radio wave snapshots of the gas giant collected by NASA's Juno spacecraft over five years (SN: 6/24/17, p. 14). Radio wave emissions from Jovian lightning appeared to pulse at a rate comparable to that of Earth's intracloud lightning — arcs of electricity that never strike ground.

If bolts extend through Jupiter's water clouds at a similar velocity as they do in Earth's clouds, then Jovian lightning might branch and extend in steps that are hundreds to thousands of meters long. That's comparable in length to the jolted strides of Earth's intracloud lightning, the researchers say.

"That's a perfectly reasonable explanation," says atmospheric physicist Richard Sonnenfeld of the New Mexico Institute of Mining and Technology in Socorro.

Alternatively, the radio wave emissions could be produced as pulses of electric current move back and forth along tendrils of lightning that have already formed rather than from the stop-and-go advancements of a new bolt, Sonnenfeld says. On Earth, such currents cause some bolts to appear to flicker.

Stop-and-go propagation appears to be a sound interpretation, says atmospheric physicist Yoav Yair of Reichman University in Herzliya, Israel. Kolmašová and colleagues "show that if you're discharging a cloud ... the physics remains basically the same [on Jupiter as on Earth], and the current will behave the same," Yair says.

If that universality holds up, it could have implications for the search for life beyond our planet (SN: 4/30/16, p. 32). Experiments have shown that lightning strikes could have forged some of the chemical ingredients needed to form the building blocks of life on Earth (SN: 4/10/21, p. 7). If lightning discharges in a similar way on alien worlds, Yair says, then it could produce similar ingredients in those places. ■

ASTRONOMY

Scientists discover a radiation belt outside the solar system

For the first time, astronomers have spotted a band of radiation surrounding a planet-sized object outside our solar system.

A belt of energetic electrons encircles a body roughly the size of Jupiter (illustrated, right) that's about 18 light-years from Earth, astronomers report May 15 in *Nature*. As the electrons move, they radiate radio waves. Such radiation belts give insight into the shape of a cosmic object's magnetic field, its interior structure and maybe even whether it has moons.

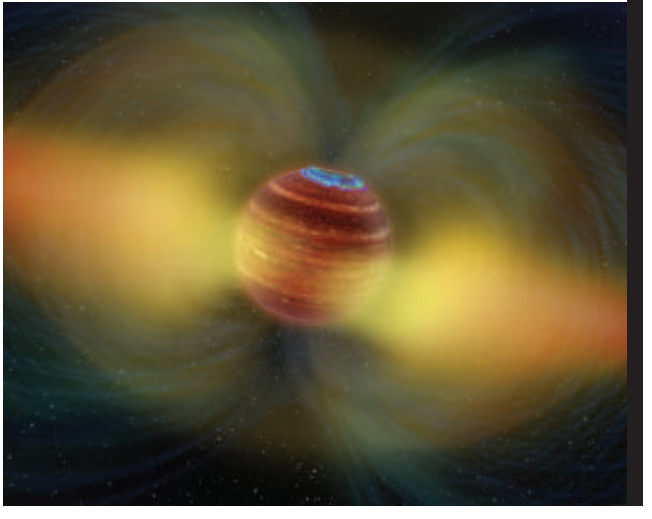
In our solar system, every planet with a worldwide magnetic field has radiation belts. Earth has the Van Allen belts, rings of charged particles captured from the sun. Jupiter's radiation belts get most of their particles from the volcanic moon Io. In these cases, the planet's magnetic field traps electrons in a bubble around the planet, like fireflies in a jar.

To find similar belts outside our solar system, astronomer Melodie Kao and colleagues observed a Jupiter-sized object called LSR J1835+3259 with a network of 39 radio dishes that are located around the world. Together, the dishes effectively created a radio telescope about as wide as Earth, which let the researchers zero in on the object's environment.

The team spotted a belt that looks a lot like Jupiter's but 10 million times as bright, says Kao, of the University of California, Santa Cruz. Nearly 80 times as massive as Jupiter, the object is either a diminutive star or a large brown dwarf, a dim starlike body not hefty enough to sustain hydrogen fusion.

One big mystery is where the energetic electrons come from. The object doesn't orbit a star and it doesn't seem to emit flares. A volcanic satellite would fit the bill, Kao says, but that's speculative. Still, the finding could help researchers interpret data from exoplanets in the future, even if astronomers can't see exoplanet belts directly.

"Exoplanet magnetism is truly at its infancy," Kao says. "Until we can characterize exoplanet magnetic fields, we'll miss entire segments of their life stories." — *Lisa Grossman*



FROM TOP: GERALD EICHSTÄDT, MSSS, SWRI, JPL-CALTECH/NASA; CHUCK CARTER, M. KAO, HEISING-SIMONS FOUNDATION

In an array of qubits, illustrated as a grid at various points in time, quasiparticles called non-abelian anyons kept a record of being moved around one another (green and red trails).

PHYSICS

Quantum 'particles' store memories

A new type of anyon may be useful for protecting information

BY EMILY CONOVER

Anyons, anyone?

Scientists have created strange new particle-like objects called non-abelian anyons. These long-sought quasiparticles can be braided, meaning that they can be moved around one another and retain a memory of that swapping, similar to how a braided ponytail keeps a record of the order in which strands cross over each other.

Two independent teams — one led by researchers at Google, the other by researchers at the international quantum computing company Quantinuum — have reported creating and braiding versions of these anyons using quantum computers. The Google and Quantinuum results, reported May 11 in *Nature* and May 9 at arXiv.org, could help scientists construct quantum computers that are resistant to the errors that currently bedevil the machines.

Non-abelian anyons defy common intuition about what happens to objects that swap locations. Picture the street game with cups and a ball, where a performer swaps identical cups back and forth. If you weren't watching closely, you'd never know if two cups had been moved around one another and back to their original positions. In the quantum world, that's not always the case.

"It's predicted that there is this crazy particle where, if you swap them around each other while you have your eyes closed, you can actually tell after the fact," says physicist Trond Andersen of Google Quantum AI in Santa Barbara, Calif. "This goes against our common sense, and it seems crazy."

Particles in our regular 3-D world can't do this magic trick. But when particles are confined to just two dimensions, the rules change. While scientists don't have a 2-D universe in which to explore particles, they can manipulate materials or quantum computers to act like they contain particles that live in two dimensions, creating objects known as quasiparticles.

All fundamental subatomic particles fall into two classes, based on the math of how identical particles of each type behave when swapped. They are either fermions, a class that includes electrons and other particles that make up matter, or bosons, which include particles of light known as photons.

But in two dimensions, there's another option: anyons. For bosons or fermions, moving identical particles around one another can't have a directly measurable effect. For anyons, it can.

In the 1990s, scientists realized that a specific version of an anyon, called a non-abelian anyon, could be used to build quantum computers that might safeguard fragile quantum information, which is easily knocked out of whack by minute disturbances.

"For fundamental reasons these anyons have been very exciting, and for practical reasons people hope they might be useful," says theoretical physicist Maissam Barkeshli of the University of Maryland in College Park, who was not involved in either study.

Google's team created the anyons using a superconducting quantum computer, where the quantum bits, or qubits, are made of material that conducts electricity without resistance. Quantinuum's study, which has yet to be peer-reviewed, is based on a quantum computer whose qubits are composed of trapped, electrically charged atoms of ytterbium and barium.

In both cases, scientists manipulated the qubits to create the anyons and move them around, demonstrating a measurable change after the anyons were braided.

Scientists have previously created and braided a less exotic type of anyon, called an abelian anyon, within a 2-D layer of a solid material (SN: 8/15/20, *p.* 12). And many physicists are similarly questing after a solid material that might host the non-abelian type.

The new studies create non-abelian states within qubits inside a quantum computer, which is fundamentally different, Barkeshli says. "You're kind of synthetically creating the state for a fleeting moment." That means it doesn't have all the properties that anyons within a solid material would have, he says.

In both cases, much more work must be done before the anyons could create powerful, error-resistant quantum computers. Google's study, in particular, produces an anyon that's akin to a fish out of water. It's a non-abelian within a more commonplace abelian framework. That means those anyons may not be as powerful for quantum computing, Barkeshli says.

It's not all about practical usefulness. Demonstrating that non-abelian anyons really exist is fundamentally important, says Quantinuum's Henrik Dreyer, a physicist in Munich. The finding "confirms that the rules of quantum mechanics apply in the way that we thought they would apply." ■

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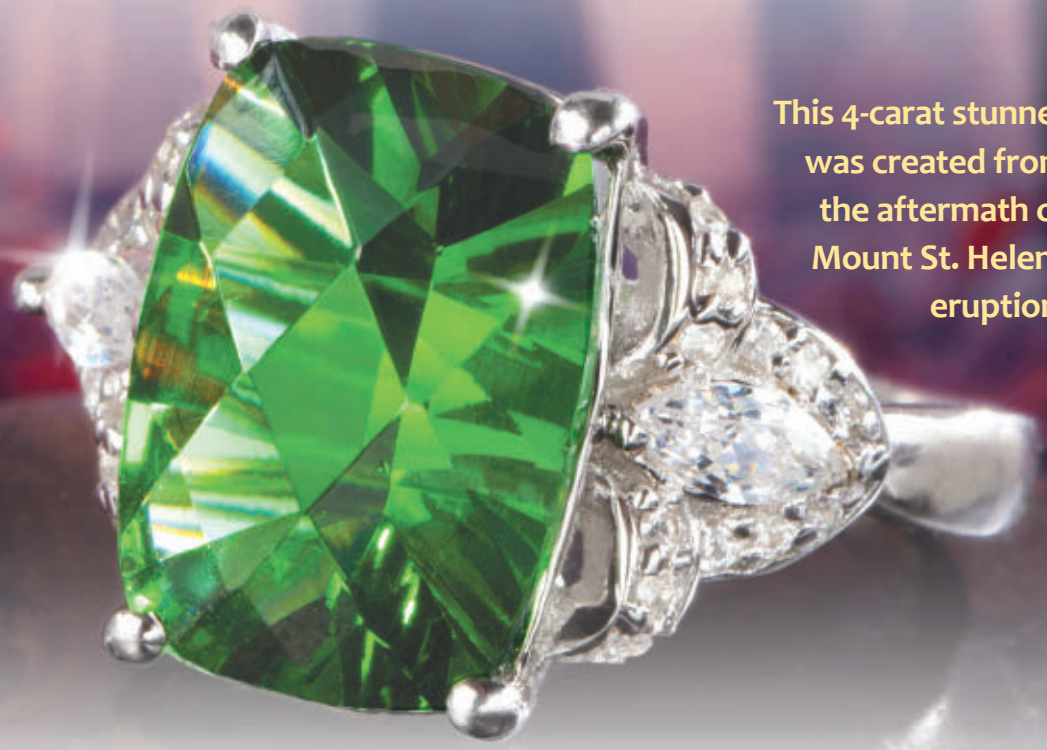

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The Amazon's Cloudy Future

Scientists race to foretell the fate of the vast forest facing deforestation and climate change **By Nikk Ogasa**

In northern Mato Grosso in Brazil, large parts of the Amazon are being cut down to make way for agriculture.

The shore of a sea of nearly 400 billion trees winds through the central Brazilian state of Mato Grosso. Here, the Amazon rainforest rubs up against the Cerrado, the world's largest savanna.

The two are distinct worlds—one a wet and verdant jungle, the other relatively dry and blanketed in wild grasses, shrubs and small trees. But no clear line demarcates the Amazon and the Cerrado. Instead, there's a messy transition zone, a continuum of vegetation that grows taller toward the rainforest. Over thousands of years, the boundary ebbs and flows, driven by natural fluctuations in climate.

"But in this formula is a new element," says ecologist Beatriz Marimon of Mato Grosso State University in Nova Xavantina. Humans, with their ambitions to domesticate the land, she says.

About half a century ago, throngs of people started streaming into the region along new highways, clearing forest for farmland and cattle ranches, she says. Fifty years is a blink in the life span of a forest nearly as old as the dinosaurs, but it's plenty of time for humans to remodel a landscape.

In 2007, earth system scientist Carlos Nobre, now at the University of São Paulo, and his colleagues suggested that much of the Amazon could transform into a savanna if deforestation exceeded 40 percent of the forest's original area, which was mostly whole before the 1970s. About a decade later, after accounting for interactions between climate change, deforestation and fire, Nobre and a colleague offered a more dire warning. If just 20 to 25 percent of the Amazon was deforested and global warming reached about 2.4 degrees Celsius above preindustrial levels, the ecosystem could collapse and much of the forest could transform into savanna and shrubland, they found. Today, humans have already deforested about 17 percent of the overall Amazon, and damaged much more, estimates suggest.

It's not yet clear how much time may remain to save the forest, or if it's already at the brink of some irreversible shift.

That the Amazon may transform into something else after reaching a point at which it cannot cope with exacerbating conditions—a "tipping point"—has raised alarms. Such a shift would imperil the forest's storied biodiversity and the livelihoods of millions of people. It would also release immense volumes of carbon dioxide and alter the global circulation of heat, vastly complicating efforts to slow climate change.

The Amazon is in grave trouble, scientists agree. Human activities and climate change are exacerbating the dry season; in some areas, it lasts four to five weeks longer than decades ago. Fires have also become more fierce. All of that is stressing the forest out.

But much like the physical transition separating the Amazon from the Cerrado, the forest's limit is probably not defined by a single, clear tipping point, many scientists now say. The Amazon is no monolith. Different parts may react to threats in different ways, Marimon says.

A multitude of poorly understood factors affect the forest's fate: The myriad forms of human actions. Climate change. The diverse capabilities and adaptations of plants. The ambit of underground water.

Ongoing research is clarifying if, when and where conditions may push the forest beyond its limits, and could help inform efforts to save the forest from potential widespread dieback. These are urgent tasks, as it's not yet clear how much time may remain to save the forest, or if it's already at the brink of some irreversible shift, says Matt Finer, director of the Monitoring of the Andean Amazon Project, or MAAP, based in Washington, D.C. In either case, he says, "we're kind of probably the last ones with the option to ponder that."

Felling the Amazon

Ecologically speaking, the Amazon is without equal. It accounts for more than half of Earth's remaining tropical forests, through which roughly 17 percent of the world's river water flows. It also houses about 1 in 4 of the world's land-dwelling species. That unfathomable bonanza includes its flowers: More types of flowers bloom in the Amazon than there are stars visible to the naked eye in the night sky. What's more, each year the rainforest absorbs about 5 percent of the world's annual CO_2 emissions from fossil fuel burning and land use changes, with its carbon reserves weighing as much as 230 million blue whales (*SN: 12/18/21 & 1/1/22, p. 6*).

Much of this vitality is sustained by the trade winds, which blow east to west across the forest from the Atlantic Ocean. The winds carry sea-born moisture into the eastern parts of the forest, where it precipitates. Once fallen, some of this water evaporates back into the air. Much of it soaks into the soil. It's absorbed by roots, courses up through plant stems and tree trunks, and is then transpired through leaves back to the sky (*SN: 4/23/22, p. 9*). A single tree in the Amazon can pump 500 liters of water into the atmosphere each day.

Winds whisk the moisture hundreds of kilometers deeper into the forest, where it rains on more trees. A single molecule of water may repeat this cycle more than five times before exiting the forest basin. The Amazon waters itself.

But this arrangement has vulnerabilities. If enough of the forest's eastern expanses are cut down, moisture may run off and out of the basin rather than sail into deeper sections of the forest that need it, Finer says. "That deforestation cuts off the whole system."

Already, about 30 percent of the Amazon's eastern third has been cleared, Finer and colleagues reported in a 2022 MAAP report. Deforestation averaged across the whole forest may not yet have crossed that 20 to 25 percent threshold, but "in that eastern third, it's way worse," Finer says. If that destructive trend continues in the east, it could decapitate the Amazon's skyborne streams of moisture, he says. Finer doesn't think the forest has yet crossed a tipping point, but, like other scientists, stresses it could be hard to know for years.

Even if this rain recycling goes bust, the forest's western

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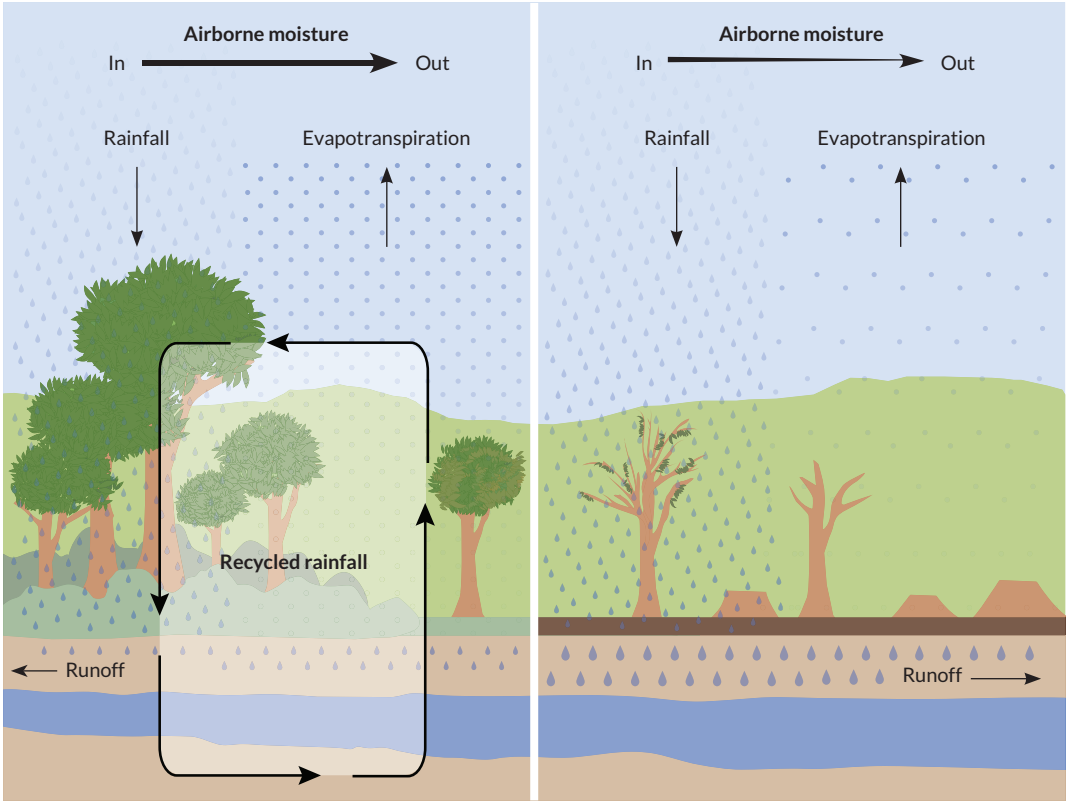


The rainforest as rainmaker
Winds carry moisture into the eastern Amazon, where it falls as rain. Much of it soaks into the soil, where some water is taken up by roots and ultimately transpired through leaves back into the air. Winds then carry this moisture deeper into the forest, where the cycle repeats (left). But cutting down trees reduces the water taken up by roots and evapotranspiration (right). That breaks the cycle, increasing local runoff and reducing rainfall in the interior.
SOURCE: L.E.O.C. ARAGÃO/ *NATURE* 2012

region — about a third of its expanse — could still hold out. This area is backed by the towering Andes, which wring westbound winds of water and ensure that heavy rain falls upon nearby forests. The area's lush vegetation shouldn't suffer too terribly from distant deforestation, Nobre says.

Deforestation doesn't just harm the tracts where trees are felled. The warming and drying that follow in deforestation's wake may spill over into the edges of intact forests nearby, affecting which plant and animal species persist there. That's one of the many ways forests become degraded, a condition that's often less obvious than outright clear-cutting.

Nonetheless, it's pervasive. About 38 percent of the remaining Amazon rainforest has been degraded, researchers reported in January in *Science*. That's an area equivalent to nearly a third of Brazil, or more than three times the size of Texas.

Degradation can take many forms, with repercussions that vary depending on the damage's nature, intensity and scope. Fires can raze parts of the rainforest. If the burned land is left alone, Amazon plants typically return on their own, bursting forth from seeds and roots in the soil. But severe fires can destroy these buried remnants too, denying some species the chance to return. As such, the forests that grow back often lack the diversity of their predecessors. Where humans have repeatedly burned the land in the past, the forest may recover more slowly and be dominated by just a few fire-resistant species even after two decades.

Meanwhile, selective logging can open a forest's closed canopy, ushering in sunlight to heat and dry the understory, killing some plants, exacerbating fires and pushing out animals.

Where degradation reduces vegetation, it shrivels transpiration. For each leaf lost, the forest's moisture loses one little gate back into the sky. During a typical dry season, severely degraded forests may release 34 percent less water back to the sky. That loss directly sabotages the forest's rain recycling, imperiling trees that depend upon it.

Because degradation can unfold in so many ways, computer simulations that project changes in the Amazon's vegetation cannot say exactly how it may contribute to a tipping point.

"It's logical to think that such degradation helps push the system towards the tipping point, if it really exists," says earth system scientist David Lapola of the University of Campinas in Brazil. But "we can't today say this percentage of degradation will make the system tip to another stable state."

A drier future

The Amazon isn't just dealing with deforestation and degradation, of course. Over the last 50 years, the average annual temperature across the forest has climbed at least 0.6 degrees C. And exceptionally severe droughts have struck the forest three times in the last two decades. Some climate models suggest that by 2060, such extreme drought conditions could occur as often as 9 in every 10 years.

Recent climate simulations suggest that if such drought years became the new "climate normal," patches of the rainforest may transition to a different state — whether that be savanna or a more open or dry forest — at different times, not all at once.

T. TIBBITTS

Some of these localized shifts could trigger a domino effect, causing nearby areas to also shift, researchers reported last year in the *Proceedings of the National Academy of Sciences*. The Amazon's southeastern forest appears to be highly vulnerable to local diebacks, while areas downwind to the west seem to be liable to the domino effect.

Projections from the Coupled Model Intercomparison Project, which coordinates and standardizes climate projections, also point to localized Amazon diebacks. For a 2022 study, researchers examined projections from the sixth phase of the project, or CMIP6, analyzing models that simulate the response of vegetation to climate change. Five of the seven analyzed CMIP6 models indicate that the risk of sudden, local diebacks will climb as the world reaches and surpasses 1.5 degrees C of global warming above preindustrial levels.

But no two projections completely agree. Even when the same amount of climate change is assumed, CMIP6 models produce different pathways, with diebacks occurring at different points. One model predicts diebacks could begin around 1.3 degrees C of warming, another at about 1.7 degrees C.

The lack of agreement comes in part because these models — and others used to predict the Amazon's fate — make different assumptions about the complex nature of the world's greatest rainforest.

Taking a closer look at that complexity may reveal ways in which the forest is more — or less — resilient than we think.

Hidden nuance in the trees

Often, talk of "the Amazon" evokes visions of dense, dripping vines and trees. But the forest is actually a messy medley of ecosystems. There are the vivacious várzeas — floodplains occupied by dense forests, grasslands and swamps that, for months of the year, become inundated under nutrient-rich water, which sustain an abundance of fauna and flora.

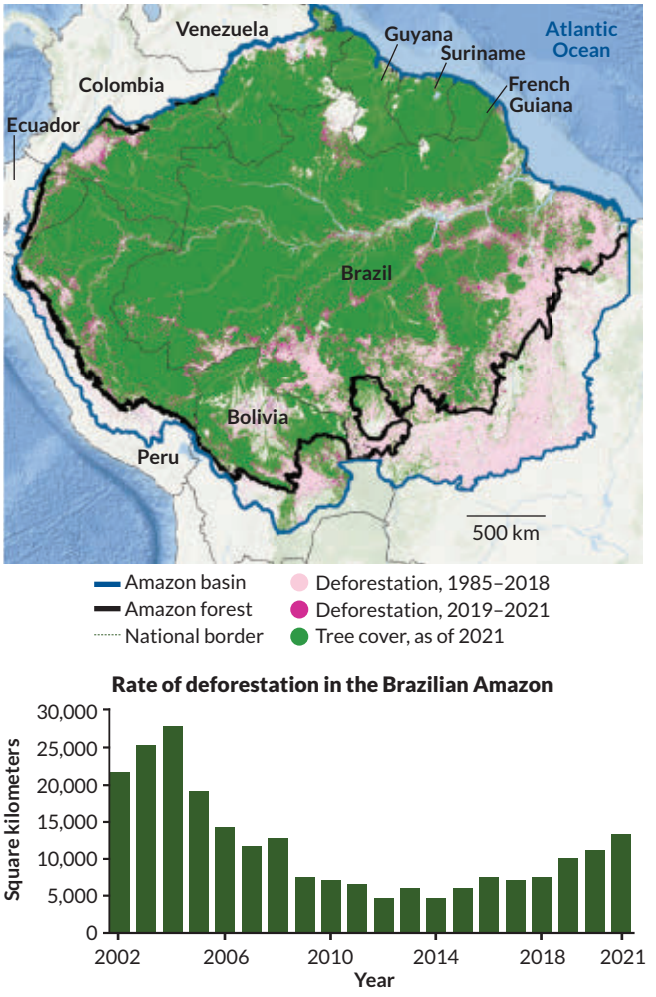
The várzea's uliginous counterpart, the igapós, consist of swamp forests that also flood seasonally, though with nutrient-poor waters as dark as maté, steeped in tannins leached from decaying plants. Igapó trees grow slowly, but they grow dense and excel at sequestering carbon.

Then there are the diverse terra firme, the tall, thick, closed canopy jungles that cover the uplands, above the flood line. Even naturally occurring white-sand savannas can be found within the Amazon's borders. As for trees, roughly 230 species are thought to dominate the forest while around 16,000 species have been cataloged in the basin.

Nonetheless, research projects often simulate the Amazon's vegetation as relatively homogenous, says earth system scientist Marina Hirota of the Federal University of Santa Catarina in Florianópolis, Brazil. They cast every tree as a broadleaf evergreen tree, the forest as a monoculture. These simplified simulations, called "big leaf" models, prevail because researchers lack data, Hirota says, but the models don't do the forest justice.

Over millions of years, the forest's myriad plant communities have evolved differently to cope with local rainfall patterns.

Where the Amazon is being lost



Rate of deforestation in the Brazilian Amazon

Toppling trees About 17 percent of the Amazon has been cleared from historic levels, including through burning to make way for agriculture. Much of that deforestation has taken place in the Brazilian part of the forest (as shown in the map at top). The rate of deforestation there reached a 21st century high point in 2004 (as seen in the chart) before dropping, though it has risen again in recent years.

Research suggests that projections may not fully capture how the lush diversity of plant traits affects the Amazon's ability to endure and adapt to stress like climate change–induced droughts.

Take for instance, embolism resistance. When soils dry, plants may inadvertently suck bubbles of air into their vascular systems, causing a sometimes-lethal blockage called an embolism. Tree species inhabiting the more drought-prone central eastern Amazon tend to grow slower but be more resistant to embolism and vascular collapse than species in the forest's west. Hirota, Marimon and their colleagues reported this finding in April in *Nature* after studying 129 tree species from 11 plots across the Amazon. The work suggests rainfall patterns have shaped plant communities' capacities to cope with drought.

Then, there's what lies underground — the groundwater — which is poorly captured by many simulations. Most investigations into the forest's response to drought have focused on upland areas

BOTH: J.S. ALBERT *ET AL*/*SCIENCE* 2023

overlying deep water tables, which roots struggle to access. But about half of the Amazon may stand atop a relatively shallow water table. That accessible groundwater could sustain plants through droughts in ways that models don't account for, says ecologist Flávia Costa of Brazil's National Institute of Amazonian Research in Manaus.

Such areas could serve as drought refugia, Costa says: "Places that do not suffer." But if drought gets too severe and groundwater recedes beyond the reach of roots, refuges could become ruinous. "Those places may be the ones that suffer the most because the plants are not adapted" to dry conditions, she says.

Hirota, Marimon and others are still studying how Amazonian plants are coping with drought to amass more information about what Hirota calls plants' "life strategies." The goal is to use the data to improve existing vegetation models and simulate more accurately the diverse responses to climate change and land use changes.

This research, and other investigations into the many capabilities and adaptations of the Amazon's plants, will be necessary to better inform projections of the Amazon's fate, Hirota says. The same, Costa says, goes for the influence of groundwater.

A third source of uncertainty in figuring out the Amazon's fate wafts invisibly through the air. Researchers had previously suggested that an atmosphere richer in CO_2 might boost the forest's growth, potentially offsetting some of the tolls of climate change. Some experts had even proposed that this "atmospheric CO_2 fertilization" could preclude a massive forest dieback.

But CO_2 and sunlight aren't all that's needed for growth. Plants also consume nutrients from soils, and Amazonian soils are notoriously lacking, especially in phosphorus (SN: 1/28/23, p. 10; SN: 4/10/21, p. 7). Using computer simulations for a 2019 study, Lapola and colleagues found that a dearth of phosphorus would probably reduce the projected growth gains associated with more abundant CO_2 by about 50 percent over 15 years. The team's conclusion: Previous projections may have overestimated the benefits of extra carbon dioxide.

No large-scale experiments have yet tested the effects of CO_2 fertilization on the Amazon. But Lapola and colleagues have almost finished constructing steel towers that will spray carbon dioxide over mature groves in the Amazon, to see how the trees respond. It may still take years to acquire meaningful results.

What comes next?

At this point, scientists don't have enough information to say when, or if, the Amazon will cross some threshold beyond which it becomes unrecognizable, Lapola says. Today's computer models are trying to open doors into the future, to peer beyond thresholds and see what's ahead for the Amazon. But with the data available today, "we're looking into a room from the hole of the lock."

That a web of local diebacks could unravel across the forest is worrisome, but that fragmented fate may carry more hope than a single catastrophic switch, Hirota says. For one, it could help dissuade people from writing the forest off as a lost cause after crossing some predicted limit.

The Amazon basin is home to a variety of ecosystems, including várzeas (top left), white-sand savannas (top right), terra firme (bottom left) and igapós (bottom right).

CLOCKWISE FROM TOP LEFT: RAMESH THADANI/MOMENT/GETTY IMAGES PLUS; BERNARDO M. FLORES; ANDIA/UNIVERSAL IMAGES GROUP/GETTY IMAGES; NATURE'S IMAGES/SCIENCE SOURCE

Some scientists have proposed that if climate change and human destruction are left unchecked, large parts of the Amazon could transform into a landscape resembling the Cerrado (shown).

BEN HUR MARIMON JR.

Resignation is a serious concern, Nobre says. "If we take for granted that the tipping point has already been exceeded, then people say forget it."

Nobre aims to restore some of the forest's most deforested areas, to tilt the Amazon away from that momentous tip, or to at least rein in the lengthening of the dry season. He and others have called for extensive reforesting along what they call arcs of restoration. "One arc over the southern Amazon, another one along the Andes," he says. Such work hasn't yet begun.

Even if it does, restoration alone cannot succeed if deforestation and degradation continue. It takes far less time to timber a tree than to grow one.

Not all human activity has harmed the forest. People from Indigenous groups have acted as stewards of the forest's biodiversity for millennia. Plants that they domesticated long ago, such as Brazil nut trees and umari trees, are still abundant in some areas near ancient settlements. Today, Indigenous territories as well as protected areas make up more than half of the forest in the Brazilian Amazon. Since 2000, only 5 percent of forest loss has occurred on these grounds. Working with the people living in these areas to stave off further deforestation and degradation will be key, researchers say.

But the forest's fate will depend on more than restoration and conservation efforts in South America. Greenhouse gases emitted by nations around the world are driving many of the challenges the Amazon faces.

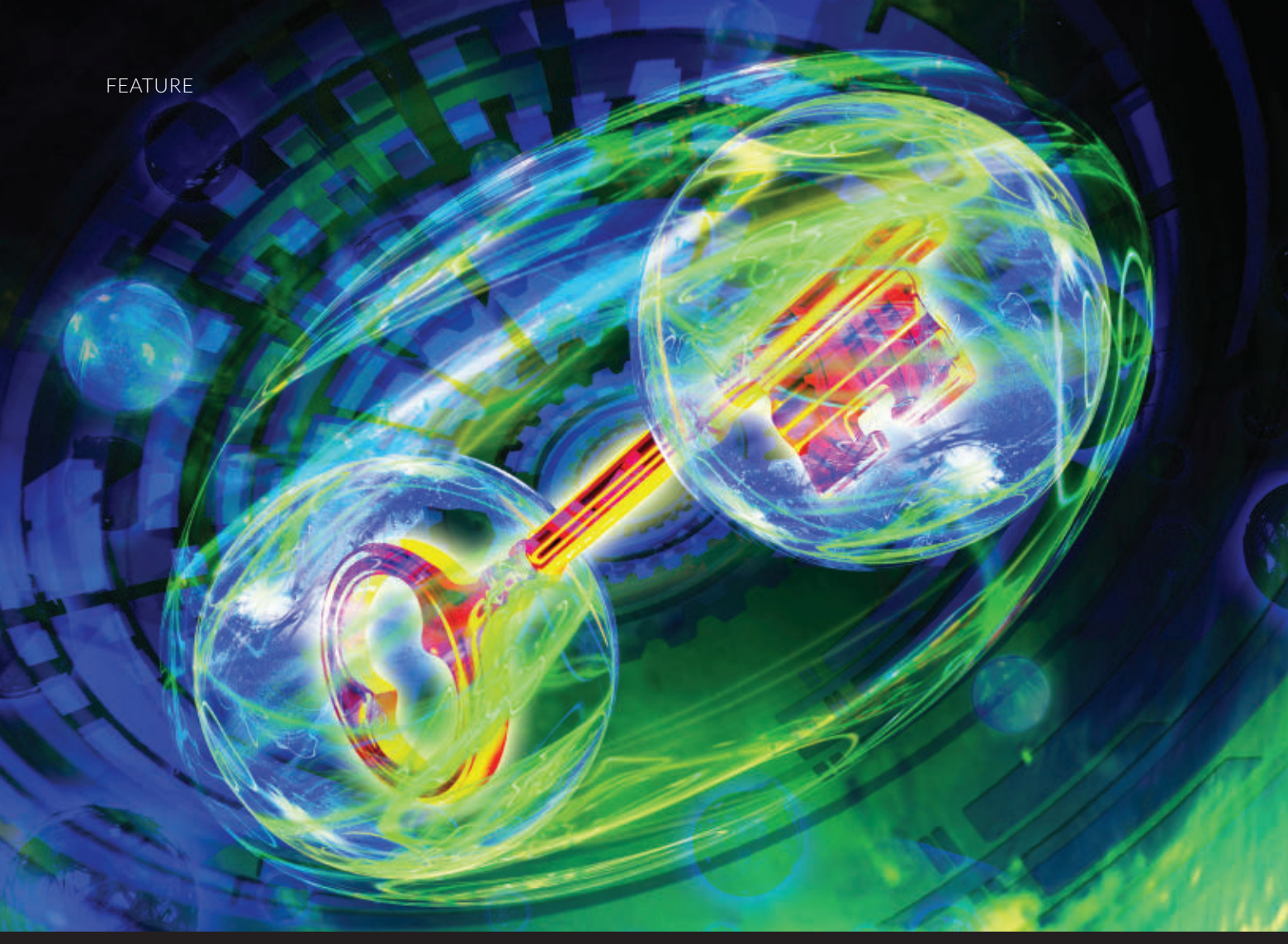
And Marimon implores people to stop buying Amazonian beef and other products that fuel the engine of deforestation. Around 75 percent of the land deforested in the Amazon is used as pastures for grazing cattle, and Brazil is now the world's largest exporter of beef.

Taking real steps to change behavior is in the best interest of all who call this planet home. Beyond the Amazon's irreplaceable biodiversity, beyond its colossal carbon stores, there are wind and ocean currents that connect the forest to regions across the globe (SN: 3/11/23, p. 9). Amazonian temperature anomalies have been linked to anomalies in the Tibetan Plateau, where glaciers that supply around 2 billion people with drinking water are shrinking, and to the West Antarctic Ice Sheet.

Back in Mato Grosso, Marimon suspects that the changes she's witnessed there could eventually unfold across much of the Amazon. Year after year, more trees disappear and the air is getting hotter. Insects that once buzzed about in throngs have vanished. And in some places, the piercing shrieks of the capitão da mata—an iconic, vociferous bird—have vanished. Shrieks that warned to all who heard them: Danger is afoot. ■

Explore more

- David M. Lapola *et al.* "The drivers and impacts of Amazon forest degradation." *Science.* January 27, 2023.
- James S. Albert *et al.* "Human impacts outpace natural processes in the Amazon." *Science.* January 27, 2023.



Saving the internet

Quantum computers will threaten today's encryption schemes. Here's what's being done.

By Emily Conover

Keeping secrets is hard. Kids know it. Celebrities know it. National security experts know it, too.

And it's about to get even harder.

There's always someone who wants to get at the juicy details we'd rather keep hidden. Yet at every moment, untold volumes of private information are zipping along internet cables and optical fibers. That information's privacy relies on encryption, a way to mathematically scramble data to prevent any snoops from deciphering it — even with the help of powerful computers.

But the mathematical basis of these techniques is under threat from a foe that has, until recently, seemed hypothetical: quantum computers.

In the 1990s, scientists realized that these computers could exploit the weird physics of the minuscule realm of atoms and electrons to perform certain types of calculations out of reach for standard computers. That means that once the quantum machines are powerful enough, they could crack the mathematical padlocks on encrypted data, laying bare the world's secrets.

Today's quantum computers are far too puny to defeat current security measures. But with more powerful quantum machines being regularly rolled out by the likes of IBM and Google, scientists, governments and others are beginning to take action. Experts are spreading the word that it's time to prepare for a milestone some are calling Y2Q. That's the year that quantum computers will gain the ability to crack the encoding schemes that keep electronic communications secure.

HARALD RITSCH/SCIENCE SOURCE

"If that encryption is ever broken," says mathematician Michele Mosca, "it would be a systemic catastrophe."

Encryption is everywhere

Encryption pervades digital life — safeguarding emails, financial and medical data, online shopping transactions and more. Encryption is also woven into a plethora of physical devices that transmit information, from cars to robot vacuums to baby monitors. Encryption even secures infrastructure such as power grids. The tools Y2Q threatens are everywhere. "The stakes are just astronomically high," says Mosca, of the University of Waterloo in Canada, who is also CEO of the cybersecurity company evolutionQ.

The name Y2Q alludes to the infamous Y2K bug, which threatened to create computer havoc in the year 2000 because software typically used only two digits to mark the year (SN: 1/2/99, p. 4). Y2Q is a similarly systemic issue, but in many ways, it's not a fair comparison. The fix for Y2Q is much more complex than changing how dates are represented, and computers are now even more inextricably entwined into society than two decades ago. Plus, no one knows when Y2Q will arrive.

Confronted with the Y2Q threat, cryptography — the study and the practice of techniques used to encode information — is facing an overhaul. Scientists and mathematicians are now working urgently to prepare for that unknown date by devising new ways of encrypting data that won't be susceptible to quantum decoding. An effort headed by the U.S. National Institute of Standards and Technology, or NIST, aims to release new standards for such post-quantum cryptography algorithms next year.

Meanwhile, a longer-term effort takes a can't-beat-'em-join-'em approach: using quantum technology to build a more secure, quantum internet. Scientists around the world are building networks that shuttle quantum information back and forth between cities, chasing the dream of communication that theoretically could be immune to hacking.

Keeping secrets

If you want to share a secret message with someone, you can encrypt it, garbling the information in such a way that it's possible to decode it later.

Schoolkids might do this with a simple cipher: For example, replace the letter A with the number 1, B with 2 and so on. Anyone who knows this secret key used to encrypt the message can later decode the message and read it — whether it's the intended recipient or another sneaky classmate.

It's a simplified example of what's called symmetric-key cryptography: The same key is used to encode and decode a message. In a more serious communication, the key would be much more complex — essentially impossible for anyone to guess. But in both cases, the same secret key is used to encode and decode.

This strategy was used in cryptography for millennia, says computer scientist Peter Schwabe of the Max Planck Institute for Security and Privacy in Bochum, Germany. "It was either used in a military context or it was used between lovers that were not supposed to love each other."

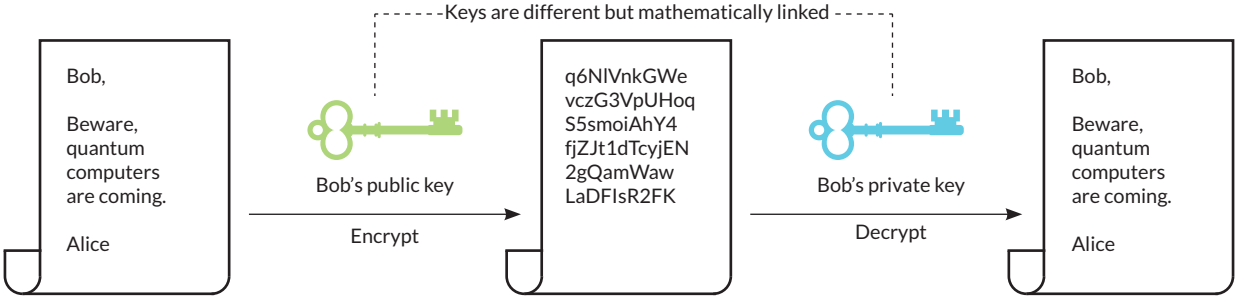
But in the globally connected modern world, symmetric-key cryptography has a problem. How do you get the secret key to someone on the other side of the planet, someone you've never met, without anyone else getting their hands on it?

To solve this quandary, in the 1970s cryptographers devised public-key cryptography, which uses special mathematical tricks to solve the symmetric-key conundrum. It uses two different, mathematically related keys. A public key is used to encrypt messages, and a mathematically related private key decodes them. Say Alice wants to send a message to Bob. She looks up his public key and uses it to scramble her communication. Only Bob, with his private key, can decode it. To any snoops that intercept the message, it's meaningless.

Public-key techniques are also used to create digital signatures. These signatures verify that someone online really is who they say they are, so you know you're really downloading that new app from Apple, not some nefarious impersonator. Only the owner of a private key can sign the message, but anyone can use the public key to verify its authenticity.

The public-key cryptography that permeates the internet is directly vulnerable to full-scale quantum computers. What's more, symmetric-key cryptography often relies on public-key cryptography to share the secret key needed to communicate. That puts the majority of internet security under threat.

Swapping secrets with strangers Public-key cryptography allows people in far-flung places who have never met to share secret information. A publicly available key is used to encode the message being sent, and a different but mathematically related private key — known only to the intended recipient — is used to decode the message. SOURCE: D. MOODY



C. CHANG

Trapdoor trouble

If public-key encryption keeps your data hidden away under the floorboards, then to read that information, you need to build a way in. You have to be able to access the data with your private key. "There's got to be a secret door somewhere in there, where if I knock the right way, it opens up," Mosca says.

Constructing such a trapdoor demands special mathematical tactics, based on operations that are easy to perform in one direction but hard in the opposite direction. Multiplying two prime numbers together is quick work for a computer, even if the numbers are very large. But it's much more time-consuming for a computer to calculate the primes from their product. For large enough numbers, it's impossible to do in a practical amount of time with a standard computer.

The challenge of finding the prime factors of a large number is behind one of the main types of public-key encryption used today, known as RSA. A hacker using a classical computer wouldn't be able to deduce the private key from the public key. Another math problem, known as the discrete logarithm problem, is a similar one-way street.

These two mathematical problems underlie nearly all of the public-key cryptography in use today. But a sufficiently powerful quantum computer would blow their trapdoors wide open. "All of those public-key algorithms are vulnerable to an attack that can only be carried out by a quantum computer," says mathematician Angela Robinson of NIST, in Gaithersburg, Md. "Our whole digital world is relying on quantum-vulnerable algorithms."

This vulnerability came to light in 1994, when mathematician Peter Shor, now at MIT, came up with an algorithm that would allow quantum computers to solve both of these math problems. In quantum machines, the bits, called qubits, can take on values of 0 and 1 simultaneously, a state known as a superposition. And qubits can be linked with one another through the quantum connection called entanglement, enabling new tactics like Shor's (SN: 7/8/17 & 7/22/17, p. 34).

"Back then, that was an interesting theoretical paper. Quantum computers were a distant dream," says mathematician Dustin Moody of NIST, "but it wasn't a practical threat." Since then, there's been a quantum computing boom (SN: 7/8/17 & 7/22/17, p. 28).

The machines are being built using qubits made from various materials—from individual atoms to flecks of silicon to superconductors (which conduct electricity without resistance)—but all calculate according to quantum rules. IBM's superconducting quantum computer Osprey, for example, has 433 qubits. That's up from the five qubits of the computer IBM unveiled in 2016. The company plans to roll out one with more than a thousand qubits this year.

That's still far from the Y2Q threshold: To break RSA encryption, a quantum computer would need 20 million qubits, researchers reported in 2021 in *Quantum*.

Mosca estimates that in the next 15 years, there's about a 50 percent chance of a quantum computer powerful enough to break standard public-key encryption. That may seem like a long time, but experts estimate that previous major cryptography overhauls have taken around 15 years. "This is not a Tuesday patch," Mosca says.

The threat is even more pressing because the data we send today could be vulnerable to quantum computers that don't exist yet. Hackers could harvest encrypted information now, and later decode it once a powerful quantum computer becomes available, Mosca says. "It's just bad news if we don't get ahead of this."

Shoring up security

Getting ahead of the problem is the aim of Moody, Robinson and others who are part of NIST's effort to select and standardize post-quantum encryption and digital signatures. Such techniques would have to thwart hackers using quantum machines, while still protecting from classical hacks.

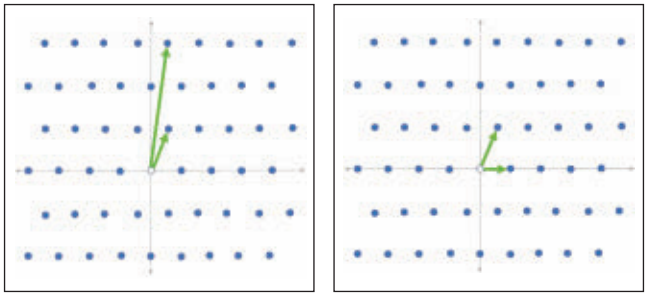
After NIST put out a call for post-quantum algorithms in 2016, the team received dozens of proposed schemes. The researchers sorted through the candidates, weighing considerations including the level of security provided and the computational resources needed for each. Finally, in July 2022, NIST announced four schemes that had risen to the top. Once the final standards for those algorithms are ready in 2024, organizations can begin making the post-quantum leap. Meanwhile, NIST continues to consider additional candidates.

In parallel with NIST's efforts, others are endorsing the post-quantum endeavor. In May 2022, the White House put out a memo setting 2035 as the goal for U.S. government agencies to go post-quantum. In November, Google announced it is already using post-quantum cryptography in internal communications.

Several of the algorithms selected by NIST share a mathematical basis—a technique called lattice-based cryptography. It relies on a problem involving describing a lattice, or a grid of points, using a set of arrows, or vectors.

In math, a lattice is described by a set of vectors used to produce it. Consider Manhattan. Even if you'd never seen a map of the city, you could roughly reproduce its grid using two arrows, one the length and direction of an avenue block and the other matching a street block. Discounting the city's quirks, such as

A lattice approach Some post-quantum encryption schemes rely on what's known as the shortest vector problem. Take a set of two long vectors (green on the left). By placing those vectors end-to-end, it's possible to trace out a grid of points (blue). The shortest vector problem is to find the shortest of the vectors (the horizontal arrow in the grid on the right) that can be used to trace out that same grid. That's not so hard in two dimensions. But when used for cryptography, the problem must be solved in hundreds of dimensions, a nearly impossible task.



D. MOODY AND A. ROBINSON/*IEEE SECURITY & PRIVACY* 2022

variations in block lengths, you'd just place arrows end-to-end until you've mapped out the whole grid.

But there are more complicated sets of vectors that can reproduce the city's grid. Picture two arrows starting, for example, at Washington Square Park in lower Manhattan, with one pointing to Times Square in Midtown and the other to a neighboring landmark, the Empire State Building. Properly chosen, two such vectors could also be used — with more difficulty — to map out the city's grid.

A math problem called the shortest vector problem asks: Given a set of long vectors that generate a lattice, what is the shortest vector that can be used as part of a set to produce the grid? If all you knew about the city was the location of those three landmarks, it'd be quite a task to back out the shortest vector corresponding to the city's blocks.

Now, picture doing that not for a 2-D map, but in hundreds of dimensions. That's a problem thought to be so difficult that no computer, quantum or classical, could do it in a reasonable amount of time.

The difficulty of that problem is what underlies the strength of several post-quantum cryptography algorithms. In lattice-based cryptography, a short vector is used to create the private key, and the long vectors produce the public key.

Other post-quantum schemes NIST considered are based on different math problems. To choose among the options, NIST mathematicians' chief consideration was the strength of each algorithm's security. But none of these algorithms are definitively proved to be secure against quantum computers, or even classical ones. One algorithm originally considered by NIST, called SIKE, was later broken. It took just 10 minutes to crack on a standard computer, researchers reported in April in *Advances in Cryptology – EUROCRYPT 2023*.

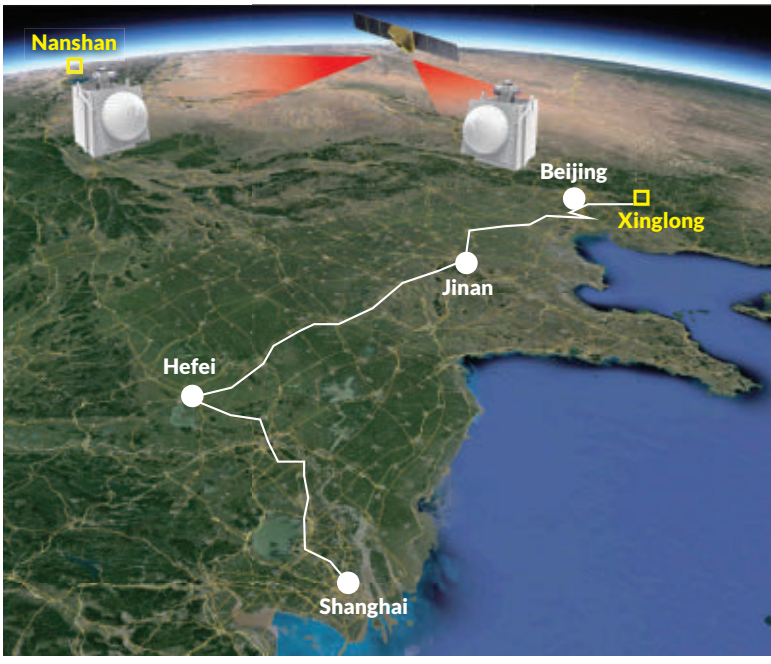
Although it might seem like a failure, the SIKE breakdown can be considered progress. The faith in the security of cryptographic algorithms comes from a trial by fire. "The more [that] smart people try to break something and fail, the more confidence we can get that it's actually hard to break it," Schwabe says. Some algorithms must perish in the process.

Quantum vs. quantum

Quantum physics taketh away, but also, it gives. A different quantum technique can allow communication with mathematically proved security. That means a future quantum internet could, theoretically at least, be fully safe from both quantum and classical hacks.

By transmitting photons — particles of light — and measuring their properties upon arrival, it's possible to generate a shared private key that is verifiably safe from eavesdroppers.

This quantum key distribution, or QKD, relies on a principle of quantum physics called the no-cloning theorem. Essentially, it's impossible to copy quantum information. Any attempt to do so will alter the original information, revealing that someone was snooping. "Someone who was trying to learn that information would basically leave a fingerprint behind," says quantum engineer Nolan Bitner of Argonne National Laboratory in Lemont, Ill.



A quantum network in China extends more than 2,000 kilometers from Beijing to Shanghai and includes a quantum satellite that beams photons to ground stations in Xinglong and Nanshan. Other quantum networks are being built and tested around the world.

This quirk of quantum physics allows two people to share a secret key and, by comparing notes, determine whether the key has been intercepted along the way. If those comparisons don't match as expected, someone was eavesdropping. The communicators discard their key and start over. If there is no sign of foul play, they can safely use their shared secret key to encrypt their communication and send it over the standard internet, certain of its security. It's a quantum solution to the quandary of how two parties can share secret keys without ever meeting. There's no need for a mathematical trapdoor that might be vulnerable to an undiscovered tactic.

But QKD can't be done over normal channels. It requires quantum networks, in which photons are created, sent zipping along optical fibers and are manipulated at the other end.

Such networks already snake through select cities in the world. One threads through Chicago suburbs from the University of Chicago to Argonne lab and Fermilab in Batavia, for a total of 200 kilometers. In China, an extensive network connects cities along a more than 2,000-kilometer backbone that wends from Beijing to Shanghai, along with two quantum satellites that beam photons through the air. A quantum network crisscrosses South Korea, and another links several U.K. cities. There are networks in Tokyo and the Netherlands — the list goes on, with more to come.

Many of these networks are test-beds used by researchers to study the technology outside of a lab. But some are getting real-world use. Banks use China's network, and South Korea's links government agencies. Companies such as ID Quantique, based in Switzerland, offer commercial QKD devices.

Y.-A. CHEN *ET AL*/*NATURE* 2021, ADAPTED BY C. CHANG

A link between a ground station (red and green lasers shown in this time-lapse image) and the quantum satellite Micius shows the potential for long-distance secure communications. The satellite beams photons to the ground station, in Xinglong, China.

JIN LIWANG/XINHUA/ALAMY LIVE NEWS

QKD's security is mathematically proven, but quantum networks can fall short of that guarantee in practice. The difficulty of creating, transmitting, detecting and storing quantum particles can open loopholes. Devices and networks must be painstakingly designed and tested to ensure a hacker can't game the system.

And one missing component in particular is holding quantum networks back. "The number one device is quantum memory," says quantum physicist Xiongfeng Ma of Tsinghua University in Beijing. When sending quantum information over long distances through fibers, particles can easily get lost along the way. For distances greater than about 100 kilometers, that makes quantum communication impractical without the use of way stations that amplify the signal. Such way stations temporarily convert data into classical, rather than quantum, information. That classical step means hackers could target these "trusted nodes" undetected, marring QKD's pristine security. And it limits what quantum maneuvers the networks can do.

It's not possible to create pairs of particles that are entangled over long distances in a network like this. But special stations sprinkled throughout the network, called quantum repeaters, could solve the problem by storing information in a quantum memory. To create far-flung entangled particles, scientists could first entangle sets of particles over short distances, storing them in quantum memories at each quantum repeater. Performing certain operations on the entangled particles could leapfrog that entanglement to other particles farther apart. By repeating this process, particles could be entangled across extended distances.

But, thanks in part to quantum particles' tendency to be easily perturbed by outside influences, scientists have yet to develop a practical quantum repeater. "When that does appear, it's likely to catalyze global quantum networks," says David Awschalom, a physicist at the University of Chicago. Not only will such technologies allow longer distances and better security for QKD, but they will also enable more complicated tasks, like entangling distant quantum computers to allow them to work together.

A European effort called the Quantum Internet Alliance aims to build a network with quantum repeaters by the end of 2029, creating a backbone stretching over 500 kilometers, in addition to two metropolitan-scale networks. The effort is "super challenging," says physicist and computer scientist Stephanie Wehner of Delft University of Technology in the Netherlands. "We are on a moon shot mission." Eventually, scientists envision a global quantum internet.

Awschalom imagines the networks becoming accessible to all. "Wouldn't it be great to be able to go to a public library and be able to get onto a quantum network?"

It takes two

QKD and post-quantum cryptography are complementary. "In order to overcome the threat of the quantum computers we need both," says physicist Nicolas Gisin of the University of Geneva and cofounder of ID Quantique. When people are exchanging information that doesn't require the utmost security—say, using a mobile phone to post cat memes on Reddit—post-quantum cryptography will be more practical, as it doesn't demand a to-and-fro of individual quantum particles. But "there are really situations where we want to make sure that the security is going to last…for several decades, and post-quantum cryptography cannot guarantee that," Gisin says.

Eventually, quantum techniques could allow for even more advanced types of security, such as blind quantum computing. In that scheme, a user could compute something on a remote quantum computer without anyone being able to determine what they're computing. A technique called covert quantum communication would allow users to communicate securely while hiding that they were exchanging messages at all. And device-independent QKD would ensure security even if the devices used to communicate are potentially flawed (*SN: 8/27/22, p. 10*).

The appeal of such extreme secrecy, of course, depends upon whether you're the secret-keeper or the snoop. In the United States, government agencies like the FBI, CIA and the National Security Agency have argued that encryption makes it difficult to eavesdrop on criminals or terrorists. The agencies have a history of advocating for back doors that would let them in on encrypted communications—or building in secret back doors.

But quantum techniques, done properly, can prevent anyone from intercepting secrets, even powerful government agencies.

"It's interesting to think about a world where, in principle, one might imagine perfect security," Awschalom says. "Is that a good thing or is that a bad thing?" ■

Explore more

- For a Q&A with Matt Scholl, chief of the computer security division at NIST, visit bit.ly/Matt_Scholl

STEM TALENT STARTS WITH TEACHERS

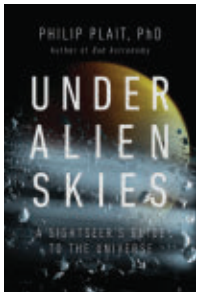
Society for Science is proud to support forward-thinking educators and creative mentors across the United States who are inspiring the next generation of scientific leaders.

Through the STEM Research Grants program, the Society has awarded $100,000 to 52 dedicated teachers from 24 states and the U.S. Commonwealth of the Northern Mariana Islands this year. As part of the program, teachers can apply for up to $5,000 to purchase specific equipment to support STEM research for their classrooms or receive $1,000 worth of equipment preselected by the Society, including Arduino electronics starter kits, trail cameras and water-monitoring kits.

With priority consideration given to educators serving student communities historically underrepresented in STEM, the program is committed to increasing access to scientific research opportunities for all young people. Since 2017, the Society has provided over $775,000 in STEM Research Grants to teachers in all 50 states, Washington, D.C., American Samoa, Guam, Puerto Rico, Peru, Mexico and Uruguay.

> “It was stressful to teach science without adequate equipment, so words cannot express the gratitude I have for receiving these funds. This just proves that no matter your background, anyone can be a scientist.”
>
> **ALFRED SANTOS**
> STEM Research Grant Recipient, 2022; Educator at Harvest Preparatory Academy in Yuma, Ariz.

Learn more about the STEM Research Grants Program and apply for a grant: www.societyforscience.org/stem-research-grants



Under Alien Skies
Philip Plait
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BOOKSHELF

What does the sky look like on other worlds?

Why is the sky blue? I remember asking my parents that question as a kid. When the sun's rays hit the blanket of air that encircles the Earth, they told me, blue light scatters more than other colors. Despite my fascination with the cosmos, I never thought to ask what the sky would look like on other worlds.

Luckily, astronomer and science writer Philip Plait has. His new book, *Under Alien Skies*, is a bewitching cosmic ride through the solar system and beyond, transporting readers aboard futuristic starships to discover what the sky might look like above faraway landscapes. Plait is the perfect captain on this expedition, vividly bringing these alien worlds to life while deftly weaving in the science to support the scenery. He even includes explanations of the space suits you'd need to stand and gaze at the skies on the moon, Mars, Pluto and other orbs.

In some cases, it's not too hard to imagine the views. Thanks to rovers, we've seen actual images of Mars' sky (SN: 8/13/22, *p.* 20). It's typically the color of rust, because the Red Planet's atmosphere is chock-full of dust that tends to scatter red light the most. Pluto's sky is vastly different. It's so far away from the sun that, even at midday, the sky is utterly black and the stars are visible. But contrary to what some articles on the internet say, the sun would not look like any other star in the sky. Standing on Pluto, the sun would appear one-fiftieth its size from Earth's viewpoint. But it would blaze as a "painfully bright" dot, Plait writes, about 160 times as bright as the moon looks to us, and it would have a faint, deep-blue halo because Pluto's thin air scatters short, blue wavelengths of light.

One of my favorite stops on Plait's tour is the comet 67P/Churyumov–Gerasimenko, a two-lobed object shaped like a big rubber ducky. He lands readers on the larger lobe. Looking up toward the sky means seeing the rocks of the smaller lobe. " 'Smaller' seems like the wrong word; it looks like an entire planet hanging over your head," Plait writes.

Jetting to the smaller lobe, Plait points out a metal pole jutting from the rocks. The pole is attached to a box, turned off-kilter. It's Philae, the lander that bounced and crashed on the comet in 2014 (SN: 8/22/15, *p.* 13). "Oh Philae," Plait writes. "It's so good to see you." Finding Philae and exploring the aftermath of its crash would show just how fragile the comet is, Plait explains. The lander shattered the rocks it hit on impact, even though it was moving slower than a typical walking speed. The loose rock and ice would appear as wispy as piles of pixie dust.

The book ends with an aptly named final chapter, "The last sky you'll ever see," which contemplates the view from close to a black hole. Going inside a black hole is out of the question; you'd be toast. But from a safe distance, a starship can get a good peek with some telescopes — good enough that it feels like you're hovering just above the event horizon, the black hole's point of no return (SN: 5/31/14, *p.* 16). Sitting there, you see … nothing. "No, that's not fair," Plait writes. After the long journey and the suspense of experiencing such a beast, you'd feel cheated if you saw seemingly empty space. Take a closer look, he says. If you squint, you can make out the rim around the black hole, where stars jostle, and then one slides along the curve of the horizon until its light flickers into that nothingness. You have a front-row seat to see the star's light being bent by the black hole's gravity. "It's mesmerizing, if a bit disconcerting," Plait writes.

If you could zoom in all the way to the center of the black hole, you'd see even weirder stuff. Exactly what, I won't reveal; I'll let you read the book and find out. I highly recommend you do. — *Ashley Yeager*

NASA's Curiosity rover took this selfie in 2018, with Mars' reddish orange sky visible above.

JPL-CALTECH/NASA, MSSS

APRIL 22, 2023

READER SNAPSHOTS

Tangible tiles

After half a century, mathematicians finally discovered an 'einstein' (below, left), a shape that forms a tiled pattern that never repeats, **Emily Conover** reported in "Elusive 'einstein' tile finally found" (*SN: 4/22/23, p. 7*). **Tom Matuseski**, a high school math teacher at Augsburg Fairview Academy in Minneapolis, was inspired to create a 3-D printed version of the tile (below, right). "I had a lesson plan … for students to design a tessellation 3-D print when I read the article," **Matuseski** wrote. "I had to try and make it." And so he did, designing printable tiles using the 3-D modeling program Tinkercad.

FROM LEFT: D. SMITH, J.S. MYERS, C.S. KAPLAN AND C. GOODMAN-STRAUSS (CC BY 4.0); T. MATUSESKI

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Hello darkness, my old friend

*A subglacial river has carved out a cavern hundreds of meters beneath the Kamb Ice Stream, a West Antarctic glacier. Inside the dark, water-filled "cathedral," scientists found signs of life, **Douglas Fox** reported in "Journey under the ice"* (SN: 4/22/23, p. 18).

Reader **Bob Masta** asked how much sunlight filters down through the ice above the cavern.

"Essentially no light gets through that thickness of ice. These are truly dark environments," **Fox** says. "The ice is basically opaque, crammed with bubbles and inclusions. So it scatters light until, after a certain depth, there's nothing left." This darkness is consistent with observations of other subglacial environments, **Fox** says, such as those beneath the Thwaites ice shelf and the Whillans Ice Stream.

Let's talk language

*MRI scans of nearly 100 native speakers of either Arabic or German revealed differences in how the language circuits of the brain are connected, **Elise Cutts** reported in "Native language shapes the brain"* (SN: 4/22/23, p. 8).

Several readers wondered what the finding might mean for people who grew up speaking more than one language.

They may have an advantage in learning new languages, says cognitive neuroscientist **Angela Friederici** of the Max Planck Institute for Human Cognitive and Brain Sciences in Leipzig, Germany. With brain connections influenced by more than one language, the brains of multilingual people would likely have "more structures to cope with the different languages, thereby even providing a good basis to learn additional languages," she says.

Listen closely

*Tomato and tobacco plants emit high-frequency sounds when they're thirsty. The finding could one day help farmers detect crops that need watering, **Meghan Rosen** reported in "Parched plants make ultrasonic clicks"* (SN: 4/22/23, p. 13).

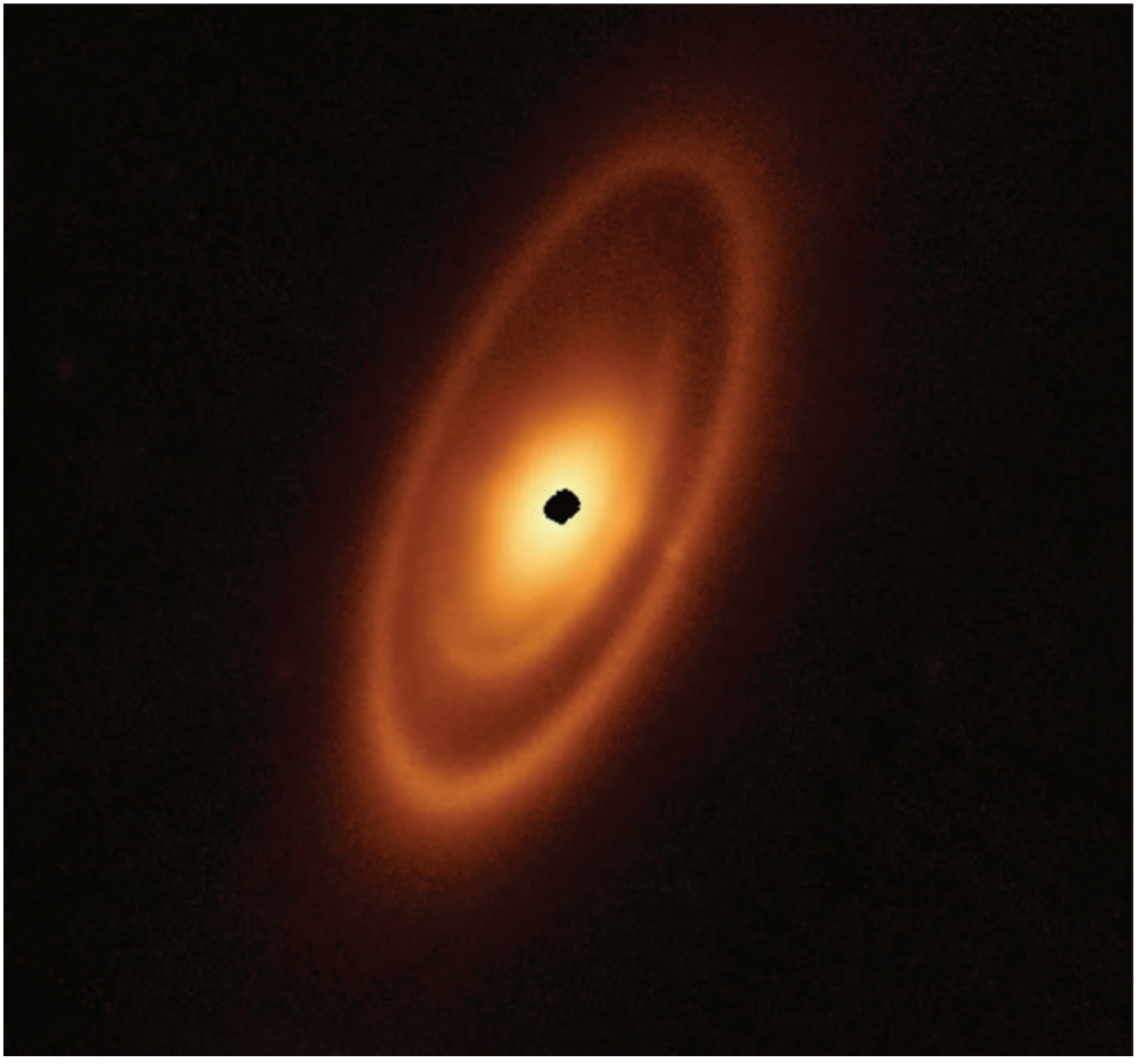
Reader **Roger Pyle** shared memories of growing up in rural Pennsylvania and hearing "sounds of corn growing" after a rain. "We used to have a truck patch of about an acre where we raised sweet corn, beans, strawberries, etc.," **Pyle** wrote. "My bedroom window faced the field where we grew the crops. The window was open most of the time in the summer as we had no air conditioning. After a dry period, when it rained overnight (and sometimes after an afternoon thunderstorm), it would get very still, and I could hear … sounds coming from the cornfield. Whether it was the sound of the rain soaking into the soil or water dripping off leaves of the corn, I don't know for sure." Although at a frequency too high for humans to hear, "the clicking noises of thirsty plants acknowledging a welcome drink" perhaps were among the sounds of the field, **Pyle** mused.

Unsung characters

*Barred from ocean expeditions because she was a woman, geologist and cartographer Marie Tharp devoted her energy to making maps of the seafloor. Her groundbreaking work offered visual support for the idea of continental drift, **Betsy Mason** reported in "Marie Tharp brought us the ocean floor"* (SN: 4/22/23, p. 24).

Reader **Charlotte Howell** was thrilled to read about Tharp. "I worked very briefly at Lamont-Doherty [Earth Observatory] in a support role back in 1978 and knew several of the scientists continuing to collect and interpret data on the seafloor spreading at the Mid-Atlantic Ridge. Though I am not a scientist, my father had a Ph.D. in chemistry and spent most of his career as a researcher.... He introduced me to the fascinating worlds of chemistry, geology, scientific thought and process," **Howell** wrote.

"Over the years, I've read several biographies of women scientists," including of Marie Curie, who pioneered research on radioactivity, and Rosalind Franklin, who contributed to the discovery of DNA's double helix structure, **Howell** wrote. "I look forward to any articles on women scientists you include in upcoming issues of *Science News*."



A sharper look at a young star system

Rings of dust encircle the star Fomalhaut in a new infrared image (above) from the James Webb Space Telescope.

Fomalhaut, a scant 25 light-years from Earth, is a young star at the center of a rapidly evolving planetary system. It was once thought to host one of the first planets outside of our solar system to be photographed (*SN: 12/6/08, p. 5*). However, follow-up observations suggested that the planet—dubbed Dagon—doesn't actually exist (*SN: 2/25/12, p. 12*).

In the new image, Fomalhaut is blacked out. An inner disk of dust plus two rings encircle the star, astronomer András Gáspár and colleagues report May 8 in *Nature Astronomy*. The diameter of the previously imaged outer ring is roughly five times that of Neptune's orbit. The inner ring had never been seen before.

That ring appears to be an asteroid belt, tilted at a jaunty 23 degrees from everything else seen orbiting the star. "This is a truly unique aspect of the system," says Gáspár, of the University of Arizona in Tucson. The tilt, he says, could be the result of undiscovered planets stirring up rocky debris.

The image also turned up a faint smudge that the team calls the Great Dust Cloud (at the 4 o'clock position of the outer ring). It's not yet clear whether it's a real feature in the ring or some bright object like a galaxy shining through from beyond.

As for the putative planet Dagon, the image adds to growing evidence that it's actually a fading, expanding cloud of dust, possibly from a collision of other planets. There is no sign of Dagon at its expected location. —*James R. Riordon*

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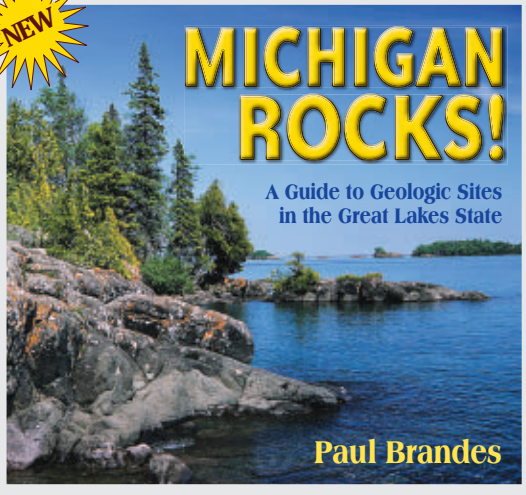

MICHIGAN ROCKS!

A Guide to Geologic Sites in the Great Lakes State

PAUL BRANDES

A good map, an urge to discover, and this guidebook are all you need to explore and become well-versed in the distinct geology of Michigan.

Michigan is the only state in the nation to border four of the five Great Lakes. This abundance of shoreline translates to a multitude of rock exposed by waves and currents. Nearly the entire history of Earth is on display in Michigan, from 3.6-billion-year-old gneisses to potholes drilled by modern rivers.

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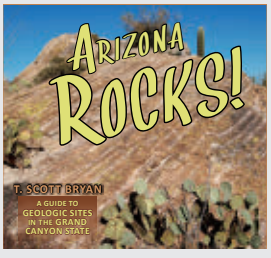

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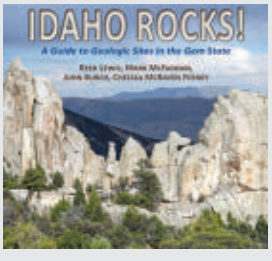

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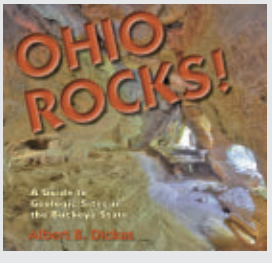

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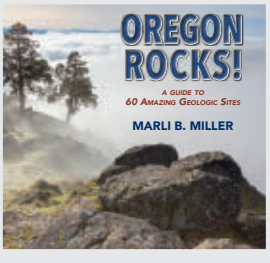

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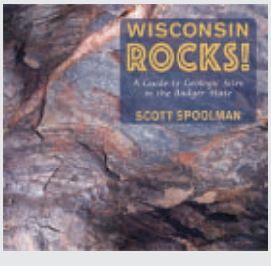

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