SCIENTIFIC AMERICAN

Extremely Metal Dinosaurs

New Treatments for Schizophrenia

Reinventing the Army Corps of Engineers

The Dark Sector

Searching for a hidden realm of particles and forces parallel to our own material world

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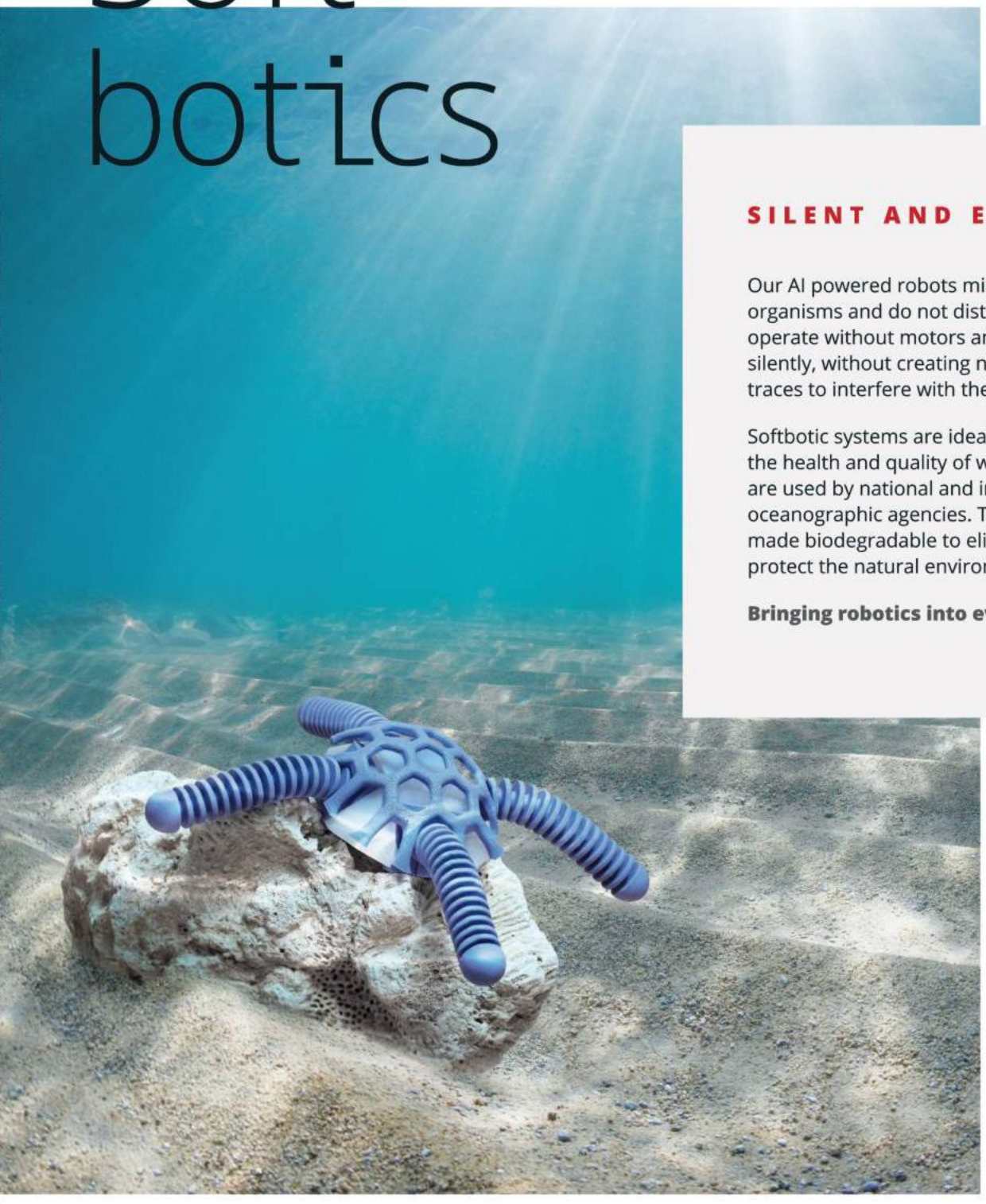
Soft botics



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SCIENTIFIC AMERICAN

FEATURES

NASA/JPL-Caltech

ON THE COVER
Evidence shows that our world is bathed in some kind of mysterious invisible matter. An increasingly popular idea posits that this dark matter might be a whole hidden sector of dark particles, including dark protons, dark neutrons and dark electrons that bind into dark atoms.

Illustration by Maciej Frolow

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Alberta Wildfire Social Media Account/Handout/Anadolu via Getty Images

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Reshaping our relationship with our world

Beautiful Brains and Armored Dinosaurs

WHEN I FIRST came across the term "neurodivergent," after it was coined about 25 years ago by activist Kassiane Asasumasu, I didn't realize the weight it would hold in society. The nonjudgmental label, which describes people with attention deficit hyperactivity disorder, autism, tics, and many other brain-based phenomena, indicates a divergence from the typical rather than a deficit. Now, after I've interacted with many diverse humans and begun raising kids whose minds and behaviors consistently both baffle and amaze me, the term feels personal: one of my main goals as a parent has been to engender in my children kindness and openness toward all that is different.

On page 54, journalist Paul Marino describes his own experience with neurodivergence: a decades-long search for a diagnosis to explain a recurring burst of involuntary movements that involve flickering his fingers rapidly on either side of his face. At one point in high school Marino was so embarrassed by this "motoring" (which he now knows is a kind of complex motor stereotypy, or CMS) that he wrapped his fingers together with Scotch tape. He describes his journey in intimate and honest language. After reading his story, I better understood not only the fascinating ways the human brain can shape thoughts and behaviors but also how being yourself can be the best medicine. As one neurologist told Marino, "a better world would be one in which we did not pathologize CMS but erased its stigma." I will share this touching feature with a loved one with tics who is incredibly kind, athletic, compassionate, smart … and be open to sharing with others why they make noises or wink for seemingly no reason.

Sometimes dysfunction in the brain can lead to mental health conditions such as schizophrenia, which is characterized by delusions and disordered thinking, among other symptoms, that can be debilitating. Journalist Diana Kwon (*page 38*) tells us how a promising new type of drug and other advances reveal a picture of the illness that is more complex than anyone had realized.

Our cover story looks at another complex puzzle. Galaxies, including ours, bathe in oceans of dark matter, which communicates with our world mainly through gravity. The problem is physicists have yet to uncover the identity of this invisible stuff. For the past 30-some years they have searched for individual hypothetical dark matter particles, to no avail. Now, on page 22, theoretical physicist Kathryn Zurek provocatively describes how dark matter may in fact be "a whole hidden sector of dark particles and forces" that could combine and interact, just as visible matter does. New experiments to detect quantum disturbances in special materials could tease out this parallel world.

Scientific American senior news reporter Meghan Bartels follows two beloved spacecraft, Voyagers 1 and 2, on their epic tour past the outer planets, across the edge of the sun's influence (the heliosphere) and into interstellar space (*page 62*). Along the way, you'll see how these iconic missions have upended what scientists thought they knew about the great beyond.

Hurricane Katrina, which barreled onto the Gulf Coast 20 years ago in August, was a turning point in the U.S. Army Corps of Engineers' approach to disaster-risk reduction. If levees and dams hadn't deprived healthy marshes of their sediments, they could have acted as baffles to the storm's deadly sea surges. Now the Corps is leaning into nature-based solutions. On page 28, author Erica Gies writes about some of the most promising Corps projects that work with nature, along with some of the setbacks.

The horned and armored dinosaurs of the Mesozoic were not to be messed with: recently discovered, exquisitely preserved fossils of two such beasts show details of their weaponry never seen before, suggesting some of the bulky spikes, blades, plates and horns of dinosaurs were far larger and tougher than previously thought. Paleontologist Michael B. Habib (*page 44*) has great fun describing this research and what it means for a long-running debate about the function of these superb accoutrements. ●

Jeanna Bryner
is interim editor in chief of *Scientific American*.

KATHRYN ZUREK
THE HIDDEN WORLD

PAGE 22 Kathryn Zurek became a theoretical physicist because she wanted to understand, mathematically, how the universe works. "It appealed to me that it was hard," she says. Zurek ultimately decided to study one of the hardest open questions in the field: What is dark matter made of? In our cover story, she explains the "hidden valley" theory of dark matter she helped to pioneer, which posits that there's an entire world of dark particles out there, invisible to the eye.

Zurek always searches for simple, physical analogs when trying to puzzle out a problem. "I think in very physical terms," she says, an approach that theoretical physicist Richard Feynman was also known for. "He could explain just about anything in terms of an electronic circuit," Zurek says. Her theory of hidden valleys has been influential in the field of dark matter, and now she's bringing her physical approach to another big open question in physics: How does gravity fit into quantum mechanics? "I'm an outsider in that community," she says, but if the sets of ideas she has brought to the field are realized in nature, "it will be precisely because I've come into a new field with a different way of thinking about those problems."

DIANA KWON
A NEW LOOK AT SCHIZOPHRENIA

PAGE 38 While pursuing a master's degree in neuroscience, Diana Kwon began reporting science and technology stories for her school's student newspaper. She had so much fun that she decided to make it her career. "I love science journalism," she says. When cool discoveries happen, "we get to see the exciting part of that whole [scientific] process." Now, as a Berlin-based journalist, Kwon focuses on neuroscience. In her article for this issue, she explores a new understanding of the complexities of schizophrenia. Recent findings have complicated what she calls the "big narrative" of schizophrenia's causes—and have pointed to the immune system's role in a subset of cases.

Schizophrenia is one of many conditions that may arise from both the mind and the body, Kwon says. She often is drawn to these boundary-defying health stories and has covered the brain-body connection in functional neurological disorders, heart conditions and even cancers. When treatments and diagnoses are siloed into one medical field, patients can lose out. "Increasingly," Kwon says, "there's a realization, among both clinicians and researchers, that these distinctions we have between disciplines are artificial and need to be broken to better serve people across all different communities."

Ryan David Brown

TRISTAN SPINSKI
A COMPLEX DIAGNOSIS

PAGE 54 The medium of photography is defined by its limits: shutter speeds, the available lighting, the background. "It's just this slight snapshot" of the world, says photographer Tristan Spinski (*above*). He sees his art as "an exercise in subtraction" and strategic ambiguity, and he "allows space for the story to pour in and fill those gaps." This feature article by writer Paul Marino details the author's quest to understand the cause of a lifelong secret, a repeated motion of his hands he calls "motoring." Spinski traveled from his own home in coastal Maine to Marino's in New Hampshire, where he used long exposures to capture the essence of Marino's motoring in still images.

Over the past 20 years Spinski has learned that he's most passionate about depicting things "on the edges of appreciation" that we see but pay little attention to. For a recent project, he spent three years photographing vernal pools, seasonal bodies of water that vary in size from a puddle to a pond. These networks of ephemeral pools are like "neural hubs" of a forest from which "life sort of blooms out," he says. "To me, now, the puddle in the forest is essential"—a discovery that also taught him about the fascinating stories one can find in their own backyard.

MARK WITTON GLADIATORS OF THE MESOZOIC

PAGE 44 Mark Witton has been drawing *Triceratops* and *Stegosaurus* since he was a kid. Now it's basically his full-time job. As a paleontologist, he has found himself immersed in the field of paleoartistry, where he uses scientific research to make educated guesses of what these long-lost creatures looked like. Those guesses have changed a lot over the decades, and dinosaur reconstructions today look very different than they did when Witton was younger. For this issue's feature on armored dinosaurs by Michael B. Habib, Witton was tasked with creating side-by-side comparisons of old versus new looks for *Stegosaurus* and *Triceratops,* along with a "new kid on the block," the armored dinosaur *Borealopelta.*

There is no set academic path for someone who wants to become a paleoartist—Witton has had to learn as he goes. For his Ph.D. thesis, he studied the anatomy of avian pterosaurs, which are "some of the most ridiculous-looking animals you can imagine," he says. He can now stare at a fossil skeleton for hours and map out the muscle groups in his mind. (Museums "have to kick me out," he says.) "When you're drawing a dinosaur, it is in essence drawing from one's imagination," even when the image is grounded solidly in fossil data. Yet "as outlandish as dinosaurs were, they were still animals living on the same planet that we do," Witton adds. "We must be careful not to make them look like aliens. They need to have an element of recognizability to them."

Pioneers of Innovation

NEW PATHS TO A HEALTHY PLANET

A conversation with Peter Schlosser, vice president and vice provost of Global Futures at Arizona State University

Peter Schlosser has spent his career studying the natural world and humanity's place within it. Few people are better placed to understand how this relationship is breaking down and the scale of action required to reshape it. To contribute to this global effort, Schlosser founded and leads the Julie Ann Wrigley Global Futures Laboratory (GFL) at Arizona State University. The laboratory, founded in 2019, serves as a prototype of a university for the future of the planet, bringing speed, scale and a transdisciplinary focus to Earth's connected systems.

> *"With these challenges there are opportunities. Trillion-dollar industries are waiting to be built."*

What is the Global Futures Laboratory's vision and mission?

Our vision is a world in which all life can thrive on a healthy planet. The mission, then, is to find options to keep our planet habitable and to increase well-being for all humankind. We're looking to relieve some of the pressure we've put on the planet's life-supporting systems, to get back towards equilibrium.

Why does our relationship with the planet need to change?

Humankind is one out of about 10 million known species but the only one that has developed the capability to over-exploit the services that the systems on our planet provide—not just for our species but for all life on Earth. We have to get back to the understanding that we are part of the Earth system.

Many researchers are working to address these problems. How is GFL's approach different?

We're looking at the planet holistically. We're not just looking at systems such as climate, energy, water, biodiversity and food. We're also looking at the social dynamics and value systems behind decision-making to understand how we got into this situation and how we can incentivize people to make decisions that would be kinder to our planet. We include the humanities, social sciences, medical sciences and arts to understand our world from all angles. From the medical perspective, for example, we have a program that measures the impact of heat on the human body.

The lab is also an experiment in how academia can be more effective in being part of society, a trusted partner, able to engage with people affected by these problems and understand what they need to make critical decisions on fast timescales.

What are some examples of ongoing projects?

We have a large effort in direct air capture, which is taking CO_2 back out of the atmosphere. We created a mechanical tree. It's a cylindrical instrument with about 100 discs that are two centimeters apart. On these discs is a substance that captures CO_2 as air passes through. We are upscaling it through a company that licenses our technology.

We're also looking at the future of water—regionally but also globally in terms of how climate change is changing water budgets because we're having more floods and more droughts. It's a natural fit for us because the Southwest is drying out.

But there is a danger that we go from denying the problems to becoming fatalistic. That would be the worst outcome. With these challenges there are opportunities. There are many trillion-dollar industries waiting to be built. We have to accept change as opportunity rather than sacrifice.

Explore the Global Futures Laboratory's work to redefine humankind's place in our world at globalfutures.asu.edu.

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Reshaping our relationship with our world

December 2024

WATERY SANCTUARIES

In "The Afterlives of Oil Rigs," Asher Radziner describes how oil rigs are habitats for marine species and explores the question of whether they should be allowed to remain after they stop producing oil.

For years I was an avid diver and dove on several oil rigs. I must admit that these were some of my most memorable dives. These rigs provide a sanctuary for an amazing variety of life, essentially an oasis in an ocean desert. Little, if any, life would exist there if not for these structures. Taking them down would destroy a well-established ecosystem, not to mention that doing so would cost a lot of money.

RANDY LANDRY *VIA E-MAIL*

A COLORFUL PAST

I thoroughly enjoyed "The Map Color Conundrum" [Math], Jack Murtagh's overview of the historical controversy over the four-color theorem, which states that no more than four colors are needed to fill in a given map so that no designated areas have the same color. Murtagh notes that Kenneth Appel and Wolfgang Haken finished a computer-aided proof of the theorem in 1976. No disrespect to Appel and Haken, but I don't regard their work as the final word on the matter. In his 1940 book *A Mathematician's Apology,* the great English pure mathematician G. H. Hardy stated, "Beauty is the first test: there is no permanent place in the world for ugly mathematics." I await a more elegant proof.

Of course, Martin Gardner published a famous "counterexample" of the four-color theorem in *Scientific American* back in April 1975.

EAMONN WATERS
RANGIORA, NEW ZEALAND

MURTAGH REPLIES: *Waters is in good company with many mathematicians who await a more elegant proof of the four-color theorem. Regarding Gardner's publication: In 1975, only a year before Appel and Haken proved the theorem, Gardner played an April Fools' prank in his long-standing* Scientific American *column Mathematical Games. He published a map with 110 regions and claimed that it could not be colored with only four colors, thus disproving what was then the four-color conjecture. Of course, the map did indeed have a four-coloring scheme (like all maps, we now know); it was just difficult to find. Gardner enlisted the help of mathematician William McGregor for the hoax and acknowledged it in his July 1975 column.*

HEALTH ANXIETY

As a psychologist, I appreciated Joanne Silberner's attention to a condition that is so often minimized and used to dismiss people's concerns in "Hypochondria's Serious Toll." But I think it is important to recognize the role of safety behaviors and negative reinforcement, concepts that weren't directly discussed in the article. They are central to a cognitive-behavioral understanding of the development and maintenance of illness anxiety disorder and somatic symptom disorder—the two separate syndromes that are referred to as "hypochondria," as Silberner notes—as well as related disorders. And addressing these concepts is central to effective treatment intervention.

DANIEL KLEINER *REHOBOTH BEACH, DEL.*

Having spent four decades as an internist, I have seen many people with hypochondria and have struggled to provide an appropriate treatment plan for these complicated patients. The article notes a book in which the author describes how he underwent multiple hospital tests for cardiac symptoms that all had normal results and how many of these symptoms were actually the side effects of a drug he had switched to on his own insistence. There is a twist to this kind of story: an aggressive response from a physician can unintentionally produce a positive feedback loop in which the patient (perhaps subconsciously) thinks, "If this is nothing to worry about, why is my doctor ordering all these tests?"

IAN J. WILSON *COLUMBUS, OHIO*

WHALES AND CARBON

I was fascinated by "Buried at Sea," Jaime B. Palter's article about proposed engineering to promote the sequestration of carbon dioxide in oceans. Recently I read about how a whale can do the work of those engineering "marvels." Whales fertilize the ocean surface, which in turn promotes phytoplankton growth. In addition to providing more food for larger animals, the increased amount of phytoplankton absorbs atmospheric CO_2. And when these organisms die and sink to the ocean floor, they take carbon with them. It seems that protecting and nurturing whale populations to bring them back to their historical numbers may be the best bet for our own future.

EVELYN WIEBE-ANDERSON
ARCATA, CALIF.

PALTER REPLIES: *The idea of restoring whale populations is attractive, mostly because it aims to rewild the ocean and bring it back to its state before human activity degraded the ecosystem. There is no direct evidence, however, that it can make a meaningful dent as a method of prompting the ocean to store more carbon. Scientists have tried to estimate how much addi-*

"Oil rigs provide a sanctuary for an amazing variety of life, essentially an oasis in an ocean desert."
—RANDY LANDRY *VIA E-MAIL*

tional carbon sequestration whale restoration can provide (both directly, such as by the entrapment of carbon in whale carcasses, and indirectly, such as by the stimulation of phytoplankton growth).

The top-line numbers for direct pathways don't indicate climate-relevant scales, although there are deep uncertainties, especially regarding the indirect pathways, that would require future research for us to understand and better quantify. Luckily, making our oceans more sustainable and restoring ecosystems can have cultural and economic value that goes well beyond dealing with carbon.

GALAXY BRANDING

I have to agree with Phil Plait's assessment that "Milkomeda" is an awful name for the potential future merger of the Milky Way and Andromeda galaxies in "The Milky Way's Fate" [Universe]. He suggests "Andromeway" would be even worse, and I have to agree again, but he is on the right track. I think a snappier name for the merged galaxy, one that would sound better and flow off the tongue with greater ease, would be the "Andy Way."
NELSON G. THOMAS *VIA E-MAIL*

CLARIFICATION

"Untangling the Vagus Nerve," by Jena Pincott [January 2025], described a 2017 study of people with treatment-resistant depression that found vagus nerve stimulation halved symptoms for 67.6 percent of them. This result refers to a decrease of 50 percent or more.

ERRATUM

"Tessellation Revelation," by Elise Cutts, incorrectly said that the faces of a polyhedron's dual correspond to the polyhedron's edges and vice versa. Rather the faces of each shape correspond to the vertices of the other.

"The Astronaut Club," by Clara Moskowitz and Zane Wolf [Graphic Science; February], incorrectly represented data regarding astronauts Christina Koch, Joe Engle, Michael R. Clifford, Susan J. Helms and Timothy Nash. Corrected illustrations can be viewed at www.scientificamerican.com/article/everyone-who-has-ever-been-to-space-charted

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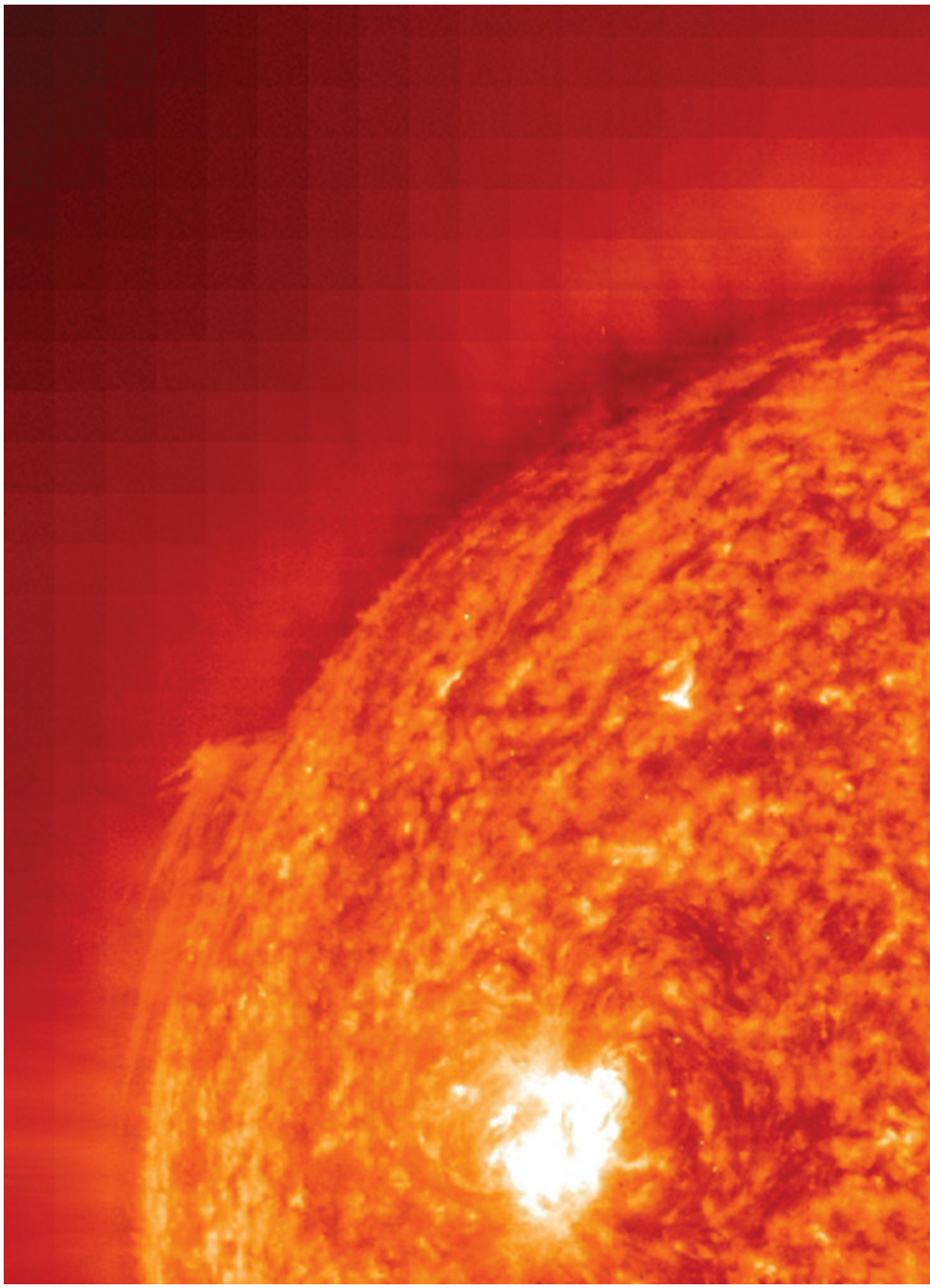
HELIOPHYSICS

Flare Notice

Earth may soon get early warning of dangerous solar activity



DETLEV VAN RAVENSWAAY/ Science Source

SOLAR FLARES ARE BURSTS of radiation from the sun's surface, sometimes followed by a bubble of magnetized plasma particles called a coronal mass ejection (CME). If they happen to spray out in Earth's direction, CMEs can cause geomagnetic storms that damage power systems on the ground or spacecraft in orbit. And solar flare radiation itself can disrupt communication networks and satellite operations.

Unfortunately, solar scientists cannot reliably predict when the sun will belch out a flare. After one is observed, every minute counts in the ensuing scramble to adjust power grids or move satellites before they get damaged.

Now researchers have used data from NASA's Solar Dynamics Observatory to show that distinctive flickering in the huge loops of roiling plasma that arch up out of the sun's atmosphere, called the corona, seems to signal that a large flare could soon occur. This link could help researchers brace for the flare and look out for signs that an incoming CME could hit Earth within a couple of days.

Emily Mason, a heliophysicist at San Diego-based research firm Predictive Science, and her colleagues observed coronal loops in magnetically active regions where 50 strong solar flares occurred. They found that the loops' ultraviolet light output varied erratically a few hours before a flare, the team told a recent meeting of the American Astronomical Society in Maryland. "It gives us one to two hours' warning, with 60 to 80 percent accuracy, that a flare is coming," Mason says.

"If we want to be able to predict solar storms earlier, then we have to predict when the flare will happen," says Mathew Owens, a space physicist at the University of Reading in England. "Small gains there are valuable."

Crucially, the researchers used a near-real-time data stream with just an hour's lag rather than working with data that have been processed to improve quality, which can take weeks. Mason and her team observed flares on the sun's outer edges from our perspective, or limbs, because that is where their light can best be seen from

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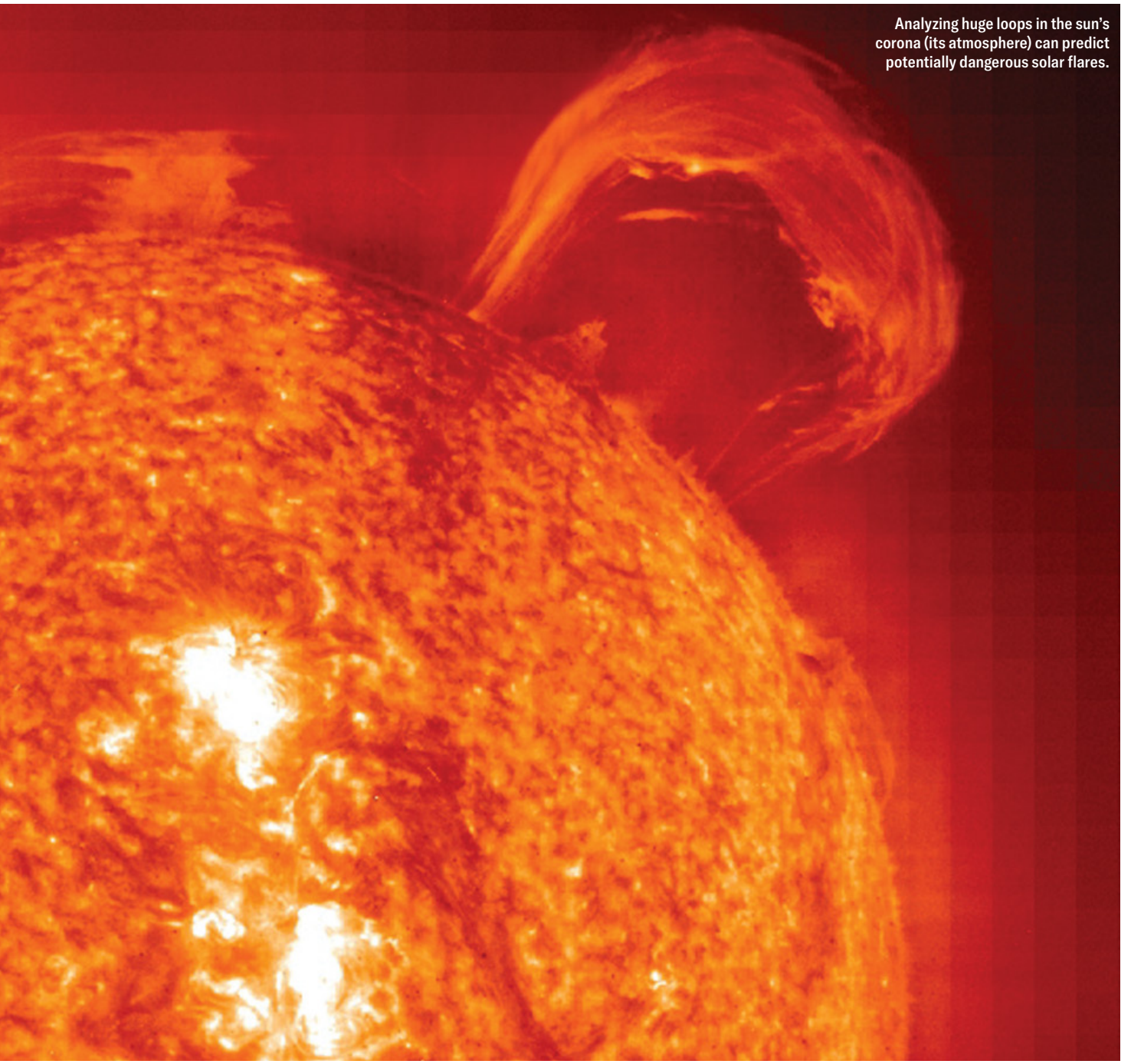
ANTS CAN TEACH SELF-DRIVING CARS TO AVOID TRAFFIC JAMS P. 15

KIDNEYS PLAY A CRUCIAL ROLE IN ENDURING EXTREME ALTITUDES P. 16



Analyzing huge loops in the sun's corona (its atmosphere) can predict potentially dangerous solar flares.

Earth. Flares on the sun's eastern limb will head away from Earth as the sun rotates, but those on the western limb may hit the planet's atmosphere, Mason says.

For now our viewpoint means we can't easily see loops emanating from elsewhere on the sun. But the European Space Agency is planning to launch a spacecraft called Vigil in 2031 that should give us a side-on perspective. "Being able to see the sun from more different angles is the single most important thing that we can do to improve our predictions," Mason says. She hopes predicting big flares can help keep astronauts and electrical systems safe. —*Chris Simms*

ANIMAL BEHAVIOR

Migration Buddies

Songbirds socialize with different species during long nighttime flights

TINY SONGBIRDS SUCH AS GROSBEAKS and warblers migrate thousands of miles, flying at night and resting during the day, to and from their wintering grounds—and unlike many larger birds, they often forgo flocks and travel independently. But recent research suggests they're not entirely alone in the dark sky.

Benjamin M. Van Doren, an ornithologist at the University of Illinois Urbana-Champaign, and his colleagues set up ground-based microphones at 26 sites across eastern North America and collected more than 18,300 hours of calls from birds in flight. The researchers found that solitary migrating songbirds seem to cooperate across species, possibly sharing information with other solo travelers about who they are and what to watch out for ahead.

The findings, published in *Current Biology*, add to growing evidence that interspecies social interactions may influence songbirds' migratory behavior far more than was previously believed. The conventional wisdom had been "that each bird is following its own internal instinct or its own experience," Van Doren says. "If it is not a young bird and has already migrated a few times, they definitely rely on memory and experience—but generally they're just on their own."

Flying in the dark presents challenges to airborne cooperation; for example, visual cues such as other birds' flight paths are absent. And it presents challenges to researcher observations, too, notes biologist Allison Pierce, who studies plover migration at the University of Colorado Denver and was not involved with the new study. To examine the process, Van Doren and his colleagues had to look—or rather listen—for alternative data: the seemingly random pings songbirds chirp out every few seconds to every minute.

"It's really been unclear why exactly they are spending all this energy and all this effort calling while they're migrating," Van Doren says. "There must be some reason or benefit to this behavior. Otherwise they're just wasting energy." To analyze what ended up being a gigantic amount of data, Van Doren and his colleagues used machine-learning technology adapted from Merlin, a bird-call-identification app developed by the Cornell Lab of Ornithology.

The scientists found that individual birds from different species were flying near one another and calling out using certain patterns, "more so than we could explain by chance," Van Doren says. So there appeared to be some reason the birds were staying in proximity. Rather than the birds finding their way from Chicago to Argentina completely solo, he says, "maybe there's actually some social information being exchanged among these billions of songbirds migrating at night, which would totally flip around our understanding of how songbird migration works."

It's still unclear exactly what information the birds may be communicating, Van Doren says. But researchers have some pretty good guesses. For instance, different bird species had different calls, but even within the same species, their "pings" varied across age or sex groups—suggesting that birds might be using such information to introduce themselves. Whatever the case, it's highly likely that "staying in touch with other individuals could help them navigate more effectively," Van Doren explains. They could be exchanging knowledge about landing spots and tricky weather conditions such as fog or rain, for example. "Migration is a very risky time even for birds that have done it before."

Scientists have previously observed that songbirds form what appear to be mixed-species flocks while searching for food and avoiding predators during the day, Van Doren adds. The new study suggests such partnerships could play a more significant role than researchers realized. Ideally, additional studies will further test these hypotheses by using more direct methods such as tagging specific birds to track them during migration. According to Pierce, "if we could take it from this big population-level scale and try to understand what the individual's doing, it is going to be a key to understanding how birds are migrating."

Van Doren adds, "To me, it speaks to the amazing complexity of how nature works—and it's exciting to be still learning new things about these well-known phenomena that are just spectacular."

—Gayoung Lee

Singing American Redstart

Brian Reinke/Getty Images

BIOLOGY

Graceful Flop

Rapid belly flops propel tiny frogs across the water

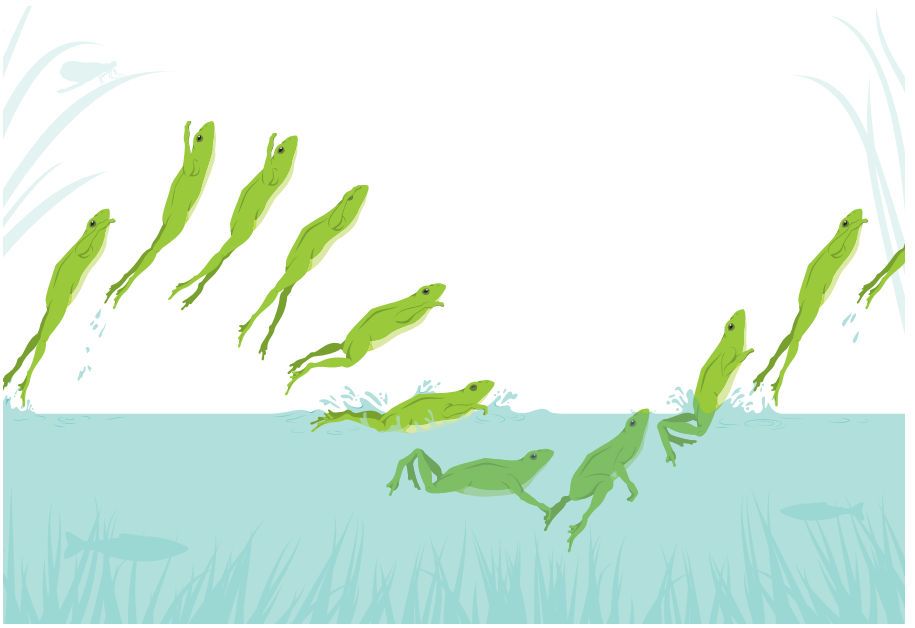
IF YOU FLICK A FLAT STONE toward a pond at just the right angle, it skips across in a series of smooth jumps. Inch-long cricket frogs seem to skitter over the surface of water with similar physics-defying grace. But when Talia Weiss, then an engineering graduate student at Virginia Tech, filmed the frogs with a high-speed camera, she saw a very different picture.

"The motion is so fast that if you look at it with the naked eye, you really can't tell the difference," Weiss says.

For a study published recently in the *Journal of Experimental Biology*, Weiss and her co-authors filmed cricket frogs at up to 500 frames per second, level with the water's surface, as the frogs moved across. Playing the footage in slow motion, the researchers found that the frogs were not hopping with just their feet breaking the surface, as older studies had described anecdotally, but were actually doing a series of belly flops—sinking for a fraction of a second and then kicking themselves upward with each jump.

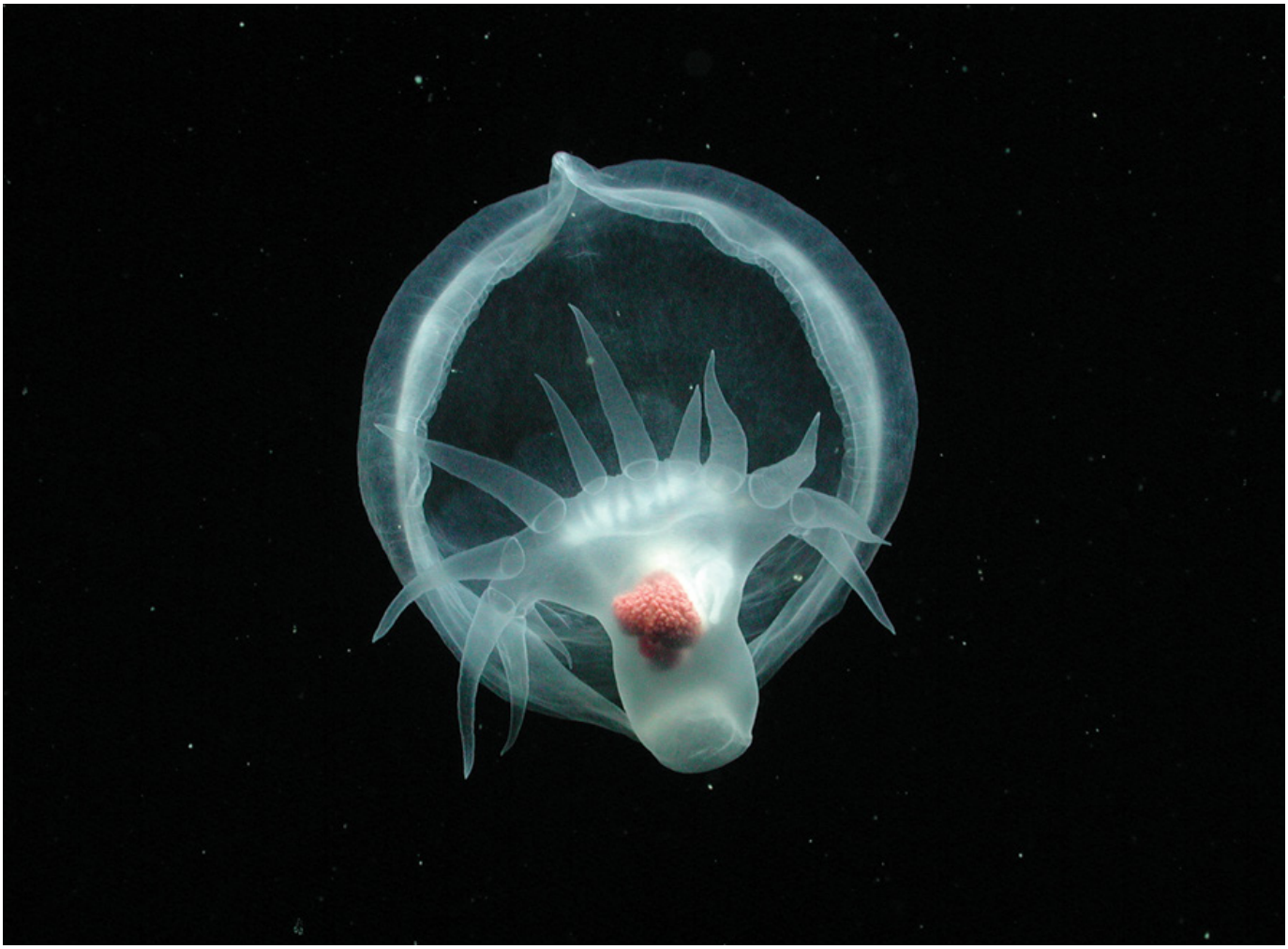
Rather than skittering across water like basilisk lizards do, the frogs were rapidly "porpoising"—leaping from the water as they swam. Weiss says their legs may be too slow for true surface hopping. "To jump on the water's surface, you have to have your legs retracted and ready to push down again by the time you're approaching the water in every jump," she explains. "And these frogs don't prepare for their landing at all; they sort of just belly flop. They don't retract their legs fast enough to immediately jump again" from the surface.

According to Jasmine Nirody, an organismal biophysicist at the University of Chicago, who was not involved in the study, "fast animal movements can be really deceiving," and the new camerawork reveals what the frogs are actually doing. By carefully analyzing such motions, "we can think about how we might be able to use [the frog's] strategy in various bioinspired robots," she adds. "Now we know what to look for." —*Rohini Subrahmanyam*



Courtesy of Jake Socha (*top*)

Graphic by Brown Bird Design



SCIENCE IN IMAGES

Mystery Mollusk

A strange creature's identity is "unhooded"

ABSOLUTE DARKNESS. Crushing pressure. Icy cold. The Pacific Ocean's "midnight zone"—between 3,300 and 13,100 feet deep—is not a welcoming place. But that hasn't deterred one delicate, baffling "mystery mollusk" species from setting up shop in this inhospitable water column.

For more than 20 years scientists at California's Monterey Bay Aquarium Research Institute (MBARI) have occasionally encountered this five-inch translucent creature with a bizarre medley of traits. Its face is surrounded by an oversized hood that it uses to enfold prey and jet-propel itself like a jellyfish. Its tail is fringed with tentacles, and if provoked, it can detach one. When touched, its hood and tail glow with a constellation of blue-green dots like an underwater planetarium.

Now scientists have determined that this deep-sea enigma is a nudibranch, or sea slug—but one so odd that it merits the creation of an entirely new nudibranch family, the researchers report in *Deep Sea Research,* Part I: *Oceanographic Research Papers*. Dubbed *Bathydevius caudactylus*, it's the first nudibranch known to live in the deep-sea water column rather than, for example, lurking on the seafloor or floating near the surface.

The animal features a unique grab bag of traits of other nudibranchs, says study coauthor and MBARI marine biologist Steven Haddock. Haddock was present when scientists first spotted the mollusk, during exploration using a remotely operated vehicle in 2000. "We were all spitballing what we thought it was," he recalls.

In the two decades since then, the researchers have observed more than 100 *B. caudactylus* and studied some in their laboratories. Genetic analysis revealed the creature probably belongs to a family that split from the other nudibranchs long ago—so even though it shares some features with other species, it evolved its eclectic range of traits independently. "Similar features can evolve multiple times, but to see it happen in such a unique kind of organism under such different circumstances than what we see in other nudibranchs is pretty cool," says Jessica Goodheart, a mollusk researcher at the American Museum of Natural History in New York City. "Maybe [such features] can evolve much more easily than we anticipated." —*Jude Coleman*

COLLECTIVE BEHAVIOR

Crawling Traffic

Ants' strategies could help self-driving cars avoid traffic jams

FROM AN AIRPLANE, cars crawling down the highway look like ants. But actual ants—unlike cars—somehow manage to avoid the scourge of stop-and-go traffic. Researchers are now studying these insects' cooperative tactics to learn how to program self-driving cars that don't jam up.

The free flow of traffic becomes unstable as the density of cars increases on a highway. At 15 vehicles per mile per lane, one driver tapping their brakes can trigger a persistent wave of congestion. "It's a kind of phase transition," like water turning from a liquid to a solid form, says Katsuhiro Nishinari, a mathematical physicist at the University of Tokyo, who studies these jamming transitions.

Nishinari's previous research had shown that foraging ants can maintain their flow even at high densities. So what's their secret? In a recent study published in *Transportation Research Interdisciplinary Perspectives,* researchers recorded *Ochetellus* ants on foraging trails and used traffic-engineering models to analyze their movement. They found that the ants don't jam because they travel in groups of three to 20 that move at nearly constant rates while keeping good distances between one another—and they don't speed up to pass others.

Human drivers at rush hour are hardly inclined to follow such rules. "We're maximizing the interests of individuals, [which] is why, at a given point, you start to have a traffic jam," says study co-author Nicola Pugno, who studies sustainable engineering at the University of Trento in Italy. But self-driving cars, if they one day become ubiquitous, could have more cooperative programming. In one vision of this future, autonomous vehicles would share information with nearby cars to optimize traffic flow—perhaps, the researchers suggest, by prioritizing constant speeds and headways or by not passing others on the road.

This vehicle network would be analogous to ants on a trail, which use scent to coordinate behavior while interacting with one another. "There is no leader," but this organization emerges anyway, says Noa Pinter-Wollman, a behavioral scientist currently studying ants at the University of California, Los Angeles. And in both ant and vehicle traffic, this type of distributed system can be "very, very strong" and resilient, Nishinari says. (Neither Nishinari nor Pinter-Wollman was involved in the new research.)

Still, ants can do a lot of things that cars—even self-driving ones—can't, Pinter-Wollman points out. Ants can forge trails as wide as they like, unlike drivers stuck on highways. The insects do sometimes jam up when confined in tunnels, but to keep things moving, "they'll find a way to walk on the ceiling," she says. Plus, unlike cars, ants don't crash; they can literally walk over one another.

Today's drivers can learn at least one thing from ants to avoid causing a traffic jam, Nishinari says: don't tailgate. By leaving room between their car and the one ahead of them, drivers can absorb a wave of braking in dense traffic conditions that would otherwise be amplified into a full-blown "phantom" traffic jam with no obvious cause. "Just keeping away," he says, can help traffic flow smoothly. —*Allison Parshall*

Fabio Di Biase/Getty Images

HEALTH

Altitude Aptitude

An unlikely organ helps Sherpas thrive at extreme altitudes

FOR MOST MOUNTAINEERS, some level of altitude sickness is inevitable. But Indigenous highlanders living on the Tibetan Plateau, known as Sherpas, have inhabited the high Himalaya long enough to have an evolutionary edge at tolerating elevation compared with lowlanders born and raised farther down. For a study in the *Proceedings of the National Academy of Sciences USA*, researchers compared Sherpa and lowlander blood samples during a Himalayan trek to investigate the Sherpas' aptitude for altitude—and they found a crucial clue in the kidney.

The thinner atmosphere up high can lead to hypoxia, a dangerous lack of oxygen. This condition, which often occurs during medical events such as heart failure, can also cause acute altitude sickness; mountaineers can become nauseated, dizzy and disoriented, in severe cases developing deadly fluid buildup in the lungs and brain. Studying the physical responses of altitude-adapted people reveals how their bodies keep them healthy during hypoxia.

Hypoxic people breathe faster to bring more oxygen into their lungs. But extra breathing also empties the lungs of more carbon dioxide than usual, which in turn reduces the production of carbonic acid in the blood. And even tiny changes in acidity risk damaging the proteins and enzymes that keep our cells functioning. Once blood acidity shifts, "the only thing that can fix it is the kidneys," says study co-author Trevor Day, a physiologist at Mount Royal University in Alberta.

To examine highlanders' blood acidity at altitude, Day and his colleagues recruited 14 Sherpas and 15 lowlanders from among university students in Kathmandu, Nepal, and ran initial blood tests at 4,200 feet. Next came a nine-day journey to 14,000 feet to take another blood sample. The lowlanders' blood became more alkaline as they ascended, but Sherpas' blood acidity didn't change; their kidneys' filtering action balanced the alkaline and acidic ions.

All study participants lived in lowland areas in the months before the expedition. This window left plenty of time to undo temporary altitude acclimation from spending time higher up, so the Sherpas' improved blood-acidity regulation is most likely from permanent differences between highlander and lowlander kidneys, the researchers say. "We think there are genetic changes that drive differences in kidney function," says Day, who hopes to isolate them.

These results complement earlier findings that Sherpas have more blood plasma than other people. This watery liquid thins their blood so it can flow faster and deliver oxygen throughout the body more quickly. "The kidney is really involved in regulating plasma volume," says biological anthropologist Cynthia Beall of Case Western Reserve University, who was not involved with Day's study. Together, these findings highlight the kidneys as unsung heroes during hypoxia and as a key focus for future research on the effects of high altitudes.

—Sasha Warren

Solovyova/iStock/Getty Images Plus

Sweet Gut
A microbe could be steering us toward the candy aisle

MICROBIOLOGY We might hate to admit it, but we aren't in complete control of our own bodies; bacteria can sometimes reign supreme, even in our hankering for a cookie or a glass of sweet tea. A recent study in *Nature Microbiology* identifies a connection between the abundance of a common bacterium in a person's gut and the amount of sugar the person consumes. The results could help researchers develop novel treatments for a variety of metabolic conditions.

Yong Q. Chen, a cancer biologist at China's Jiangnan University, and his team had been investigating the role of a protein called free fatty acid receptor four (FFAR4) in mice's fat-metabolism process. Initially they put the rodents on a high-fat diet. "One day I suggested using a high-carbohydrate [high-sugar] diet for comparison, and the results were surprising," Chen says. "We expected that a fatty acid receptor may regulate fat preference. Surprisingly, it modulates sugar craving instead."

Chen's team found that less FFAR4 in mice correlated with a greater preference for the high-sugar diet. The researchers also compared FFAR4 levels in both mice and humans with diabetes with those in counterparts without the condition, and the levels turned out to be significantly lower in the diabetes groups. That's where the gut microbiome comes in; the scientists also found that in mice, lower FFAR4 levels were tied to a decreased abundance of a gut microbe called *Bacteroides vulgatus*.

The researchers investigated how this bacterium might be involved and found that a metabolite produced by *B. vulgatus,* pantothenate—better known as vitamin B_5—triggers production of the hormone GLP-1, which regulates appetite. In other words, less FFAR4 means less *B. vulgatus*, less pantothenate and less GLP-1.

This newly identified interplay of receptors, hormones and appetite reveals just one of the stealthy ways our gut microbes work to keep us healthy.

"I was happy to find that the study further supports the existence of intrinsic interactions between host and microbiome," says Sergueï O. Fetissov, a physiologist at the University of Rouen Normandy in France, who was not involved in the research. He says the identification of pantothenate from *B. vulgatus* as a molecule that stimulates GLP-1 secretion and reduces sugar preference is "a major finding" because it could open up new treatments for type 2 diabetes.

Elisa Caffrey, a microbiology and immunology doctoral candidate at Stanford University, agrees, noting the potential of vitamin B_5 supplementation or even a drug to increase the amount of FFAR4, although more research, including clinical trials, is needed first. (Caffrey was also not involved in the study.)

But there are still unanswered questions. *B. vulgatus* isn't the only microbe that influences GLP-1 production; Fetissov's team previously found that *Escherichia coli* also stimulates its release. Comparing *B. vulgatus* with other GLP-1-regulating factors needs further exploration, Chen says. —*Claire Maldarelli*

Illustration by Thomas Fuchs

NUTRITION

Still Processing

Ultraprocessed foods give grocery consumers little choice

MOST U.S. GROCERY STORES seem to offer endless options in their aisles, which are full of cereals, pastas and baked goods available in hundreds of shapes and flavors. But a closer look at these foods' ingredient lists shows that in some ways, there's not much choice at all. A recent study found that most of the products on our grocery shelves have one big thing in common: they're highly processed.

Grocery stores, not fast-food outlets or convenience stores, are the primary source of ultraprocessed foods in U.S. diets. Such foods are made using industrial processes and ingredients that aren't found at home. To measure just how prevalent these foods are on shelves, researchers used a machine-learning algorithm to analyze more than 50,000 items at three major chain stores that sell groceries in the U.S.: Whole Foods, Walmart and Target. The results, published in *Nature Food,* revealed that highly processed options dominated the inventory at all three retailers. But Walmart and Target stocked a higher proportion than Whole Foods, which offered a slightly greater variety of minimally processed choices.

Having a wide array of brands available gives shoppers the "illusion of choice," says study co-author Giulia Menichetti, a statistical and computational physicist at Brigham and Women's Hospital and Harvard Medical School. Despite the variety in their packaging, most ultraprocessed foods share a common formula: they're high in sugar, salt and oil, and they typically contain additives that enhance their flavor, color and shelf life. Certain industrial processes also alter the texture of the raw ingredients, and these steps can strip foods of their nutrients.

Diets high in ultraprocessed foods have been linked to poor health, including higher risks of obesity, type 2 diabetes and heart disease. Not all these foods are equally bad for you, however. A 2024 study by researchers at the Harvard T. H. Chan School of Public Health found that diets high in sugary drinks and processed meats were associated with a higher risk of cardiovascular disease than diets low in these foods, but the opposite was true for ultraprocessed breads, cereals, yogurts and dairy desserts. But even though such foods can be part of a healthy diet, the new findings show that options within those categories are sometimes limited. Among breads, for example, consumer choices are often dominated by shelf-stable varieties that contain extra sugar and other additives instead of whole wheat bread that is minimally processed without additives.

Blaming health risks exclusively on the ultraprocessing of foods might oversimplify the problem, says Maya Vadiveloo, an associate professor of nutrition at the University of Rhode Island and chair of the American Heart Association's lifestyle nutrition committee. Diets high in ultraprocessed foods are often dominated by items loaded with saturated fats, salt and added sugar, Vadiveloo says, which suggests some harm might come from poor nutrient balance rather than processing alone. But some research suggests that ultraprocessed foods—which often lack protein and are designed to be easy to eat and highly palatable—can lead to overconsumption and corresponding weight gain, too.

While researchers learn more about the specific harms of ultraprocessed foods, the challenge for consumers lies in the limited alternatives available. In some categories, consumers face little to no real choice, according to the *Nature Food* study. Certain products—such as chips, bread and pizza—were almost universally ultraprocessed across the three stores. Other categories such as cereals, milk and snack bars offered more options that ranged from

Most ultraprocessed foods are high in sugar, salt and oil, with additives for flavor, color and shelf life.

Emmanuel Faure/Getty Images

minimally processed to highly processed. But the choices depend on where you shop. The cereals at Whole Foods, for example, had a wider range of processing and contained relatively less sugar and fewer flavor additives compared with the other two chains' cereals, which were far more likely to contain corn syrup.

Affordability complicates the picture. Menichetti and her colleagues found that generally, as the level of processing increased, the price per calorie decreased—a trend that was most pronounced in soups, cakes, macaroni and cheese, and ice cream. On average, ultraprocessed foods cost about half as much as their minimally processed counterparts, which reinforces nutritional inequalities, Menichetti says. "This is hitting a specific segment of the population," she adds.

The real proportion of ultraprocessed foods on our shelves could be much, much higher than has been reported, says Barry Popkin, a distinguished professor of nutrition at the University of North Carolina at Chapel Hill, who was not involved in the study. He adds that the authors used a "guesstimate" of what foods counted as ultraprocessed, as well as "a sample representing about an eighth of the unique packaged foods in the U.S."

The study's new scoring method marks a shift from the widely used NOVA classification, which defines ultraprocessed foods as those containing additives or industrial ingredients. The authors' system, called FPro, goes a step further. It estimates the degree of processing by analyzing a food's nutrient profile—in other words, it recognizes that "processed" foods exist along a spectrum. The team is now refining the model to predict the specific industrial processes a food undergoes before reaching consumers.

Beyond the complexities of scoring processed foods, Popkin offers a simple rule to follow: shop for items around a store's perimeter as much as your budget allows—"the produce, the fish, the dairy," he suggests. And although a processing score might distinguish between similar-looking items, less processed doesn't necessarily mean healthy. A cookie is still a cookie, Vadiveloo says, no matter how it is processed.

—Lori Youmshajekian

Source: "Prevalence of Processed Foods in Major U.S. Grocery Stores," by Babak Ravandi et al., in *Nature Food*. Published online January 13, 2025 (*data*)

Quantifying Degree of Processing in 42 Foods

Researchers assigned a food processing score, or "FPro" value, to each product in a database of more than 50,000 food items and sorted the products into 42 categories. The results show that foods within the same category can vary widely from minimally processed to highly processed—and that in some categories, a high degree of processing is virtually unavoidable.

Graphic by Amanda Montañez

ENVIRONMENT

Smelling Trouble

Dogs play pivotal roles in finding invasive species

One of the dogs trained to track down spotted lanternflies

FROM SNIFFING OUT rare species to tracking down poachers, dogs aid conservation efforts in a surprising variety of ways. And a growing list of successes shows how our best friends' legendary noses can be an especially powerful weapon in the battle against invasive organisms. Lately dogs have proved to be particularly useful allies against one infamously unwelcome guest: spotted lanternflies.

Native to Asia, these insects were seen in Pennsylvania in 2014 and soon spread across the eastern and central U.S. The species is especially threatening to vineyards, as it can severely damage grapevines over time.

"Once it's spread into a new area, getting rid of that infestation early on is really important," says Angela K. Fuller, an ecologist at Cornell University. But that also means finding and destroying spotted lanternfly egg masses, whose light-brown, dirtlike camouflage makes them extremely difficult to see.

For a recent study in *Ecosphere*, Fuller and her team pitted dogs against humans at finding spotted lanternfly eggs in various scenarios. The researchers spent several months training a Labrador retriever and a Belgian Malinois to find the eggs, and then they set the dogs to work in 20 Pennsylvania and New Jersey vineyards. Humans did better within the vineyards, where they could search systematically up and down the vines—but the dogs detected over three times more egg masses in nearby forested areas. Fuller suggests that dogs could also be more effective in vineyards with lower-level infestations, catching the scent in large areas that would be too time-consuming for humans to search.

"I think it is a very nice and thorough study," says Nathaniel Hall, an animal behaviorist at Texas Tech University who studies dogs' sense of smell and was not involved in the research. "It is helping lay the groundwork for use."

According to Ngaio Richards, a canine handler and forensic ecologist at the University of Florida and at Working Dogs for Conservation, this is an ever expanding field of research—and practical use. "Worldwide, detection dog teams are being integrated into efforts to deter, monitor and combat the presence of invasive species," she says, from insects and plants to fish and mammals.

In North America, trained dogs inspect watercraft to detect invasive mussels before they catch a ride to new waters. Dogs have also been tested at finding longhorn beetles, brook trout and nutria. In Montana, dogs identify dyer's woad, an invasive plant that can harm native vegetation and is hard for humans to detect during parts of its life cycle.

"Dogs tend to be an excellent real-time detector that is hard to match," Hall says. "I think there is an untapped capacity for broader use." —*Gennaro Tomma*

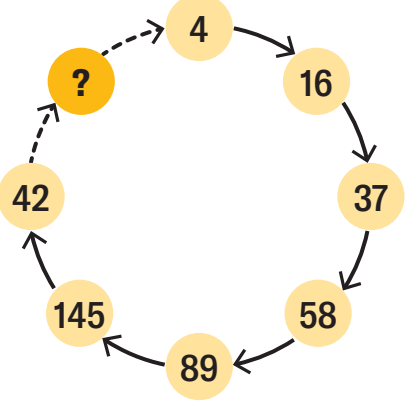
MATH PUZZLE

Finish the Cycle

By Heinrich Hemme

EIGHT NUMBERS emerge in sequence according to a certain system. One number is unknown. Can you figure out what it should be?

For the solution, visit www.ScientificAmerican.com/games/math-puzzles

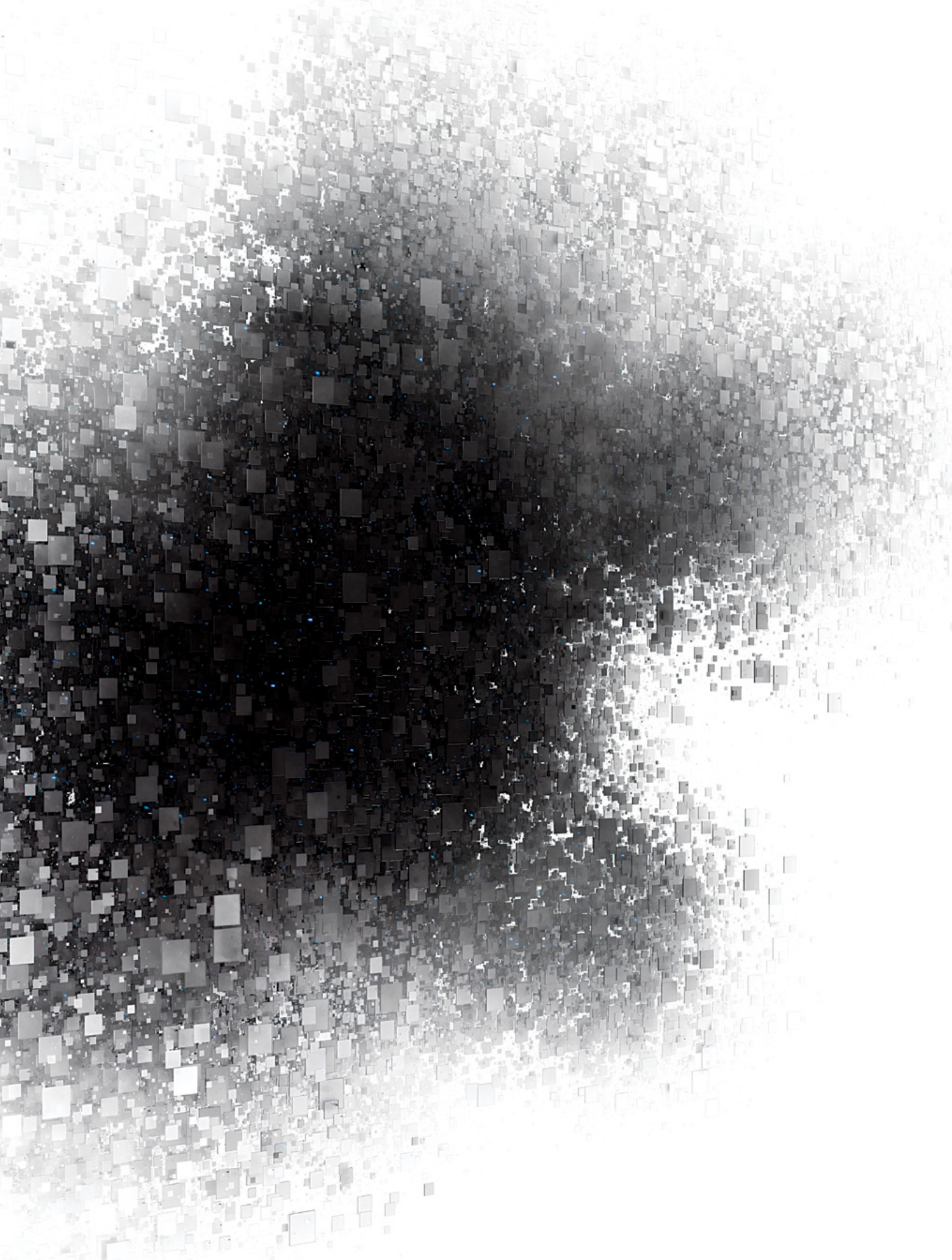


Angela K. Fuller (top); *Spektrum der Wissenschaft* (bottom)

The Hidden World

Dark matter could be an entire dark sector of the universe, with its own particles and forces—and researchers are designing experiments to search for it

BY KATHRYN ZUREK
ILLUSTRATION BY MACIEJ FROLOW



HAVE YOU EVER STOOD BY THE SEA and been overwhelmed by its vastness, by how quickly it could roll in and swallow you? Evidence suggests that we are suspended in a cosmic sea of dark matter, a mysterious substance that shapes galaxies and large structures in the universe but is transparent to photons, the carriers of the electromagnetic force. Our galactic home, the Milky Way, is submerged in dark matter, but this hidden body but does not devour us, because its forces cannot touch the regular matter we're made of.

Everything we know about dark matter comes from measuring its gravitational pull, but gravity is the weakest of nature's forces—so feeble that the electromagnetic forces that bind atoms to make a chair we can sit in are enough to counteract the gravitational force of the entire Earth. Just as we need the electromagnetic force to tell us about protons, neutrons, electrons and the richness of all the particles we know of—collectively called the Standard Model of particle physics—we need more than gravity to unlock the secrets of the dark side. As a result, the past three decades of the search for dark matter have been characterized by null results. For most of that time, researchers have been looking for a single particle to explain dark matter.

Yet dark matter might not be one particular particle—it may be a whole hidden sector of dark particles and forces. In this dark sector, particles would interact through their own independent forces and dynamics, creating a hidden world of cosmology running parallel to our own. There could be dark atoms—made of dark protons, dark neutrons and dark electrons—held together by a dark version of electromagnetism. The carriers of this force, the dark photons, might (unlike our photons) have mass, allowing huge dark atomic nuclei—so-called nuggets—to form. And the totally different dynamics of dark matter in this dark sector would have different effects on the evolution of normal matter throughout time. The interactions of nuggets in galaxies could help form supermassive black holes in the centers of galaxies, causing them to grow larger than they otherwise would.

Kathryn Zurek is a theoretical physicist at the California Institute of Technology. Her research focuses on the intersection of particle physics with cosmology, astrophysics and the quantum nature of gravity.

As other, simpler theories of dark matter have failed to find experimental confirmation, the dark sector concept has gained traction. My colleagues and I have also developed novel plans for experiments that can search for this type of dark matter. These experiments use techniques from condensed matter physics to attempt to uncover a sector of the cosmos we've never searched for before.

WHEN I ENTERED THE DARK matter hunt in 2005, physicists were focused on searching for dark matter whispers from the weak force. Despite its name, the weak force is much stronger than gravity, and scientists suspected that dark matter might communicate with our world through this force. They built many extremely sensitive experiments, buried underground where everything is quiet, to attempt to hear such murmurs.

It was an exciting time because astrophysicists were also seeing unexplained

data coming from the center of the Milky Way that might have been a sign of dark matter producing a haze of photons from some kind of interaction with the weak force. I found these ideas intriguing, but I wasn't convinced that the Milky Way signal came from dark matter. It seemed premature to focus the search for dark matter on theories related to the weak force. In addition, many processes from ordinary physics produce the microwave photons that were emanating from the center of our galaxy.

At the first dark matter conference I attended after graduate school, I took a bet with a primary proponent of the "dark matter haze" idea, Dan Hooper of the University of Wisconsin–Madison. Hooper thought we could confirm that these observations were caused by dark matter within the next five years. I took the skeptical position. The stakes of the bet: whoever lost would have to say that the other was right in each of their scientific talks for one year. It was a consolation that if I lost, I could still bask in the joy of dark matter having been discovered. This bet would accompany me for the next 13 years of my scientific career.

Sometimes our assumptions end up binding us, preventing us from finding the solutions we seek. The first ideas for the nature of dark matter focused on solving the theoretical problems of the Standard Model, which describes not just the known particles but the quantum forces (electromagnetism, the weak force and the strong force). Two puzzles of the model are why the weak force is so much stronger than gravity (what physicists call the hierarchy problem) and why the strong force—the force that binds atomic nuclei—doesn't notice the difference between mirrored particles and antiparticles (called the strong charge conjugation–parity, or strong CP, problem). Particle physicists hypothesized that adding new particles to the Standard Model could help us understand why the known particles behave like they do. These new particles might also exist in the right quantities to explain dark matter.

Two categories of particles emerged as popular candidates. One group, called WIMPs (for weakly interacting massive particles, lest you doubt the field has humor), features in solutions to the hierarchy problem. Another set of proposed particles, axions (after the laundry detergent, as a metaphor for cleaning up the

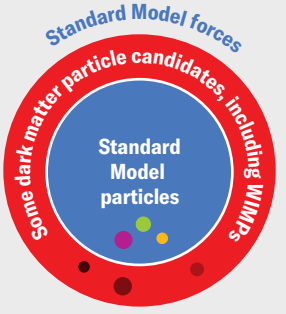
Dark Matter Options

Scientists have traditionally thought that the invisible matter pervading our universe most likely is made of a single type of particle. An increasingly popular idea suggests, however, that dark matter might be made of an entire "dark sector" of hidden particles.

TWO WAYS OF THINKING ABOUT DARK MATTER

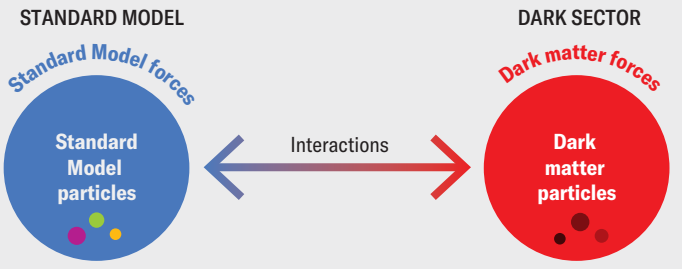
Paradigm 1

In the traditional paradigm dark matter is part of a solution to perplexing aspects of the Standard Model forces and has its interactions fixed by being able to solve those problems. In contrast, hidden sector dark matter is not dependent on resolving Standard Model puzzles.



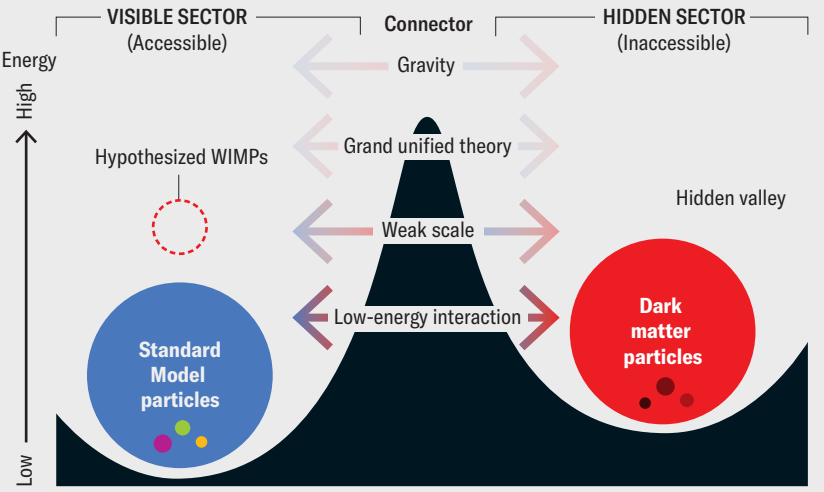
Paradigm 2

The new paradigm, on the other hand, envisions a separate set of "dark forces" to go with the dark sector particles.



DARK SECTOR PARTICLES AND THE HIDDEN VALLEY

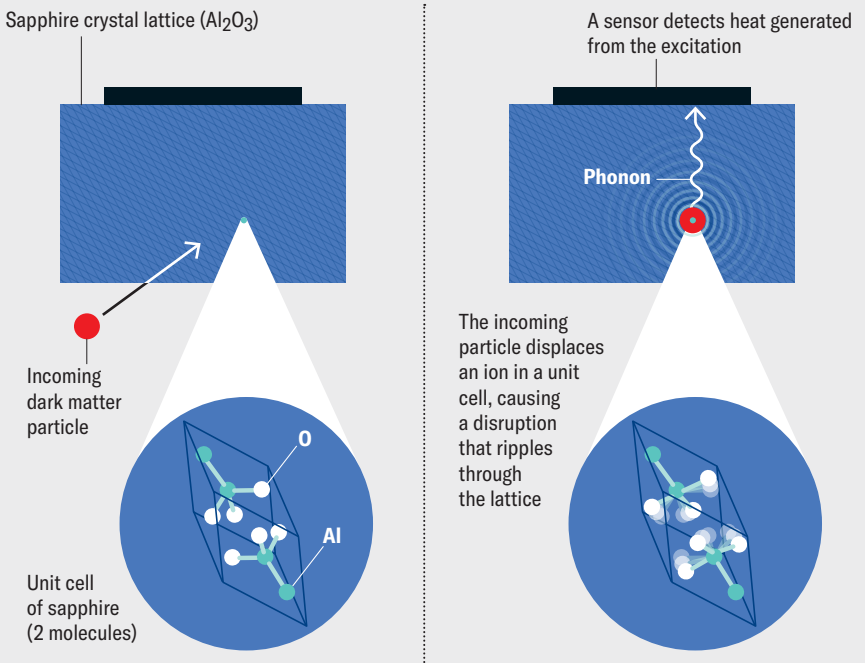
In this model, dark matter particles could occupy a so-called hidden valley of the energy scale. The dark sector particles would exist at lower energies than some traditional hypothesized dark matter particles such as WIMPs—and may not have been observed in experiments simply because their interactions with ordinary particles are much weaker than the weak force. To detect the hidden valley, we must find a connector—an interaction between regular and dark matter that can tunnel through the accessibility barrier lying between them.



Graphics by Jen Christiansen

Detecting Dark Matter with Crystal Lattices

Reaching the dark sector through laboratory experiments will require different strategies than traditional dark matter searches. If dark sector particles interact with regular matter (aside from gravitationally), they are likely to induce collective excitations, called phonons, in the crystal lattice structure of regular matter. The crystal lattice can be thought of as a pattern of "unit cells" that repeats over and over. A proposed experiment aims to search for phonons in a lattice of sapphire caused by dark matter.



problem), offered a solution to the strong CP problem.

I thought, however, that we should question the premise that dark matter also solved the Standard Model problems. My imagined particles didn't interact via any Standard Model forces—they would have their own independent forces and dynamics—so they couldn't solve that model's mysteries. They were also much lower in mass than WIMPs and occupied a hidden valley of the energy and mass scale for particles. This idea, which I proposed around 2006, went counter to the trend in high-energy physics, which focused on building huge experiments, such as CERN's Large Hadron Collider near Geneva, to produce the increasingly massive particles that theorists envisioned. In contrast, hidden valley particles would occupy much lower-energy territory and may not have been observed in experiments simply because their interactions with ordinary particles are much weaker than the weak force.

Without the idea that dark matter should solve either the hierarchy problem or the strong CP problem, an entire range of new models became theoretically viable and consistent with observations of our universe. I focused on the idea that the hidden valley provided a natural host for the dark matter sector. The different dynamics of dark matter in the dark sector compared with WIMPs would have different effects on the evolution of normal matter throughout time.

As my colleagues and I studied the possible implications of a dark sector over the next decades, the range of observable consequences in our universe blossomed. The field looks completely different now. Dark sector theories have been aided along the way by fortuitous experimental anomalies.

THE LUCKY ANOMALIES arrived in 2008 from experiments that had been looking for WIMP dark matter. By this time experimentalists had already spent two decades building Earth-based experiments to look for dark matter from the supposed sea that must be passing through Earth at all times. In 2008 three of these saw a mysterious, unexplained rise in "events" at low energies. An event, in this case, means that a single dark matter particle may have slammed into a regular atomic nucleus in the detector and given it a kick of energy. The experiments registered events that could have been caused by dark matter particles weighing a few times the mass of the neutron.

The excesses in these experiments electrified me because they were consistent with a theory of hidden valley dark matter I had proposed the previous year. I called this theory asymmetric dark matter. The theory was based on the idea that the amount of dark matter in the universe is determined by how that matter interacts with neutrons and electrons. We can take this number, set by theory, and combine it with the total mass of all the dark matter in space (which we know from astronomical observations) to calculate the mass of the most common dark sector particles. It turns out that the theorized particles should weigh about as much as neutrons—just what the experiments were observing.

The arrival of these anomalies made the field of hidden sector dark matter very popular. The online repository for new physics papers exploded with studies suggesting possible explanations for the excesses with different types of hidden sectors. It suddenly seemed I might lose my bet that dark matter would keep itself hidden. But the observations and the theories weren't quite lining up, and the models became more baroque and contorted to fit the experimental data. By 2011 my belief that the anomalies could be evidence of dark matter faded.

Not everyone agreed. Hooper, ever the optimist, still thought that the anomalies could be dark matter, so he upped the bet and threw in two top-shelf bottles of wine. Eventually, though, further checks of the anomalies convinced most physicists that most of the observations must have a mundane explanation, such as a background signal or detector effects contaminating the data. My top-shelf bottles of wine from Hooper arrived during the pandemic in 2020.

But that wasn't the end of the story. The long-term impact of these anomalies opened researchers' minds to new theories of dark matter beyond WIMPs and axions. This change was aided by the fact that decades' worth of experiments designed to find WIMPs and axions had so far turned up nothing. Even the Large Hadron Collider, which many scientists expected to find WIMPs and other new particles, found nothing new except for the last unconfirmed piece of the Standard Model, the Higgs boson. More and more physicists recognized that we needed to widen our search.

In 2014 I moved from the University of Michigan to Lawrence Berkeley National Laboratory, where I turned my attention from dark matter theories to devising new methods of dark matter detection. Working in this area radically broadened my horizons in physics. I learned that studying the fundamental forces of nature is not sufficient to understand how dark matter might interact with regular matter. For such rare and weak communications between particles, the interactions between the fundamental constituents of matter (the nucleons and electrons in atoms) become paramount. In other words, to understand how a dark matter particle might affect a typical atom, we must consider the small interactions among the atoms arranged in a crystal lattice inside a material. Imagine the coils in an old-fashioned mattress: if one part of a coil gets pushed down, it propagates waves through the entire mattress.

Because many materials work like this, it stood to reason that if dark matter were to disturb one atom in a lattice of "normal" matter, it would set up a propagating disturbance. These collective disturbances, which involve many atoms, are quantum in nature and are called phonons or magnons. Understanding phonons is the domain of condensed matter and solid state physics, which focus on the collective effects of many atoms within a material. Because materials can be made up of lots of different kinds of atoms and molecules, with different bonds between them, the collective disturbances take on many forms, becoming a zoo of possible interactions.

One of my challenges was to understand how dark matter might interact with these collective phenomena. To do that, I needed a useful model that described all the complicated effects with just a few parameters. I found that I could predict how likely different kinds of dark matter were to interact with a material if the force governing the interaction was the same as the force responsible for dark matter's abundance in our universe.

I ran into some practical challenges. Not all physicists speak the same physics language. In addition, each field tends to focus on just a few questions when studying a physical system. I was interested in very different questions than those that interest most practicing condensed matter physicists. And as a dark matter physicist collaborating with condensed matter physicists on collective excitations for the first time, I had barriers to surmount. Once I discovered how to rephrase my understanding of the dark matter interaction problem in the jargon used by condensed matter and atomic physicists, my students, postdocs and I were able to progress much more quickly.

In time, a new world of collective phenomena opened before us. We discovered that condensed matter and atomic, molecular and optical physicists had fun applying their portfolio of materials and detection mechanisms to the hunt for dark matter. After a few years of playing with an abundant array of ideas, we realized we needed to focus on just a few for experimental development. We ended up picking two materials that seemed like promising targets, both for their fundamental dark matter interactions and for how feasible their use in experiments was. Now we are actively designing experiments using these materials that we hope to run in the coming years.

The first category is polar materials, such as quartz and sapphire, which produce strong phonons with a collective energy that is a good match for dark matter and which seem like they would communicate well with a dark photon. The second material is superfluid helium, which is free from many of the defects that plague solid materials with crystal lattices. This liquid features light nuclei that may have a relatively good chance of interacting with dark matter.

FROM OUR ARCHIVES
What If We Never Find Dark Matter?
Tracy R. Slatyer and Tim M. P. Tait; September 2024.
ScientificAmerican.com/archive

For the next steps, our experimental partners are leading the way. My former Lawrence Berkeley Lab colleagues have developed two of the most promising ideas. Matt C. Pyle has proposed an experiment called SPICE (Sub-eV Polar Interactions Cryogenic Experiment), which would use a polar material such as sapphire for a detector. Another experimentalist, Daniel N. McKinsey, has envisioned the HeRaLD (Helium and Roton Liquid Detector) project, which would use superfluid helium.

Our theoretical work suggests that small samples of the target materials—one kilogram or less—could be enough to begin testing our theories. Although these samples would not require much material, they would have to be free of defects and be placed in very quiet and contaminant-free environments. Fortunately, through earlier generations of dark matter experiments searching for WIMPs, Pyle and McKinsey already have experience in reducing sources of noise and radioactivity by working deep underground.

Although all the theoretical ideas are in place for these experiments, it will take a long time to put them into action. Both projects have received a round of funding from the Department of Energy's Office of Science to further develop the concepts. Over the past four to five years, however, we've discovered new background processes that might imitate the signals we're hunting for, which we'll have to find ways to block. Because of these large backgrounds, the detectors are not nearly sensitive enough yet to discover dark matter. It may take a decade or more, as it did for the earlier generations of WIMP experiments, to learn how to make these detectors so quiet that they can listen for dark matter whispers.

Still, what we have achieved in the past 20 years is a dramatic opening of the theoretical possibilities for dark matter and the ways to find it. The fundamental nature of the dark matter that pervades our universe is still unresolved. As I work on this problem, I like to think about the building of cathedrals in centuries past, which were constructed over generations, each stone carefully placed on the last. Eventually, by building our understanding of dark matter bit by bit, we hope to reach a true comprehension of all of nature's constituents. ●

A SOFTER CORPS

ENVIRONMENT

The U.S. Army Corps of Engineers has uncharacteristically been working with nature instead of bulldozing it into submission. Will this enlightened approach prevail?

BY ERICA GIES

Floodwater inundates Pájaro, Calif., on March 12, 2023, after the Pájaro River, swollen with rain from an atmospheric river storm, breached local levees.

CONTROLLING NATURE by bulldozing dirt and pouring concrete has long been the guiding vision of the U.S. Army Corps of Engineers. For 250 years that ethos inspired both awe and disgust. "In my science training, the Army Corps destroyed everything. They're the enemy," says geomorphologist Julie Beagle, who spent much of her early career working to repair ecosystems damaged by "gray" infrastructure such as dams and levees built by the Corps. "My first boss had a sign on her desk that said, 'Kill the Corps.'" To such critics, damaging nature was the Corps's core competence.

So plenty of people were skeptical in 2010 when the Corps rolled out an Engineering with Nature (EWN) initiative, saying it now aspired to work with nature rather than dominate it—a dramatic change in culture and practice. Engineers and scientists are moving constrictive levees farther from riverbanks and reconnecting rivers with floodplains. They are reusing sediment dredged from shipping channels to strengthen disintegrating tidal marshes. They are partially acquiescing to rivers' chosen paths while retaining navigation channels.

The initiative is relatively small; there are seven EWN programs sprinkled across the Corps's 43 districts (five of which are international). But the changes convinced Beagle four years ago to leave her job at the San Francisco Estuary Institute and become chief of environmental planning for the Corps's San Francisco district. She is now one of four "practice leads" who demonstrate and teach EWN across the Corps's 37,000 employees. One example of her pioneering work is a big project in central California's Pájaro River basin designed to protect communities from flooding while recharging groundwater to aid farmers and restoring habitat for threatened fish.

Beagle's career move was risky, given the Corps's inertia. Its long insistence that it could and should reshape nature for economic benefit has dominated U.S. civil works culture and has been exported globally through Corps projects in more than 130 countries, a practice some call "hydrocolonialism."

Beagle says many people from her adviser's generation "really rolled over" when she and several other mid-career scientists she knew went to the Corps. But she saw the move as an opportunity to be "a cultural changemaker" in an agency that has remade vast landscapes and waterways. With a $7.2-billion budget for civil works in fiscal year 2025, the agency's employees oversee 24,000 miles of levees; 926 harbors that they keep dredged for shipping; 749 dams; 350 miles of beaches and dunes; numerous navigation channels and locks; and seawalls and bulkheads along hundreds of miles of coast. How the Corps thinks and what it does shape our world.

The consequences of its decisions can be deadly. The most horrific failure in recent memory occurred during Hurricane Katrina in 2005. More than 1,400 people in New Orleans and the Gulf region died when levees and floodwalls gave way; 80 percent of New Orleans lay underwater, some areas for 43 days. The Gulf's famous marshes help to protect human communities from storm surges, but more than a century of levees and dams on the Mississippi River had deprived the marshes of 70 percent of the sediment they need to stand up to a relentless sea. More than 2,000 square miles have eroded away since the 1930s. Shipping canals have sliced and diced freshwater marshes, providing pathways for salt water to infiltrate and kill vegetation and for storm surges to rear up and overtake near-shore communities. Katrina bowled straight up a wide navigation channel called the Mississippi River–Gulf Outlet that the Corps had cut through protective marshes.

Erica Gies
is author of *Water Always Wins: Thriving in an Age of Drought and Deluge* (University of Chicago Press, 2022). She wrote about the radical reconstruction of nearly dead urban streams in our April 2022 issue.

Shae Hammond/MediaNews Group/The Mercury News via Getty Images (*preceding pages*)

Levees are built to control nature, but nature often wins, as it did during the Pájaro River flood.

DRONE BASE/Reuters/Redux

The Corps's subsequent shift toward nature-based solutions—working with or mimicking natural systems—is part of an increasingly mainstream global movement. The 160,000-member American Society of Civil Engineers issued a policy statement last summer supporting the practice. People are increasingly recognizing the need for nature-based solutions as climate change is making floods and droughts more severe, and changes in land use—urban sprawl, industrial agriculture and forestry, levees and dams—have dramatically altered the water cycle and eroded healthy ecosystems that for centuries acted as buffers to destruction.

Nature-based solutions mean restoring the health of degraded ecosystems so they can provide clean water, absorb floods, store carbon, grow food and support life. Eileen Shader, senior director of floodplain restoration at American Rivers, a nonprofit that advocates for healthy waterways, says that in some cases, "you're solving the problem by unbuilding." Still, the Corps's concept of nature-based solutions tilts more toward engineering and concrete. As Jeff King, national lead of the EWN program, puts it, projects fall somewhere on "a continuum of green-gray."

The approach could rapidly become more widespread thanks to a Corps rule that went into effect in January 2025 that requires the agency to consider nature-based options on par with gray infrastructure options whenever feasible. The rule also expands the traditional cost-benefit analysis to factor in environmental and social gains of projects, even if it's impossible to assign a dollar figure. It is "the most significant policy-change update for the Corps in a generation, without a doubt," says biologist Todd Bridges, who in 2010 created the EWN program out of the Corps's research division, where he worked for 30 years.

Within weeks after President Donald Trump took office this year, his new administration began purging federal government websites of language that seemed progressive, freezing funds for scientific research, and dismantling departments that support human rights, science and the environment. It's reasonable to ask whether EWN—a progressive shift in a conservative agency—would be a target. The Project 2025 manifesto guiding many administration actions mentions the Corps only once, in passing, but that doesn't mean the agency will go untouched. At the end of January, in an unusual act, Trump ordered the Corps to release water from two federal reservoirs in California, with a stated goal of letting it flow about 200 miles south to help fire-ravaged Los Angeles. The Corps released 2.2 billion gallons, but the water did not come close to reaching the city. Local water managers scrambled to prevent flooding of nearby towns, while farmers were dismayed to see water they will need in the summer flushed away.

THE U.S. ARMY CORPS OF ENGINEERS is the engineering wing of the U.S. Army. Despite its military basis, its workforce today is 98 percent civilian. Its civil works

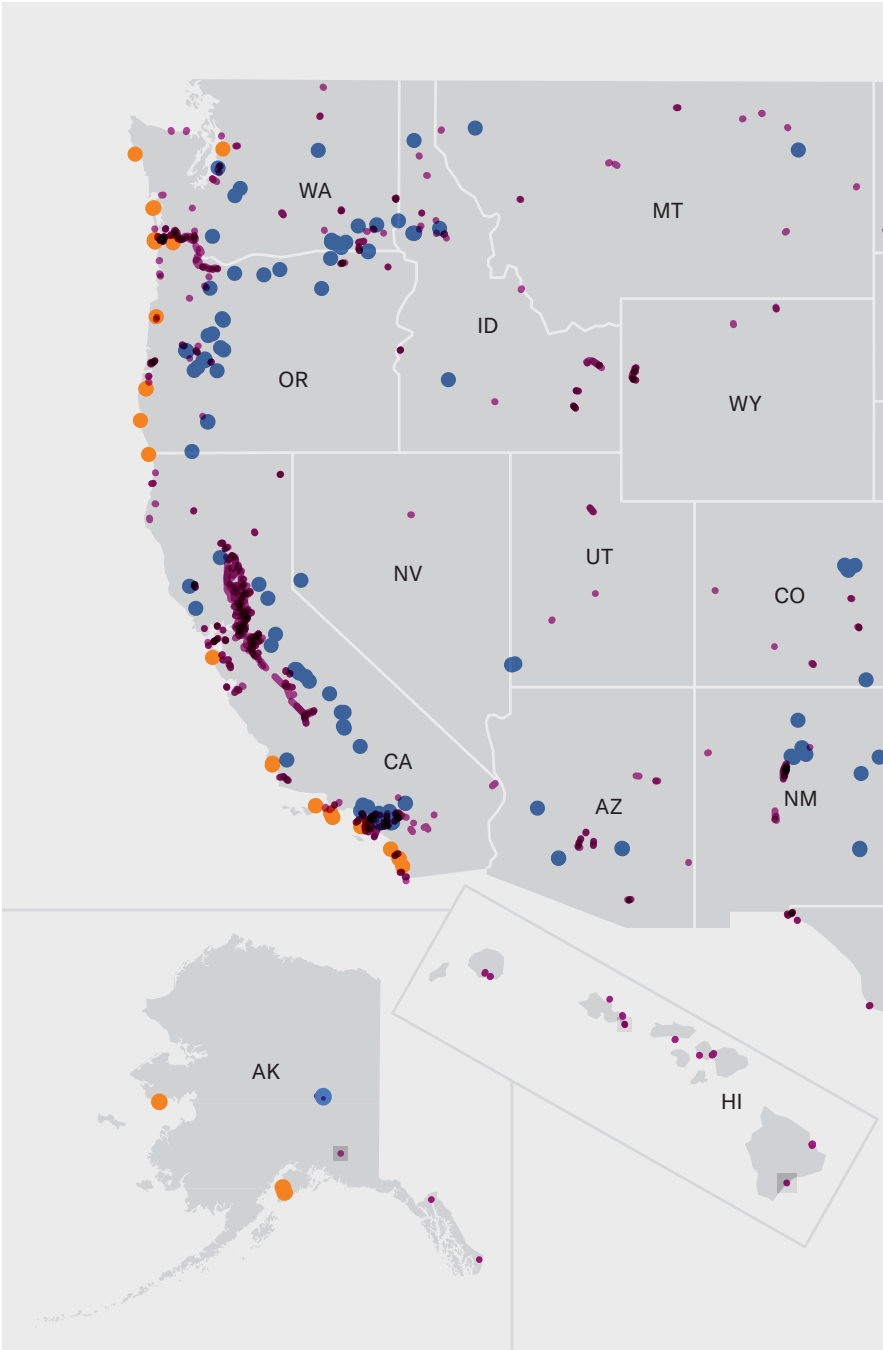
division is tasked with navigation, reduction of flood and storm damage, and environmental restoration. Local groups lobby Congress for work in their areas, and Congress authorizes projects and partial funding. Congressional authorizations have historically proscribed a single objective, such as flood-risk reduction, a narrow focus at odds with the systems-oriented thinking required for nature-based solutions.

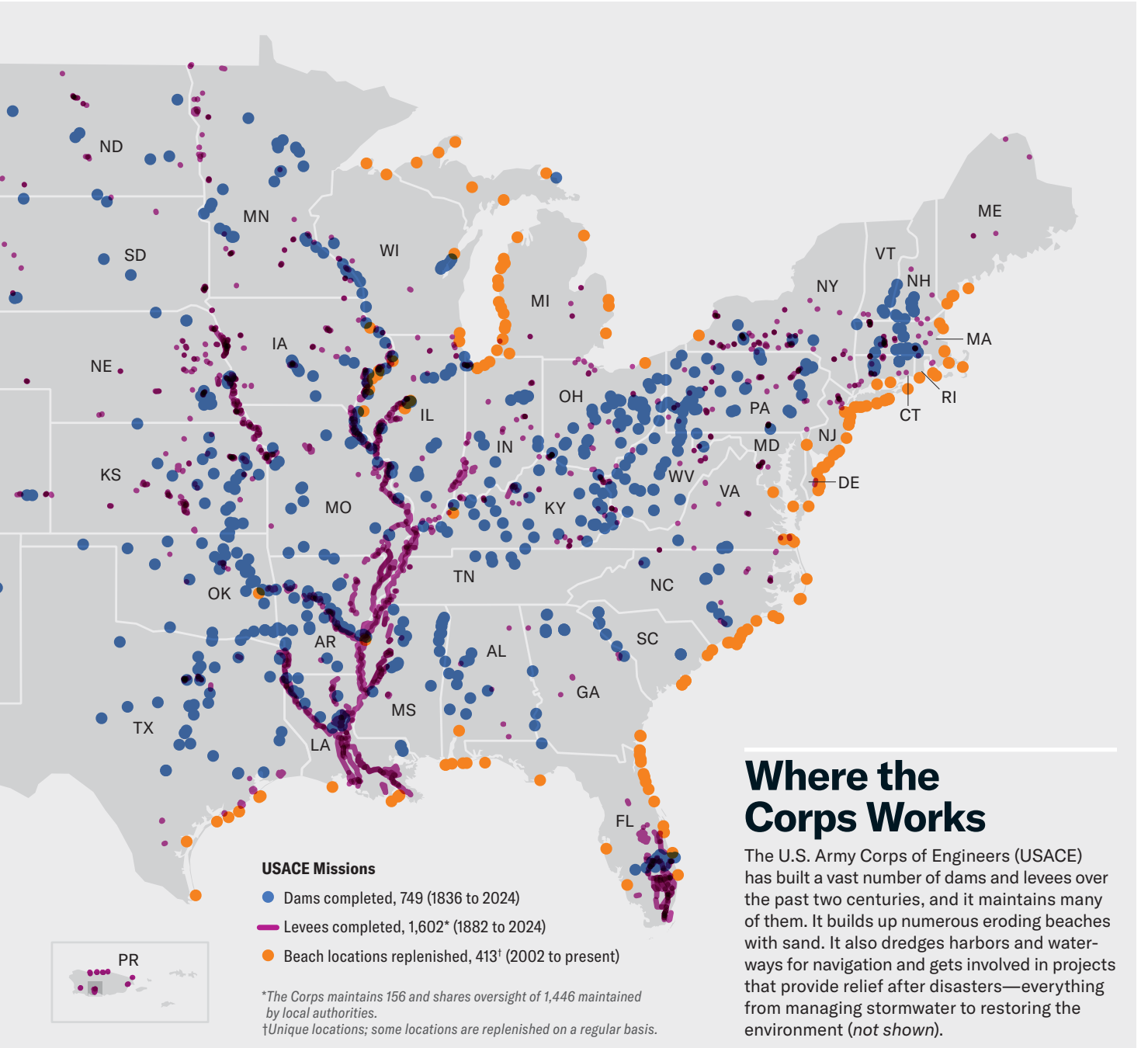
The Corps's urge to try to control nature was solidified in the mid-19th century, when dueling congressional reports outlined how to reduce Mississippi River flooding and ensure navigation. One advocated for a hybrid engineering-nature approach—using not only levees but also outlets to release high river flows, as well as wetlands to absorb rain. It lost out to another vision authored by a Corps engineer who argued for a levees-only approach. The belief that strong walls can best protect communities has dominated the engineering psyche ever since. But the unintended consequences can be extreme.

Florida's Kissimmee River was an early, expensive lesson. In response to prolonged flooding in 1947, the Corps wanted to rush away high river water instead of letting the river overflow onto its floodplains and wetlands. To create a straighter channel with faster water flow, it spent nine years, from 1962 to 1971, cutting out the river's natural meanders that slow water, shortening the waterway from 103 miles to just 56. The work dried out thousands of acres of wetlands and floodplains, harmed wildlife and increased the flow of pollution into Lake Okeechobee. Damage was immediate and so extensive that Congress authorized the Corps to put back the curves. "A hallmark of 20th-century engineering is that people simplified the natural in order to get what we want," says Bridges, now a professor of practice in resilient and sustainable systems at the University of Georgia's College of Engineering. Then he corrects himself: "What we think we want."

Simplifying the natural order can even worsen the problem engineers are trying to solve. Today 3,500 miles of levees line the Mississippi River. Each levee constricts space for water, raising the surface level higher, speeding up its flow, and worsening flooding for communities that lack a levee or are near one that breaks. Yet the Corps evaluates each new levee on its own immediate merits, not in conjunction with those on the rest of the river. As geomorphologist Nicholas Pinter of the University of California, Davis, has written, even the Corps has acknowledged that the result is "'death by a thousand blows,' through the incremental loss of floodplain land to development."

Another unintended consequence is that levees encourage people to move into harm's way. The Great Flood of 1993 left areas around the Missouri and upper Mississippi Rivers above flood stage for up to 195 days. The Corps worked with a St. Louis levee district to build a 500-year levee—an awkward term meaning the levee would limit the risk of flood in any given year to 0.2 percent (statistically, there is a one-in-500 chance of a flood happening any year). The levee made people feel safe enough to build, in the first decade alone, 28,000 new homes and more than 13 square miles of commercial and industrial development and roadways on land that had been underwater. But it's a false sense of security, revealed by a dark industry joke that there are two kinds of levees: ones that have failed and ones that will fail. "People think, 'Why do I flood?'" says Jo-Ellen Darcy, board chair of American Rivers. "Well, you're living in a floodplain. They're not named that for no reason." Indeed, floodplains are a classic nature-based solution. Their job, Darcy says, is "to absorb floods, and they can't do that if people are living there with concrete structures and malls."





Where the Corps Works

The U.S. Army Corps of Engineers (USACE) has built a vast number of dams and levees over the past two centuries, and it maintains many of them. It builds up numerous eroding beaches with sand. It also dredges harbors and waterways for navigation and gets involved in projects that provide relief after disasters—everything from managing stormwater to restoring the environment (*not shown*).

Sources: National Inventory of Dams; National Levee Database; USACE's Dredging Information System (*data*)

Map by Ripley Cleghorn

Katrina was a turning point in the Corps's approach, says Jane Smith, who was a senior research scientist there for 42 years and is now a professor of coastal hydrodynamics at the University of Florida. When Smith and her colleagues ran models after the storm, she says, "we started to see how incredibly important the wetlands were in terms of protection from hurricane storm surge and waves." Before that, "we didn't really think of the natural features that provide protection as being part of our projects," she adds. But Bridges recalls that many Corps employees outside the research division weren't ready to hear it. He says an engineer told him, "We don't need any of that tree-hugger science."

Before joining American Rivers, Darcy led the Corps's civil works as an assistant secretary of the U.S. Army from 2009 to 2017. During her tenure she emphasized an important tweak in language used by the Corps. "It wasn't 'flood control,'" she explains. "Nobody can control a flood." She used "flood-risk reduction," which acknowledges that reality—and sends a message within the Corps and to the public about the limits of what's possible.

Shader, at American Rivers, works with the Corps nationally and says the agency's current openness to what she considers effective nature-based solutions varies geographically. "San Francisco is absolutely the lead," she says. "They have a dedicated staff that is

Julie Beagle is leading an innovative Army Corps project that shows how to work with nature. Reconfiguring levees along the Pájaro River and its tributaries to slow down rushing storm water will protect people nearby, resupply underground aquifers and restore fish habitat.

working to create interdisciplinary teams and integrate these concepts into every project." That's partly thanks to Beagle, who showed people across the Corps how to take a big standard project and insert nature-based solutions.

IN MARCH 2023 an atmospheric river storm struck central California, bursting three levees on the Pájaro River and flooding the eponymous town, which is populated by farmworkers and surrounded by fields of berries and greens. The disaster wasn't a surprise; the four- to 12-foot-high levees lining the river and its two tributaries, Corralitos Creek and Salsipuedes Creek, dated to 1949 and promised just eight-year flood protection—which equates to a 12.5 percent chance of flooding in any year. In 1966 Congress authorized the Corps to build taller, wider levees, but partly because the economics of protecting the low-income community didn't seem to work out, the project never moved forward.

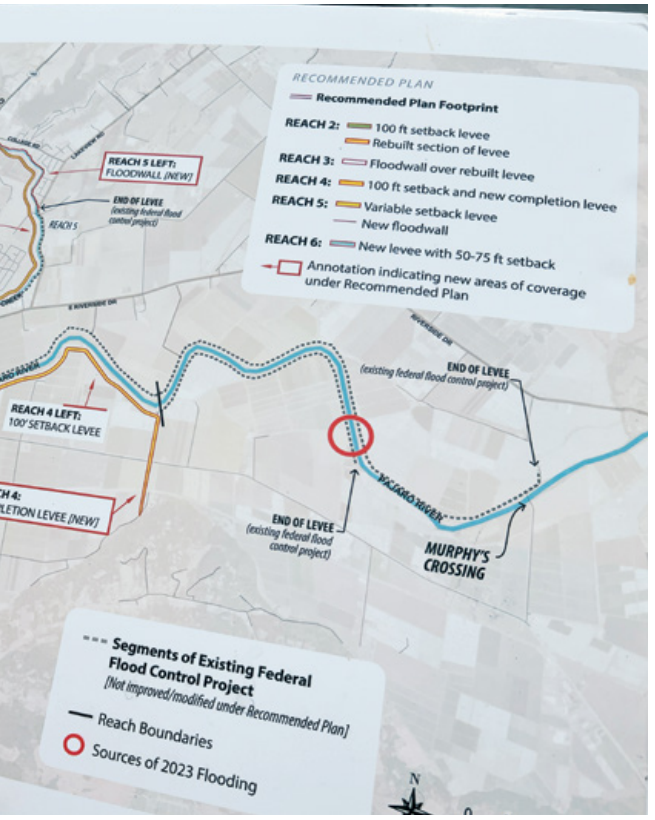
The Corps later realized that adequate protection required giving the waterways more room. It wanted to move some of the long earthen levees that run for 13 miles along both sides of the waterways farther back from the banks. These "setback levees" would create extra space between the levees to hold more water during high flows, reducing overflow flooding.

That solution required local people to give up some of their land, and residents resisted for decades. But as the toll of repeated floods mounted, they finally gave in, says Mark Strudley, executive director of the Pájaro Regional Flood Management Agency, a local partner to the Corps. Strudley says farmers in the area realized they were having a hard time cultivating that soggy land, anyway. In October 2024 the Corps broke ground on the multiyear project, known internally as "100 for 100." It bought up to 100 feet of landowners' properties along the waterways, offering in return 100-year flood protection: a 1 percent chance of flooding in any year.

But Beagle saw that this standard project could be tweaked to simultaneously solve another local problem: a declining groundwater table caused by farmers' overpumping. When a wild river runs high, water overflows the banks, spreads across the floodplain and slows. It has time to sink underground to supply aquifers, deposit soil nutrients and fine dirt that continually reshape the river, and create habitat that supports fish. But in the decades that the river and its tributaries had been cut off from their floodplains, water squeezing through the levee-narrowed river channel had run faster. Speed gave it power to cut down into the earth, leaving the creeks about 10 to 25 feet lower than the surrounding farmland. If the Corps just set the levees back, Beagle knew, the river would reach the riverbanks only when it ran really, really high. Most of the time water would still be stuck down in the channel, speeding away. It wouldn't have a chance to replenish groundwater, redistribute soil or help fish.

Beagle and Strudley convinced the Corps to turn the plan into an EWN project by pointing out that the change would in fact save money. To build the new, wider levees, the Corps would have had to truck in dirt, which is expensive. Instead it will excavate much of the dirt from the former farmland that will now be

Erica Gies



Erica Gies

inside the setback levees. It will also dig in a way to re-create some of the river's natural functions, fashioning side channels and earthen steps from the new levees down to the creek. When the river runs high, the channels and steps will slow water, giving it time to sink underground inside the setback levees. This action will refill dwindling groundwater reservoirs and increase flood protection by ensuring some water gets absorbed by the ground and moving the rest of it downstream over a longer period.

The design will also allow sediment swishing around within the wider riverbed to create an accessible floodplain again. The river will reshape what the engineers build, and that's okay, Strudley says. "'Correcting' is fighting physics," he says, "which in general doesn't end well and wastes a lot of money."

The higher water table will allow farmers to pump water more easily and will feed the creek in the dry season. Slow water inside the levees will allow algae and plankton to grow, feeding fish such as the South-Central California Coast steelhead, a threatened species, and providing refuges where they can rest during their mating migration upstream. The more natural waterway will attract other wildlife, perhaps creating recreation spots for residents and even attracting ecotourists.

Although multiple benefits are beyond the singularly focused congressional authorizations, local and state partners want them. Strudley worked with California's Department of Water Resources, which ponied up the local funding because it is motivated to reverse dropping water tables. "Recognition of those benefits is why the state invested," Strudley says.

> "You could call the 20th century the century of reinforced concrete. My hope is the 21st century is the century of nature."
>
> —TODD BRIDGES *UNIVERSITY OF GEORGIA*

"Multibenefit is how you get things done these days. The Army Corps is catching up to that."

Scientists from universities in the area are studying those benefits, measuring how 100 for 100 will affect groundwater recharge, sediment movement and fish populations. Quantifying the benefits is fundamental, says King, the national head of EWN, "because engineers have to feel comfortable understanding how these things are going to perform."

Many of these concepts are commonplace in restoration circles, Beagle says, but not so familiar to engineers. "Reading the landscape and understanding how nature works is a different set of skills," she says. The Corps has a manual for how to build a levee, but it does not have one for floodplain reconnection. It will soon, though. Beagle has co-written national guidelines for floodplain reconnection in the same format as Corps instructions for building a levee, with "equations, loadings, shear stresses, things like that," she says.

Part of Beagle's role is to educate Corps employees from other districts as they do rotations in the San Francisco district. "It's really, really satisfying to watch these ideas take off," she says. She still encounters resistance, however. Some colleagues complain that nature-based solutions are a headache and more expensive because they think these approaches mean adding bells and whistles to an existing project. Yet engineering with nature is often less expensive, Beagle says: "A healthier system maintains itself to a larger degree."

EACH OF THE CORPS'S SIX other EWN proving grounds has its own Pájaros—projects that showcase new approaches. Monica Chasten, head of EWN in the Philadelphia district, is shoring up disintegrating marshes near the southern tip of New Jersey in a 24-square-mile area known as the Seven Mile Island Innovation Lab. Her specialty, coastal engineering, is fundamentally different from civil engineering. "It's not like designing a bridge," she says. "Not everything is exact. It's almost like an art."

Hurricane Sandy was a revelation in the region because marshes and dunes did an especially good job of protecting people. Softer than seawalls, they absorb wave energy rather than bouncing it onto neighboring stretches of coast. But sea-level rise and sediment scarcity threaten to destroy half of the region's marshes by 2100. The scarcity is partly the result of a long-standing Corps practice. When it dredged fine sediment to maintain coastal shipping channels, it

Engineering with nature can save money because a functional ecosystem is likely to require less maintenance than fully engineered infrastructure.

dumped the material into inland basins to simplify compliance with regulations aimed at protecting coastal areas from possible pollutants in the sediment. But in 2023 chief of engineers Lt. Gen. Scott A. Spellmon (now retired) realized the Corps was throwing away valuable material and set a goal that by 2030 it would reuse 70 percent of everything it dredged.

Chasten says her district is on track to go beyond that. Some of the fine-grained sediment the Corps dredges from the New Jersey Intracoastal Waterway floats in from the marshes to begin with, so Chasten's team is pumping clean sediment back into the needy marshes. The impact will be transformative, predicts Lenore Tedesco, executive director of the Wetlands Institute, a New Jersey organization that works on the Atlantic and Gulf coasts and is a partner to the Corps. "We've built 30 to 50 years of resilience into that marsh," she says.

A thousand miles away the Corps's St. Louis district is following nature's lead to unravel a problem that the agency helped to create there: floodplain occupation. Edward Brauer, a hydraulic engineer and an EWN project lead, has been relinquishing part of a floodplain to the Mississippi River in Dogtooth Bend, a 17,000-acre chunk of Illinois inside a U-shaped turn of the river that borders Missouri.

In the 19th century the area was a rich, shifting blend of wetlands, floodplain lakes, bottomland hardwood forest, cypress and tupelo slough, and cane thickets. "The river did what rivers do and meandered across the landscape," Brauer says. Levees the Corps installed to create farmland were essentially seeking to stop time. But "it's a constant battle with the river," EWN founder Bridges says.

And the river is on a roll. The area has flooded increasingly often—in 1993, 2011, 2016, 2017 and 2019—

Erica Gies

repeatedly washing out roads, ruining crops, and flooding homes in Olive Branch and Miller City. During major breaches, one third of the Mississippi's flow gushes overland, taking a shortcut across the U. In 2019 Dogtooth Bend was inundated for nearly nine months.

Letting the river make the cut might be the most nature-based solution. But the Corps also has a mandate to maintain shipping channels. Brauer is trying to negotiate a truce. Residents tired of repeated flooding have accepted buyouts. On those newly available lands, Brauer's district is restoring natural floodplains and bottomland forests—habitat for at-risk species that also accommodates the river, reducing the frequency and force of its thrusts across the bend. The vegetation slows water and catches sediment that might otherwise move downstream, reinforcing the existing channel instead.

PROJECTS SUCH AS PÁJARO, Seven Mile and Dogtooth Bend may become more common thanks to key points in the new rule: requirements for equal consideration of nature-based solutions, as well as a broader cost-benefit analysis. The rule, called for in congressional legislation dating back to 2007, was drafted in 2013, but passage was stymied for years by congresspeople who didn't want the Corps to stop weighting economics over all other things. That dynamic shifted in 2021 when R. D. James, appointed by Trump as the assistant secretary for civil works, became concerned that low-income communities suffering from the massive 2019 Mississippi River floods were being bypassed by the standard cost-benefit analysis. So he wrote a memo outlining the inclusion of social and environmental factors.

Still, the new rule does not correct a fatal flaw in standard cost-benefit analyses. A gray project's destruction of natural systems' services—absorbing floods, cleaning pollution, providing water in the dry season, generating food, storing carbon dioxide—is not counted against its benefits. Nor does the Corps deduct for a project's likelihood of increasing flood risk in neighboring communities that are not protected.

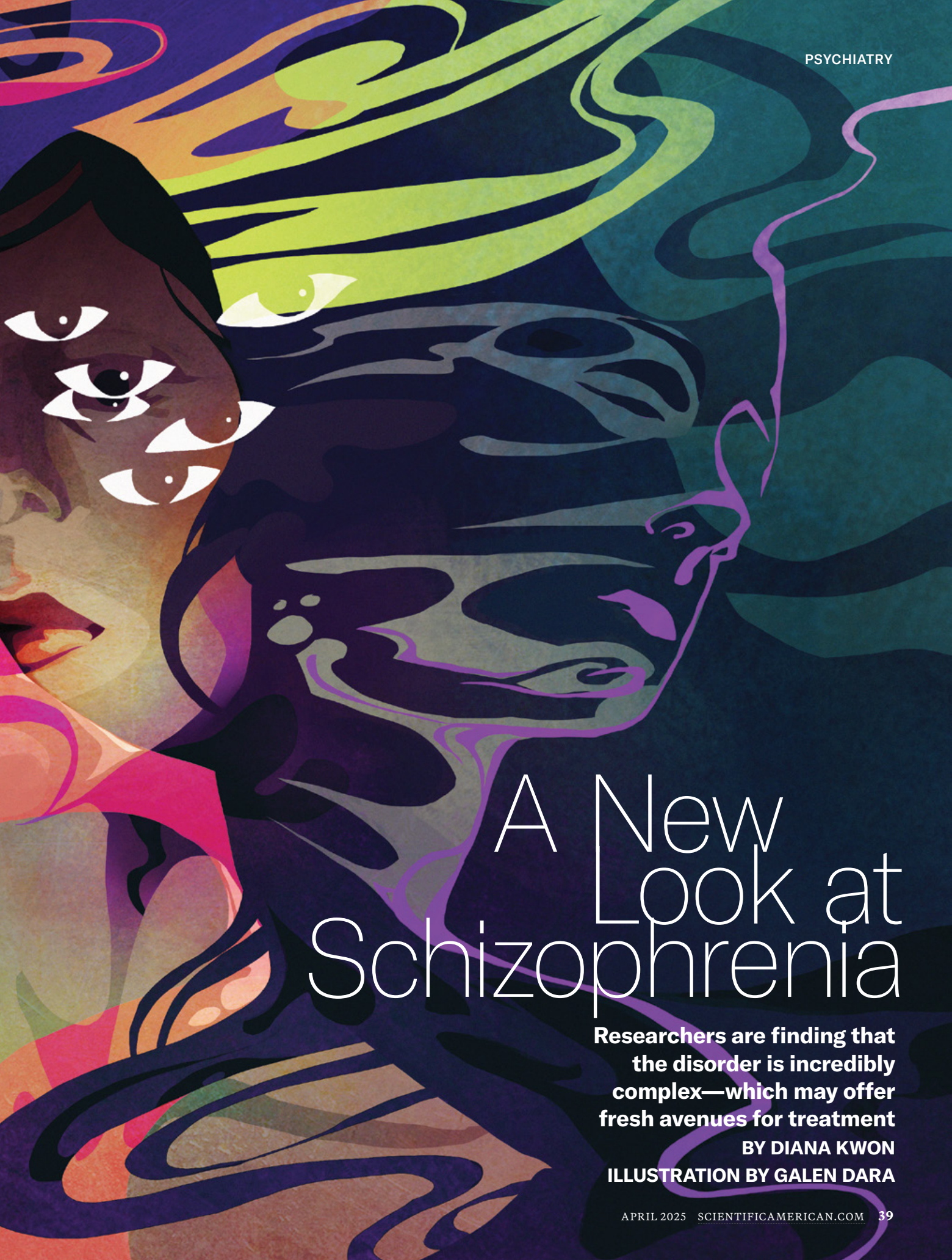
American Rivers provided input for the rule, and Shader says she's glad it finally passed. But she's concerned that it doesn't provide criteria for choosing between nature-based solutions and gray projects, such as accurately tallying the potential losses. "So it really depends on that individual district and the nonfederal sponsors' interests," she says.

Trump is likely to choose a new assistant secretary for civil works in his current presidential term. Michael L. Connor, who held that position until October 2024, said then that he's hopeful the rule will not be overturned. "I don't think this is a politically controversial rule," he says. "We were directed to carry this out by the Water Resources Development Act in 2020 that was enacted during President Trump's term and by a split Congress," he said. "[It's] an initiative that has broad support across the spectrum." Although the new administration was disrupting government in its early days, Darcy says examples of local partners gaining multiple benefits may be politically powerful enough to convince the president and Congress to leave the new rule alone.

Perhaps it is dawning on people throughout Congress and the Corps that "the control of nature"—the title of writer John McPhee's 1989 book about the Corps—is futile. McPhee wrote then that "the Corps has been conceded the almighty role of God." Subsequent decades have been a reckoning with the almighty power of nature. Regardless of the rule's fate, the Corps is part of an ongoing, global shift toward nature-based solutions as people recognize the design savvy of harnessing that power. "The 20th century, you could call it the century of reinforced concrete," Bridges says. "My hope is the 21st century is the century of nature." ●

FROM OUR ARCHIVES

The Mississippi Levees. *Scientific American* editors; May 25, 1867. Scientific American.com/archive



A New Look at Schizophrenia

Researchers are finding that the disorder is incredibly complex—which may offer fresh avenues for treatment

BY DIANA KWON

ILLUSTRATION BY GALEN DARA

CHARLENE SUNKEL WAS 19 when she started hearing voices and strange thoughts began filling her head. People wanted to infiltrate her mind, to poison her, to rat her out to the police. She stopped making eye contact, convinced that it would enable others to steal her thoughts. Once sociable and outgoing, Sunkel withdrew from friends and family, worried that they were conspiring against her. On her way to work, she had visions of men in hoods from the corner of her eye. As the illness progressed, she lost the ability to understand what people were saying, and when she spoke, the words would not come out right. About a year after her symptoms started, Sunkel was diagnosed with schizophrenia.

Delusions, hallucinations and disordered thinking are collectively known as psychosis. These "positive" symptoms are among the most widely recognized aspects of schizophrenia. For about two thirds of patients with schizophrenia—which affects approximately 23 million people around the world—traditional antipsychotic drugs are often highly effective at treating psychosis. But these drugs frequently come with problematic side effects. And they do little to help with the so-called negative symptoms of schizophrenia, such as emotional flatness and social withdrawal, or with other issues involving thinking and memory referred to as cognitive problems.

Until quite recently, all antipsychotics worked in essentially the same way. They blocked the activity of dopamine, a chemical messenger in the brain involved in motivation, learning, habit formation, and other processes. The successful treatment of psychosis with dopamine blockers led many clinicians to believe that they understood schizophrenia and that its underlying cause was an imbalance in dopamine. When a particular antipsychotic did not work in a patient, all doctors needed to do, they thought, was up the dosage or try another dopamine-targeting drug.

But the arrival last September of a new drug, KarXT, supports an emerging awareness among clinicians that schizophrenia is more complex than most of them had realized. KarXT is the first antipsychotic to target a molecule other than dopamine. It may be a key aspect of the disorder in some people, but dopamine is just one of many different neurotransmitters involved in the illness. That complexity may provide fresh avenues for treatment.

To Thomas Kabir, a senior researcher at the University of Oxford with a lived experience of psychosis, KarXT's potential to not only reduce symptoms of psychosis but also improve thinking is especially exciting. "People typically don't have hallucinations and delusions for years on end," he says. "It is the cognitive issues that really affect people's day-to-day lives."

Perhaps most significant, a growing body of evidence suggests that schizophrenia, which can involve alterations not only in the brain but also in the body—particularly in the immune system—does not look the same in everyone who has the condition. "There is no schizophrenia. There are *schizophrenias,*" says Romina Mizrahi, a professor of psychiatry at McGill University. What clinicians need now, she adds, is a way to categorize individuals based on the underlying biology of their illness so that treatments can be better tailored to their needs.

SCIENTISTS HAVE BEEN TRYING to understand the neurobiological underpinnings of schizophrenia for more than a century. German psychiatrist Emil Kraepelin, who in 1893 penned one of the earliest official descriptions of schizophrenia, called it *dementia praecox,* meaning "premature dementia." Because the condition tends to show up in adolescents or young adults, Kraepelin held that schizophrenia was a neurodegenerative disease, similar to those that often afflict the elderly.

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In contrast, Swiss psychiatrist Eugen Bleuler, whose long hours with patients at the Rheinau psychiatric hospital in Zurich led to more than a decade's worth of meticulous notes about their behavior, held that the disorder did not always involve progressive deterioration or begin solely in adolescence. In 1908 he coined the term "schizophrenia," meaning "split mind," to characterize the fragmentation of mental functions that he saw as central to the condition.

Bleuler was prescient in other ways. He referred to "the group of schizophrenias," reflecting his view that it was a collection of disorders with a range of severity, a spectrum of symptoms and variable outcomes. And he postulated that the ailments have both a biological and a psychological basis. The tendency for schizophrenia to run in families has since been documented—the disorder is about 80 percent heritable. But specific genes have been difficult to pin down, and researchers suspect hundreds of them might be involved. Many studies also point to the importance of the environment. Adverse experiences in childhood, being exposed to infections in the womb, growing up in cities and heavy cannabis use all contribute to increased risk.

Despite growing evidence of schizophrenia being rooted in changes occurring during childhood, Kraepelin's idea that schizophrenia is neurodegenerative persists—although it is hotly debated. In some patients, symptoms worsen over time, and this progression is often accompanied by tissue loss in the brain. Several researchers have argued that this deterioration can instead be attributed to factors secondary to the illness, such as poverty and stress.

When antipsychotic drugs first emerged, they seemed to drastically simplify the picture. In the 1950s a pair of psychiatrists in France discovered serendipitously that chlorpromazine, a compound designed to be an anesthetic for surgery, helped to address hallucinations and delusions. Chlorpromazine and the other antipsychotics that followed brought an end to an era of crude and often dangerous treatments for schizophrenia, such as lobotomies.

At first, no one knew why chlorpromazine and its derivatives worked. Later studies in mice revealed that these medications blocked receptors for dopamine. (Receptors are molecules that serve as code-locked doors, allowing only certain molecules, in this case dopamine, to enter a cell.) These findings, along with observations that high doses of amphetamines—drugs known to release dopamine—can cause short-term psychosis in healthy people, paved the way for the so-called dopamine hypothesis of schizophrenia. It posits that the symptoms of schizophrenia are caused by an excess of dopamine in the brain.

Though effective at treating psychosis, dopamine blockers are no panacea for schizophrenia. They come with a host of side effects, such as tremors resembling those in Parkinson's patients (who suffer from a paucity of dopamine), sedation, and significant weight gain that can subsequently lead to an increased risk of diabetes and heart problems. In fact, cardiovascular disease is one of the most common causes of death in people with schizophrenia who have a long history of using dopamine blockers.

In the years after her diagnosis, Sunkel was hospitalized multiple times and prescribed many different medications that came with debilitating side effects, including intense restlessness, tremors and sedation. One drug led to spasms so severe that she was unable to move or speak. Though deemed "treatment-resistant," a label given to people whose symptoms do not improve after two or more drugs, Sunkel ultimately found clozapine, a dopamine-blocking antipsychotic.

Despite its side effects, the medication has significantly helped to improve her quality of life, says Sunkel, who is now in her 50s and working as chief executive officer of the Global Mental Health Peer Network in South Africa. But in up to 60 percent of people with treatment-resistant schizophrenia, clozapine, too, can be ineffective.

FOR DECADES THE ONLY AVAILABLE antipsychotic drugs were dopamine blockers. From the 1990s onward, however, researchers began employing techniques such as positron-emission tomography (PET), an imaging method that enables them to view the activity of specific molecules inside the living brain. That work suggested a more complicated story.

Neuroscientists used PET imaging and other means to identify neurochemical alterations in the brain that are associated with schizophrenia. They found dopamine activity to be increased in a specific region of the striatum, a structure located deep in the brain that is largely involved in helping us forge mental links between disparate events or things. This anomaly may increase the chances of someone with schizophrenia making false associations or having misperceptions. In addition, scientists discovered that dopamine levels are lowered in the prefrontal cortex, thereby interfering with executive functions such as problem-solving and emotion regulation, which can be impaired in people with the condition.

These studies also shed light on why antipsychotics don't always work. In 2012 Oliver Howes, a professor of molecular psychiatry at King's College London, and his team reported that people who do not respond to traditional antipsychotics have different patterns of dopamine activity in the brain than those who do respond.

Such investigations established that dopamine is not the only neurotransmitter involved in schizophrenia. Others include glutamate, a key molecule involved in activating neurons. A group led by psychiatrist John Krystal of the Yale School of Medicine, as well as others, has demonstrated that ketamine—a drug that blocks the activity of glutamate—can produce symptoms of psychosis in healthy people. Large-scale searches for genetic variants associated with schizophrenia have also revealed that alterations in genes involved in glutamate signaling are among the key risk factors for developing the disorder. In recent decades many glutamate-targeting drugs have been developed, but none have yet made it through clinical trials.

Another key neurotransmitter, called acetylcholine, acts on muscarinic receptors found throughout both the body and the brain that are involved in such processes as movement, memory and learning. The new schizophrenia drug, KarXT, which is marketed and sold as Cobenfy by Bristol Myers Squibb (BMS), selectively activates muscarinic receptors in the brain. In clinical trials, the drug was found to be effective in treating psychosis and seemed to improve cognitive function, without the side effects that make traditional antipsychotics difficult for patients to remain on for long periods. The drug did have gastrointestinal effects, most of which were mild.

Although more data are needed on the long-term effects of KarXT, the drug has enthused researchers in the schizophrenia field because of its unique mechanism of action that doesn't directly target dopamine. Exactly how the drug works to ease the symptoms of schizophrenia, however, remains an open question. Figuring out this mechanism could be a "game changer" for our understanding

of the disease, Howes says. (Howes has worked as an adviser to Karuna Therapeutics, which discovered the drug before being acquired by BMS.) "The fact that you can target an entirely new set of receptors and still help someone tells us that there's something missing from our understanding of schizophrenia and psychosis," Kabir says.

THERE IS INDEED another, startlingly different way in which schizophrenia can arise. April Burrell was a healthy, vibrant 21-year-old until a traumatic event changed everything. She developed psychosis and hallucinations and eventually went into a completely catatonic state, unable to move or communicate. She was diagnosed with a severe form of schizophrenia and admitted to the Pilgrim Psychiatric Center in Brentwood, N.Y., where she would spend nearly 20 years.

It was only when Sander Markx, a psychiatrist at Pilgrim, gathered a multidisciplinary team and ordered a full medical workup that Burrell's doctors discovered her blood contained autoantibodies—antibodies that were attacking her own body, damaging cells in her brain. She received a new diagnosis of neuropsychiatric lupus, an autoimmune disease. After six months of an intensive immunosuppressive treatment regimen, Burrell made an almost full recovery in 2020. "You would've thought she was a brand-new person," her brother, Guy Burrell, told the *Washington Post* in 2023.

Autoimmune encephalitis, a disease that occurs when the body's own immune system attacks the brain, was discovered less than two decades ago. Before it was known, many of the people with this illness would have—like Burrell—received a diagnosis of schizophrenia despite some subtle differences between the two conditions. In people with autoimmune encephalitis, for example, symptoms tend to appear more rapidly and be more severe.

Some of the first cases of autoimmune encephalitis were reported in 2007. Josep Dalmau, a neurologist then at the University of Pennsylvania, and his colleagues published descriptions of patients who had autoantibodies against the NMDA receptor, the protein in the brain on which glutamate—one of the key neurotransmitters that are altered in people with schizophrenia—exerts its action. In the years since, researchers have documented more than two dozen autoantibodies that target the brain. A diagnosis of autoimmune encephalitis, which often requires the detection of autoantibodies in the cerebrospinal fluid (CSF), the liquid washing through the brain and spinal cord, can be life-changing. Some patients who receive immunotherapy make a full recovery.

Clear-cut cases of autoimmune encephalitis are rare. According to some estimates, about 1 percent of people with psychosis have autoantibodies whose specific target in the brain has been identified. But determining the true prevalence is difficult because lumbar punctures, which are required to obtain CSF, are rarely carried out in psychiatry clinics, where most people with psychosis go for treatment.

According to psychiatrist Ludger Tebartz van Elst of the University of Freiburg and its associated hospital in Germany, where lumbar punctures for people with psychosis are routine, his team has found uncharacterized neuronal autoantibodies (meaning autoantibodies that are not clearly established as causes of psychosis) in approximately 20 percent of patients with psychosis and other psychiatric conditions. Accordingly, Tebartz van Elst and others advocate using the term "autoimmune psychosis" to describe the ailments of these patients.

The question of whether these nonspecific autoantibodies might play a meaningful role in schizophrenia and other disorders of psychosis has been a matter of intense debate in recent years. Studies of their prevalence in people with psychosis—which often examine blood because CSF is not always obtainable—have turned up inconsistent results. Researchers have also found these antibodies in healthy people, raising doubts about their clinical significance.

Others believe the immune system might contribute to psychosis even in the absence of autoantibodies. Cases of psychosis triggered by infections such as influenza, syphilis and, more recently, COVID-19 are scattered throughout history. In addition, epidemiological studies have reported a greater number of mental disorders such as schizophrenia in people who are born in the winter, when infections are more prevalent, compared with those born in the summer. Assessments from countries that keep national registries of medical data, such as Denmark, have revealed that the more infections a person has, the higher their risk of developing schizophrenia.

Whether infections can directly cause psychosis remains uncertain, but over the years many studies have provided evidence for the immune system being the culprit. Genomic investigations of people with schizophrenia have implicated genes linked to key proteins involved in the immune system. Further, the brain's resident immune cells, the microglia, are overactive in people with schizophrenia, leading some scientists to suggest that they are involved in the disorder.

Researchers are now studying whether the immune system might be at play in a greater proportion of people who receive a schizophrenia diagnosis. Some groups are conducting clinical trials to investigate whether immunotherapies could help people with schizophrenia and other psychosis-related disorders who do not meet the criteria for an autoimmune disease.

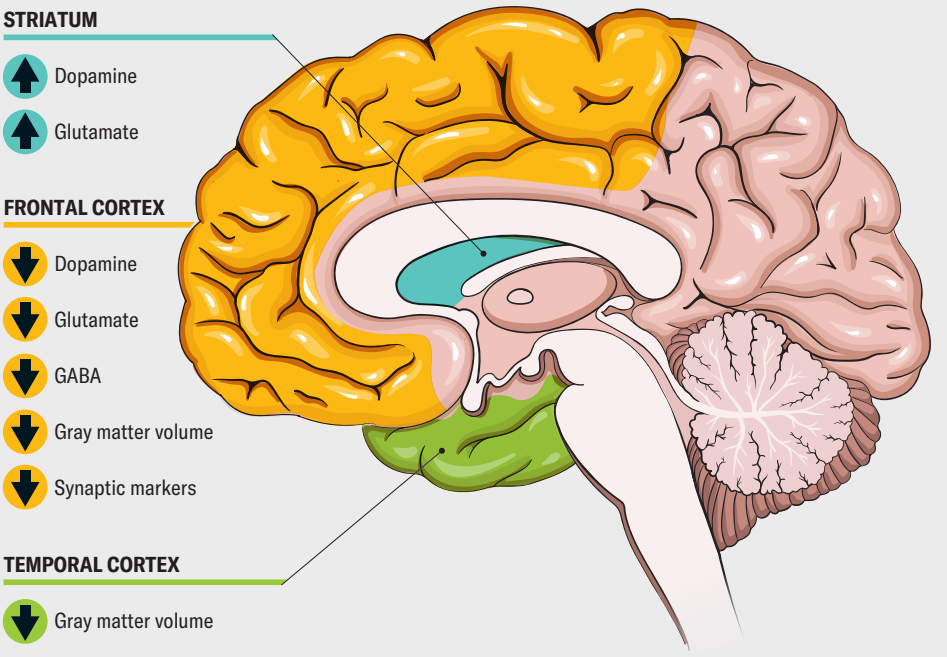
At Oxford, Kabir, psychiatry professor Belinda Lennox and their colleagues are currently conducting a clinical trial to examine whether rituximab, an antibody used to treat arthritis and other autoimmune disorders, can effectively treat psychosis in people who have detectable neuronal autoantibodies in their blood. Janet Cunningham, a psychiatrist at Uppsala University in Sweden, and her team are carrying out a similar study in that country. If even a small percentage of these individuals respond to these therapies, it would be transformative, Lennox says, "because you can potentially cure their lifelong illness."

There is much excitement around the possibility of immunotherapies for psychosis, although experts caution against focusing solely on the immune underpinnings of the disorder. Patients can sometimes see autoimmune psychosis as a more palatable diagnosis than schizophrenia because it may provide a more promising road to recovery—and because it avoids the stigma surrounding the word "schizophrenia." But immunotherapies are not without their risks. Medications such as cortisone, which are often used in cases of autoimmune psychosis, come with their own side effects, including bone fragility, slow wound healing, and psychological effects such as mood swings and confusion.

Cunningham says it's important to remember that existing antipsychotics do help many people with schizophrenia and other psychosis-related disorders. "We've gotten to the point where a lot of people are being helped with the medication we have," she says. "Now we have to be looking at the ones we are not able to help."

Schizophrenia in the Brain

Early researchers described schizophrenia as resulting from an excess of dopamine, a chemical messenger in the brain involved in motivation, learning, and other processes. Scientists have since discovered that other molecules such as glutamate, which activates neurons, and gamma-aminobutyric acid (GABA), which inhibits neurons, are also altered in people with the disorder. Gray matter volume and the density of synapses, or brain connections, are reduced. But not everyone diagnosed with schizophrenia exhibits the same alterations, indicating that the disorder might have subtypes.



Source: "Schizophrenia: From Neurochemistry to Circuits, Symptoms and Treatments," by Oliver D. Howes et al., in *Nature Reviews Neurology*, Vol. 20; December 2023 (*reference*)

KABIR, THE OXFORD RESEARCHER who has lived experience of psychosis, first fell ill while he was a university student. His priority then was staying out of the hospital and completing his degree. The quickest way to do that was to take medication. But later, once his symptoms had stabilized, he added in talk therapy, which he says helped both with psychosis symptoms and with other problems such as depression. One of the biggest limitations of today's treatments, according to Kabir, is that people with psychosis tend to get treated very similarly—the same set of drugs, often at similar doses—despite research suggesting people may need different medications and different doses based on factors such as sex, age or stage of their illness.

Some experts say that to identify the most effective treatment for each patient, clinicians may need to determine an illness's underlying cause. At Tebartz van Elst's clinic in Freiburg, patients who come in after experiencing psychosis get a full workup, which often involves neuroimaging, blood tests and a lumbar puncture, to rule out any secondary cause for the symptoms. Such extensive tests are not the norm, however. In many parts of the world, including the U.S., whether a person will receive these types of tests depends largely on whether they end up in the office of a psychiatrist or a neurologist.

Several large, ongoing efforts are aimed at trying to better characterize people with schizophrenia. The Psychiatric Biomarker Network, led by Steven E. Hyman of the Broad Institute of M.I.T. and Harvard, was established in 2018 with the goal of finding biomarkers in cerebrospinal fluid. The Accelerating Medicines Partnership Schizophrenia, launched in 2020 by several public and private institutions in the U.S. and the European Union, has a similar aim. Researchers hope to find markers that can identify people in the "prodromal" phase of schizophrenia—the period before symptoms appear.

Being able to identify people during this phase will "open up the possibility of trying to develop preventive treatments," Howes says. His team has identified prodromal signs such as neuroimaging markers and early symptoms such as the "Truman sign," where people feel a nagging sense that something strange is going on—akin to the way the protagonist of the 1998 movie *The Truman Show* felt while unknowingly living on the set of a reality TV show. "If you can prevent the illness to begin with, you can prevent all the disability and the chronic course that sometimes develops."

Numerous questions remain open, such as to what extent the immune system is involved in schizophrenia and how neurotransmitters might be altered in different subgroups of people with the illnesses. Researchers have also identified other potentially important mechanisms that might underlie schizophrenia, such as abnormalities in metabolism. Preliminary research suggests that eating a ketogenic diet, which is high in fat and low in carbohydrates, might ease some of the symptoms of the disorder. Talk therapy is also emerging as helpful in treating people with schizophrenia. For example, cognitive-behavioral therapy, which focuses on helping people adjust their ways of thinking and behaving, can reshape thought patterns that underlie psychosis or help patients deal with negative symptoms such as low motivation or a diminished ability to experience pleasure.

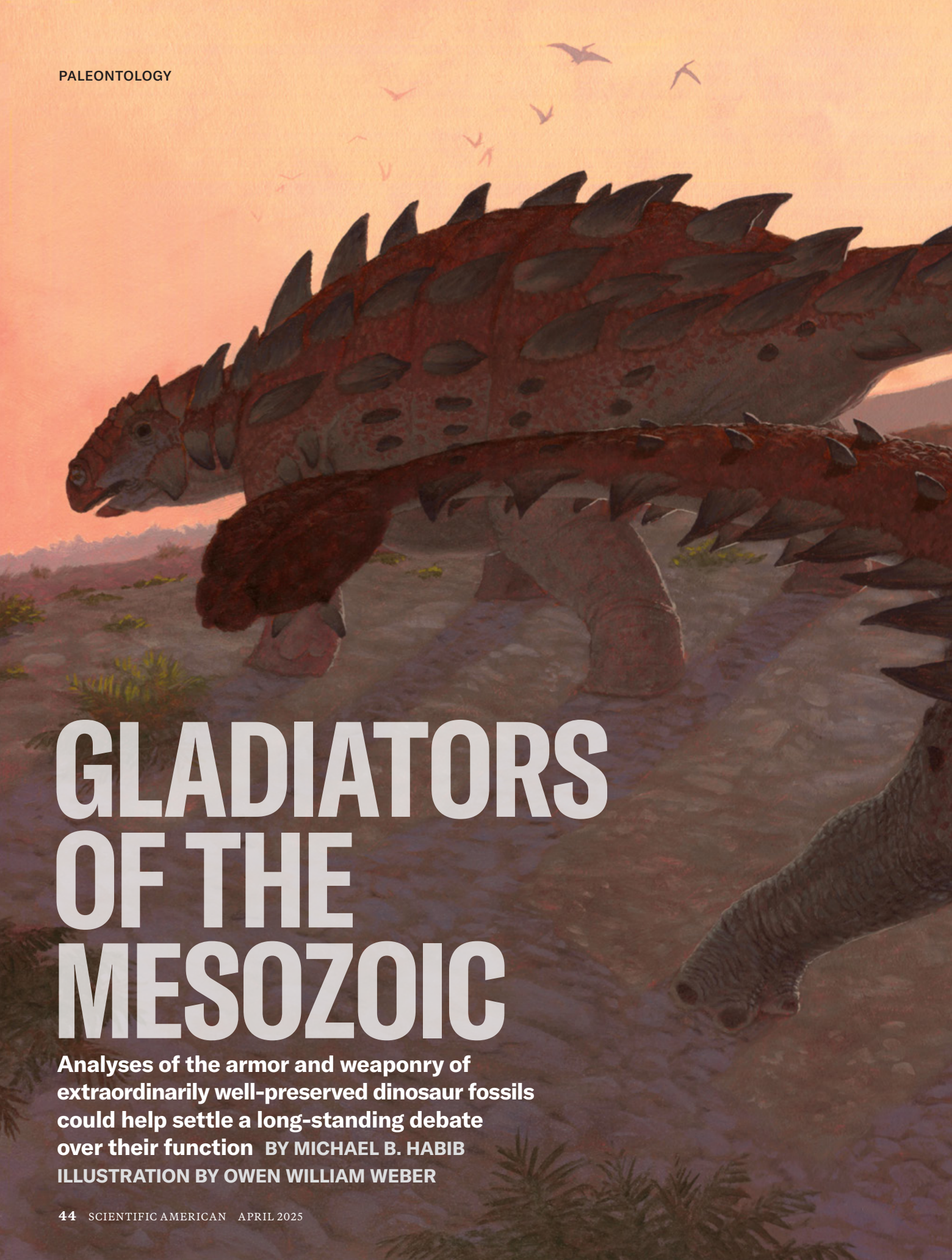
Ultimately the hope is to provide better, more targeted therapies for people with schizophrenia. Some clinicians say the field of oncology has a blueprint for how to deal with such complex ailments. Cancer, which was once seen as a single disease, is now viewed as a collection of many diseases with different causes and mechanisms, all unified under a single name. In the same way that personalized therapies are becoming increasingly popular in oncology, researchers see this approach as the future for treating schizophrenia and other mental illnesses.

"Precision medicine is something that I think will emerge as a bigger and bigger part of the story of schizophrenia treatment," Krystal says. Eventually, he hopes, doctors will be able to tell patients, "You've got this biology, you need that treatment. That is where I think the future of understanding this biology of schizophrenia will take us." ●

FROM OUR ARCHIVES

A Talking Cure for Psychosis. Matthew M. Kurtz; March 2023. ScientificAmerican.com/archive

Graphic by Ni-ka Ford



GLADIATORS OF THE MESOZOIC

Analyses of the armor and weaponry of extraordinarily well-preserved dinosaur fossils could help settle a long-standing debate over their function

BY MICHAEL B. HABIB

ILLUSTRATION BY OWEN WILLIAM WEBER

Two *Zuul* engage in combat.

IN THE PANTHEON OF DINOSAUR ROYALTY, sauropods may have been the biggest and tyrannosaurs the deadliest. But the ceratopsians, ankylosaurs and stegosaurs were the most metal dinosaurs of all. With their horns and spikes, body plates and tail clubs, these horned and armored dinosaurs have long captured popular imagination. In the early 1900s American paleoartist Charles R. Knight depicted one of these weapon wielders, the plant-eating *Triceratops,* as a worthy adversary of carnivorous *Tyrannosaurus rex; Stegosaurus* makes regular (and formidable) appearances in the *Jurassic Park* movie franchise that began in 1993. Yet despite our enduring fascination with these "living tanks," as armor-bearing dinosaurs have been described, many details of their anatomy—including the composition and even the functions of their impressive accoutrements—have remained unknown.

The problem stemmed from the scarcity of fossils of these animals that, even when found, often consisted of mere scraps. These recovered specimens also preserved only the hard bony parts, not any of the associated soft tissue. In their efforts to reconstruct armored dinosaurs as they were in life based on this meager evidence, paleontologists took what they thought was a conservative approach and assumed that the bony remnants of the armor of these long-dead dinosaurs constituted the bulk of the armor in life. Those reconstructions revealed some magnificent creatures—ceratopsians equipped with three-foot-wide frills, stegosaurs brandishing 30-inch-long tail spikes, nodosaurs bristling with shoulder spikes nearly a foot and a half in length.

But in recent years researchers have unveiled new fossils that preserve aspects of armored dinosaur anatomy never seen before. These incredible specimens reveal the true makeup of dinosaur armor and weaponry. With this new information in hand, my colleagues and I have performed new mechanical analyses of the horns, spikes and plates of heavily armed and armored dinosaurs. Our fresh look at these armaments shows that they were even more impressive than previously thought.

Michael B. Habib is a paleontologist and biomechanist at the Natural History Museum of Los Angeles County and the University of California, Los Angeles. He studies the anatomy and motion of pterosaurs, birds and dinosaurs.

Triceratops, an iconic member of the ceratopsians, or horned dinosaurs, roamed western North America between 68 million and 66 million years ago.

Francois Gohier/Science Source

The findings may settle a long-running debate over the primary function of these spectacular structures.

OUR DISCOVERIES are based primarily on two extraordinary fossils first announced in 2017. One was an armored dinosaur with a massive tail club that Victoria Arbour, now at Canada's Royal BC Museum, and David Evans of the Royal Ontario Museum named *Zuul* for its resemblance to the monster from the 1984 movie *Ghostbusters*. The second fossil came from a nodosaurid, a type of armored dinosaur known for its wicked shoulder spikes. Caleb Brown of the Royal Tyrrell Museum in Alberta and his colleagues called this animal *Borealopelta*, meaning "shield of the North."

The specimens of both *Zuul* and *Borealopelta* represented species new to science, but what makes these fossils truly thrilling is their exquisite condition. They are among the best-preserved dinosaur remains ever discovered, exhibiting not only the bony portions of the armor but also associated soft tissues. With these fossils, researchers could, for the first time, observe the material composition of the elaborate body coverings of armored dinosaurs.

Before the discoveries of the *Zuul* and *Borealopelta* fossils, some scholars had deduced that the bony armor pieces (called osteoderms) on the likes of *Ankylosaurus* and *Stegosaurus* were just cores of bone that supported an outer covering made of keratin (the same material that hair, nails and horns are made of). The new specimens confirmed this speculation, demonstrating that the armor of these dinosaurs had an outer layer of keratin, which was supported by the bony osteoderms.

Moreover, this keratinous covering was far more substantial than previously constructed. The *Borealopelta* fossil, which preserves the most armor, shows that keratin sheaths increased the linear dimensions of the thickest parts of the armor by 30 to 40 percent. But because the keratin in this specimen is partially worn away, we know that it was even thicker in life. Having examined this fossil myself, I suspect that the increase could have been significantly larger than 40 percent.

This insight into the structure of the armor revolutionized our understanding of these dinosaurs. First, it meant that the armor's performance was far different (and more impressive) than previously recognized. Second, because most dinosaur armor shows telltale signs of connections to a keratin sheath, the keratin-to-bone ratios of the *Borealopelta* and *Zuul* armor probably extend to other dinosaurs with bone-cored armaments. That is, the spikes, plates and horns of all dinosaurs with armor—from horned ceratopsians to plated stegosaurs—were probably more than 40 percent larger in life than what we see in their skeletons.

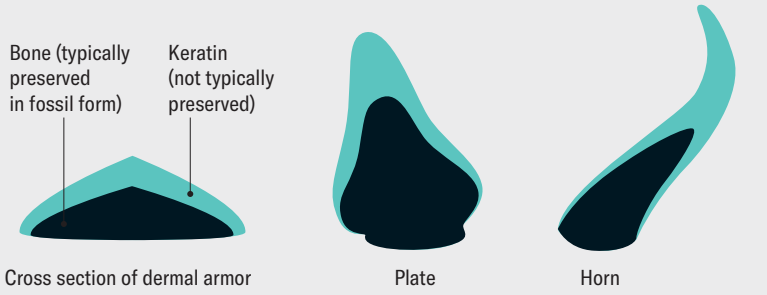
TO UNDERSTAND the extraordinary implications of having armor made largely of keratin, we must look at the material properties of keratin. Key to this discussion are a material's strength and its toughness. Strength is the resistance of a material to being broken by being deformed. If you have a rod of a given material and it's difficult to snap that rod in half, then the material is strong. Toughness, in contrast, is the measure of a material's ability to absorb energy. If you can hit a chunk of a material very hard and it survives, then it's tough; if it breaks when struck, then it's brittle. There are often trade-offs between these two properties. Materials that are very strong are often comparatively brittle. Take glass, for example: it's quite strong, but even a light impact can cause it to shatter. The fragility of glass is a result of low toughness, not low strength.

When viewed this way, keratin is a special biological material. Unlike bone, which is very strong but brittle, keratin is only moderately strong but extremely tough. It makes for ultraresilient weaponry and armor.

Consider the keratin quills of African porcupines, which can mortally wound lions foolish enough to at-

Tough as Nails

Recent discoveries suggest that the bony plates, horns, frills, clubs and spikes of armored dinosaurs were sheathed in a thick layer of keratin, the same material that's in nails and hair. This keratin component may have increased the sizes of these appendages by 40 percent or more. The material properties of keratin make it incredibly tough, capable of absorbing huge amounts of energy from impacts during fights between rival animals. The combination of a tough keratin sheath and a strong bony core made for armor that was virtually unbreakable.



STRENGTH VS. TOUGHNESS

A strong material requires more force to break it; however, strong materials are often brittle—meaning that they can't absorb much energy.

STRENGTH

The ability of a material to resist breaking.

TOUGHNESS

The ability of a material to absorb energy without failing. The opposite of tough is brittle.

Bone is a biomaterial that is strong but brittle. Keratin is only moderately strong, but it's extremely tough—like a dense rubber. You can bend it much more easily than bone, and if you had a tube of it, you could bend and break it fairly easily. But if you just hit it really hard, then it holds up very, very well.

Graphic by Jen Christiansen

This 110-million-year-old fossil of *Borealopelta,* a nodosaurid ankylosaur from Alberta, Canada, is one of the best-preserved dinosaur fossils ever found (*left*). Not only are the bony plates, or osteoderms, that covered the body present in this specimen (*top right*), but so, too, is the keratin that covered the bony plates (*middle right)*. The keratin-bone composite of the armor made it at least 20 times tougher than armor made solely of bone and may have been able to withstand impacts as forceful as that of a high-speed car crash. The fossil also includes a pebbled mass that appears to be the remnant of the animal's last meal (*bottom right*).

Robert Clark

Zuul, another beautifully preserved armored dinosaur, lived in Montana 76 million years ago. The fossil includes a complete skull and a tail club. Analysis of injuries to the animal's flanks suggests that they were inflicted by the tail club of another *Zuul.*

tack the heavily armored rodents. Bone can break when subjected to the high bite forces of lions. But the keratin quills soak up the energy from the bite and retain enough of their shape to function as lethal spears that the porcupine can drive deep into its attacker's face and jaws.

Even more relevant to the discussion about armored dinosaurs are the horns of living antelopes, sheep and goats. Bighorn sheep ram one another with hefty cranial appendages made not solely of bone but of thick keratin built around a bony core. The overall physical properties of the horns in these great mammalian jousters arise from the pairing of the tough outer keratin and the stronger, but more brittle, bony core. This combination marries the best of both worlds: the tough keratin sheath can absorb a lot of energy, and the strong, stiff core resists bending and breaking.

The structure of the horns of living antelope also means the contact surface is inert. Damage to keratin does not cause pain or bleeding. In contrast, bone is a living tissue with substantial blood supply and nerve endings. Having exposed bone as armor is dicey—damage to it can lead to hemorrhaging or debilitating pain.

THE DATA FROM *ZUUL* and *Borealopelta,* along with comparisons to modern animals, tell us that the armor of dinosaurs was not a stiff, brittle bone armor. It was an exceptionally tough bone-keratin composite. The thick outer keratin did the heavy lifting—as the surface of the armor, it was taking the hits. Any damage to the keratin when the animals came to blows would have been trivial, with no bloodshed or pain. The core, made of bone wrapped in skin tissues, provided strength and produced the keratin, sensing hits and replacing losses. The net effect was a rugged, self-repairing armor capable of absorbing immense amounts of energy.

Brown (whose team described *Borealopelta*) and I are actively studying the energy-absorption capacity of this armor. In the fall of 2024 I announced the first estimates from our work at the annual meeting of the Society of Vertebrate Paleontology. These preliminary estimates suggest that the thickest parts of the armor on *Borealopelta* might have been able to absorb an energy volume roughly similar to that of a high-speed automobile collision. At minimum, the bone-keratin composite

The New Armored Dinosaurs

The revelation that the armor of dinosaurs was sheathed in a thick layer of keratin means that armor structures were tougher than previously supposed. It also implies that armored dinosaurs were even more imposing—and deadlier—than earlier reconstructions made them out to be. Not only were their horns, spikes and plates larger and more extensive than researchers thought, but the animals were adapted to wield them to lethal effect.

Clues from fossil and modern animals hint at the primary function of the armor. For one thing, dinosaur armor seems to have been tougher than it needed to be for defense against predators. For another, antelopes and other modern-day animals with keratin-bone weapons use them in intraspecific conflicts. Researchers therefore suspect that dinosaur armor was used chiefly in battles between members of the same species who were competing for mates or territory.

With permission of ROM (Royal Ontario Museum), Toronto, Canada. © ROM

structure of this animal's armor would have increased its toughness by 20 times that of armor made purely of bone. Such tough armor would be quite valuable in a world of predators that, experts agree, had very high bite forces. Armor made mostly of bone, with just a thin covering, would have almost certainly cracked or shattered under attacks from these predators. In this regard, it was clearly an advantage to have the outer, "business end" of the armor composed of keratin.

That said, the armor of *Borealopelta* seems to have been overbuilt for withstanding the bite of a large, predatory dinosaur. And a predator would have struggled to directly bite *Borealopelta*'s low, wide body. I wondered if there were any situation in which a predator could deliver a full-force bite to one of these living tanks and do any real damage to the armor.

In 2019 I teamed up with physicist Seamus Blackley and his team of engineers in southern California to find out. We designed and built a mechanical test of *Borealopelta*'s armor for a Canadian Broadcast Channel program. In it, we pitted a synthetic version of the armor against a model of the largest predator *Borealopelta* could encounter, the theropod dinosaur *Acrocanthosaurus*. In developing the bite rig for this model, we made sure it accurately represented the head size and shape, bite force, and tooth properties of the predator. We then tested a worst-case scenario in which the predator somehow managed to slice into *Borealopelta*'s armor at a steep angle. Even with those odds stacked up against the armor, and despite the fact that we were using just a small, bite-size chunk of it, the enormous and frankly terrifying bite rig had to hit the armor in exactly the same place *twice* before doing real damage to it.

We never built the grandest, most heavily armored parts of *Borealopelta*. Instead we modeled the less intimidating armor that covered the back half of its body. One can confidently assume that any attempt by a predator to have a go at the front of *Borealopelta* would have been futile—and probably an excellent way to get killed.

BOREALOPELTA, which was unveiled in 2017, is a genus of nodosaurid dinosaur new to science. The soft tissues preserved in the fossil—including keratin and pigmented skin—have allowed for a detailed reconstruction of the animal as it was in life (*left*). The reconstruction, bristling with spines and thick, horny plates, contrasts sharply with 20th-century representations of subdued nodosaurs with blunt armor (*right*).

Graphic by Mark Witton

Stegosaurus, known for its vertical back plates and spikey tail, lived in the western U.S. and Portugal during the Late Jurassic period, between 159 million and 144 million years ago.

Jon G. Fuller/VWPics/Redux

Whereas the back end of the animal was covered in an impressive series of small keratin-covered osteoderms that formed an interlocking mosaic, the front end of *Borealopelta* (and other nodosaurs) was straight-up outrageous. Bladed plates covered the beast's neck, and massive spikes protruded from its shoulders. It looked like a war machine from the video game World of Warcraft.

During the analysis for the CBC test, I came to refer affectionately to the massively fortified area of *Borealopelta* running from its neck to its shoulders as the "kill box." Anything that found itself in that location while up against an angry *Borealopelta* was not long for this world. That is . . . unless the animal squared up in that danger zone was *another Borealopelta*.

PALEONTOLOGISTS HAVE LONG debated the function of dinosaur armor: Did it serve as protection against predators, weaponry for combat with members of their own kind, sexual display, or some combination of these roles? These new discoveries may tip the scales. If the armor of *Borealopelta* was tougher than it needed to be for predator defense, then perhaps protection against meat-eating dinosaurs looking for a meal was a secondary function of this feature. In that case, what might the armor's primary function have been? We can look to those living animals with elaborate bone-keratin weaponry for insights.

In the modern world, such structures can be used to fight off a predator, but their primary functions are nearly always related to display and fighting within the same species. In biology, we call such an encounter intraspecific combat, and it can be absolutely brutal. Bighorn sheep ram one another with roughly 60 times the force needed to shatter a human skull. And they do it over and over again, sometimes for hours. Deer have been filmed with the head of a rival impaled on their antlers. Incidentally, deer get away with using pure bone weapons without a keratin component because the bone of mature antlers is dead and so doesn't bleed if damaged, and deer shed their antlers annually.

Contrary to the Hollywood narrative of predators

STEGOSAURUS was traditionally reconstructed with a green body, reddish back plates and white tail spikes (*right*). This new reconstruction (*left*) is informed by the coloring of large modern animals living in hot, dry settings like the ones *Stegosaurus* inhabited. Countershading would have shielded the skin from ultraviolet radiation and deterred predators; black and yellow accents would have called attention to the fierce keratin-sheathed plates and tail spikes.

Graphic by Mark Witton

facing herbivores in a duel to the death, actual hunting is about catching a meal, not a prize. To that end, most predators target juveniles. A carnivore needs to eat; it doesn't need to prove itself. The most epic battles in the animal world are not between predator and prey; they're between the armed and armored *herbivores,* who fight for status and mates.

Perhaps the same was true in the Mesozoic. In a study of *Zuul* published in 2022, Arbour and her colleagues showed that the animal had sustained, and healed, injuries to its flanks that were most consistent with being hit by the tail club of another *Zuul.* Furthermore, baby nodosaur specimens show that the kill box of these animals didn't fully develop until later in life—even though predation risk would have been higher when they were small. These findings, combined with the overbuilt nature of *Borealopelta,* suggest that at minimum the most extreme weapons of armored dinosaurs were mostly used in combat between rivals of the same species. Because this pattern also matches what we see in the world today, the best available explanation for dinosaur armor is that it was an adaptation to battles within the same species. That it could also dispatch a would-be predator in grisly fashion when needed was a bonus.

THANKS TO THE TWO OUTSTANDING armored dinosaur specimens *Zuul* and *Borealopelta,* we now know what to look for to identify thick keratin armor in fossil animals—and we see the telltale signs everywhere. From fibrous, blood vessel–filled bone edges in the plates of *Stegosaurus* to grooves along the horns of *Triceratops,* evidence for robust keratin sheaths is commonplace; it's been hiding in plain sight all along.

Keratin not only would have changed how the armor structures performed—increasing their toughness while decreasing their strength—it also would have fundamentally changed how these animals looked. This insight has led to the latest in a long series of visual updates to dinosaurs that have come from a rethinking of their anatomy that began in the late 1970s. Over the past decade quantitative assessments of posture, gait and skeletal mechanics have become well established in paleontology. As a result of these analyses, hunched ceratopsians and slump-tailed *Stegosaurus* from a century ago have given way to more erect, muscular builds with heads held high. Ankylosaurs are now envisioned as low, extrawide battering rams rather than vaguely melon-shaped animals.

The corrected postures and anatomies yield reconstructions that are simultaneously more dazzling and more lethal than the ones scientists generated before. These animals weren't just armed to the hilt, they were also adapted to wield their weapons to the deadliest effect. Far from being the passive animals imagined in centuries past, armored dinosaurs were among the most dangerous creatures in their ecosystems, magnificent to behold but terrifying to face in combat. Few animals would have dared challenge such imposing beasts apart from their equally well-equipped rivals. They were the gladiators of their time, ready to do battle at a moment's notice in their quest for status, mates and territory. ●

FROM OUR ARCHIVES
The True Colors of Dinosaurs. Jakob Vinther; March 2017. Scientific American.com/archive

TRICERATOPS was historically portrayed with saggy skin like an elephant's (*right*). But fossil evidence suggests that, in addition to having a keratin-enhanced frill and horns, this animal was covered in scales. *Triceratops* coloration is unknown, although like most dinosaurs it was typically envisioned with drab greenish hues. This new reconstruction (*left*) takes color cues from modern-day red river hogs, which engage in face-to-face combat like *Triceratops* did, as well as large turtles and bovids.

NEUROSCIENCE

Stuck in medical limbo for decades, one man tries to find the cause of his unusual behaviors

BY PAUL MARINO

PHOTOGRAPHS BY TRISTAN SPINSKI

A Complex Diagnosis

The author, Paul Marino, "motors" when his neurological condition manifests itself—often when he is feeling excited or engrossed.

HAVE TIME TO KILL until my neurology appointment at Kennedy Krieger Institute, a renowned children's hospital in Baltimore. I'm 42, but I traveled some 500 miles today to rectify something missing from my childhood, when I sought answers in vain about a neurological phenomenon that was virtually unknown to science. So I pop into the nearby George Peabody Library. Its colossal atrium, six stories of ornate neo-Greco alcoves, towers up and around the open marble floor. I am at a wood desk, writing freely in my notebook, when a familiar impulse comes on strong. My body begins to "motor." Remembering I'm in public, I suppress it, as usual. But then, in the spirit of my trip, a radical and frightening whim occurs to me: *What if I just did it?* I look around. A lone librarian stamps books; a couple of tourists stare up at the glass ceiling. *What am I afraid of?*

As far back as I can remember, I did this "thing" when I was excited or engrossed. I brought my hands up, flickered my fingers against one another and grimaced. My imagination zoomed.

That's how I played, too. When I had fun with my G.I. Joe figurines—artifacts of my 1980s childhood—rather than smashing good Gung-Ho against the nefarious Cobra Commander, as other kids might have done to breathe life into them, I would simply position the figures in front of me on the coffee table and motor—a word I use to describe my physical movements and the mental energy that drives them. In my mind's eye, the characters brimmed with kinetic energy: flaring, vivid, cinematographic. It's also how I drew. Each time I added a line or color, I would pause and motor, visualizing the subject like a model in my mind.

My parents chalked it up to a childhood quirk. They assumed I would outgrow it, and in grade school it appeared I did. Having been teased about it, I began subconsciously to suppress it. It kindled up in me constantly, but only when I was safely out of sight—any time I shut the bedroom or bathroom door—did I let myself go. It never even diminished. I did it every day, throughout each day, so that I was hardly aware of it.

Motoring often derailed my focus, though. When I did homework in high school, the scenes in history books set me off. Again and again I had to find my place in the text. Once, in frustration, I bundled my fingers together with Scotch tape.

There was a sinister side, too. I became hyperabsorbed in positive ideas, but in the same way, frustration, anxiety or insult could send me into a feedback loop of obsession, emotional amplification and physiological arousal. Many nights in bed when I wished I were sleeping, such episodes left me sweating, my heart racing and my brow chafed from the friction of my hands flickering against it.

Worst was the shame, the duplicity. I presented as a pretty cool kid—smart, funny, athletic, pimply yet handsome—but the grim fact, as I saw it, was that I was a freak. If discovered, my secret had the power to humiliate me beyond repair. My slim chances with the girl of my dreams would drop to zero.

The times I got caught were jarring. "Paul, you still do that?" my mother asked after glimpsing me through a door ajar. From a dark corner of the basement, my older teenage brother stepped into the light—"What are you doing?!"—and burst into laughter and mimicry. "Are you okay, man?" asked a field trip chaperone whom I hadn't noticed in a nearby bunk.

I figured that I had manifested the thing myself, like an unsightly habit or infantile attachment, too weak of character to shake it. Time and again I scolded myself and swore off it, with no effect. I thought I must be the only person in the world who did it.

My search for answers began in the early 1990s, before Google was even a noun. In a small Massachusetts town, a pediatrician who was seeing me nodded and uttered, "Hmm," but his pen didn't budge. My

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Marino sits in his living room, in a house he built by himself on an old foundation while working as a reporter, writer, multimedia storyteller—and occasional builder.

shy description seemed to contradict itself: "When I'm imagining something, this thing happens with my hands. I don't do it on purpose, but I can stop it." In his defense, I suppose that kids' morphing, innervated bodies prompt many concerns that pediatricians are accustomed to dismissing. Even if he had looked into it, there wouldn't have been anything to find.

HARVEY SINGER, a pediatric neurologist at Johns Hopkins University and Kennedy Krieger, began his search for information about this condition around the same time. "We were seeing patients who were sent to us with the diagnosis of having tics," he told me in a recent interview. "But we were saying, 'Come on, these aren't tics. These fit best into the category known as motor stereotypies.'"

Simple stereotypies are as common as drumming your fingers or twirling your hair. In some people, they're more pronounced but still not concerning. I have a friend who yells "Scoot, scoot!" and claps his hands when he's excited, for example. The term "stereotypy" comes from the Greek *stereós* ("firm") and *týpos* ("impression") and is a medical variation of "stereotype," which has a similar etymology. The kids being brought to Singer were engaging in more complex behaviors, however: arm flapping, finger wiggling, grunting, grimacing, and other actions often associated with intellectual disabilities such as level 3 autism and Down syndrome. Yet they seemed okay developmentally.

Singer told me there was no significant discussion in the literature. A leading medical text at the time had just one short paragraph on stereotypies, which said more about what they weren't—not tics, not autism, not tardive dyskinesia—than what they were. Another source, that era's *Diagnostic and Statistical Manual of Mental Disorders* (*DSM-III*), listed a "stereotypy/habit disorder" with extreme behaviors such as eye poking and hyperventilation. A poster at the 1993 Symposium on Hyperkinetic Movement Disorders in Boston described three otherwise typical boys with "unusual, complex, repetitive stereotypic movements." The sources contained no information on the cause, persistence, treatment or impact of noninjurious stereotypies.

"There were lots of unanswered questions," Singer said. "The only way to get them resolved was to do it ourselves."

AFTER COLLEGE I WENT WEST, as one does, to seek my fortune in the arts. At age 25, I wondered whether more prodigious success might arrive if this *thing* didn't interrupt my writing so often. I was referred to a neurologist in San Francisco, who described my condition as a tic disorder and prescribed me guanfacine, a drug that

reduces tics by interacting with neurotransmitters. The doctor said that as a side effect, the medication would make me lethargic.

Back in my apartment, I contemplated the bottle of pills. I would be trading one problem for another. I had come this far in life as I was. What I had wanted more than treatment, I realized, was a diagnosis. I tossed the pills and shelved my search for almost a decade.

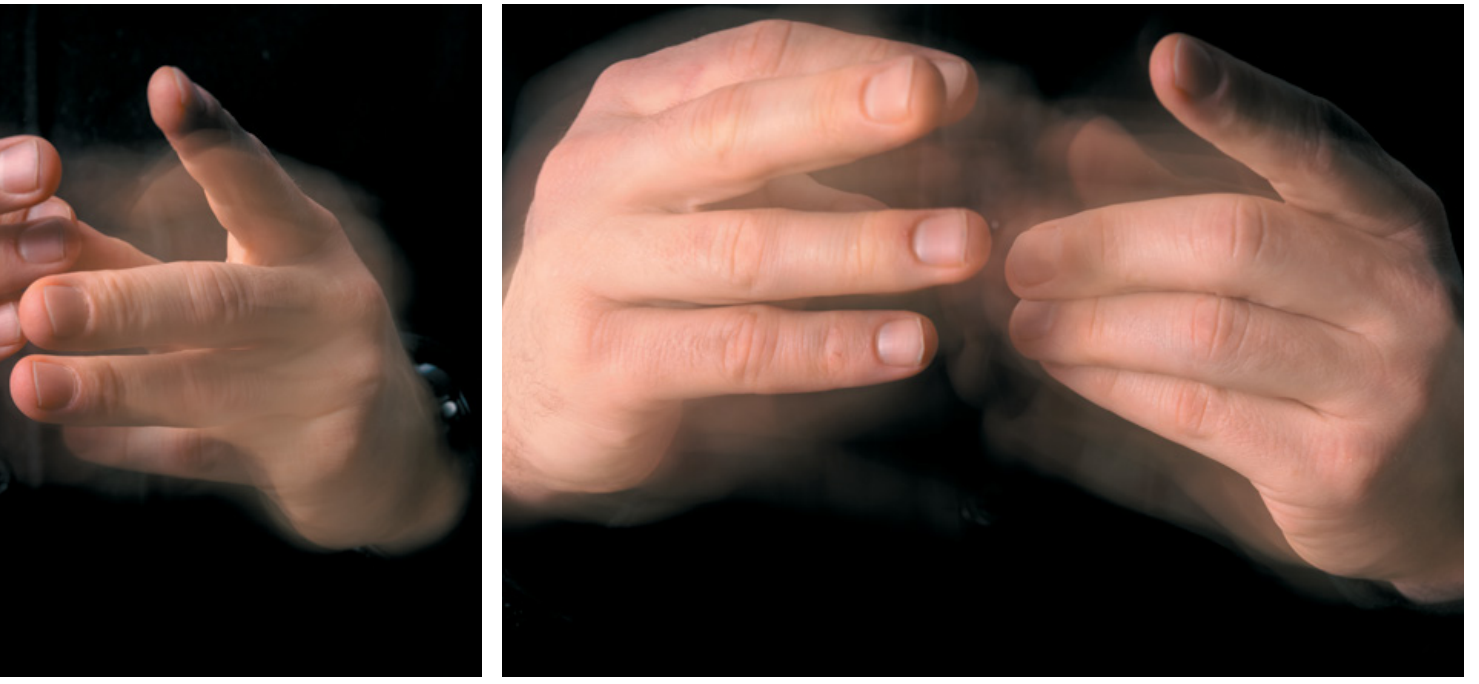
In 2004 Singer's team published a paper entitled "Repetitive Arm and Hand Movements (Complex Motor Stereotypies) in Children." The researchers went on to produce a brain-imaging study in 2005 and a longitudinal follow-up of 100 pediatric patients with CMS in 2008. Prior scholarly descriptions had postulated psychogenic causes, but the findings from Singer and his colleagues suggested biological ones. Almost half of the children in their studies had neurological comorbidities—attention deficit hyperactivity disorder (ADHD), obsessive-compulsive disorder (OCD), tics—implying some biochemical or neuroanatomical commonality. What's more, a Mendelian pattern of inheritance appeared: a quarter of the study participants' families reported a relative with motor stereotypies, suggesting a genetic factor.

Singer's quest to understand CMS happened to correspond with major advancements in brain research, imaging and genetics. In 1986 researchers from Johns Hopkins and the State University of New York Upstate Medical University identified a neuronal pathway that regulated motor movements. Complex and fluid, the cortico-striato-thalamo-cortical (CSTC) loop relies on several neurotransmitters. Signals travel from the frontal cortex, which processes emotions, attention, social cues and impulses, inward to the striatum, part of the basal ganglia, which determines the appropriate motor responses. From there the signals advance through the thalamus, a switchboard for motor signals, and back to the motor cortex, which commands the body to execute movements.

The advent of functional magnetic resonance imaging (fMRI) in 1991 and the launch of the Human Genome Project in 1992 helped to revolutionize the etiology of movement disorders. Researchers discovered gene mutations associated with Huntington's disease and Parkinson's disease. Johns Hopkins got its first fMRI machine in 1999, which helped scientists more firmly link dysfunction in the basal ganglia, in the deep center of the brain, to Tourette's syndrome and dystonia, which causes involuntary muscle contractions. Further work connected multiple movement and emotional disorders to the CSTC loop. Parkinson's was linked to dopamine deficiency in the striatum, and Huntington's was linked to degeneration in the striatum and atrophy in the frontal cortex. Tic disorders, OCD and ADHD were all strongly associated with CSTC abnormalities.

In 2005, when Singer conducted an imaging study of CMS, he found that the children being referred to him had significantly reduced volume in parts of the CSTC loop. In 2010 psychiatrist Roger Freeman of the University of British Columbia and his colleagues published "Stereotypic Movement Disorder: Easily Missed," a study of 42 children. In 2016 Singer and his co-workers documented reduced levels in the cortex of the CSTC's inhibitory neurotransmitter, known as GABA. Their most recent fMRI study, in 2021, revealed reduced connectivity between the prefrontal cortex and the striatum, a branch of the CSTC associated with goal-directed behaviors.

These findings and those of other researchers were lining up. Children tended to present stereotypies at around two years of age. The movements varied—



Finger flickering is an outward display, driven by what's happening in Marino's mind. His highly repetitive movements have been the same since he was in grade school.

arm flapping, finger flickering, grimacing, rocking—but the triggers were the same: excitement, engrossment, boredom, anxiety. And a simple distraction could suppress them. The movements almost always persisted into adolescence, although most children "privatized" them like I had. Freeman even noted a possible role of the syndrome in creativity.

Clearly influenced by the research, the *DSM-5,* released in 2013 and not updated until 2022, dedicated several pages to stereotypic movement disorder, the diagnostic name for CMS. It included refined diagnostic criteria and sections on its onset time, prevalence, persistence, possible causes and comorbidities. But because studies so far have all involved pediatric patients, what happens after adolescence remains a mystery. For adults, "there are basically no data," Singer said.

In my early 30s, after relocating and switching careers multiple times, I found myself studying journalism in New York City. People there understand that riders of the subway include the rarest subsets of humanity. Once, stepping off my train, I glimpsed a man flapping his hands near his face, which restarted my yearning to know, above all, whether I was alone.

This time, armed with search engines, I looked up every relevant term I could think of: "hand flapping," "spasms," "trance." I shuffled through page after page of links about autism. Adding the term "suppressed" led me to a video of a man with Tourette's bravely demonstrating the true, private intensity of his tics; painstakingly, I even read the comments. Number 75 was from someone named Digibullet23. When I read this person's words, I knew right away. "I have Tourette's, it's all I think it could be," Digibullet23 wrote. "Besides being caught by a cousin in the dark years ago, I have been able to hide it from everyone." Our movements sounded almost identical: "I get overexcited, I put my hands to my face with a couple fingers out on each side for a few seconds. It's really hard to explain."

Like a sign of life underneath the rubble, Digibullet-23's testament lit new fervor in my digging. The answer seemed imminent. I quickly found the Johns Hopkins web page on motor stereotypies. Mouth agape, I read the studies by Singer and Freeman. I wept, laughing tears of relief.

Even self-diagnosis can be life-changing. I had always lacked effective language to articulate or legitimize this thing, but now I could invoke a bona fide medical term to help explain myself, find information and connect with other people like me. I joined dedicated support groups on social media with thousands of members worldwide. The people were mostly parents of children with CMS, but I found several adults, too, whom I contacted by phone. Although we were strangers, we were so glad to relate our experiences that, in a few cases, we spoke for more than an hour.

The hereditary factor, coupled with secrecy, produced incredible stories. Wendy C., 47, of Hertfordshire, England, with whom I spoke again recently, had never heard of CMS when the behavior appeared in her young daughter. Only later did Wendy reveal to her husband that, in private, she did the same thing. They did some research and relayed their discovery to the grandparents. That's when Wendy's mother came out: so did she!

Similar midlife revelations are common for conditions that are hard to explain, stigmatizing or unfamiliar to physicians. A surgeon with Tourette's, Carl Bennett—a pseudonym given him by neurologist Oliver Sacks when he described the doctor in a 1992 *New Yorker* article—was 37 when he first heard his

As a child and teenager, Marino instinctively suppressed his motor stereotypies when people were around. Today he still largely refrains from motoring in public, but now that he finally has a diagnosis after decades of searching, he has accepted his condition and is more transparent about it.

condition named and described on a radio program. Bennett's wife later told Sacks about that moment: "He got all excited and hollered, 'Helen, come listen! This guy's talking about what I do!'" That was in 1977, three years before Tourette's was added to the DSM. "He was excited to hear that other people had it," she said. "It was good to put a label on it."

Of course, I had labeled myself. But I still couldn't be sure that what I had was CMS.

IN 2023 SINGER and researchers at Yale University published a DNA-sequencing study of 129 parent-child associations in which the child had CMS, as well as 853 controls. It identified at least one gene associated with CMS. But there's no getting rid of the condition. "We don't have any great medicine that's been identified," Singer said. Donald Gilbert, a pediatric neurologist at the University of Cincinnati College of Medicine, who trained with Singer, said there are situations where stereotypies are so problematic for a patient that he might prescribe an antiadrenergic agent. He's interested in a new dopamine blocker, ecopipam, but it is not yet approved by the U.S. Food and Drug Administration for tics. If kids are motivated, Gilbert also recommends a cognitive-behavioral therapy program developed by Singer's clinic.

Handling the symptoms "starts with awareness training," said clinical psychologist Matt Edelstein, who conducts the CMS program at Kennedy Krieger. "We want kids to be able to think about their bodies and self-monitor when they're engaging in stereotypies." Edelstein uses a game-based approach with patients as a nonaversive introduction to suppression. He concedes that suppression is a skill children may find on their own, as I did—in my uninformed and isolated kind of way. I like his approach better. "Stereotypies aren't bad, and we're never going to talk about them as being bad," Edelstein said; he uses the word "phenomenon" instead of "disorder" to describe them.

Edelstein and Singer both confirmed something else evident on social media forums: many parents worry about their kids' CMS more than the children do. According to a recent Pew Research Center survey, U.S. parents' top concerns for their kids are mental health and bullying. To reduce movements, some parents have tried heavy metal detoxifiers, acupuncture and elimination diets. Many parents, however, seem to think a better approach for children would combine education,

self-awareness and teaching their kids to accept themselves as they are.

After all, CMS isn't all bad. Like "islets of ability" in people with autism and reported advantages of ADHD, CMS may have a silver lining. Freeman aired this perspective early on. "Most children said they liked their stereotypies," he and his co-authors reported in their 2010 paper, noting a positive connection to fantasy, daydreaming and visualization.

Tammy Hedderly, a pediatric neurologist at Evelina London Children's Hospital, found that children with CMS often experience detailed visualizations while motoring. In a 2016 paper, she and her colleagues describe intense imagery movements (IIM) as a subset of CMS. "It's almost, in some children, like a superpower," Hedderly said, "and not something to be pathologized." Of the adults she has diagnosed with the condition, a remarkable proportion are architects, designers, writers, producers, musicians, artists and "numbers people," she told me.

"It's part of my experience through my own consciousness," said Byrne Klay, a 45-year-old man in Maryland who self-identifies as having both CMS and IIM. A professional musician and visual artist, Klay belongs to the small and brave contingent of people who don't suppress their stereotypies in public. His bandmates are used to him pulsating his fists and grimacing during rehearsal. Klay, who plays about a dozen instruments, said that when he's motoring, he can visualize music and abstract ideas vividly—"I'll see it, I'll hear it, and that's when the movements are prone to come out." He said he wouldn't get rid of his CMS if he could.

Like me, Klay has learned on his own to use self-awareness to emotionally regulate and avert prolonged, toxic episodes. When I recognize that my condition is diverting me from important tasks or absorbing me in a negative fixation, I bring myself back to reality gently and without reprisal. "Okay, buddy, stay focused," I tell myself.

Hedderly recommends mindfulness or a modified form of cognitive-behavioral therapy to people so they can enjoy IIM when it's constructive. Her aim with patients is to prevent them from becoming "maladaptive daydreamers." Although this term is not listed in *DSM-5,* researchers have used it to describe excessive, vivid daydreaming that is frequently accompanied by motor stereotypies. Potato, potahto.

How adults with CMS fare in life is something that Singer and I both want to know. His team is currently conducting an adult quality-of-life study that should tell us. "It's interesting that the movements themselves didn't appear to be inhibiting," he said about the data so far, "whereas the psychosocial aspect of quality of life was more of an issue."

IN THE GEORGE PEABODY LIBRARY, I'm thinking of Freeman. He has retired, and I couldn't interview him for this story. I spoke to him several years ago, however, and he shared a vision that struck me as unthinkable. He suggested that a better world would be one in which we did not pathologize CMS but erased its stigma. "You don't understand," I told him. I insisted that what I do is alarming, grotesque. He replied that social norms are relative and change constantly. I'll never forget him reminding me that people used to go around spitting tobacco juice in public. "They had spittoons in post offices and banks," he said. "Can you imagine?" People with CMS ought to motor in public and let others get used to it, he said; they would feel much better about themselves.

I decide to test his hypothesis. *Here's to you, Dr. Freeman,* I say to myself. I do a little finger flickering like I would at home alone. It looks like I'm casting a hex on my notebook. I feel comically exposed, as when I forget my towel after a shower and streak past the front windows. *There, that wasn't so bad. No one's even looking.* Now I really go for it. I bring my hands up to the sides of my nose and let them motor intensely. My face widens out in a big lemon juice grimace, and my imagination whirls—this place, this trip! It's a rush!

I look around. The librarian keeps right on stamping, unfazed. The tourists might have glanced, but I doubt they think any less of me. It's not like they're pointing and conferring, and anyway, what do I care what they think? Only if we dare to be our authentic selves can we feel accepted—that's the kind of advice I love to shell out, but when it comes to myself, I've been a hypocrite.

When I get to Kennedy Krieger, I expect one of Singer's protégés to meet me, but to my surprise, Singer enters the room to see me himself. With a white goatee and glasses, he seems grandfatherly—not at all pedantic or commanding, as I had feared, but warm, mild-mannered and earnest. I'm comfortable enough to demonstrate my movements. To rule out other diagnoses, he has me track his pen light with my eyes, do a little math, hop on one foot. He asks me what triggers my movements, what inhibits them, whether I feel any premonitory urge and what makes them stop. "You've either read all the research and are faking it very well," he says to me, facetiously, "or you've got complex motor stereotypies."

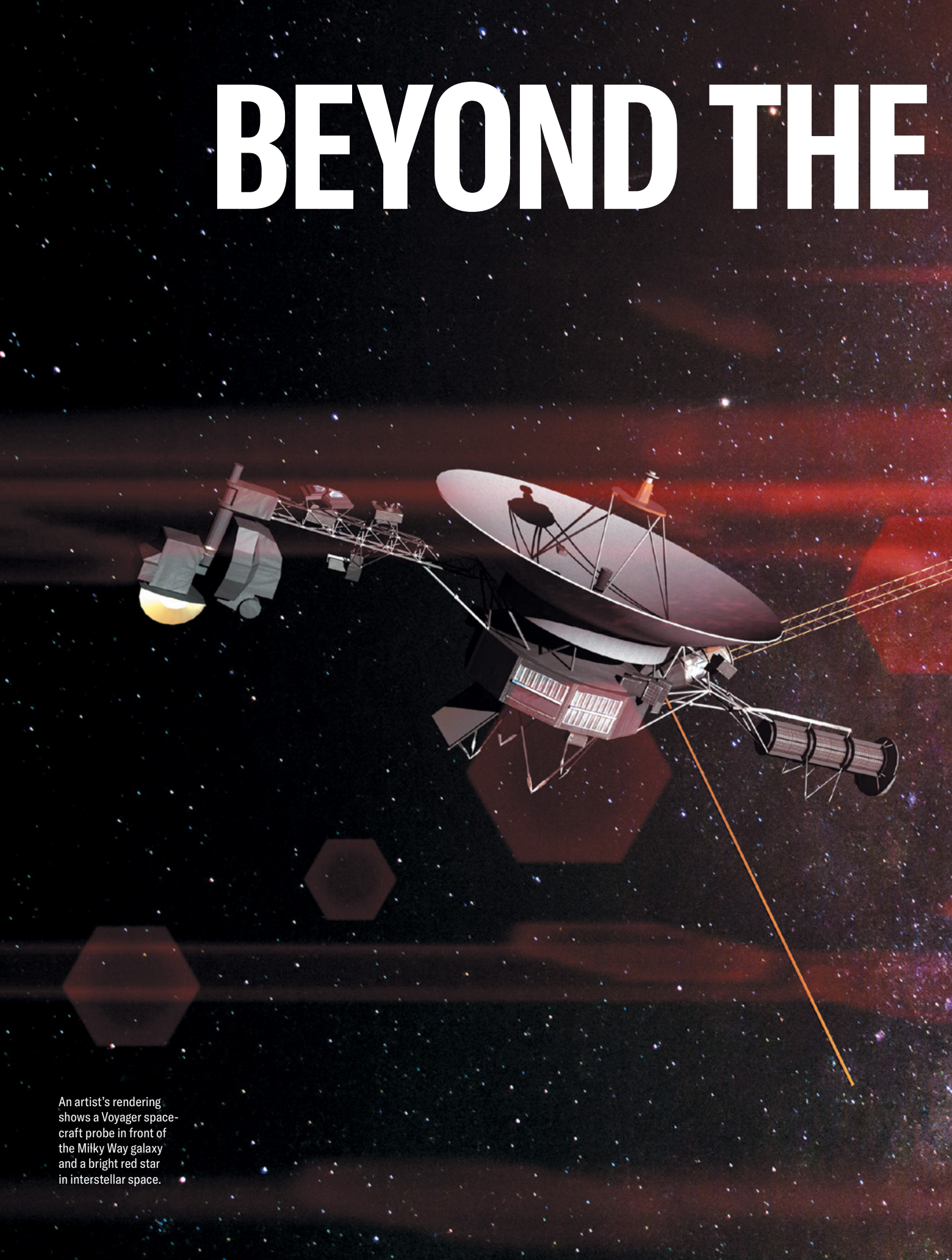
It's what I expected, but I needed to hear it. Singer offers to answer any questions, although he admits there is still a lot to learn about CMS. He introduces me to his assistant so I can participate in the adult quality-of-life study. He notes that behavioral therapy is available now for adults, but that doesn't much interest me. I've already resolved what troubled me most: uncertainty.

Outside the hospital, heading back to the airport, I descend the Baltimore subway stairs feeling an odd mix of satisfaction and disappointment. A long journey is over. I officially belong to the 15 to 20 percent of the population considered neurodivergent, whose brains, for better or worse, are atypical. All I can do is own it. At the turnstile a middle-aged man in stylish street wear blurts out Tourettic mandates as he strides past me with a confident gait. No one but me looks twice. ●

FROM OUR ARCHIVES

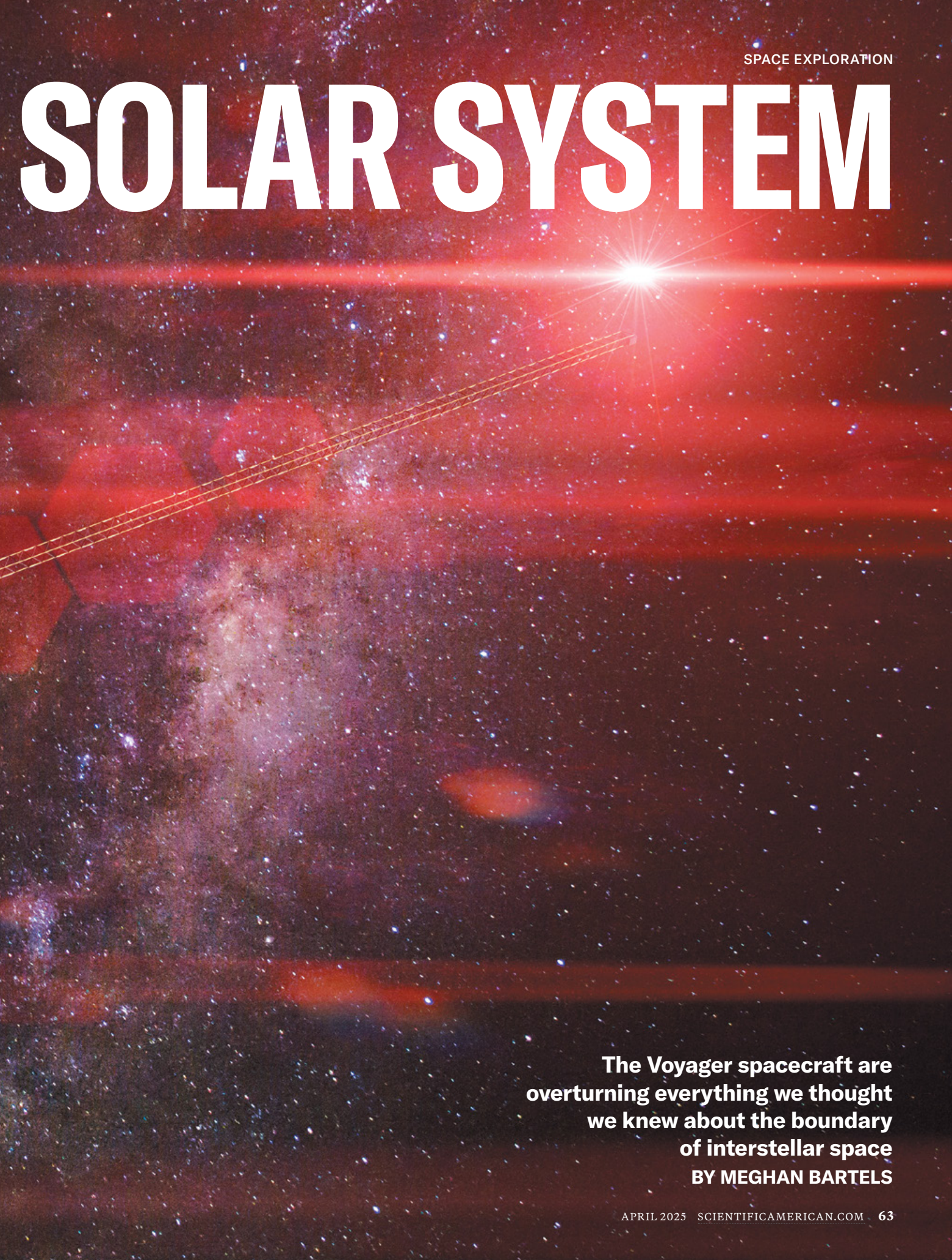
An Elusive Brain Disorder. Z Paige L'Erario; July/August 2023. Scientific American.com/archive

BEYOND THE



An artist's rendering shows a Voyager spacecraft probe in front of the Milky Way galaxy and a bright red star in interstellar space.

SOLAR SYSTEM



The Voyager spacecraft are overturning everything we thought we knew about the boundary of interstellar space

BY MEGHAN BARTELS

IN HUMANITY'S MILLENNIA of staring at the stars and decades of launching probes to explore our universe, only two spacecraft carrying working instruments have ever managed to escape the bubble of space governed by our sun.

The twin Voyager spacecraft were launched in 1977 on an epic tour of the outer planets; both swung past Jupiter and Saturn, and Voyager 2's itinerary later included Uranus and Neptune. The two probes have trekked ever outward since, and several of their instruments have continued observations despite the challenges of aging technology and waning power supplies. In 2004 Voyager 1 reached the termination shock, the beginning of its yearslong transition to interstellar space. Voyager 2 crossed the same threshold in 2007.

In the years since, the twin spacecraft have been providing us with our only direct view of what lies on the outskirts of and beyond the region of the sun's influence on space, an area scientists call the heliosphere. The Voyagers' findings have revealed countless new puzzles about the outer heliosphere and interstellar space. These iconic spacecraft are now running out of time, but scientists are busy finding new ways to study the territory's mysteries.

"We know now how little we know about the heliosphere," says Merav Opher, a space physicist at Boston University. "It's way more complex, way more dynamic than we thought."

HERE'S WHAT SCIENTISTS DO KNOW: We Earthlings may simplistically think of the sun as a compact, distant ball of light, in part because our plush atmosphere protects us from our star's worst hazards. But in reality, the sun is a roiling mass of plasma and magnetism that radiates particles billions of miles out into space in the form of the solar wind. The sun's magnetic field, which travels with the solar wind, also influences the space between planets. The heliosphere grows and shrinks in response to changes in the sun's activity levels over the course of an 11-year cycle.

"You see these dramatic 11-year bumps, mins and maxes, dips and peaks throughout the whole entire heliosphere," says Jamie Rankin, a space physicist at Princeton University and deputy project scientist of the Voyager mission. And, she notes, astronomers of all stripes are trapped in that chaotic background in ways that may affect their data and interpretations. "Every one of our measurements to date, until the Voyagers crossed the heliopause, has been filtered through all the different layers of the sun," Rankin says.

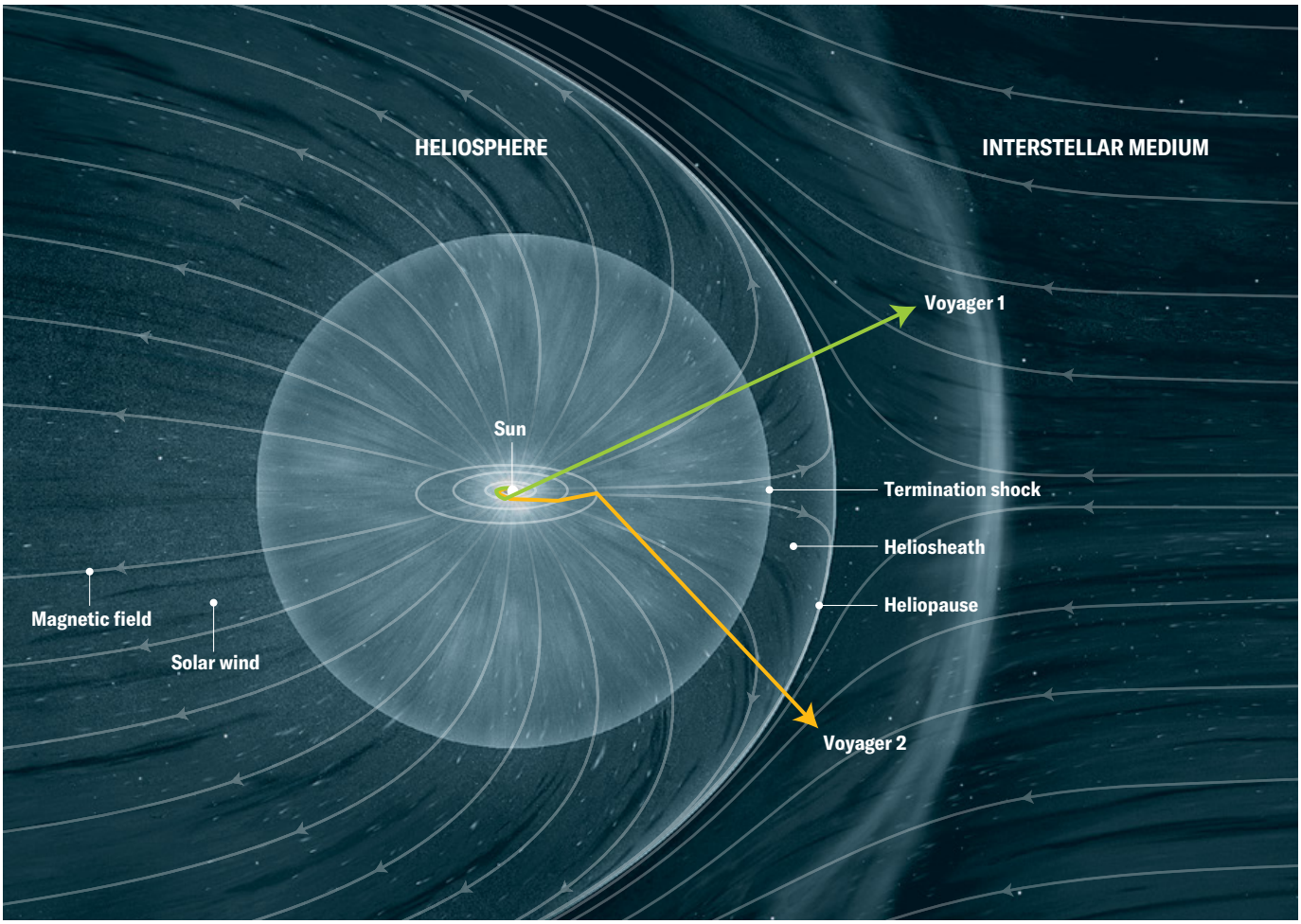
The Voyagers earned their fame when they, too, were subjected to the sun's whims. When the twin spacecraft originally launched, they were designed to take advantage of a rare alignment—happening just once every 176 years—that made it surprisingly economical to slip past all four outer planets: Jupiter, Saturn, Uranus and Neptune.

The Voyagers discovered that Jupiter's moon Io was a nightmarish, volcanic world nothing like Earth's inert, gray moon. Voyager 1 surveyed Saturn's large moon Titan and its thick, hazy atmosphere, composed predominantly of nitrogen, just like our own. Voyager 2 was the first and remains the only spacecraft to fly past Uranus and Neptune, worlds where it discovered superfast winds, more than a dozen moons and six new rings, as well as Uranus's strange, tilted magnetic field and Neptune's so-called Great Dark Spot storm system. The solar system would never look the same again.

Even before launch, the poetry of the mission was

Meghan Bartels
is senior news reporter at *Scientific American.*

dotted zebra/Alamy Stock Photo (*preceding pages*)



clear. Astronomer Carl Sagan spearheaded an effort to equip each spacecraft with a Golden Record, a symbolic gesture to any other intelligent life in the universe. Each record, made to withstand the hazards of interstellar space, encoded a map of our location in the universe, photographs of daily life on Earth, and greetings and songs in countless languages. They offer a love-laden portrait of humanity to anyone who happens to find them in the centuries the spacecraft will spend floating through the cosmos.

On their trek to interstellar space, the Voyagers had to cross a set of boundaries: first a termination shock some seven billion or eight billion miles away from the sun, where the solar wind abruptly begins to slow, then the heliopause, where the outward pressure from the solar wind is equaled by the inward pressure of the interstellar medium. Between these two stark borders lies the heliosheath, a region where solar material continues to slow and even reverses direction. The trek through these boundaries took Voyager 1, the faster of the twin probes, nearly eight years; such is the vastness of the scale at play.

Beyond the heliopause is interstellar space, which Voyager 1 entered in 2012 and Voyager 2 reached in 2018. It's a very different environment from the one inside our heliosphere—quieter but hardly quiescent. "It's a relic of the environment the solar system was born out of," Rankin says of the interstellar medium. Within it are energetic atomic fragments called galactic cosmic rays, as well as dust expelled by dying stars across the universe's eons, among other ingredients.

The interstellar medium varies across the galaxy, with denser and more tenuous areas alternating across the Milky Way's spiral arms. Our sun and the bubble it creates plow through this interstellar medium, and the interaction between the sun's dynamics and the interstellar medium influences the shape of the heliosphere.

What that shape is, however, scientists don't yet know. The heliosphere's shape may resemble that of a comet, with a long tail trailing a compact nose where the sun pushes into interstellar space. Or perhaps the

A diagram of the heliosphere shows the solar system with the solar wind and sun's magnetic field flowing out to meet the interstellar medium. Scientists don't yet know the shape of the heliosphere but are familiar with its three-part boundary, consisting of the inner termination shock and outer heliopause, in part because of observations gathered by the twin Voyager probes.

"The Voyagers are very much like biopsies of the heliosphere. We know nothing about the global three-dimensional structure of the outer heliosphere from just these two sets of points."

—DAVID McCOMAS *PRINCETON UNIVERSITY*

Graphic by Matthew Twombly

interplay between the sun's magnetic field and the interstellar medium molds the bubble into a croissant-like shape, with two lobes stretching away from our star. The heliosphere could also take some other form that scientists haven't even considered yet; certainty about it is difficult from our limited view on Earth. "It's like we're goldfish trying to measure our goldfish bowl from the inside, and we can't even get to the edges," says Sarah Spitzer, a space physicist at the Weizmann Institute of Science in Rehovot, Israel.

The Voyager probes are the accidental exceptions to this challenge. By 1989 they had completed their planetary observations and primary mission yet were still in good health. NASA kept them going, albeit after turning off instruments that wouldn't produce interesting data without planets to observe. Years passed, and the Voyagers trekked ever outward, swimming toward the walls of our cosmic goldfish bowl.

BUT THE GOLDFISH weren't floating idly by. In 2008 NASA launched the Interstellar Boundary Explorer (IBEX), which orbits Earth and samples particles called energetic neutral atoms that stream in from the edge of the heliosphere. Scientists can use IBEX measurements of these particles' characteristics to reconstruct some of what's happening far out there, billions of miles away.

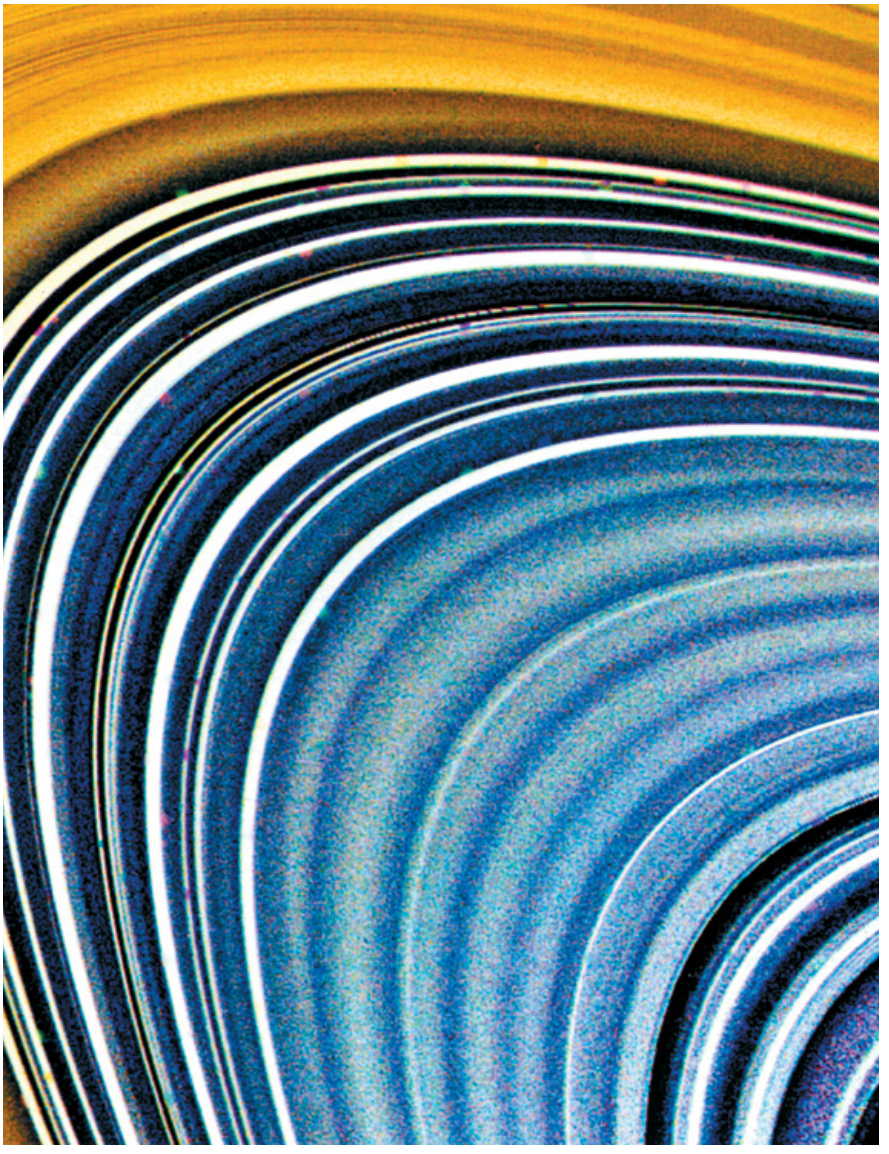
Among IBEX's key contributions is the discovery of a ribbon of energetic neutral atoms draped across the heliosheath. Scientists think the ribbon may be caused by particles that bounce in and out of the heliosphere. But in an example of cosmic bad luck, the Voyager spacecraft weren't able to directly study IBEX's ribbon: they zipped past on either side of it. "Right between them is the biggest, most glaring thing in the outer heliosphere," says David McComas, a space physicist at Princeton and principal investigator of IBEX.

It's exactly the kind of situation that shows the limitations of relying on local observations of something as all-encompassing as the vast province of our star's influence. "The Voyagers are very much like biopsies of the heliosphere," McComas says. "We know nothing about the global three-dimensional structure of the outer heliosphere from just these two sets of points."

IBEX is still observing, having lasted much longer than originally planned, and the spacecraft has managed to gather data throughout a complete 11-year solar cycle to watch the heliosphere's response to the sun's activity. But McComas is also hard at work getting another mission he leads ready for launch this autumn. He describes the Interstellar Mapping and Acceleration Probe (IMAP) mission as "IBEX on steroids," with the same basic capabilities but at higher resolutions and taking additional measurements.

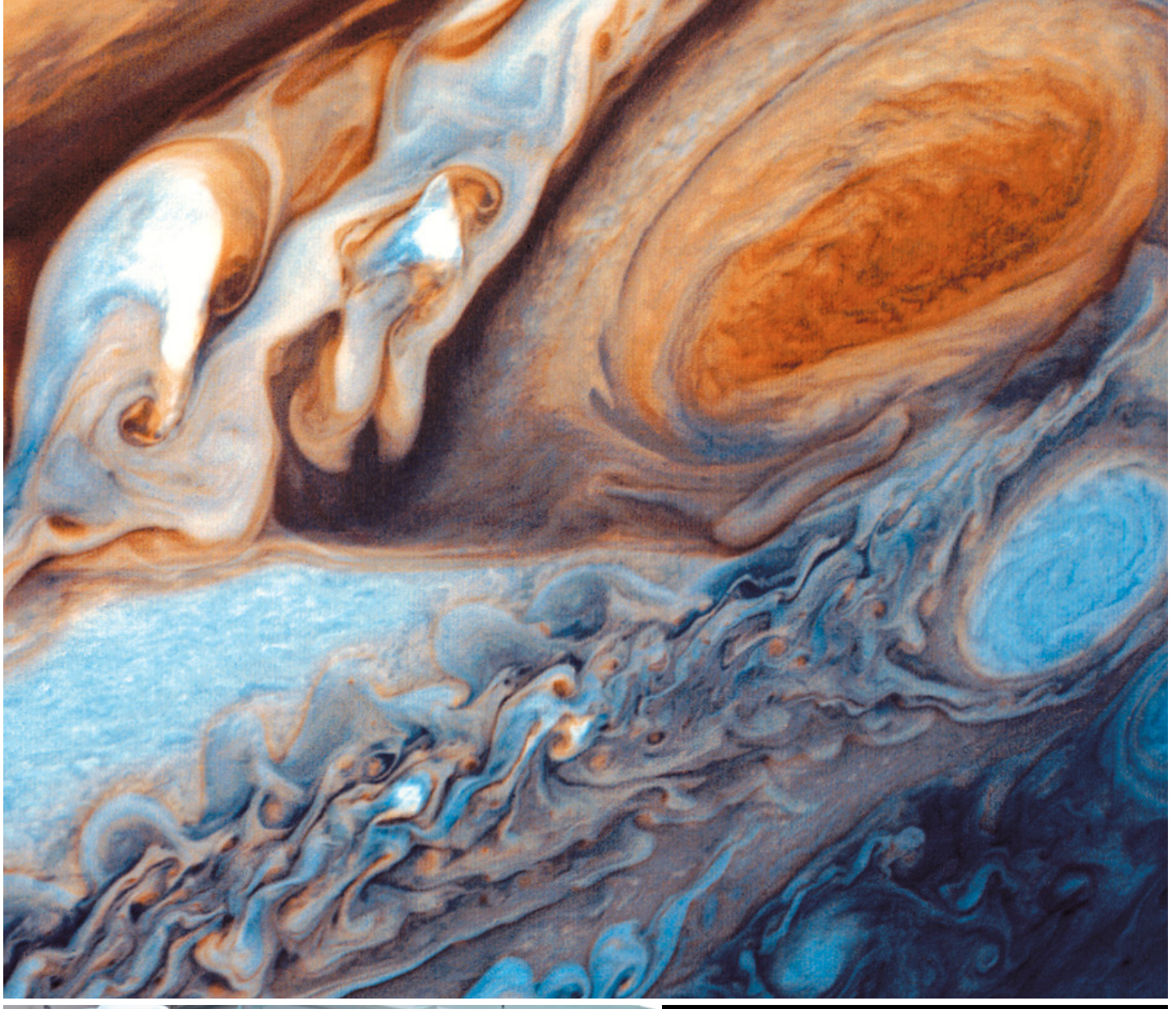
IMAP will travel to what scientists have dubbed Lagrange Point 1, a stable orbit path about one million miles toward the sun from Earth. From this vantage point, the spacecraft will catch a host of particles: the same energetic neutral atoms that revealed the IBEX ribbon; so-called pick-up ions that begin as atoms in the interstellar medium, pick up a charge near the sun and reverse course to head back out toward the heliopause; and grains of interstellar dust—debris from dead stars—that sneak into the solar system. Meanwhile the probe will also observe the sun's magnetic field and the structure of the solar wind to reveal why particles travel the way they do. With these tiny messengers, IMAP scientists hope to build a clearer map of our heliosphere and a sharper picture of what lies beyond it.

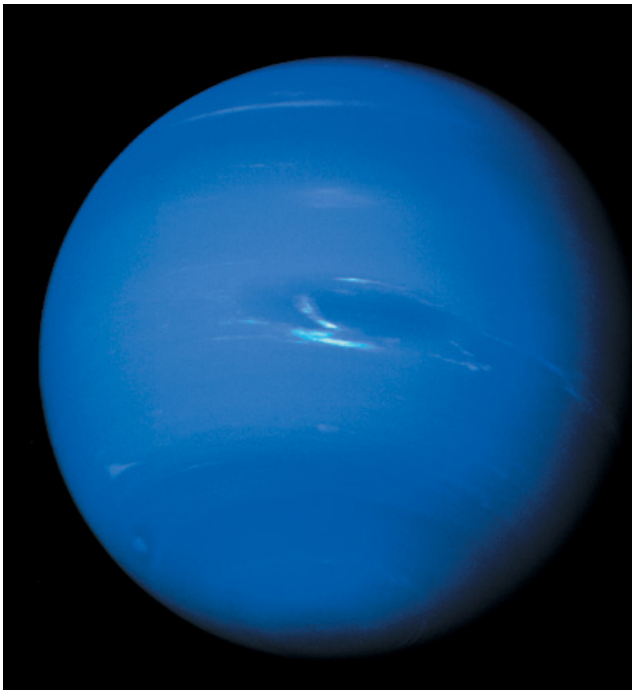
Other scientists are scheming to collect more observations from the region directly. One more spacecraft is already on track to follow the Voyagers out of the heliosphere: NASA's New Horizons mission, which whizzed past Pluto in 2015. The spacecraft finished studying the dwarf planet (and, in 2019, an even more distant rocky object called Arrokoth) and is on course to cross the heliopause in perhaps another decade or so. Scientists hope its



Clockwise from left: The picture of Saturn's C-ring (*blue-white*) and B-ring (*yellow*) was produced by Voyager 2 in 1981. Jupiter's Great Red Spot was seen during Voyager's 1979 flyby. The image of Neptune was based on data gathered by Voyager 2 in 1989. Engineers work on a high-gain antenna, designed to communicate with Earth, for one of the Voyager spacecraft in 1975.

NASA/JPL





instruments will still be working then, ready for humanity's third expedition beyond the sun's influence.

Scientists have also designed a would-be mission, dubbed Interstellar Probe, that, unlike the Voyagers and New Horizons, is tailored to illuminate the outer reaches of the heliosphere and beyond. It would use a massive rocket to take a fast track out of the solar system, carrying instruments to study plasma and magnetic fields instead of planets. Ideally, it would travel far enough to look back and discern our heliosphere's elusive shape from a distance. But that mission was not recommended as a priority in a recently released Decadal Survey that charted U.S. heliophysics for the coming decade, and this rejection has hurt the chances of the nation's scientists sampling the interstellar medium anytime soon. (Researchers in China may be more fortunate because that country is pursuing an interstellar mission of its own.)

FOR NOW SCIENTISTS ARE STUCK poring over the signals dribbling back from the Voyagers. In some ways, they have a wealth of information: about two decades' worth of data on the boundary to interstellar space and what lies beyond from two craft at two different locations. And the returns are rich in oddities, with one spacecraft apparently crossing the termination shock five different times, perhaps as the heliosphere billowed in and out in sync with the solar wind's fluctuating strength.

But the Voyagers' distant observations remain mere breadcrumbs, tantalizing glimpses of a region that lies *nearly* out of our reach—exactly the type of data that raises more questions than answers. For example, scientists expected that the magnetic fields of the heliosphere and interstellar space would be dramatically different, but the probes have found otherwise. In 2020 Voyager 1 entered a strange "pressure front"—a sudden increase in the magnetic field that scientists can't explain. And even though both spacecraft are years beyond the heliopause, they continue to see small traces of the sun's activity in the material they sail through, expanding scientists' understanding of how far our star's influence reaches.

And, of course, the Voyagers are aging. They are by far NASA's longest-observing spacecraft, dreamed up by scientists who never imagined the mission might go on to outlive them. At each probe's heart is a nuclear core to power instruments and communications, but they are running on about half the power they launched with and are weakening every year. Voyager 1 has had serious episodes affecting its communications in the past couple of years, and Voyager 2 briefly lost its orientation to Earth. At this point any glitch could easily be the end.

One thing is certain: no matter when their mission concludes, the Voyager spacecraft will leave scientists wanting more data from interstellar space. "The instruments are going to be shut off before we get the full picture," Opher says. "But having the Voyagers extended as much as we can, it's priceless." ●

NASA/JPL-Caltech

An updated version of Voyager's iconic "Pale Blue Dot" image, originally released in 1990, shows Earth as a faint speck in a streak of sunlight. The image was taken by Voyager 1 when it had completed its planetary flybys and was 3.7 billion miles away from the sun.

FROM OUR ARCHIVES
Voyagers to the Stars. Tim Folger; July 2022. ScientificAmerican.com/archive

Energy-Efficient AI Is Critical

The real innovation in artificial intelligence must be in powering it more sustainably **BY THE EDITORS**

ARTIFICIAL INTELLIGENCE is everywhere: it's designing new proteins, answering Internet search questions, even running barbecues. Investors are captivated by it—and so is the U.S. president. Just after taking office, President Donald Trump announced his support for Stargate, a company worth up to $500 billion, bankrolled by some of the biggest players in this space, to facilitate AI development in the U.S.

But the data centers and other infrastructure needed to develop and run the technology are incredible electricity hogs. And with Trump's declaration of a "national energy emergency"—an undisguised ploy to increase fossil-fuel production—AI's energy needs are poised to make climate change even worse. The technology is already responsible for massive greenhouse gas emissions that cause climate change. If Stargate and the many other companies developing AI platforms do not insist on cleaner and more efficient energy, they will only aid in the destruction of our planet.

This technology's many flavors include the buzzy generative AI, the basis of ChatGPT and Google's year-old search-answer system. During its operation, generative AI guzzles electricity in two stages, requiring warehouse-size data centers to house the necessary computing.

Developers must first train the AI model on vast stores of data, which takes countless hours and requires enormous computing capabilities. Training one ChatGPT precursor consumed enough electricity to power 120 average U.S. homes for a year. Every time a model is upgraded, it must be retrained. The sudden release of the DeepSeek chatbot out of China—reportedly trained for a fraction of the price of ChatGPT and similar U.S. systems—may lead to less energy-intensive processes, but it's too soon to know for sure.

And the demand doesn't stop once a model is trained. Each query the AI receives requires it to consider everything it has been fed, then synthesize an answer from scratch in a process called inference, which also requires energy. Compared with search engines, text-generating systems can easily use 10 times as much energy to address a query, and sometimes they use dozens of times more. Image generation requires even more energy—as much as 50 percent of the amount needed to fully charge a smartphone, one study found.

Many analyses interpret this energy use for the training and large-scale operation of AI as an increased cost to the system's owner. For example, one estimate suggests that if Google uses generative AI to produce 50 words of text per answer in response to just half of the queries it receives, it will cost the company some $6 billion.

But the truth is, we all will have to pay when this exorbitant energy use inflates the cost of the kilowatt, regardless of our personal interaction with the technology. The scale of consumption is simply too large, and as AI sneaks into ever more aspects of daily life, its energy use is projected to skyrocket. At the industry scale, it's difficult to isolate AI from other computing demands, but data centers serve as a convenient proxy, given that the rise of the technology has led to their boom.

The numbers are staggering: In the mid-2010s U.S. data centers used about 60 terawatt-hours per year. (One terawatt-hour is the equivalent of one billion kilowatt-hours, the unit used to measure electricity consumption in most U.S. homes.) By 2023, a recent report from Lawrence Berkeley National Laboratory found, that number had nearly tripled to 176 terawatt-hours; demand is expected to rise to between 325 and 580 terawatt-hours by 2028. At that level, data-center energy use would potentially account for between 6 and 12 percent of total U.S. energy consumption, up from 4 percent in 2023.

Even as commercial energy demand continues to grow, people are already seeing higher residential energy prices in

Illustration by Martin Gee

some regions where thirsty technologies such as AI are taxing the grid.

Amid this skyrocketing energy demand, work to decarbonize energy production is progressing too slowly both in the U.S. and globally. Climate change is already unfolding around us, worsening disasters ranging from the Los Angeles fires to Hurricane Helene to extreme heat and causing surprising and long-lasting consequences. Reducing the harm of climate change requires ending fossil-fuel use as quickly as possible. Sudden, huge demand from any industry makes that more difficult.

Sure, large technology companies *could* offer valuable resources to support the energy transition. The Stargate investment is expected to rely in part on solar power. Before leaving office, President Joe Biden opened public lands to data centers running on clean energy as a way to encourage its use for computing.

But because solar, wind and hydropower production rates can vary with weather and other factors, nuclear energy is particularly appealing to ever thirsty AI technology companies, raising fears of nuclear waste contamination. Most notably, Microsoft has a deal to restart the infamous Three Mile Island fission facility that was the site of the worst nuclear accident in the U.S. Meanwhile OpenAI CEO Sam Altman is throwing his support behind, among other things, nuclear fusion, a technology that looks unlikely to provide energy at any significant scale until 2050 at the earliest.

Even if AI companies lean heavily on clean power and don't worsen the climate crisis, the technology's seemingly insatiable need for energy remains concerning. And efficiency improvements, though vital, may not be enough. The so-called Jevons paradox, which posits that making a resource cheaper or more efficient can increase its use rather than shrinking its footprint, may be a factor. Wider highways invite more cars, and the Internet has led to doomscrolling as a time-consuming preoccupation that encourages more energy use.

While technology companies push AI, we need to push them for not just small innovations in efficiency but big ones that keep the energy footprint of the U.S. reined in. The alternative may be an AI-enabled barbecue that chars the world. ●

Wildfires Threaten Astronomy

Worsening conflagrations menace both lives and clear skies

BY PETER MCMAHON

LAST SUMMER I and many others around the world watched in horror as wildfires reduced nearly a third of the town of Jasper, Alberta, to ashes and incinerated some 150 square miles of the surrounding Jasper National Park. Although I now live and work in Tucson, Ariz., the devastation still felt personal: Jasper is part of a dark sky preserve I helped to create in the Canadian Rockies and is where my wife and I spent nine years building a stargazing tour company and planetarium.

The disastrous convergence of two forest fires in late July saw 300-foot-high flames launch charred pine cones and embers out ahead of the blaze. The fire generated lightning strikes and downdrafts as it moved, accelerating the hellish inferno.

Roughly 25,000 people fled before the fire hit, and a firefighter died battling it. Unlike some, our business endured, but it was not unscathed: smoke had marred our telescopes and other equipment. Insurance claim estimates for wildfire-related damages in the park may eventually top $1 billion Canadian.

Yet as damaging as this event was, it foretells possibly greater harm and disruption. As wildfires have grown in number and intensity in recent years, they have increasingly threatened our ability to see and study the heavens. If we don't find solutions soon, such blazes could top light pollution as the most pervasive threat to astronomical observation. Many cherished views of the cosmos could figuratively go up in flames.

On a mountain summit in Arizona's Sonoran Desert, a dead oak tree blackened by fire stands about three feet from a dormitory at Kitt Peak National Observatory, where I currently serve as the visitor center operations manager. The charred tree is a reminder of how close an earlier disaster came. A lightning strike in June 2022 sparked a wildfire that swept across the Baboquivari Mountains, destroying four buildings and approaching within dozens of feet of some of Kitt Peak's 22 major research telescopes.

Days after the Jasper tragedy last summer, another wildfire forced pre-evacuation preparations at Kitt Peak, with tarps at the ready to cover telescopes and safeguard equipment.

The problem is getting worse. Wildfires have already destroyed several major telescopes at Australia's Mount Stromlo Observatory. And in 2020 California's Sierra Remote Observatories came close to destruction from a wildfire that covered telescope optics in ash and debris.

During the 2022 wildfire season, I stood with my staff at a stargazing event at the top of the Jasper SkyTram, looking down the valley as fire snaked along the shores of Jasper Lake, 15 miles away. Although that fire never reached the town of Jasper, its smoke sporadically scuttled our views of the heavens for weeks at the Jasper Planetarium. Originating in Alberta, British Columbia, California, and other regions, smoke from such fires can blot out the stars at sites even thousands of miles away.

Meteorologist Alan Rahill, whose Clear Sky Chart is a trusted planning tool for astronomical observers, lamented a gloomy forecast to me recently: "For the second half of this century, we won't see blue sky anymore between March and December. Clear nights will become pretty rare." Yet there's hope for those willing to try to

Peter McMahon is a director and co-owner of the Jasper Planetarium, as well as owner and manager of the Ontario Planetarium. He currently serves as operations manager of the Visitor Center of Kitt Peak National Observatory near Tucson, Ariz.

Wildfire smoke rises over Jasper National Park in Alberta, Canada, on July 24, 2024.

adapt. Both professional and amateur astronomy institutions are finding ways to protect against wildfires, their causes and their effects:

Kitt Peak is installing specialized detectors to provide early warnings for lightning strikes on the mountain. It has partnered with a local alliance of firefighters, naturalists, ranchers, and others on a master plan for future emergency responses.

Lowell Observatory in Flagstaff, Ariz., collaborates with local authorities on prescribed burns and strategic firebreaks to protect its grounds. Griffith Observatory in Los Angeles has upgraded its fire-suppression systems and building materials; it closed during the wildfires in January but did not come under direct threat.

At the Jasper Planetarium (which has reopened since the July wildfire), we've added a radio telescope capable of peering through the murk, offering live radio maps of distant galaxies.

Fixing the underlying problem, though, will require orders-of-magnitude more effort than simply adapting to a "new normal" of more—and more intense—wildfires. Bob McDonald, science popularizer, fellow astronomy enthusiast and Order of Canada recipient, points out to me: "The increase in wildfires and droughts around the world is a sign that climate change is no longer an issue for future generations. It is in our face, here and now."

In his recent book *The Future Is Now,* McDonald argues that COVID shutdowns inspired many to see that we have the tools to reverse climate change through alternative energy, carbon capture and energy storage. "The smoke is a clear signal that it's time to get on with it and clear our skies, not just for astronomy but for human health," he told me.

Will many people care enough to act if another observatory is destroyed by wildfire? I hope so. Will more people notice if some astronomical research is no longer possible because the skies above some telescopes are too choked with smoke? Maybe. But I fear the wake-up call may only be received too late, when nature lovers gaze up into a summer sky full of ash instead of stars and anxiously ask: "What happened?" ●

Why People Like Expressive Faces

Grins and frowns do more than just broadcast emotions

BY EITHNE KAVANAGH, JAMIE WHITEHOUSE AND BRIDGET WALLER

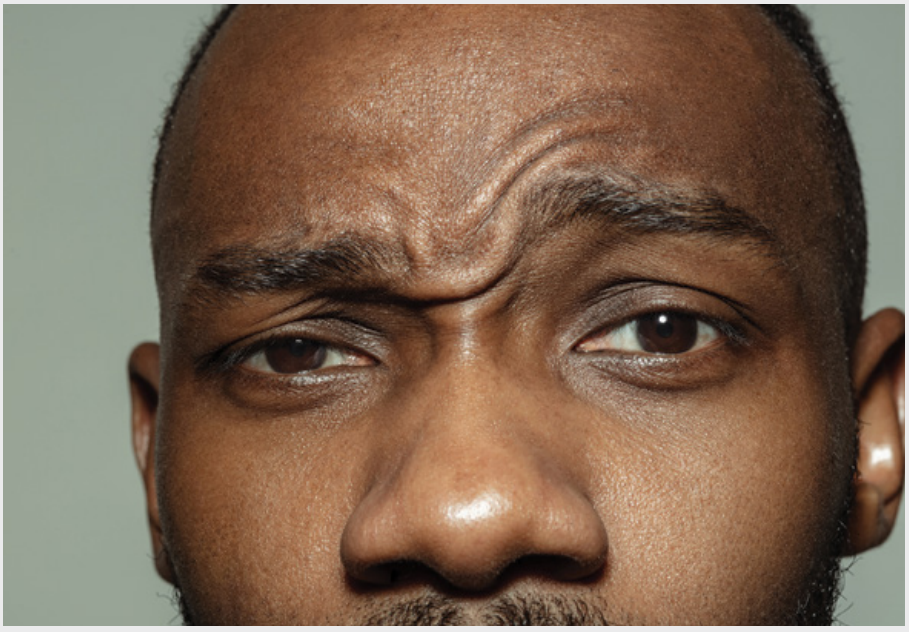
A SKILLED CARD PLAYER—eyes hidden by dark shades, features kept as still as possible—looks at their hand. Any small giveaway that they're bluffing or holding great cards could lose them a painfully large sum of money. Sometimes it helps to have a "poker face."

Yet in day-to-day life—when socializing with family, friends or new acquaintances, for example—you might be better served by letting your features fly free. Our research shows that moving your face in some way, whether you're smiling, raising an eyebrow or wrinkling your nose, may help people warm to you more.

In a study published last year, we found that people who were more facially expressive were more liked by a new social partner, which could explain why humans have evolved to have such expressive faces. Indeed, our species is probably the most facially expressive. People produce, on average, 101 facial movements per *minute* in a typical social interaction.

To understand why facial expressivity is so beneficial, we first need to emphasize just how crucial social bonding is to human survival. Throughout most of our evolutionary history, our species has relied on tight-knit communities to keep ourselves fed, sheltered, and protected from predators and dangerous outsiders. Managing social relationships was literally a matter of life or death. Otherwise you might have faced the tiger in the bushes alone. Any

Alberta Wildfire Social Media Account/Handout/Anadolu via Getty Images



Master1305/Getty Images

skill or behavior that improved someone's ability to create and maintain lifesaving bonds was likely to persist in our gene pool and cultural repertoires over the generations. And our research suggests that facial expressivity may fall in this category.

In our study, 52 people were filmed in an online social interaction with a researcher who posed as another participant. These dialogues played out over a video platform, so people could see one another's faces. Unbeknownst to the real participants, the researcher orchestrated various challenging social scenarios such as telling an awful joke or demanding 80 percent of a reward in a negotiation. These situations mimicked everyday experiences such as social conflict, embarrassment or an attempt to make a good impression.

Throughout, we observed how people's faces moved. We also obtained recordings of more than 1,300 participants in free-flowing conversations with other (real) participants online. Automated software then coded the small facial muscle movements they made during these interactions.

Interestingly, more agreeable, extroverted or neurotic people, as measured by a questionnaire, were more facially expressive. People with these personality traits may devote more time and energy to social interactions—perhaps because they enjoy socializing or have greater-than-average concerns about how they come across to others. And that added effort could be worthwhile, we found. After these interactions, the participants and their social partners rated how much they liked each other—as did 176 other participants who viewed video clips of these people. The pattern was clear: people who were more facially expressive were more liked by others.

But why would facial expressivity improve someone's ability to build social bonds? Imagine meeting someone new and trying to figure out how good a fit they might be as a friend, colleague or romantic partner. You might wonder whether you can trust them, whether they will help you or harm you—and whether you can even begin to understand each other. Someone who is easier to read may seem to be a more appealing prospect than someone who is more guarded.

Our findings support this interpretation. After their social interaction, participants reported their thoughts and feelings at various points throughout the exchange. Later we compared what those people were thinking with what other participants who saw videos of their conversation "read" in their face. It turns out that more facially expressive participants were indeed broadcasting what was on their mind through their face. And people viewing these interactions thought the expressive participants *appeared* easier to read, which strongly related to their likability.

Simply put, being facially expressive may give others a sense that they understand you, which they like. This in turn supports the suggestion that the key function of facial expressivity is to make us more predictable. Our work also underscores that facial expressions do far more than just communicate emotions. We might raise our eyebrows to show we're listening intently, share a knowing smile with a friend or use a stern look to stop someone in their tracks. Sending these kinds of messages doesn't involve any particular emotional state. We also found that likability tracked with expressivity and *not* with a particular emotion. You might guess, for instance, that people with cheerful expressions are best liked. But although happy expressions were highly likable, expressive people were better liked even when they weren't especially smiley.

Furthermore, we found that participants' level of expressivity didn't change across situations or with different social partners, even as the specific emotions involved shifted. This suggests that facial expressivity is a consistent trait of an individual rather than something that changes depending on the context.

That last finding may leave you wondering why some people remain comparatively inexpressive across situations. We want to investigate that question in future research. For some, the costs of revealing oneself may outweigh the benefits, and there could be alternative routes to being an attractive social partner.

Clearly, regardless of how expressive we tend to be overall, we can also make choices about sharing more of ourselves in certain situations. Being more open and expressive may be scary—leaving people vulnerable—but our work shows that it comes with rewards. So for now we think it's best to leave your poker face at the card table. ●

Eithne Kavanagh is a senior lecturer and research fellow at Nottingham Trent University in England.

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Calming an Inflamed Gut

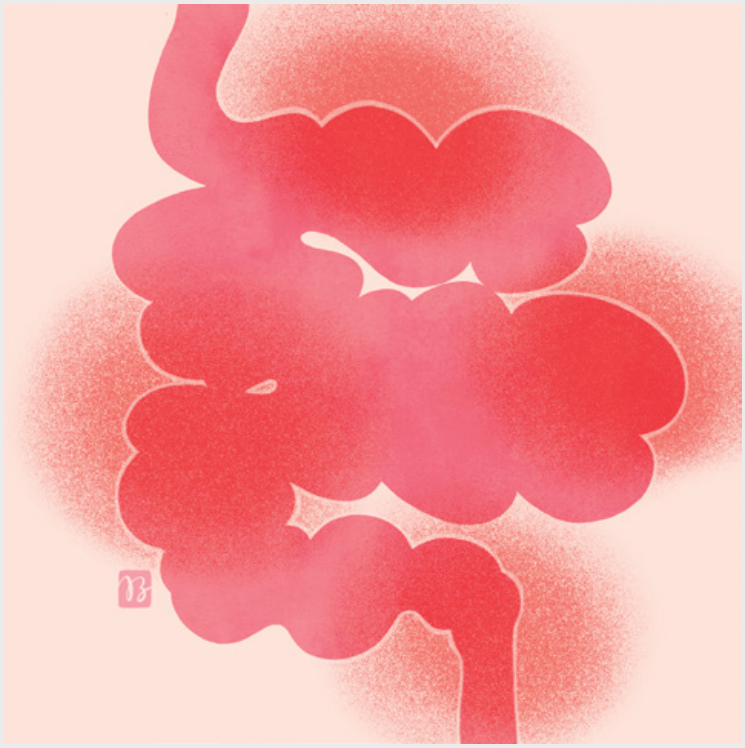
New drugs, and diets, soothe painful inflammatory bowel disease BY LYDIA DENWORTH

I **RECENTLY MET** a 26-year-old chef named Caroline Horvatits whose story is simultaneously distressing and hopeful. About a decade ago, during high school, Caroline was stricken by gut pain so severe she couldn't sleep and missed her midterm exams. After a colonoscopy, a gastroenterologist diagnosed her with ulcerative colitis (UC), a disease where the body's immune cells overreact and attack the colon—part of the large intestine—leaving open sores in the lining.

Colitis is one form of inflammatory bowel disease, or IBD, and there weren't a lot of treatment options at the time. Caroline tried some long-standing anti-inflammatory drugs, such as steroids. But her mother worried that they had too many side effects. Eventually, Caroline dropped the drugs and focused on her diet.

Her experience wasn't unusual. When gastroenterologist Bruce Sands of the Icahn School of Medicine at Mount Sinai in New York City started practicing 30 years ago, he says, large numbers of his IBD patients couldn't be helped. But much has changed, he says, especially in the past 10 years. There are far more possible—and precise—medications for the more than two million American adults and more than 100,000 children and adolescents with colitis or the other major form of IBD, Crohn's disease.

Both UC and Crohn's involve chronic inflammation of the gastrointestinal tract that is terribly painful and distressingly unpredictable. Flare-ups come on suddenly. They can lead to bleeding, cramping, diarrhea and unhealthy weight loss. Whereas colitis occurs in the lining of the colon, Crohn's affects the entire GI tract.



The growing variety of drugs target different types of cells in the immune system, and that gives clinicians and patients more options. There are six separate mechanisms of action for these drugs that have been recognized by the Food and Drug Administration. "Every time we find a new mechanism of action, we find another group of patients who can be adequately treated," Sands says.

The goal of most of these medications is to interrupt inflammation and the ensuing tissue damage. Researchers now better understand how different immune cell types sustain inflammation, and that has led to the identification of more precise targets. Gastroenterologist Alan Moss, chief scientific officer of the New York–based Crohn's and Colitis Foundation, says that older drugs such as the steroid prednisone suppress the entire immune system. But "we now have drugs that are unique to treating the colon and the cells that attack the colon," he says. What this means, Moss notes, is that "people are at much lower risk of getting more systemic side effects such as infections."

Lydia Denworth is an award-winning science journalist and contributing editor for *Scientific American*. She is author of *Friendship* (W. W. Norton, 2020).

For example, one of the most recently approved drugs, risankizumab (marketed as Skyrizi), blocks receptors for the cytokine interleukin-23 (IL-23), which is involved in many autoimmune diseases, and thereby interrupts the inflammatory cascade. Still others target cell proteins called phosphate receptors that affect the trafficking of immune cells into GI tract tissues. In 2024 Sands reported successful clinical trials for a drug that binds to TL1A, another protein that moves excessive numbers of immune cells into the bowels.

These days there's also more precision in dosing, Moss says. Physicians adjust up or down based on how active the disease is, and they can now account for things such as weight, age and comorbidities.

Even so, "it's estimated that we're leaving probably half of our patients without remission, and they tend to cycle through one thing after the other," Sands says. A better way of addressing the disease might be combination therapy. A 2023 proof-of-

Illustration by Jay Bendt

concept study published in the *Lancet* reported on 214 patients randomly assigned treatment with a drug that inhibits tumor necrosis factor (TNF, which is the name of the wider family of proteins involved in gut inflammation), or with an anti-IL-23 drug, or with both. Of those who received both drugs, 83 percent achieved remission at 12 weeks versus 61 and 75 percent of those treated with just one drug. Researchers are also working to identify predictive biomarkers that would fine-tune treatment. Pediatric gastroenterologist Sana Syed of the Duke University School of Medicine has studies underway collecting detailed data on blood components, tissue, and more. She will then use machine learning to try to look for signs that indicate which patient will respond to which drug, so she can highlight them at diagnosis.

That's especially urgent in the pediatric population, for whom there are only two FDA-approved treatments, both anti-TNF medications. "None of the recently approved or emerging therapies that are currently used to treat adults are within a decade of approval in children," Syed says. Pediatric doctors still use those drugs but do so without precise treatment guidelines.

Drugs are not the only way to treat IBD. The past decade has also brought much greater appreciation of the role of environment, Moss says. Nutrition, stress and pollution all are factors. One piece of strong evidence for the particular importance of nutrition is that the incidence of IBD has grown at an alarming pace in parts of the world where it was once rare, such as Asia, Latin America and Africa. "It's probably because they're now adopting our westernized diets," Moss notes. Specific nutritional triggers vary from patient to patient, but ultraprocessed and sugary foods seem to contribute to the disease. Diets high in fiber, fruits and vegetables, however, often reduce symptoms.

That is what helped Caroline. Two years of a very limited diet healed her gut—and inspired a career. She and her partner now run a small farm in central New York State and have a cooking business focused on fresh food. "I live mostly symptom-free," Caroline says. The hope is that, whether with drugs or diet, far more people will soon be able to say the same. ●

Deep Time

COSMIC CLIFFS, CARINA NEBULA

In the depths of the depths something begins,
although in truth—the simultaneous—
it's likely already arrived at its end,

vapors cohered, cores long burning,
diamonds smoldering within eons stacked
into depths. Always far from us, sparks begin

to flare inside proteins. Conical shells stretch monstrous
in our own alien waters. Earth upon Earth has opened
and already come to the iced or flaming end

of everything except sludge or scales or fur. Nestled
in the hoodoo-ed peaks, stars ignite like forest fires
surging on the heights, red-hot beginning

named apocalypse. Praise it, the breath
emptying and filling. Our new Earth already
holds its end, and stars' lives dazzle us

in their stalled, single moment. As far as we're
concerned, it's always now. The universe
endures. In time's deeps, everything begins
to engulf us, red galaxies winking from the end.

Julie Swarstad Johnson, an archivist and librarian at the University of Arizona Poetry Center, has served as poet in residence at Lowell Observatory in Flagstaff. She is author of the collection *Pennsylvania Furnace* (2019) and co-editor, with Christopher Cokinos, of *Beyond Earth's Edge: The Poetry of Spaceflight* (2020).

Illustration by Masha Foya

Is the Lottery Ever a Good Bet?

The surprisingly subtle math behind Powerball and Mega Millions BY JACK MURTAGH

HERE'S A THOUGHT challenge for you: Let's say I have chosen a particular moment in time from the past nine years. I am thinking of a specific (and totally random) year, month, day, hour, minute and second between April of 2016 and today. Could you guess it? No chance? You have a better chance of guessing a specific second from a nine-year span than you have of winning Powerball.

The October 2023 Powerball made headlines for topping a colossal $1.7-billion jackpot, the second largest in the game's history. Everybody knows that your chances of winning the lottery are slimmer than slim. But when rollover jackpots accumulate to record-size prizes, could the potential massive payout ever offset the rarity of winning? In other words, is the lottery ever a good bet? The answer might surprise you because even a good bet can turn out to be a bad idea, mathematically.

Mathematicians sometimes separate good bets from bad ones by using a concept called expected value. Consider the example of betting on the outcome of a die roll. It costs $1 to pick a number between one and six. If you guess the roll correctly, you win $1, and if you guess incorrectly, you lose your dollar. Would you take that bet? It seems unfair because you stand to win exactly as much as you stand to lose ($1), but you're much more likely to lose (five out of six rolls lose).

What if it cost only $1 to play, but you would win $100 if you guessed correctly? Suddenly the prize feels large enough to compensate for the likelihood of losing. Some probabilistic reasoning can tell us exactly what cutoff value should make one feel tempted to play rather than inclined to dismiss.

Clearly, the relevant variables are how much it costs to play, how much you stand to win and the probability of winning. The expected value of a bet becomes a weighted average where the possible outcomes (wins and losses) are weighted according to the probability of each occurring:

$$\text{Expected value of a bet} = (\text{Probability of winning}) \times (\text{Winning amount}) - (\text{Probability of losing}) \times (\text{Losing amount})$$

The solution to this equation reveals how much money you could expect to win (or lose if it's a negative number) per bet in the long run if you were to make the bet many times. For example, with our dollar bet on the outcome of a die roll, the probability of winning is ⅙, the probability of losing is ⅚, and we stand to lose or win $1:

$$\text{Expected value} = (⅙) \times (\$1) - (⅚) \times (\$1) = -0.667$$

If we took this bet many times, then in the long run we'd expect to lose about 67 cents per bet on average. A similar calculation with the $100 payout yields an expected value of almost $16, clearly a good bet. This framework also allows us to calculate a payout at which the bet is perfectly even, where the expected value over the long run is $0. For a die roll, this equilibrium payout comes to $5 because you're five times more likely to lose than win, so a reward five times larger than the cost balances out the risk.

Let's apply the expected-value lens to Powerball. The jackpot starts at about $20 million, and a ticket costs only $2. The probability of hitting the jackpot: one in 292,201,338. Crunch these numbers, and that ticket has an expected value of about −$1.93. You'd get more value out of those two bucks if you traded them for a dime.

This calculation ignores several subtleties for simplicity's sake. For one, it assumes you take the annuity option, which doles out your winnings in yearly installments for 29 years rather than the lump-sum cash payment (the annuity is worth more in the long run). Second, taxes ensure that you never walk away with a full purse. Winning big would slot you into the highest tax bracket, so 37 percent of your windfall would end up going to Uncle Sam (this doesn't include state taxes, which vary across states). Powerball also awards smaller prizes for partial matches of the drawn numbers, but we've considered only the jackpot. There's one more major consideration I've left out that I will discuss later. But factoring all these details into the math will only make that −$1.93 seem generous—the ticket is actually worth even less.

Still, a $20-million jackpot pales in comparison to $1.7 billion. If nobody wins a jackpot, the running total for the prize rolls over into the next drawing. When the pool keeps growing over many consecutive weeks, surely there's a point at which the massive prize overrides the minuscule chance of winning? After all, the probability of matching all six Powerball numbers doesn't change, and the cost of a ticket doesn't increase. It turns out that not only are massive jackpots still often bad bets, but they also, paradoxically, tend to be worse bets.

A multibillion-dollar payout seems to offset the roughly one-in-300-million chance of winning to yield a positive expected value for a ticket. Indeed, this claim often circulates in the media buzz around mega jackpots. But it overlooks a crucial detail: multiple people could hit the jackpot and therefore split the winnings. We need to add more terms to the expected-value calculation to account for all the possible outcomes:

$$(\text{Probability of holding the only winning ticket}) \times (\text{Jackpot}) + (\text{Probability of splitting the jackpot with one other ticket}) \times (\text{Half the jackpot}) \ldots$$

And we would have to keep expanding it to account for more winners and smaller fractions of the total.

We've established that winning the lot-

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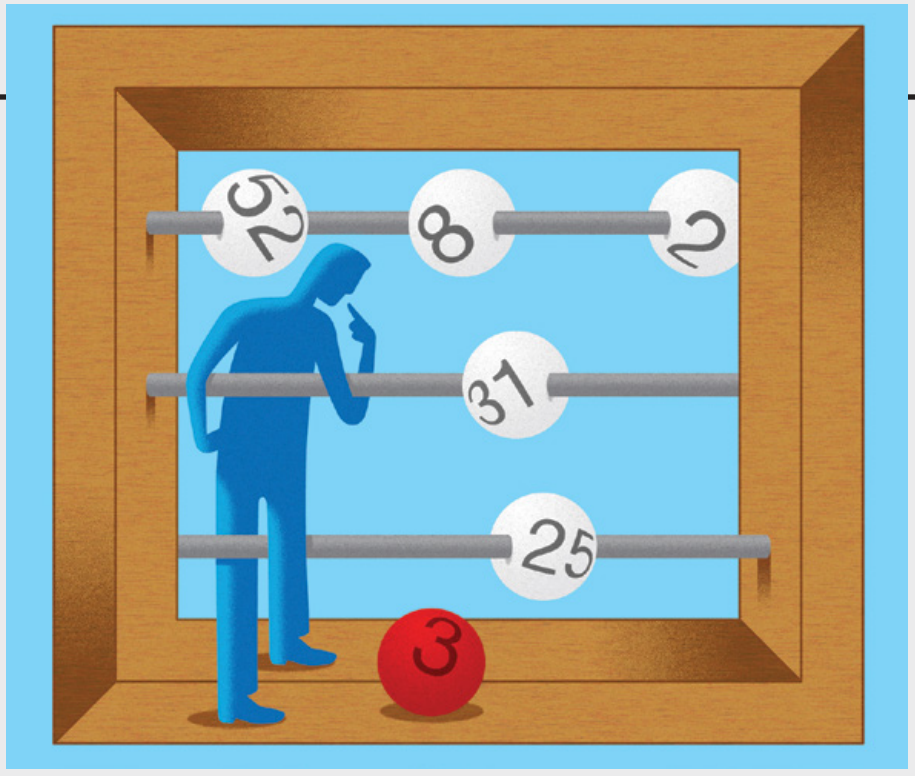


tery requires overcoming super low odds. Wouldn't two winners on the same draw entail super-duper low odds? Sometimes, but when hundreds of millions of tickets are sold, collisions can actually become more likely. For example, the first jackpot to ever reach $1 billion occurred in 2016, and it overachieved at $1.56 billion. The hype surrounding the new record drove a buying frenzy, and more than 635 million tickets were sold. (That's more than 20 times the number of tickets sold in an average Powerball drawing that year.)

With so many tickets in circulation, the probability of more than one winner exceeded 60 percent! Indeed, three winners ended up splitting the grand prize in 2016. When factoring in the total number of players, tax withholdings and secondary prizes for partial matches, even this gargantuan jackpot didn't offer a positive expected value. We omitted the pot-splitting detail from our $20-million Powerball expected-value calculation because smaller jackpots draw smaller crowds and carry a more negligible chance of splitting. Plus, at –$1.93 expected value, we hardly needed another factor to convince us that it was a bad bet.

Side note: the 60 percent figure assumes that numbers played on tickets are picked at random, which isn't precisely the case. Even though all sequences of six lottery numbers are equally likely to win, many people handpick their numbers, and they tend to choose sequences that mean something to them, such as birthdays or anniversaries (which results in many numbers under 31). People also seem to prefer odd numbers and numbers that aren't multiples of 10, perhaps because they seem more random. This behavior increases the chance of the pot being split for draws with smaller random-looking numbers but decreases it for other draws. So, although you can't increase your numbers' chance of being drawn, you can decrease your chance of splitting the jackpot by choosing large even numbers and including multiples of 10.

The buying manias have subsided since 2016. In fact, the two biggest jackpots in U.S. lotto history (in November 2022 and October 2023) attracted few enough buyers that the expected value of a ticket tipped into positive territory, even after adjusting for caveats such as taxes and pot-splitting. Lotteries occasionally offer what we're referring to here as a "good bet." Smaller state lotteries might be even better places to look for positive expected value because they tend to generate less hype and sell fewer tickets.

Don't empty your rainy-day fund at the nearest convenience store just yet. Despite conceding that the expected value of a ticket may occasionally look attractive, I'm going to backpedal and explain why I still think the lottery is a bad bet.

Lotteries with positive expected value are rare. As we've seen, larger jackpots don't necessarily mean larger expected value. And, critically, you probably won't be able to identify a positive value in time to place a bet, because ticket sales numbers don't get published in advance of drawings. So, although lotteries can offer a good bet, predicting which lotteries is a gamble in itself. Furthermore, even if you could identify the right gambles, expected value may not be the best proxy for a "good bet." Expected value is useful for medium-size problems such as a $100 die roll but may not capture all the relevant considerations in extreme situations like lotteries. Sometimes even a good bet is a bad idea, it turns out.

For one, expected value is premised on long-run behavior. You don't actually expect to win $16 when you bet on our $100 die roll. In fact, you can't win $16; you'll either lose $1 or win $100. The $16 is what you'd expect to win per bet on average if you kept playing repeatedly. Lottery wins are so rare that this long-run average can never realistically be achieved. Second, money loses value as you keep amassing more. Your second $50 million won't bring you as much joy as your first $50 million. Expected-value analysis treats every dollar equally and doesn't account for the diminishing marginal returns. Relatedly, expected value ignores personal risk aversion. People tend to dislike losing money more than they like winning it. As a result, even though expected value is great for mathematical evaluations of probabilistic systems, it doesn't fully model human psychology and decision-making.

Now to backpedal on my backpedaling: A lottery ticket costs $2. Players aren't buying an investment; they're buying permission to fantasize for a couple of days. We all make frivolous purchases, and most of them have zero probability of netting us a fortune. The money spent on lottery tickets also doesn't just get dumped into the ocean. Much of the revenue funds public services such as education. There has even been some research suggesting that anticipation from playing the game makes people happy regardless of the outcome. So, although I can't recommend playing the lottery on a mathematical basis, there's more to a happy life than math. Or so I'm told. ●

Illustration by Thomas Fuchs

Understanding Childhood Screenings for Autism

The predictive value of screening depends on how common a condition is

BY CHRIS SHELDRICK

AS WE STRIVE to keep our kids safe, healthy and happy, detecting and treating developmental and other conditions early is essential. For this reason, pediatric care emphasizes the importance of screening for everything from developmental delays to emotional problems to autism. Unfortunately, screening results are not always reassuring. For example, when results of a screening questionnaire come back as "positive" for, say, autism, panic can set in. What does this result mean, and why does the doctor think your child is autistic?

It turns out these screening results don't offer simple "yes" or "no" answers as to whether a child has a condition. Identification depends a lot on estimates of how common the condition is. Detecting uncommon ones, such as autism, is much harder than anyone would like. Parents should know this when hearing about their child's scores. Understanding why requires knowing a few basic facts about the science of screening.

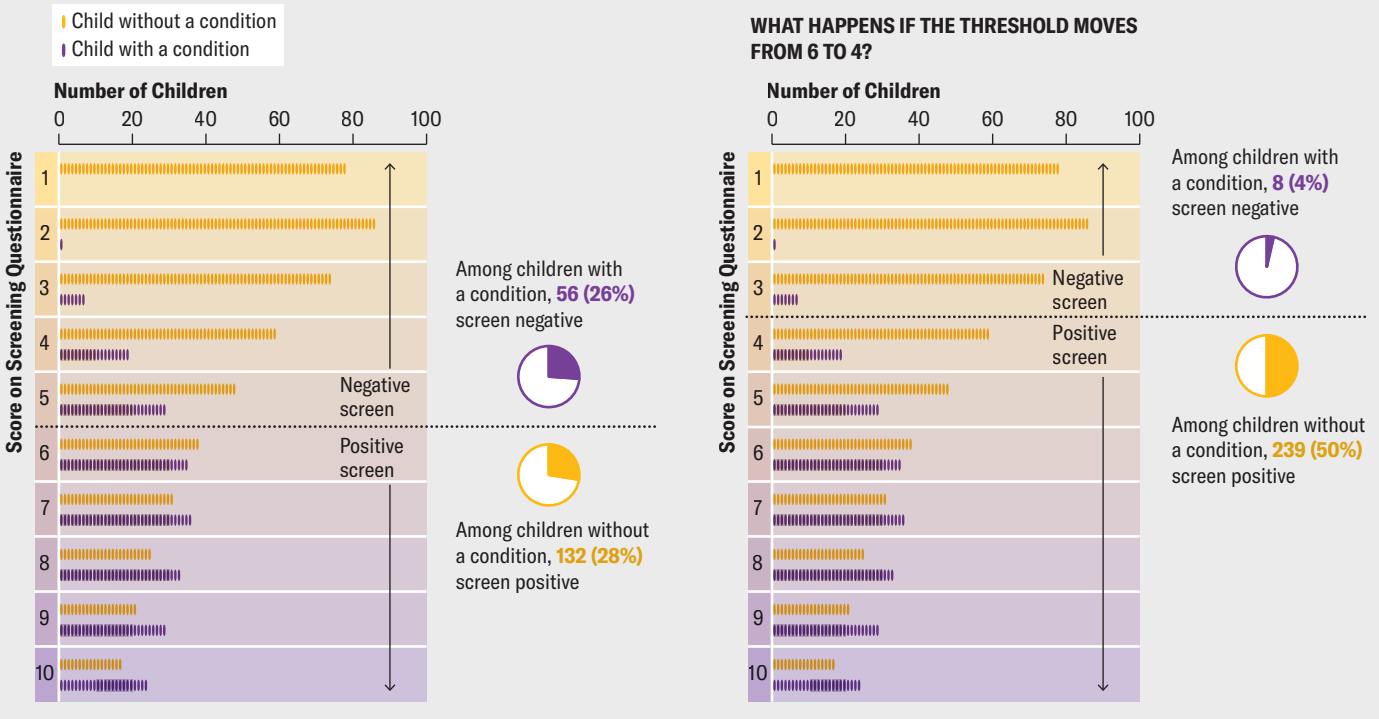
Simply put, a screening questionnaire is a standardized set of questions designed to identify or predict one or more conditions or potential health or quality-of-life issues. For example, a screener for autism usually includes questions about behaviors that are known to be early signs, often focusing on how children communicate. Typically, each answer is scored—for example, a "yes" response may receive a 1, and a "no" response may receive a 0. Sometimes, particularly for developmental milestones, the child's results are compared with those of same-age children as part of the evaluation. Either way, answers are combined to generate a total score.

Most screening questionnaires also have thresholds, or "cut scores." Scores above this threshold are said to be positive. Medical professionals are accustomed to this language, but it can be confusing to parents. Positive results most often indicate risk, such as a higher chance of being autistic or having another condition.

How do we know that positive scores indicate a higher probability of a given condition? Scientists describe screeners that can confirm this relation as "validated." Ideally, studies have been conducted that compare screening scores with the results of a highly accurate independent evaluation. If research demonstrates that the chance of having a condition is higher among children who screen positive than among those who

Chris Sheldrick is a psychologist who researches screening and intervention programs designed to improve mental health for children and families. More important, he is a proud father.

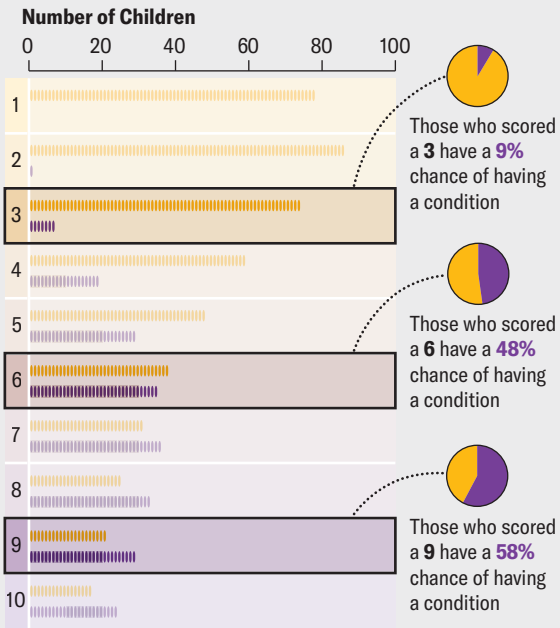
Every Screening Threshold Comes with Trade-Offs



Source: Chris Sheldrick (data)

Graphics by Amanda Montañez

Predictive Value Varies for Different Scores



screen negative, then the screening questionnaire is said to have diagnostic accuracy. If it identifies children who will develop a condition in the future, the questionnaire is said to have predictive validity.

A good screening tool can help you estimate the probability of having a condition. Imagine that hundreds of parents complete a "validated" screening questionnaire designed to detect not just autism but developmental and behavioral issues in general. Let's say one in three children has a developmental or behavioral condition that we would like to identify.

In our hypothetical sample, let's assume 289 children have a positive screening result with a threshold score of 6, and of those, 157 actually have a condition. Thus, we estimate that 54 percent of children who screen positive for a condition will have one. Scientists call this positive predictive value, or PPV. That seems simple enough: if a screen is positive, the child has a 54 percent chance of having a condition, right? Not so fast—there are at least four caveats to keep in mind.

First, no matter how much science is behind these questionnaires, there are trade-offs to every screening threshold. Let's say that in our example screening group, with a threshold score of 6, 26 percent of children with a condition screen negative. People who worry about underdetection might want a lower threshold. If the threshold were moved to a score of 4, most of the children with a condition would screen positive. On the other hand, 46 percent of children in our example who screen positive with a score of 6 don't have a condition. People who worry about the strain on families may want a higher threshold, in which case a score of 6 would no longer be positive.

Second, given these trade-offs, it is also worth considering the screening score itself. In our example, a score of 6 or higher indicates a positive result. Imagine 73 children have a score of exactly 6, and only 35 of them have a condition. That's 48 percent, which has lower accuracy than the positive predictive value of 54 percent. This situation is not uncommon. PPV represents an average of all positive screening scores. Thus, PPV tends to overestimate probabilities for scores near the threshold and underestimate probabilities for very high screening scores.

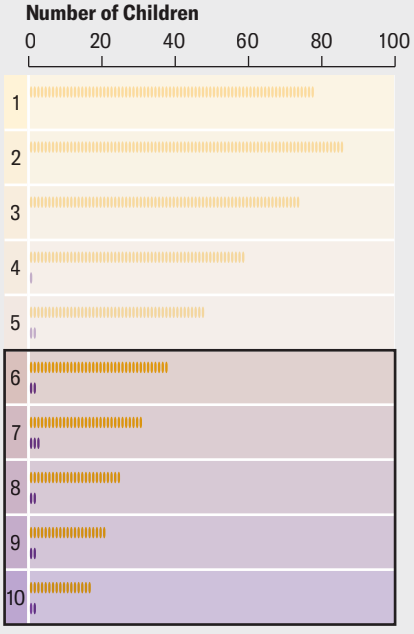
Third, predictive probabilities are strongly affected by prevalence—the proportion of children in the population who have a condition. All the examples described so far refer to the same screener—that is, the same proportion of children with a condition screen positive, and the same proportion of children without one screen negative. Prevalence makes a critical difference, however. When the prevalence of a condition in children is 2.8 percent (the current estimate for autism) and a child has a positive score of 6 or above for that condition, the chance that the child actually has it is only about 8 percent.

One way to understand this calculation is to consider that when prevalence is low, there are many nonautistic children for every autistic child. Each one of those nonautistic children has some chance—however low—of a "false positive" screening result. When prevalence is low, the number of false positives can swamp the number of true positives, even for an accurate screening test. Frankly, this fact blew my mind when I first learned about it, but all such tests are affected by prevalence in this way. Predicting uncommon events is not easy. (For example, if you test positive for influenza, your chance of having the illness is lower if it's not flu season.)

Finally, there's a reason I put quotes around "validated" when introducing our imagined questionnaire. Nothing is perfect, and we should always ask questions about how past research applies to future children growing up in different places. "Validated" screeners can be useful and are worthy of our attention—but we should use our judgment, too. ●

Predictive Value Is Affected by Prevalence of Conditions

In this distribution of scores the number of **children with a condition** reflects the current estimate for the prevalence of autism in children (2.8 percent).



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Preventing the Next Pandemic

Anthony Fauci offers lessons from COVID-19 for the future

BY TANYA LEWIS

ANTHONY FAUCI BECAME a household name during the COVID pandemic. But the genially stubborn infectious disease doctor, who spent decades at the helm of one of the U.S. government's most important medical research institutes, had made his mark well before that.

Born and raised in Brooklyn, N.Y., as the grandson of Italian immigrants, Fauci became a physician who would go on to spend almost 40 years as director of the National Institute of Allergy and Infectious Diseases (NIAID), part of the National Institutes of Health. He was a member of the White House Coronavirus Task Force during President Donald Trump's first term and served as chief medical adviser to President Joe Biden. He has worked under a total of seven U.S. presidents, overseeing the government's response to the HIV/AIDS pandemic, avian influenza, anthrax attacks, Ebola outbreaks and, of course, COVID.

Fauci, now age 84, chronicles his wide-ranging career in his memoir *On Call: A Doctor's Journey in Public Service* (Viking, 2024). He describes his unwavering commitment to furthering science—regardless of which political party was in power—and to meeting the needs of patients.

His first big challenge came during the dark early days of the HIV/AIDS crisis in the 1980s, when a mysterious new illness began sickening and killing large numbers of people in the U.S.—predominantly gay men at first. President Ronald Reagan's administration was slow to take action, provoking anger, anguish and frustration among the gay community and supporters. As head of the NIAID, Fauci became the prime target of that ire; some activists went so far as to call him a "murderer." Taking their criticisms to heart, Fauci met with activists to hear their concerns. He eventually won their trust by including them in policy discussions and expanding access to life-saving treatment.

After 9/11 he helped to lead the government's response to anthrax attacks and the potential threat of biowarfare. He also navigated international outbreaks of bird flu (a variant of which is currently spreading among cattle and poultry and in farm workers in the U.S.) in the late 1990s and 2000s, the Ebola outbreak in West Africa in 2014–2016, and other crises.

In January 2020 Fauci confronted a challenge the likes of which hadn't been seen in at least 100 years: COVID. Soon the rest of the world was facing it, too. As part of Trump's Coronavirus Task Force, Fauci had a direct role in issuing public health advice to the U.S. And as head of the NIAID, he oversaw development of one of the COVID vaccines. Fauci writes in his memoir that Trump had initially seemed to support him but that the president and his allies quickly turned on Fauci for speaking plainly about the dangers COVID posed to the nation. He received death threats and was repeatedly grilled and maligned by right-wing members of Congress over policies around masking and social distancing, as well as the origin of the COVID-causing virus SARS-CoV-2.

Still, Fauci remained outwardly unfazed in his mission to protect lives. In late 2020 two safe and highly effective mRNA vaccines against SARS-CoV-2 (one of them the result of work at the NIH) were unveiled and began to be administered. Estimates suggest COVID vaccines saved more than 14 million lives worldwide in a year.

Fauci retired from the NIAID in December 2022. Since July 2023 he has been a distinguished university professor at the Georgetown University School of Medicine and the McCourt School of Public Policy.

SCIENTIFIC AMERICAN spoke with Fauci about his long, distinguished career in medicine and public service, the challenges he faced during multiple epidem-

Tanya Lewis is a senior editor covering health and medicine at *Scientific American*.

Illustration by Shideh Ghandeharizadeh

ics—and the lessons that could help prepare us for the next one.
An edited transcript of the interview follows.

The last time I interviewed you was in January 2020. So a lot has happened since then.
Yeah, I would say I think a lot has happened in the world since then.

What was it like working in the government during the height of COVID, and how did you handle the challenge of communicating the dangers of a totally new virus when experts' knowledge was changing day to day?
We were dealing, essentially, with a moving target because SARS-CoV-2 and COVID-19 were truly unprecedented. The worst-possible-case scenario is what actually happened to us, where we had an outbreak that lasted intensively for two and a half years and in total duration for well over four years. Communicating with the public became a real problematic issue because unlike with other diseases, our knowledge of—and the actual reality of—the virus evolved over months and years.

For example, in the first few months, from the information we were getting from China, it was felt that this was a virus that was not transmitted efficiently from human to human. But it became clear that the virus was transmitted *very* efficiently, and about 60 percent of the transmissions were from someone who had no symptoms at all—which was really unprecedented in respiratory illnesses.

And then, as the months and years went by, the big surprise was that the virus kept on changing. We had different variants. It is difficult when the public wants definitive answers that are immutable when you're dealing with an evolving situation. One lesson learned from this for the next time is that we must make it very clear when we're speaking to the public that we are dealing with evolving information. And we've got to make it clear that that is because the virus and the outbreak are changing—not because scientists are flip-flopping.

Do you think now, with the benefit of hindsight, there were some things that we could have communicated better early on—for example, the airborne spread of SARS-CoV-2?
The outbreak killed 1.2 million Americans, so certainly there were many things that could have been done differently. We were trying our best in the public health arena, and our main goal was to save lives.

The World Health Organization took a long time to tell the world that we were dealing with a virus that was spread by aerosols. I mean, we were getting information about aerosol spread in the early months of the outbreak, and it wasn't until well into the real height of it that the WHO said, okay, yeah, now we know it was aerosol transmission. The virus stays in the air and can float around, and you can get infected when you're on the other side of the room.

Did that contribute to public backlash? There was this idea that masks didn't work, and there was a lot of confusion. But once we knew that there were aerosols involved, that shifted the kinds of masks that people needed, right?
Masking is a very complicated issue. There are many, many factors. The idea of pushing back on public health regulations by people who felt that their liberties were encroached on when people were telling them they had to wear a mask under certain circumstances—I guess that's understandable. We're a country of free spirits. But that worked against a unified public health intervention that would have been helpful. Now, when you look back at all the data, there's no question that mask wearing saved lives. Of course, masking was one of many things that we could have been doing, including improving indoor air quality through air filtration and ventilation.

Pandemics are almost invariably respiratory-borne because that's how very large numbers of people get infected. The lesson learned is the importance of paying attention to proper ventilation in classrooms and places of work and of installation of HEPA filters in places where there are a lot of people in a closed room. So ventilation needs to be addressed, and it's not something you can do overnight.

As a society, we've got to pay attention to the fact that respiratory illnesses are important even when they don't result in a full-blown pandemic. That's the reason that when you build new structures or when you certify structures, you keep in mind the importance of good ventilation.

We're currently facing outbreaks of H5N1 avian influenza in dairy cows and poultry in the U.S. and Canada, and there have been several dozen human cases. I know you've dealt with avian flu before in a global context. How are we handling the current situation?
You know, we're at the point where we're seeing more and more cow herds getting infected and more and more cases arising in people. I've dealt with H5N1 going way back to 1997, when it was noted in the very highly pathogenic form in chickens in Hong Kong, and authorities prevented an outbreak by essentially culling all the chickens in the region. Then, in 2003 and later on, there were more blips on the H5N1 radar screen.

So we've had a number of human infections with H5N1, but, thank goodness, there hasn't yet been a transmission from human to human. Historically, when H5N1 infected humans, it had a high degree of mortality. It didn't spread from human to human, but it had a 30 to 40 percent fatality rate, which is horribly high for a respiratory virus. I mean, even the terrible pandemic flu of 1918 only had a 1 to 2 percent mortality rate.

The somewhat encouraging news is that the H5N1 that's infected humans now has not generally caused serious illness. [*Editor's Note: After this interview occurred, the first U.S. H5N1 death was reported.*] It predominantly causes a conjunctivitis and mild systemic symptoms. There's been one case of a person who actually was hospitalized and went into intensive care, but the overwhelming majority did not have serious disease. The sobering news is that that can change because the virus infects more than one species—and we know it can infect pigs.

Pigs are on farms with chickens and with cows. Chickens and cows could infect a pig, and then a human virus can go into the pig. And then you could get a reassortment of a virus that has some of the dangerous qualities of H5N1 and some of the capability of spreading from human to human of a human virus. That could make this something we really have to be concerned about, and that's the reason the Centers for

Disease Control and Prevention says that although currently the risk in general is low, we still have to pay close attention to the possibility that that might change.

Do you worry that we are not doing enough to contain the outbreak in cows and chickens and other animals?

In the early years of COVID, I said, "We've got to flood the system with testing." My recommendation—and I'm not alone in this; many of my public health colleagues and my infectious disease colleagues say the same thing—is that we should be doing more widespread serosurveillance testing [testing for antibodies from prior infection]. Maybe a large number of people are asymptomatically infected, and you really need to know that if you're trying to monitor what the spread of this virus would be.

Do you think we are any better prepared for a pandemic today than we were five years ago?

I would hope so. I hope that we would learn the lessons of that at the local public health level. You know what? When I evaluate, retrospectively, how we did with COVID, for the sake of clarity, I put it into two separate categories: what the scientific response was and what the public health response was.

I think anyone who looks at the data would agree that we get an A+ for the scientific response, because the decades of investment in basic and clinical biomedical research allowed us to do something that was completely unprecedented: namely, to create in less than one year—from the time the viral sequence was made available publicly on January 10, 2020, to the time that we had a very well-tested-in-30,000-people clinical trial—a vaccine that went into the arms of persons that was safe and highly effective.

We need to keep up the investment in the science to do the same thing with future pandemics, including the possibility of H5N1. In particular, the public health response really needs to be improved. We have, in many cases at the local public health level, some antiquated means of making information available in real time to the people, for example, at the state and CDC level who are the ones who are going to be making decisions.

Do you think our disease readiness and our ability to respond effectively are more of a scientific problem or really a human-behavior one? And if it's the latter, how can we address the deep divisions and skepticism of science we see in this country?

I think you just hit on the most important aspect of our weakness in response. As I just mentioned, I don't think it's scientific. I think we've done very well scientifically. I think it is a human-element issue. I think the worst possible situation that you can have when you're in the middle or the beginning of an evolving pandemic is the profound degree of divisiveness that we have had and still have in our country. It's like being at war. The common enemy is the virus. And we were acting in many situations and in many respects as if we were enemies of one another.

Someone, for ideological reasons, not utilizing a lifesaving intervention such as a vaccine is tragic for that person and their family. Red states were undervaccinated against COVID compared with blue states, which were better vaccinated, and the hospitalization and death rates in red states were higher than in blue states. That is very painful to me as a public health person—that people, good people, got ill and lost their life because, ideologically, they didn't want to make use of a lifesaving intervention.

The challenge ahead of us now, if we face any other threat such as bird flu, is that people might resist the same public health measures.

I think we have a ways to go. We really have very, very much more in common than we have differences. And, you know, ideological differences and differences of opinion are healthy. They make for a very vibrant society. But when those differences turn into divisiveness, then that gets in the way of what I would consider the most effective response in a public arena for something as devastating as a pandemic.

I did want to talk about some of your early career, especially your work in HIV/AIDS. Like SARS-CoV-2, it was a very new virus, and you received a lot of pushback—in this case from the activist community. How did you gain the trust of people in that community?

I gained their trust because they justifiably were pushing back against the rigidity of the federal government in both the design and the implementation of clinical trials that didn't take into account the desperate situation these young, mostly gay men were facing in the mid- and late 1980s.

The regulatory approach of the Food and Drug Administration was very, very strict and didn't really consider the urgent nature of the people needing interventions. So people rebelled. They became confrontational, iconoclastic and disruptive because they wanted a seat at the table.

When the scientific and regulatory community didn't listen to them, they became very provocative and very disruptive. One of the best things I think I've ever done in my life was to see through the confrontation and the theatrics and to listen to what they were saying. I came to the conclusion that if I were in their shoes, I would be doing exactly what they were doing. And that's when I reached out to them, embraced them and brought them into the circle of decision-making about clinical trials. We put them on many of our advisory boards.

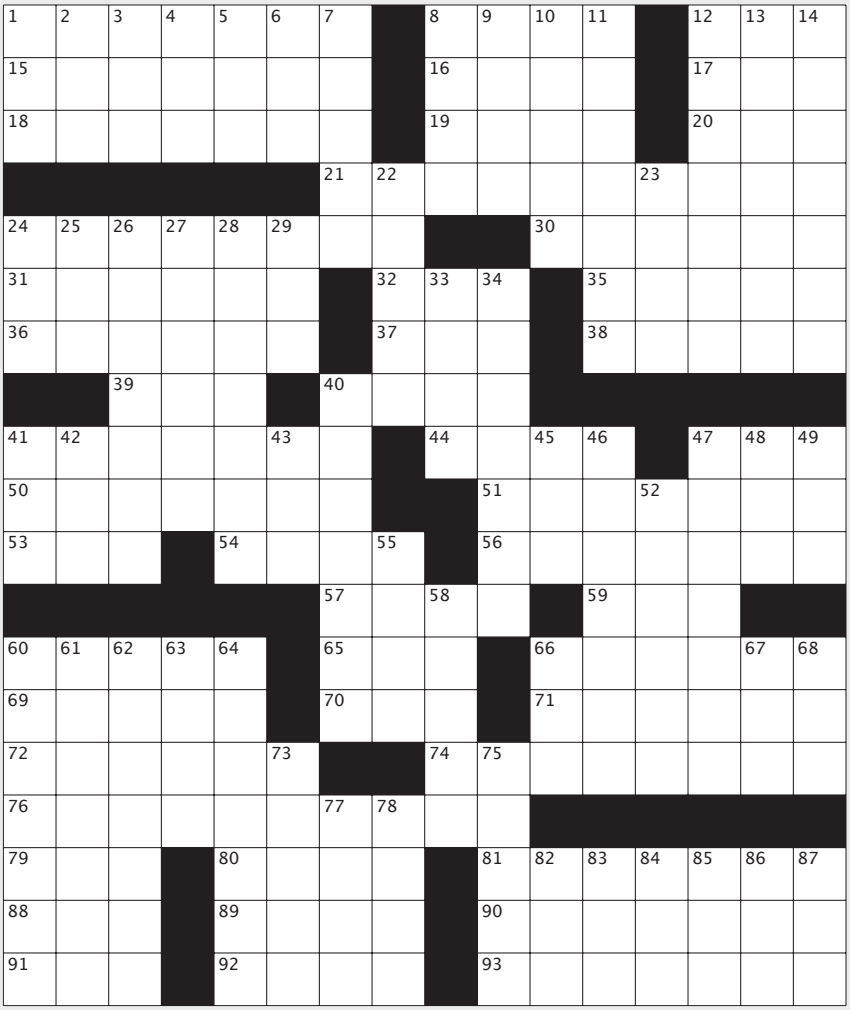
It didn't turn around overnight. It took quite a while, but we went from confrontation to really a productive collaboration. Now, 40 years later, some of those people who were so-called rebelling against us are some of my closest friends and colleagues. So I think HIV was a very good example of the importance of reaching out to the community that's involved and listening to what its members are saying.

Finally, what has retirement, or semiretirement, been like? Do you have any hobbies?

No, I've never been a hobby person, Tanya. I'm on the full-time faculty at Georgetown University in the School of Medicine and the McCourt School of Public Policy. When I decided to step down from the NIH, first of all, I wanted to write my memoir. Since leaving the NIH, I went from dealing predominantly with physicians and scientists who are at the advanced-degree level to working with students at the predegree level, which is really a lot of fun. So that's what I'm doing with myself, and I'm enjoying it very much. ●

Blacked Out

By Aimee Lucido



Across

1 Viewing a solar eclipse requires special ones
8 Suddenly lose it
12 Pursue romantically
15 Game that may be a bad bet even if its expected value is above zero (*page 76*)
16 Base runner's goal
17 Chicago airport code
18 Chappell Roan or Sabrina Carpenter
19 Sweden's first winner of the Eurovision Song Contest
20 Festival following Ramadan, informally
21 Topic up for debate
24 Activist Alexandra or Jacques-Yves
30 Grapple, in dialect
31 Words to live by
32 It might be wireless
35 2MASS J05551028+0724255, alf Ori and KAR 1, for Betelgeuse (*page 84*)
36 An Indigenous highlander whose kidneys have likely adapted to avoid altitude sickness (*page 16*)
37 Apple phones run on it
38 Lock of hair
39 Neither's partner
40 Bonus book material printed after the main text
41 Mold into a new form
44 High-fat, low-carb diet
47 Playfully shy
50 Favorite film among weather experts
51 Oprah Winfrey forerunner Phil
53 NBC comedy show, briefly
54 Acquires biological fuel for growth
56 Susses out
57 Swiss peak featured on the Toblerone logo
59 ____ loss for words
60 Speaker of the quote "It's like being at war. The common enemy is the virus." (*page 80*)
65 Before, to a poet
66 The world's largest social networking app for LGBTQ people, according to its website
69 Cinema legend Welles
70 Org. with narcotics detection dogs
71 Often abbreviated title
72 Monarch-related
74 *Wonder Woman* publisher
76 Term that might refer to a hidden world of different particles and forces rather than a simple, singular particle. Also something you can literally find three times (using 18 squares) in this puzzle (*page 22*)
79 The Monkees' "____ Believer"
80 Katz of *Hocus Pocus*
81 Scales span them
88 Grandma, to some
89 Award similar to a Tony
90 Flickering corona loop, in relation to a solar flare (*page 10*)
91 Letters that come after a Chat?
92 Animals used to combat invasive species worldwide (*page 20*)
93 23andMe offering

Down

1 ____-1 (molecule that helps to regulate blood glucose in the body) (*page 17*)
2 John, in England
3 Energy-carrying molecule
4 Rds.
5 Background in show business?
6 Ruler division?
7 Southern neighbor of Turkey
8 *Inside the NBA* analyst, to fans
9 Asian fusion chain started by and named for a celebrity chef
10 The largest flower ever encased in it was a *Symplocos kowalewskii*
11 Type of blouse
12 Quaint lament
13 Black-and-orange birds
14 Peculiarity
22 Nile Valley region
23 Bygone monarch
24 Ruler divs.
25 "What an incredible sight!"
26 Tongs or an ice cream scoop
27 Pabst product
28 Superlative
29 That girl, in Spain
33 Huge gem, slangily
34 Welcomed at the door
40 Docked, as a ship
41 Shares on X, for short
42 2010 initiative that aspires to build with the environment instead of against it (abbr.) (*page 28*)
43 Word before hen or fowl
45 Large amount
46 Province on four Great Lakes
47 Italian red wine
48 No longer cool
49 "Absolutely!"
52 Condition often flagged by questionnaire in childhood (*page 78*)
55 Achy
58 Duane ____ (pharmacy chain)
60 Wading across
61 Welcome center offering
62 R. E. Lee foe
63 Bop on the bean
64 Angry and impatient
66 Yukon maker
67 Boxing Day mo.
68 B&O and others
73 Luxury Italian car, informally
75 Arena roarer
77 Field of math used to prove the Pythagorean theorem (abbr.)
78 Sends into overtime
82 Is able to
83 ____-la-la
84 Insect that avoids traffic jams with workmates (*page 15*)
85 Compete (for)
86 "Banana" has two
87 Pepper (but not salt), for short

For the solution, visit www.ScientificAmerican.com/games/science-crosswords

An antique German sky atlas shows the position of the star Betelgeuse.

What's in a (Star's) Name?

With billions of stars in the Milky Way, we need some standardization **BY PHIL PLAIT**

BETELGEUSE! Betelgeuse! Betelgeuse!"

Did it explode? No? Okay, then.

But it seems fair to ask: Why "Betelgeuse"? It's an odd-seeming name for a star. That's because it's a corrupted translation of the Arabic phrase *yad al-jawzā',* which roughly translates to "the hand of Orion"—a decent moniker for the star that does represent the constellation's upraised arm.

A lot of star names we use today are in fact Arabic in origin. Alexandrian astronomer Claudius Ptolemy created a star map of the sky for his wildly popular book *Mathematical Treatise,* written in Greek around C.E. 150. It was translated into Arabic more than 1,000 years ago and acquired a nickname, *Almagest*—itself a corruption of the Arabicized version of the Greek word for "the greatest"—and many of those Arabic versions of star names were kept even when the map was translated into different languages. Rigel, Deneb, Aldebaran, and many more of the brightest stars in the sky trace their names back to such quirks of ancient publishing.

Phil Plait is a professional astronomer and science communicator in Virginia. He writes the *Bad Astronomy Newsletter.* Follow him on Beehiiv.

Others started more as nicknames, such as Polaris, named for its position in the sky near the north celestial pole, and ruddy Antares, which literally means "rival of Mars." Still others are named after astronomers who studied them, such as Barnard's Star and van Maanen's star. This naming methodology is obviously less than ideal, and it sometimes leads to confusion over what a star should actually be called.

You might think we'd run out of names quickly because there are many thousands of stars visible to the unaided eye at night. Fewer than 1,000 stars have proper names, however, so that doesn't seem like a crisis—which is a good thing because there are hundreds of billions of stars in the Milky Way! The problem isn't naming them so much as naming them *consistently.*

Different ancient cultures had their own names for stars, but as the world became more interconnected, astronomers tried many systems to standardize names and naming, with varying degrees of success.

One of the first in the early modern era,

Ilbusca/Getty Images

published in 1603, was dreamed up by German astronomer Johann Bayer. He named each star according to its apparent brightness ranking in a given constellation, using a Greek letter and the genitive (possessive) case of its constellation name. So, for example, the brightest star in Orion would be called Alpha Orionis, the next brightest Beta Orionis, and so on. There are two problems with this system, however. First, the Greek alphabet is only 24 letters, so that limits the names you can create this way. Second, stars can change in brightness over time, wreaking havoc on the ordering of a constellation's star names.

About a century later English astronomer John Flamsteed came up with the idea of using numbers instead of letters, which obviates one of Bayer's problems. Also, instead of using stars' sometimes varying brightness, he designated them by their position in a constellation, starting with the western edge of the constellation and moving east. Under this system, 1 Orionis is not the brightest star in Orion but the one closest to its western edge.

This approach has problems, too. Constellation borders weren't officially defined until the International Astronomical Union approved them in 1928, so Flamsteed's catalog occasionally listed stars as being in one constellation when they were actually in another. Also, Flamsteed cataloged only stars he could see from England, which excludes a large part of the southern sky that's invisible from that latitude.

Then there's the Bonner Durchmusterung catalog and its updates, created by astronomers at the Bonn Observatory in Germany in the mid- to late 1800s. This list was the last great catalog assembled before photography revolutionized astronomical observation. It covers stars as faint as ninth magnitude, sorting them by their declination (like latitude but on the sky). After that came the Henry Draper catalog of the early 20th century, named for an American amateur astronomer and astrophotographer. The Draper catalog includes spectroscopic information on stars and thus gives more details on associated stellar characteristics (such as temperature, size and composition).

As telescopes and photographic equipment got better, fainter stars could be seen, meaning catalogs got a lot bigger. There were also more attributes of stars to note, including their physical motions in the sky relative to one another, which are usually apparent only after many years of careful observation. All-sky surveys became possible, too, as bigger telescopes were built in the Southern Hemisphere, creating a need for even bigger and better catalogs. By the 1990s the numbers had become, well, astronomical. One project, the U.S. Naval Observatory catalog, used observations made on thousands of wide-field glass plates to organize a staggering one billion objects made from more than three billion observations, listing stars as faint as magnitude 21 (about a million times fainter than the dimmest star you can see by eye).

An unavoidable problem here is that any given star can have a lot of names, even if we stick to the legitimate ones.

When the Hubble Space Telescope was being built, astronomers realized that to properly point it, they needed a very accurate list of star positions and brightnesses. So a team at the Space Telescope Science Institute created the Guide Star Catalog, which currently includes nearly a billion stars. These objects are observed by special sensors on Hubble that then use the known positions of the stars to determine where the telescope needs to be aimed.

There are still more catalogs, but the newest and most complete is from Gaia, a European Space Agency mission whose purpose was to measure the brightness, positions, motions, and colors of stars and other cosmic objects with phenomenal accuracy. The Gaia team releases a new dataset every few years as updated measurements home in on stellar characteristics. The most recent release contains new information about nearly two billion stars in the Milky Way.

These more modern datasets (and there are far too many to mention individually here) include so many stars that any kind of naming is hopeless. Instead they generally identify an object by using an alphanumeric designation combining the catalog name with the star's position in the sky; for example, you might see a star listed as 2MASS J05551028+0724255 in the Two-Micron All-Sky Survey, representing the coordinates 05 hours, 55 minutes and 10.28 seconds of right ascension and 07 degrees, 24 minutes and 25.5 seconds of declination. Another name for that star? Betelgeuse.

I often notice ad campaigns on social media and elsewhere from various disreputable "star-naming" companies. These businesses promise you the ability to give a star (sometimes of your choosing, sometimes not) a name that will go in a catalog somewhere or be used by astronomers or—get this—get saved in a vault. So fancy! To be very clear: this is nonsense. These are vanity sales, and no astronomer anywhere will ever know or use the star names purchased from these companies. Many of these sellers target grieving people, inviting them to name a star after a loved one who has died, and I personally find such messaging disgusting. Don't fall for this egregious scam.

Anyway, an unavoidable problem here is that any given star can have a lot of names, even if we stick to the legitimate ones. A *lot.* Our old friend Betelgeuse, for example, has no fewer than 46 designations listed at SIMBAD, a database of astronomical objects beyond the solar system. Sure, in this case everyone just calls it "Betelgeuse" because that's its recognized name (and it's fun to say because of the movie *Beetlejuice*), but for other stars the name used can depend on which astronomer is observing it and how it's being observed. A star might have been discovered in an infrared astronomical survey but also independently in a radio-wave observation, so different astronomers will call it different names depending on what part of the spectrum they're most familiar with.

But I'm okay with this variation; it gives us a certain flexibility with naming, and it's not hard to look up which names go with what star.

And of course, in the end, a star by any other name would shine as sweet. ●

Drought Whiplash

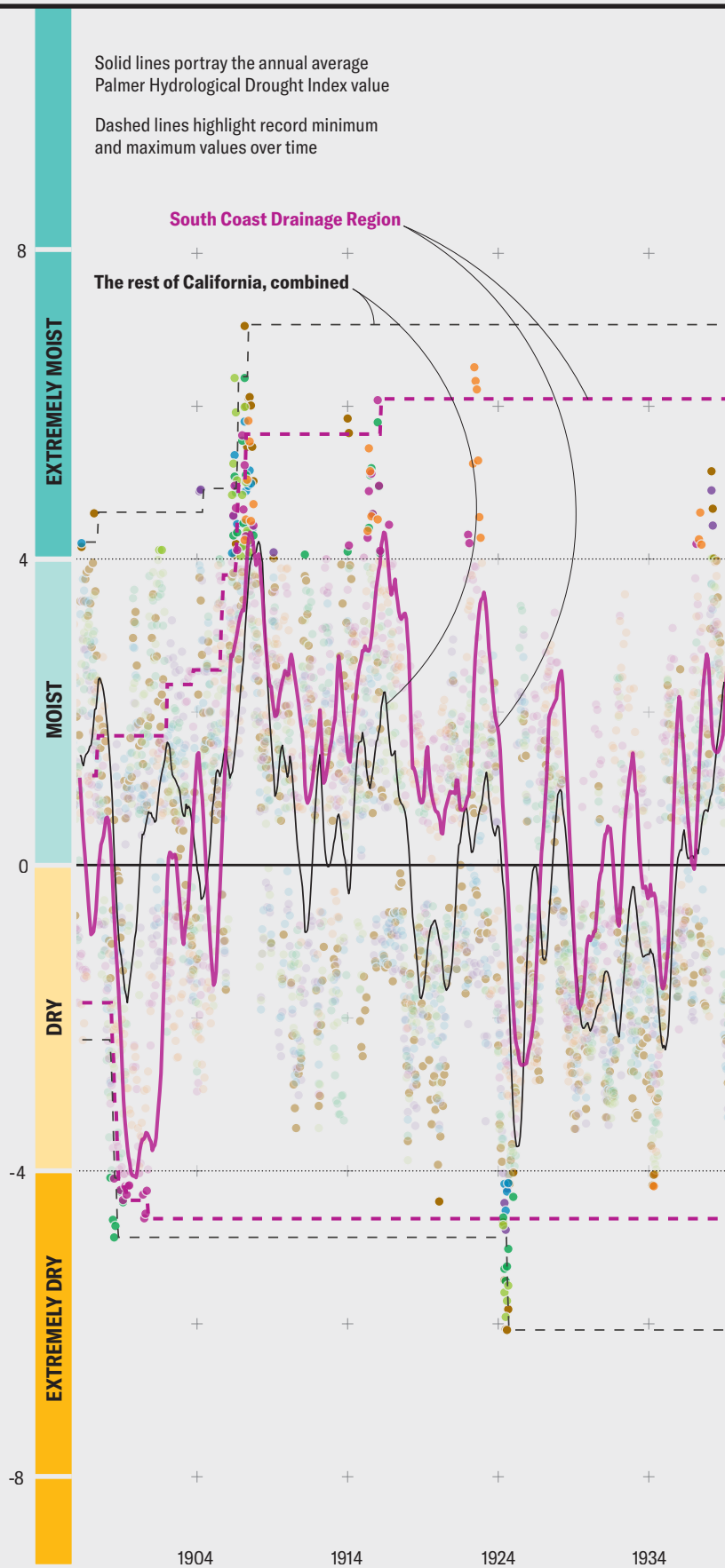
California is experiencing wider swings between wet and dry spells

TEXT BY CLARA MOSKOWITZ
GRAPHIC BY WESLEY GRUBBS/
PITCH INTERACTIVE

THE DEVASTATING FIRES in California early this year came after a particularly unfortunate weather pattern—an exceptionally wet period of about 18 months, followed by an exceptionally dry spell. The wet duration encouraged grass and brush growth, and then the lack of rain dried it all out, priming it to catch on fire and spread quickly.

"It was a classic example of wet-to-dry whiplash," says Daniel Swain, a climate scientist at the University of California, Los Angeles. And such whiplashes may be getting more common. "With climate change, it's not just that we're seeing things get drier and drier. There's also a trend toward more variability, with wider swings between wet and dry," Swain says.

The warming climate is leading to what scientists call the "expanding atmospheric sponge" effect. Warmer air can hold more water vapor than cooler air, so the atmosphere is like a kitchen sponge that gets larger. If water is available, the atmosphere will absorb more of it, and when you wring out the sponge, you get more precipitation. But if there is no water to absorb, that thirstier air sucks more moisture out of the landscape, from bodies of water, surfaces and plants, drying everything out.

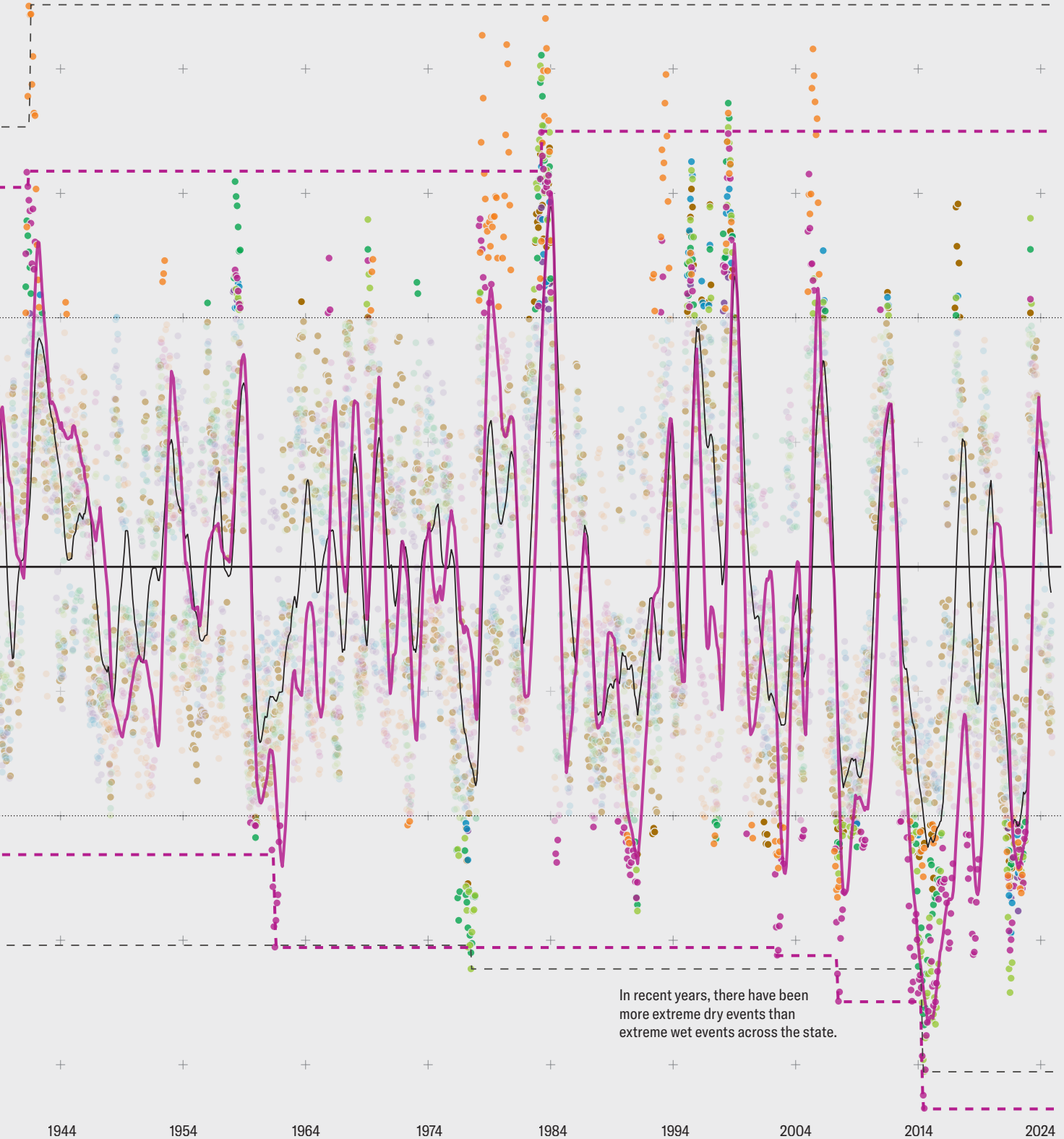


PALMER HYDROLOGICAL DROUGHT INDEX
This measurement uses reservoir and groundwater levels, among other factors, to measure drought. Each dot represents the drought level for one month in one region of California.

- North Coast Drainage
- Sacramento Drainage
- Northeast Interior Basins
- Central Coast Drainage
- San Joaquin Drainage
- South Coast Drainage
- Southeast Desert Basins

Source: National Oceanic and Atmospheric Administration's National Centers for Environmental Information (*data*)

INCREASED VARIABILITY OVER TIME
The range between wet events and dry events has generally grown over time as wet-period index values held relatively steady and dry periods dropped lower on the scale.



50, 100 & 150 Years

1875, Better Long Bridges: "The bridge shown is composed of a middle truss and two end trusses. The arches under the end trusses constitute compression chords. The [heavy] curved line is a chain which is under constant tension, anchored at each end, and the ends sit on curved beds of rollers. The arches and chords are hinged, so the structure is free to move according to thermal demands, and hence maintain its rigidity."

MYSTERIOUS GAMMA RAYS FROM SPACE

1975 "As a result of the Partial Test-Ban Treaty of 1963, which prohibited nuclear explosions in space, the U.S. launched five satellites to act as monitors. Each satellite was equipped with a detector designed to respond to gamma rays from a nuclear explosion. Detectors aboard two or more satellites could determine the position of the source. When the records were examined, it was found that the detectors had been triggered by occasional bursts of gamma rays, but that the source could not possibly be anything near Earth.

Each burst lasts about 10 seconds and does not seem to recur. An average of four bursts per year have been detected since 1967. The sources appear to be distributed randomly over the sky. Theories about their origin have proliferated. Perhaps the gamma rays were produced in events that gave rise to the radio outbursts of quasars. Or perhaps they originated in the shock waves from supernovas. Or they were associated with flare stars or X-ray sources within our own galaxy. There are even more exotic theoretical possibilities. In *New Scientist,* Andrew Fabian and James Pringle of the University of Cambridge remark: 'Let us hope that the rate of discovery of new bursts exceeds the rate of production of new theories.'"

CLEARING SNOWY ROADS WITH T.N.T.

1925 "Snow that buries some of the mountain roads of the western states many feet deep will make a sudden departure from its resting place in the spring if experiments with explosives result as planned. According to the American Automobile Association, T.N.T. was strung last fall along some of the localities known to drift worst. This explosive was prepared in a long tube of lead containing a ribbon of T.N.T. In the spring, when the last snowfall has occurred, the long explosive snake will be detonated, and if, as hoped, the snow instantly flies from the highway, the new method will be used on a larger scale after subsequent winters."

TODAY'S FORECAST: HEAVY STATIC

"There has been an ever-growing desire on the part of broadcasters, as well as audience, to have the Weather Bureau forecast radio reception conditions just as it does the weather. Some study has been undertaken of static and its relation to weather conditions. 'These fragmentary reports and experiences lead us to believe that radio weather forecasts, for at least a day or two in advance, may be practicable,' states an official of the Weather Bureau. Static forecasts would be a boon to broadcasters in arranging for feature programs. And it would be a boon for listeners to know whether to have that radio party tomorrow night or the following night."

CLEARING SNOWY ROADS WITH FIRE

1875 "The heavy snowfalls have brought home the great need of rapid removal from thoroughfares. We recently examined a novel invention using an intensely hot blast of flame. The machine consists of a small steam boiler, beside which another receptacle to contain naphtha is placed, located on the front portion of a low wagon, the body of which is of iron. Extending downward from the bottom of the vehicle are one or two rows of tubes. Steam jets mingle with ignited vapor and become highly superheated. The mouth of each tube emits a steady stream of flame, certainly sufficiently powerful to demolish several inches of ice or snow by merely passing over. It is proposed to put six machines on Broadway [in Manhattan] at the beginning of every snowstorm. A few people with brooms could quickly drive the water produced off toward the sewers."

SNAKE-EATING SNAKE

"A wonderful poisonous snake has just found a home in the London Zoological Gardens. This is a snake-eating snake, called *Ophiophagus,* found in India, and the Andaman and Philippine Islands. It is the largest of known venomous snakes. Shortly after its arrival it was fed by the keeper, who put an ordinary English snake into its cage. The *Ophiophagus* quickly devoured the English snake by bolting him headfirst. In general appearance this new snake is very like a common cobra. The head is exceedingly lizard-like. The eye is exceedingly clear and bright. When disturbed it hisses loudly, and shows its temper by extruding its long, black, forked tongue, which it vibrates with marvelous celerity."

Scientific American, Vol. XXXII, No. 17; April 24, 1875

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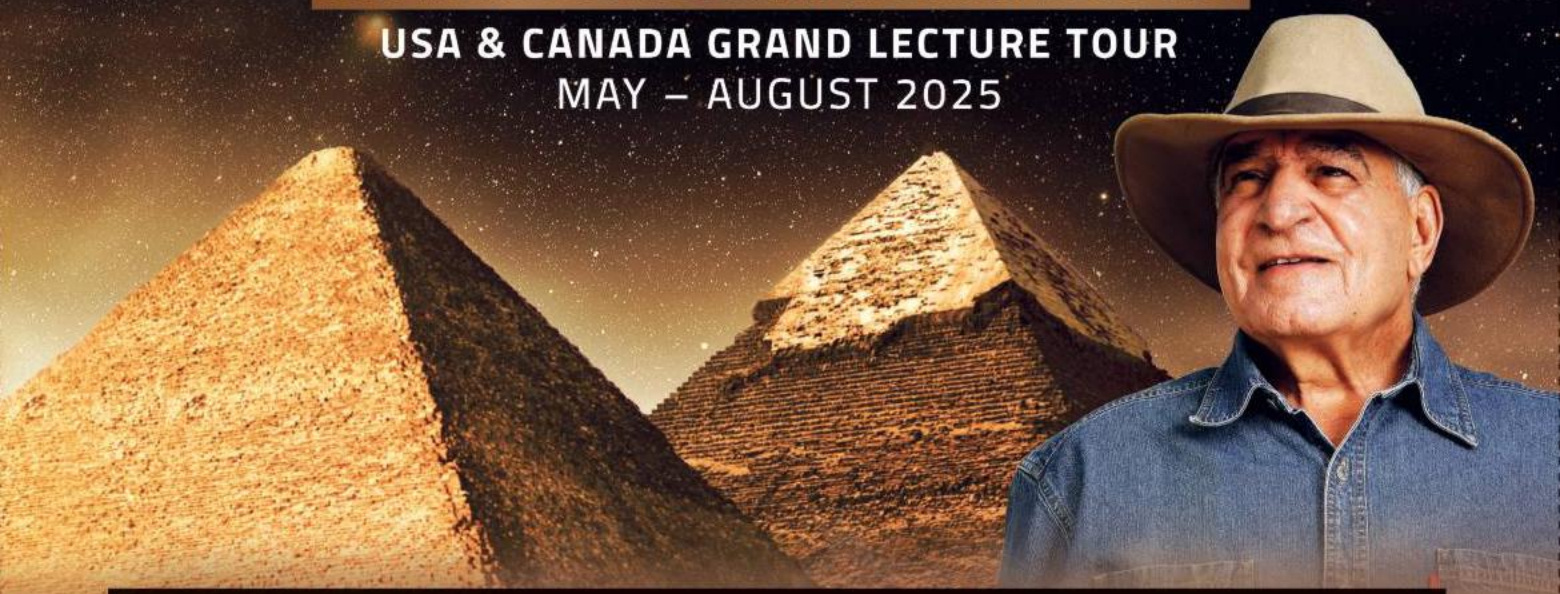

THE LOST PYRAMID • MISSING ROYAL TOMBS • NEW FINDS AT THE VALLEY OF THE KINGS • PROGRESS IN THE GOLDEN CITY





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June 11	Nashville, TN
June 14	Atlanta, GA
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July 21	Philadelphia, PA
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July 26	Vancouver, BC – Canada
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