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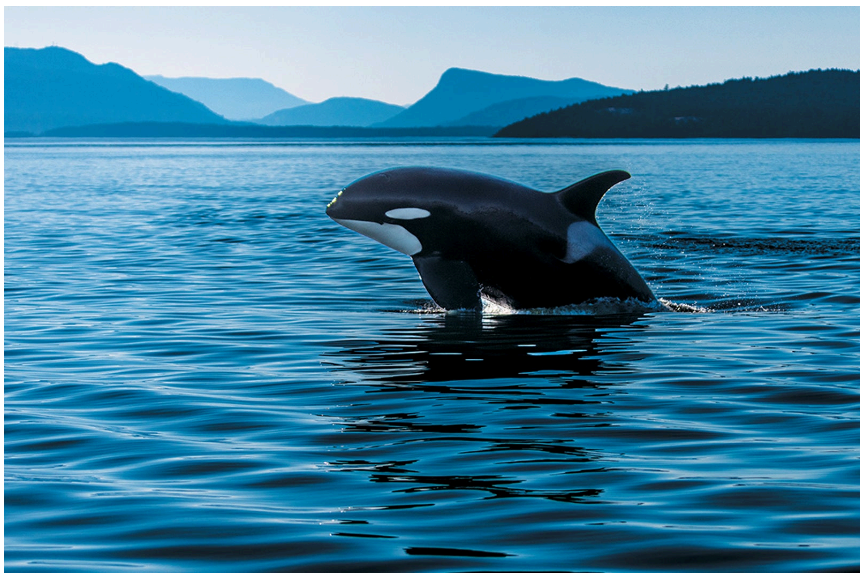
Features

- ## These Orcas Are on the Brink—And So Is the Science That Could Save Them
  Inside the desperate rush to save the southern resident killer whales
- ## Mysterious Bright Flashes in the Night Sky Baffle Astronomers
  Celestial transients shine furiously and briefly. Astronomers are just beginning to understand them
- ## Meet Your Future Robot Servants, Caregivers and Explorers
  Robots are poised to play a much bigger role in daily life at home, at work and in the world
- ## Interoception Is Our Sixth Sense, and It May Be Key to Mental Health
  Disruptions in interoception may underlie anxiety, eating disorders, and other mental health ailments
- ## Global Warming Could Skew Reptile Sex Ratios and Lead to Extinctions
  The sex of many turtles, crocodilians, and other reptiles is determined by the temperature at which their eggs incubate. Global warming could doom them
- ## Heart and Kidney Diseases, plus Type 2 Diabetes, May Be One Illness Treatable with Ozempic-like Drugs
  These three disorders could really be “CKM syndrome,” which can be treated with drugs like Ozempic

These Orcas Are on the Brink—And So Is the Science That Could Save Them

Inside the desperate rush to save the southern resident killer whales

By Kelso Harper edited by Seth Fletcher



Eclipse (J41) is one of 74 orcas remaining in the southern resident population.
Jeffery DelViscio

Like many people who visit San Juan Island, I came here for the orcas. This little patch of forest and farmland off the coast of Washington State is one of the best places in the world to encounter them. But you can’t schedule an orca sighting, so on a sunny July day I was killing time, wandering a lush meadow, when a bolt of adrenaline struck: I had missed three calls from Deborah Giles, a researcher at the SeaDoc Society, a marine science nonprofit. The southern residents had been spotted nearby for the first time in months. I had 40 minutes to meet her on the far side of the island.

The southern resident orcas have lived off the coast of the Pacific Northwest for thousands of years. They don’t associate with any of the estimated 50,000 other orcas living around the world, even those who share the same home waters. They have their own language, customs and culture, and they are the most studied population of orcas on Earth. But because of human encroachment on the shores and waters of their territory, they are in dire trouble.

I arrived at Giles's mooring just moments before she did. She lives on whale time, meaning she will drop anything to get on the water with southern residents, the focus of her research. She told me she hasn't taken a vacation away from San Juan Island in years—it's just not relaxing. What if the southern residents appear while she's gone?

"Come on, pup, let's go!" Giles called, urging a little brown-and-white dog down the metal dock. The pup, named Eba, appeared immune to being rushed and trotted behind at the farthest extent of her leash, tongue lolling, black eyes squinting in the afternoon sun. As Giles climbed into a small motorboat and took her place behind the wheel, her husband and research partner, Jim Rappold, lifted Eba onto the bow, placing her on a carpeted platform that he built specially for her. Giles's research assistant Aisha Rashid handed everyone life vests and strapped a peach one around Eba. I hunkered down in the back near the boat's onboard wet lab—a large metal box that holds a centrifuge, various vials, and other research equipment.

We sped off through Haro Strait on the western side of the island. The southern residents used to spend so much time swimming up and down this channel that the locals took to calling the routine the "west side shuffle." The whales would use the strait's steep underwater canyon to corner their preferred cuisine: big, fatty Chinook salmon. But as Chinook populations have declined, so have southern resident sightings near the island.

Over the past century the world around these whales has changed dramatically. Metropolitan centers bloomed on their coastlines, and their core habitat transformed into a bustling waterway. The Salish

Sea grew toxic from pollutants, and the fish the orcas evolved to hunt with deadly precision became scarce. In a single whale's lifetime, humans have put the southern residents on a path toward extinction.

Deborah Giles has cataloged the southern resident killer whales that inhabit the waters around the San Juan Islands in the Pacific Northwest for more than two decades. She is an orca researcher at the SeaDoc Society.
Jeffery DelViscio

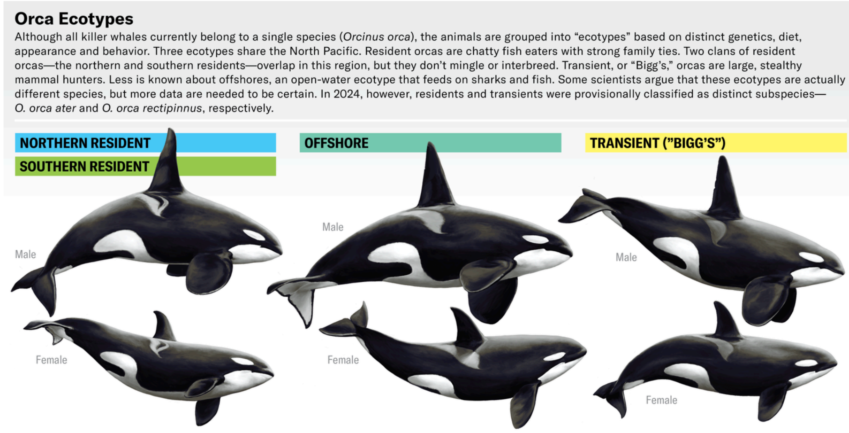
Giles and other scientists have devoted their careers to understanding and reversing the decline of this ancient population. By building out a picture of the whales' health, habits and diet, researchers are deciphering the many ways humans impact their lives and guiding conservation actions that may mean life or death for the orcas. But the research itself is now at risk, too. Actions by the Trump administration threaten to stall, diminish or stop a swath of conservation studies at a crucial juncture for southern residents —and for other populations that hang by a human-made thread. "The science is endangered now," Giles said, "just like the whales."

Orcas, like humans, are cosmopolitan animals. We live on every continent; orcas live in every ocean. Much like us, the whales have adapted to environments from the icy Antarctic to the balmy Gulf of California by being smart, social creatures. They pass down knowledge about where to forage and how to hunt. They share food and collectively care for their young. They even have their own cultural trends. In the 1980s, as human teens donned parachute pants and leg warmers, southern resident adolescents took to wearing dead salmon “hats” on their heads.

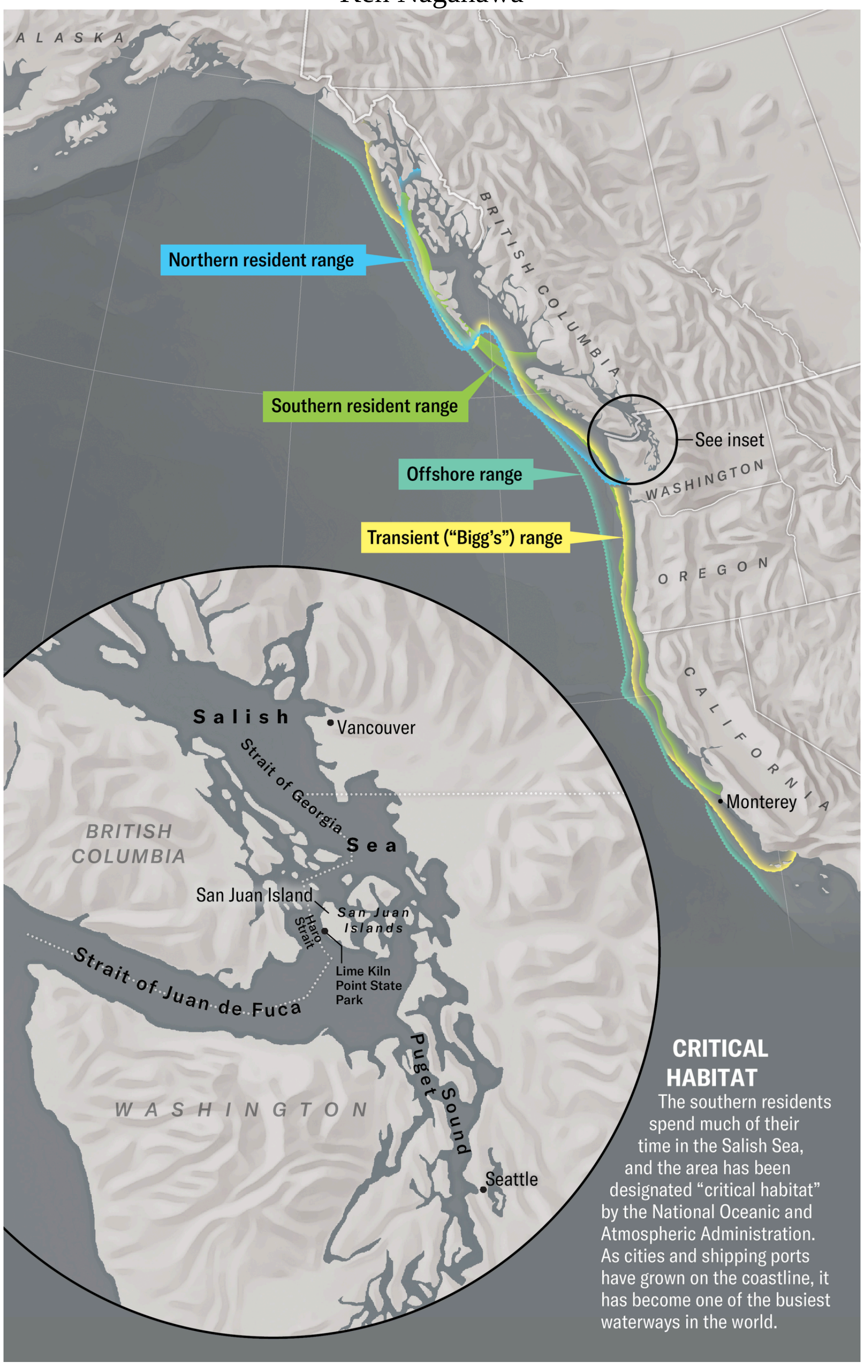
With big, wrinkly brains and high levels of intelligence, orcas seem likely to have complex internal lives. “They’re clearly very smart animals; they’re just different from us,” says Amy Van Cise, an assistant professor at the University of Washington, who studies orcas and other cetaceans. “Killer whales don’t write books, but killer whales can echolocate. Can you echolocate?” In 2018 a southern resident whale named Tahlequah made headlines for carrying her deceased newborn for 17 days in what became known as a “tour of grief.” The mother traveled nearly 1,000 miles with her baby draped over her forehead or held gingerly in her mouth; in January 2025, when another calf died, Tahlequah repeated the ritual.

Also like us, orcas are deeply familial creatures. Resident killer whale offspring stay with their mothers for their entire lives, forming a nearly inseparable family group called a matriline. A handful of matrilines together form a pod; pods are led by older females, who can live for a century, more than twice as long as most males.

The southern residents comprise three pods: J, K and L. Historically the pods spent much of April through October in the Puget Sound and near the San Juan Islands, often gathering as a “superpod.” In colder months the pods tend to split up and spend more time on the outer coasts of Washington State, Oregon and even California. No matter how far apart, though, the pods are tied together by their shared language, diet, habits and behaviors—a culture distinct from that of any other population.



Ken Naganawa



Daniel P. Huffman; Sources: NOAA (*resident ecotype range data*); NOAA, Fisheries and Oceans Canada and Center for Whale Research, via a map by Emily M. Eng in "Hostile Waters," in *Seattle*

Humans and killer whales share a long, complicated history. Indigenous communities of the Pacific Northwest lived peacefully alongside orcas for thousands of years. Each tribe has its own relationship with the animals, whom they generally view as sacred—often as guardians of the sea or as family members under the waves. But settlers who arrived in the 1800s took a different view: orcas became feared and reviled as a source of competition for fishers, a vermin species to be avoided or, better yet, exterminated.

Then, in 1965, the world's first captive performing orca, Namu, opened hearts—and wallets—at the Seattle Marine Aquarium. The whale's surprisingly gentle nature (he even let his captor, Ted Griffin, ride on his back) shocked and enraptured onlookers. Soon aquariums around the globe began putting in orders for their very own killer whale, and over the next decade more than 50 orcas were captured from the Salish Sea or killed in the process. Most of these whales were southern residents. By the time the practice ended in the mid-1970s, the population had shrunk to just 71 whales.

Scientists initially had hope that the southern residents would recover. Their numbers rebounded to 98 whales by the mid-1990s. "Then, all of a sudden, we started to see this decline," says Kim Parsons, a supervisory research biologist at the National Oceanic and Atmospheric Administration's Northwest Fisheries Science Center.

At the time, Parsons was studying the southern residents as an undergraduate and could recognize every individual. Over the course of six years a fifth of southern residents died, including Parsons's favorite whale, J3. "He had this really cool dorsal fin," Parsons says. "It almost looked like it was on backward." The precipitous decline couldn't be explained by the generational losses of the captive era alone. What was going on with the southern residents?

After millennia of relative quiet, the Salish Sea is now one of the busiest waterways in North America. Around nine million people live in the surrounding drainage basin, meaning ample urban, industrial and agricultural runoff has made its way into the water. When researchers began digging into the southern residents' decline, they found an alphabet soup of toxic chemicals in the whales' blubber: polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs), dichlorodiphenyltrichloroethane (DDT). Pollutants accumulate in the flesh of animals at every level of the food chain, but they get concentrated at higher levels, and orcas sit at the very top.

But this couldn't have been the full story, because neighboring orcas that share much of the same habitat didn't experience the same decline. These other whales, known as transients—also called "Bigg's" killer whales after pioneering orca researcher Michael Bigg—eat mammals, which are a level higher on the food chain than the fish eaten by residents, so they tend to accumulate even more pollutants. The key difference: Transient orcas had plenty to eat. Southern residents did not.

Transients' favored prey—such as seals, sea lions and porpoises—have proliferated since the Marine Mammal Protection Act of 1972 made hunting them illegal. But a combination of river damming, habitat destruction, overfishing and pollution has caused numbers of the southern residents' preferred prey, Chinook salmon, to plummet since the 1980s. Eight populations of Chinook made their way onto the endangered and threatened species lists before the southern residents joined them in 2005.

> "Killer whales don't write books, but killer whales can echolocate. Can you echolocate?" —Amy Van Cise, *University of Washington*

In her early research, Giles found that the southern residents' lack of prey is compounded by the nearly constant disturbance the orcas experience from boats in and near the Salish Sea. The jetlike sounds of container ship engines can reverberate for miles, and many boat engines emit noise in the same frequency range that the whales use to communicate. In 2008 Giles began working with colleagues to attach acoustic devices to the backs of orcas with suction cups, allowing the team to eavesdrop on the whales as they hunted. The researchers found that in noisy waters, "females will just say, 'Screw it. I'm not even going to try to forage,'" Giles says. "Males will try but miss because if vessel noise is too loud, it masks the whales' ability to echolocate and find food." The northern resident killer whales provide another comparison: they spend more time in quieter, less polluted waters off the coast of British Columbia, and their numbers have doubled since the capture era.*

Today 74 southern residents remain. Decades of research have identified these three factors—pollution, vessel disturbance and lack of food—as central to the decline of the southern residents. But each of these evolving threats is a universe unto itself, with countless variables and unknowns.

The boat motor roared, and a whitewater mist prickled my skin as we neared the northern edge of Haro Strait. The sea was smooth, protected on all sides by forested islands. A towering container ship heaved across our path, and its exhaust joined a yellow-green haze that hung low across the otherwise cloudless sky. Then, just after we cleared the ship's roller-coaster wake: "Whale!" Rappold shouted.

I whipped around just in time to glimpse a giant black-and-white body crashing back into the sea. Giles smiled—we had found the southern residents.

Like corn kernels in slowly heating oil, the orca sightings began sparse and unpredictable. But at some imperceptible moment, things shifted; suddenly black fins, white tails and entire submarinelike bodies were popping out of the water just a few hundred feet away.

Research biologist Kim Parsons first studied the southern resident orcas in the early 1990s, just before the population experienced a steep decline. Parsons works at NOAA’s Northwest Fisheries Science Center.
Jeffery DelViscio

Giles called out behaviors for Rashid to document. “Spyhop!” she yelled when a whale periscoped its enormous head out of the water and sank back down. “Tail slap!” Giles shouted as an orca’s fluke rose up and smacked the water’s surface.

As the boat neared the whales, Giles pulled out three laminated sheets from behind the steering wheel. They bore photographs of a few dozen gently rounded dorsal fins—snapshots of each of the southern residents. Giles examined the fins and saddle patches (a swirly white marking behind the dorsal fin) to identify these whales as part of J-pod. But we’d found only a handful of the 27 pod members, which was unusual. Giles told me that the pods had been splitting up more in recent years, perhaps as a “divide and conquer” strategy to make the most of scarce food.

“Baby breach!” Giles called as a small body (by orca standards) shot out of the water, arced in the air and smacked back down with a belly-flop splash. A second, roughly one-ton baby followed suit. In a stroke of luck, we’d found the two southern resident calves who had survived this year. Two others hadn’t made it.

At the bow of the boat, Rappold watched Eba closely. The dog’s demeanor was shifting. Her body became stiff, alert, and her ever-wagging tail dropped low. She stretched over the bow, leaning her snout as close to the glassy surface as she could manage. An orca leapt out of the water in the distance, but no one looked up. All eyes were on Eba now—she had caught the scent of killer whale poop.

“Let’s find it!” Rappold said, egging Eba on.

It is hard to collect whale poop. First, of course, you have to find the whales. Then one has to poop, and you need to find that poop before it sinks, gets dive-bombed by seagulls or breaks up in rough water. That’s where Eba comes in: her powerful nose helps Giles home in on scat while she follows the whales at a distance.

As a scent-detection dog, Eba helps Giles home in on floating killer whale poop for collection and analysis. The researchers can measure a given orca’s levels of hormones and toxic chemicals, among other factors.
Jeffery DelViscio

But orca poop is worth the effort because it is a data treasure trove. With just a pea-size glob of scat, biologists can genetically decode which individual whale produced the sample. They can measure that whale’s levels of toxic chemicals and catalog the bacteria and parasites in its microbiome. Hormone analysis reveals whether the whale was pregnant, and successful pregnancies are a key marker of population health. As they accumulate data over years, researchers are fleshing out a picture of southern resident health to clarify exactly how pollution, vessel disturbance and lack of prey cumulatively impact the orcas’ bodies. This work may also reveal new threats—a new contaminant or bad bacteria, perhaps—and identify struggling whales early on.

Scientists also use scat samples to get a detailed look at what these orcas eat. Until the early 2000s, researchers could study orca diets only by cutting open the stomachs of recently deceased animals or happening on them mid-hunt. Scat samples are easier to come by (relatively speaking) and provide more detailed information.

By checking fragments of DNA in a sample against a library of fish genomes, Parsons and Van Cise can identify the exact species a whale ate over a roughly 24-hour period and in what relative amounts—for instance, 60 percent Chinook salmon, 30 percent chum salmon, 10 percent halibut. Their research has shown that although the southern residents eat mainly Chinook, they also rely on a mix of other species that fluctuates throughout the year. Chum and coho salmon in particular appear to be more important than previously thought in the late summer and early fall. But the researchers still need more samples, especially between October and April, to get a full picture of the southern resident diet. Giles says it’s important to know all of what the whales eat—and where and when—to ensure that they have what they need year-round. If, for example, fishery managers knew the southern residents typically eat a lot of chum in the Puget Sound in November, they could theoretically adjust the harvest of that stock to account for the whales’ needs.

> “The science is endangered now, just like the whales.” —
> Deborah Giles, *The Seadoc Society*

Whining softly, Eba began crab-shuffling over to the right side of the bow. Giles turned the boat to follow her path. When Eba shuffled back to the left, Giles swerved again. They followed this zigzag pattern to stay in the “scent cone” of the feces, homing in closer with each pass.

Eba became even more restless. She propped her front paws on the bow and yelped like a capuchin. (I silently wondered whether that’s how she got her nickname, “Fluffy Monkey.”) We had to be getting close. Giles slowed the boat, and Rappold searched the water intently.

“Hit, hit, hit!” Rappold yelled. He tossed a handful of cereal puffs in the water to mark what he saw. Giles cranked the boat back around, leaned out from behind the steering wheel and squinted past a bright glare on the water. A trail of bubbles floated in a choppy slick, iridescent in the slanting sunlight.

“Well, what do you think?” Rappold asked Eba softly. He turned back to Giles.

“It’s very weird,” Giles said. They scanned the dark surface for any signs of scat. The boat bobbed idly, water lapping against it. The outboard engine hummed. Eba barked. The hopeful, frenetic energy from moments before began to fade with the slick. Giles decided there was nothing for us to collect; we should move on.

With just a small amount of scat, scientists such as Amy Van Cise can examine the state of an orca's health and analyze its diet in great detail. Van Cise teaches at the University of Washington.
Jeffery DelViscio

Giles turned the boat around and pointed us back toward the orcas. Eba grew frenzied as we pulled away, yelping and barking, stomping around the bow and looking up expectantly at Rappold. She had sniffed admirably, but Eba doesn't get her reward—playtime with a rope toy—until Giles successfully collects a scat sample.

Giles tried to console Eba. "Good job, let's find the next one!" Eba barked at her twice. "Phew, she's mad," Giles murmured, steering us toward the dorsal fins on the horizon.

As important as other species might be in the southern residents' diets throughout the year—and as eager as Giles and her collaborators are to know about them—Chinook still make up the bulk of the orcas' diets. But Chinook conservation is enormously complex. There are dozens of Chinook populations across hundreds of rivers from California to Alaska, each facing unique challenges, such as impassable dams, overfishing and urban development. And at each stream and tributary, it takes a lot of research, time and effort to demonstrate that Chinook conservation is a worthwhile priority for the species itself and for the whales.

To this end, Parsons and Van Cise are working to tease even more detail from the genetic mayhem of whale poop and identify which salmon runs the southern residents rely on most. “If we can target our management to specific rivers,” Van Cise says, “that might make it easier to conserve the right populations.” With proper funding, she says, they could probably tackle this genomic conundrum in the next few years. But with the way science funding plummeted in 2025, it might not happen at all.

Days after Donald Trump took office in 2025, his second administration began hollowing out federal science agencies, and it aims to shrink them further in 2026. Already the administration has canceled thousands of research grants totaling billions of dollars. “I’ve watched funding source after funding source just shutter its doors,” says Van Cise, who relies almost entirely on funding from NOAA, the National Science Foundation (NSF) and the Office of Naval Research. She says she’s lucky that she hasn’t lost any current grants, but she also hasn’t received any new grants—and her funding is starting to run out. This is a crucial time for her; as an early-career research professor, she is just now establishing herself in the field. “If research funding continues the way that it is,” Van Cise says, “I could watch my career die before it really even gets off the ground.”

In March 2025 Giles applied with partners at the San Diego Zoo Wildlife Alliance for an NSF grant to fund three years of an ongoing research project. Together, the researchers use drones to fly through an orca’s blow and collect samples of its breath, which adds a new dimension for studying the animal’s health and microbiome. They are also beginning to use infrared cameras to see whether the whales are suffering from illness or injury (hot spots can signal inflammation). But less than a month after the group submitted its application, the NSF returned it—unopened. Giles was told that was the fate of more than half of NSF applications at the time.

NOAA is central to the conservation of all endangered marine species. Staff scientists conduct research, and managers craft recovery plans, designate critical habitat, and work with states, tribes, and other nations to preserve vulnerable species. In 2025 the Trump administration thinned the agency by more than 2,000 employees through layoffs, early retirements and a deferred-resignation program. One such employee was Lynne Barre, the southern residents' recovery coordinator for two decades. Barre hadn't been planning to retire at 55 years old, but with the mass firings of probationary employees, the frozen budgets, "the uncertainty and the chaos," she felt it was her best option. Barre says a colleague likened the situation to being on a pirate ship that someone lights on fire: "Then your choice is to walk the plank and either jump off yourself or be stabbed in the back [until you] jump off." The Northwest Fisheries Science Center and the West Coast Regional Office—where the majority of 's southern resident work takes place—lost almost 30 percent of their staff in 2025, including many researchers with decades of expertise. "That's a huge hit to our workforce," Barre says.

A J-Pod baby and mother play in the Salish Sea. Southern resident killer whales have strong family ties and rarely separate from their close relatives.
Jeffery DelViscio

So where does that leave the southern residents? All the scientists I spoke to agree: the southern residents don't have time to spare. "It's a critical time," Parsons says. "The population has been at this fairly low-level status for a long time, and that's not a great sign."

In 2025 Washington State enacted a new regulation requiring boats to stay at least 1,000 yards away from the southern residents; at that distance a whale tail looks smaller than a sesame seed. (Research vessels like Giles's can travel within 50 yards of the whales.) The goal is to allow the whales to hunt more easily, without a cacophony of boat motors muddying their echolocation. Van Cise says it took years of research to support this intervention, and it will take years—and more research—to see what impact it has. Barre says the same will be true for any actions related to the whales' health or diet. "If we don't have that strong foundation of science, we're not going to make very good decisions," she says, and with such a small group of whales, there is a thin margin between recovery and the "vortex of extinction"—the point of no return.

Toward the end of our encounter with the southern residents, a mother and baby beelined toward our boat. Their slick black bodies surged rhythmically out of the water every 10 yards or so. Giles turned off the motor, and we all fell silent—except Eba, who yelped and whined. The whales emerged with heavy sighs just a few yards away. The baby tumbled around at the surface, flipping her white belly to the sky and rubbing up against her mother's back. She rolled onto her side and flapped one little pectoral fin out of the water. When her mother ducked back down and began to swim away from us, she followed.

Giles didn't collect any scat samples that day. As the whales headed south at sunset, we peeled off toward San Juan Island. There were no southern resident sightings for the rest of the week.

On my last night with Giles, we visited the place where locals used to see orcas almost every day of the summer: Lime Kiln Point State Park. It sits on the western side of the island and is home to a stately white lighthouse, a food truck (The Blowhole: Snacks with a Porpoise) and the spot we were headed to—Orca Whale

Watching Point. It’s where Giles saw orcas for the first time, in 1987.

Giles led us to a craggy mound of rock at the edge of the water. The last ripe orange rays of sun snuck under her hat and tangled with the wind in her hair. She sat quietly, gazing just offshore at tasseled heads of bull kelp bobbing in the surf.

“I remember looking out to the ocean, and all of the southern residents were right there,” Giles recalled, “foraging just right here, right off the kelp bed.” Below the dark, jagged water in front of us, the seafloor plummeted to nearly 1,000 feet—the deepest channel in the San Juan Islands. It was a rare place where both humans and orcas gather, just a few yards apart.

“Four decades of time that I’ve known about these whales, and I have just watched them fail to recover,” Giles said, looking down at a photo of her 18-year-old self kneeling on the same rocks, an orca frozen mid-breach behind her. “I’ll just keep trying to figure out how to help them so we can see breaching whales right off Lime Kiln again, every day.”

**Editor’s Note (12/17/25): This paragraph was edited after posting to correct the description of Giles’s work in a project that involved attaching acoustic devices to the backs of orcas.*

Kelso Harper is an award-winning senior multimedia editor at *Scientific American*. As a producer, editor and host, they work on short documentaries, social videos and *Scientific American*’s podcast *Science Quickly*. They have a bachelor’s degree in chemistry from Johns Hopkins University and a master’s degree in science writing from the Massachusetts Institute of Technology. Previously, they worked with *Wired*, *Science*, *Popular Mechanics*, and *MIT News*. Follow them on LinkedIn and Instagram.

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https://www.scientificamerican.com/article/these-orcas-are-on-the-brink-and-so-is-the-science-that-could-save-them

Mysterious Bright Flashes in the Night Sky Baffle Astronomers

Celestial transients shine furiously and briefly. Astronomers are just beginning to understand them

By Ann Finkbeiner edited by Clara Moskowitz

Olena Shmahalo

Long, long ago a cloud of stars circled a galaxy-size black hole, safely at a distance. Then about 200 million years ago one member of the cloud bumped another, a sun-size star, and sent it toward the black hole. The black hole was a million times more massive than the sun-size star, and its gravitational pull proportionately stronger, so the star was drawn closer and closer—until it got too close. Some of the star's gas was pulled into an orbiting stream around the black hole that widened into a flat pancake called an accretion disk. The rest of the star came apart in a sudden and great flash of light.

On September 19, 2019, just before noon, the flash reached the 1.2-meter mirror of the Zwicky Transient Facility in southern

California. Astronomers named the flash AT2019qiz and noted that they hadn't seen it three days before. On September 25, 2019, the 10-meter Keck I telescope in Hawaii identified AT2019qiz as a so-called tidal disruption event—a flare-up that occurs when a black hole's gravitational tides rip a small object apart. The star the size of the sun exploded with 10 billion times the sun's luminosity.

But AT2019qiz wasn't finished yet. An entirely unrelated star, maybe from the same cloud, was on an orbit that intersected AT2019qiz's newly created disk. Each time this other star splashed into the disk, it flashed, though less brilliantly than the original, pulled-apart star. In December 2023 the brightness of AT2019qiz (now the name of the disrupted star, the accretion disk and the flaring star that ran into them) peaked, dimmed down and then shot up again—a pattern that repeated nine times. Each flash marked a pass of the interloper through the disk, which occurred every 48 hours. Between 2019 and 2024, astronomers observed AT2019qiz with telescopes on the ground and in space, at wavelengths from x-ray through ultraviolet, optical and infrared. The multitelescope, multiwavelength data together confirmed that AT2019qiz was first a tidal disruption event and then a "quasi-periodic eruption." Both are examples of phenomena astronomers call transients. Both involved unspeakable violence on unearthly scales. Neither could have been identified 20 years ago.

Transients, which are astronomical objects that appear suddenly from nowhere and usually disappear soon after, contradict the standard truth that the universe changes predictably and slowly over billions of years. They include what the typically staid National Academy of Sciences called "the most catastrophic events in spacetime." They are astronomically sized objects that change on human timescales—in seconds, hours, days—which is a combination of size and speed that seems impossible. If we didn't observe them, says astronomer Vikram Ravi of the California Institute of Technology, "you'd never know that physics allows these things to exist."

But physics says everything not forbidden will, sooner or later and with some probability, happen. And astronomers, noticing these improbable things and knowing that nothing is one of a kind, began to find many more, all at the far reaches of physics. Between 1976 and 2012, the number of transients listed on the International Astronomical Union's official Transient Name Server was around five each year. Between around 2013 to 2015, that number jumped to about 100. Since 2019, scientists have seen roughly 20,000 a year. At press time, the total was 175,953 transients. Chart this rise, and it looks like a long tail with an elephant attached.

The growth has been the result of a large number of astronomical surveys, most still ongoing, "vacuuming the whole sky," says experimental physicist Christopher Stubbs of Harvard University. For instance, the Zwicky Transit Facility, which started the jump in detections in 2019, scans the entire northern sky every two nights and compares each evening's images with the ones taken two nights before. And the Vera C. Rubin Observatory in Chile, which came online in 2025, will soon survey the entire southern sky every three nights, identifying changes within 60 seconds of their detection to create near-real-time movies of the sky and finding 10 million changes every day. The elephant will go seriously nonlinear.

With such a large amount of data, astronomers can begin to study credible demographics: that is, they can move from just finding these wild, unlikely creatures to figuring out what they are. Because things that happen once and disappear are hard to study, the transients' identities—the physics that drives them, the processes that produce them—are still speculative. Most of their names are just adjectives, and "when the transient's name is a description," says astrophysicist Raffaella Margutti of the University of California, Berkeley, "that tells you we know nothing intrinsic about them." That's about to change.

Scientists sort transients into two main groups: events involving the deaths of stars and events around supermassive black holes in the centers of galaxies. The first known transients fell into the former category: they were supernovae, or massive stars that blow up. Before the 1600s, astronomers confidently knew of five of them; now they count tens of thousands. Supernovae fit into two general categories. One kind is the dead core of a star pulling gas from a nearby star, piling up mass until nuclear fusion restarts and goes critical and the whole thing pops off like a 20-billion-billion-billion-megaton thermonuclear bomb, which it is. It explodes in a day, stays bright for days to weeks, and fades out over months.

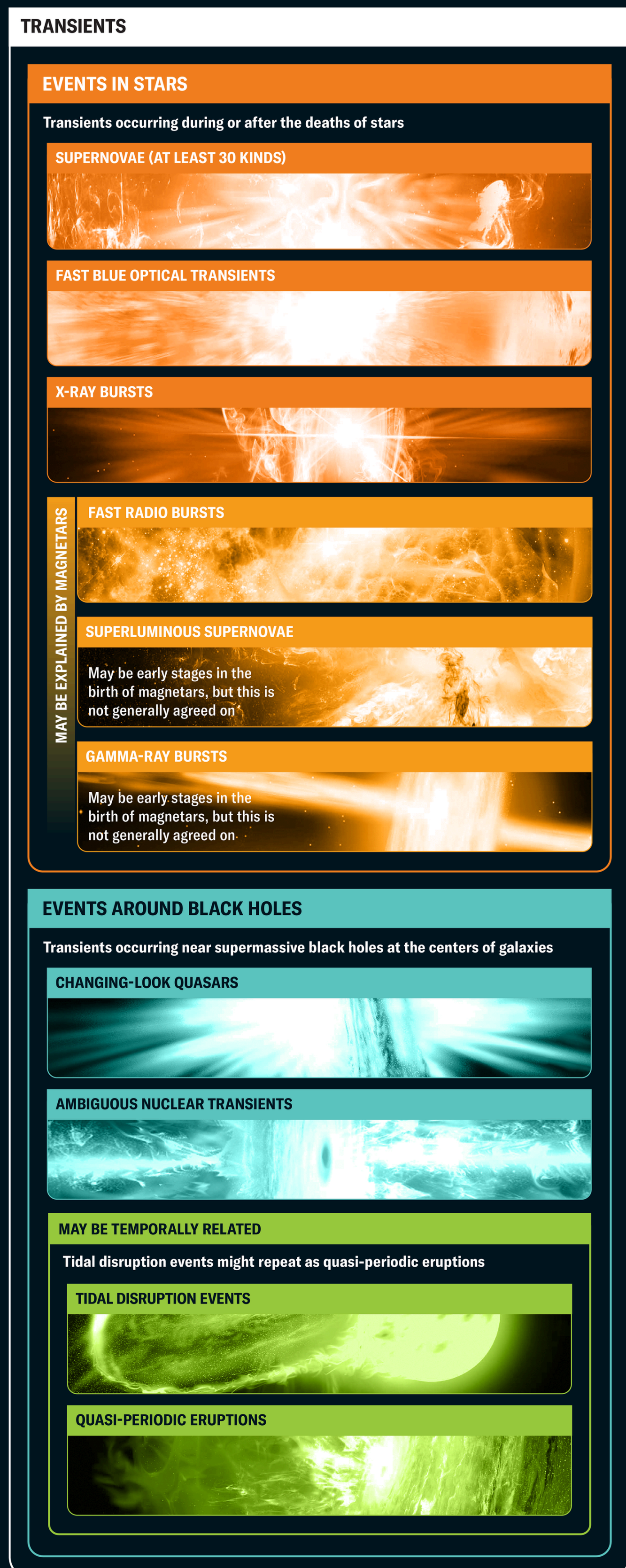
The other type of supernova is called a core collapse: A star burns through enough of its fuel and is massive enough that the outward push of its radiation loses to the inward pull of its gravity. Its core collapses in on itself so thoroughly that its electrons meld with the nuclei of its atoms until the star is made mostly of neutrons—a neutron star—and it shrinks in the space of one second from a radius of about 6,000 kilometers to about 10 kilometers. The collapse causes a shock wave that breaks out of the star's remaining atmosphere with a flash called a shock breakout, and minutes later the star is as bright as 10 billion suns. It fades out over months; the remnant is called a neutron star.

Beyond these two main categories, though, are many variants—the Transient Name Server identifies 31 types so far. One new kind, called a gap transient, is dimmer and probably less massive than other supernovae, and nobody knows why it explodes. Another is a superluminous supernova, twice as luminous as a core collapse supernova; it has the light of 20 billion suns, and nobody knows why it's so bright. Supernovae are by far the most numerous of the stellar-death transients, but, as astronomer James E. Gunn of Princeton University points out, stars have "a vast number of interesting ways to die."

Celestial Transients

Astronomers are discovering an ever growing catalog of mysterious flashes and bangs in the night sky. These events, called transients, often arise and then disappear over hours and days, much more quickly than the usual astronomical phenomena. Sometimes they outshine entire galaxies.

Scientists don't understand the physics powering many of these transients, but they think the objects fall into two main categories: those that originate in the deaths of stars and those that occur near the supermassive black holes at the centers of galaxies.



Ron Miller (*illustrations*) and Jen Christiansen (*graphic*)

In 1967, for instance, the U.S. Vela satellites detected surprising flashes of extremely energetic gamma rays that could have been (but weren't) illegal nuclear tests in Earth's atmosphere; the *National Enquirer* thought similar flashes seen later might be a space war between alien civilizations. Eventually astronomers pooled data from the U.S. and the U.S.S.R. to identify the flashes, which were the first known gamma-ray bursts—a class of transients now understood to be "the brightest of the brightest," says astrophysicist Peter Jonker of Radboud University in the Netherlands, who observes space in high-energy wavelengths. Their light rises in seconds to the brightness of a trillion suns, and they last for seconds to hours. The fastest ones might be massive stars going supernova, collapsing so thoroughly that they don't stop at neutron stars and instead condense into star-size black holes that aim high-intensity jets of plasma at Earth.

Gamma-ray bursts may or may not be related to other high-energy stellar deaths called fast x-ray transients. Discovered in 2008, they number only around 70, although this tally will soon change. China's Einstein Probe, an x-ray satellite telescope that began collecting data in mid-2024, should find 50 to 100 fast x-ray bursts a year.* "The next few years could be dramatic," says astronomer Mansi Kasliwal of Caltech. Meanwhile, because fast x-ray transients are still rare, no one is ready to say what they are—maybe massive stars exploding, maybe neutron stars colliding before disappearing into black holes.

Another dramatic rarity is called a fast optical blue transient, or FBOT—"fast" because although it explodes at the same outrageous brightness as a superluminous supernova, its light rises and falls not in months but in days. The first FBOT, found in 2018, is officially named AT2018cow and is called Cow for short. Since then, scientists have seen 12 more Cow-like FBOTs. Astronomers know they're not supernovae—"the energy source of the normal supernovae doesn't work" for Cows, Margutti says—but aren't sure what they are. Maybe they flash when a nearby star's mass piles up onto a neutron star or a modest-size black hole, or maybe they represent shock breakouts from a star that puffed up in its later years. "Whatever they are," says astronomer Anna Y. Q. Ho of Cornell University, who helped to find the original Cow, "they're interesting."

In 2007 radio astronomer Duncan Lorimer and astrophysicist Maura McLaughlin, who are colleagues at West Virginia University and married, were looking in the archives of a radio telescope survey at a small galaxy 200,000 light-years away. They were interested in pulsars, which are rotating neutron stars that release jets of radio light from their magnetic poles. These lighthouselike jets sweep the sky so that whatever is in their path is exposed to a metronomically regular radio pulse every few seconds to milliseconds.

In the course of their search, Lorimer and McLaughlin found a radio spike that lasted a few milliseconds, but it didn't pulse and was so bright it saturated the telescope's instrument. Lorimer calculated its distance as seven billion light-years away. "Oh," he thought, "it's really far." Anything that distant and still that bright had to be sending out a billion times more energy than nearby pulsars.

This odd find is now called the Lorimer Burst. Surveys have since identified several thousand of these so-called fast radio bursts scattered throughout other galaxies, emitting in one millisecond the radio energy sent out by the sun in 100 years. "These things are weird," Lorimer says.

Some of these possible stellar death transients could be related to a deeply strange object called a magnetar. Magnetars existed only in theory until they were observed in 1998. Their weirdness quotient is high even among transients. A magnetar is a neutron star that “rotates ridiculously fast,” making a full turn in milliseconds, says Daniel Kasen of the University of California, Berkeley, “but with a ridiculously high magnetic field.” The strength of the sun’s magnetic field is somewhere around 10 gauss; a magnetar’s is 10^{14} gauss or higher. That field is “so high it’s unstable,” Ravi says. “It chaotically reconfigures itself.”

> Transients are astronomically sized objects that change on human timescales—in seconds, hours, days.

The object’s magnetic field lines twist and snap and reconnect, and in the process they send out flares. The combination of absurdly strong magnetic fields and absurdly fast rotation leads to lots of explosive physics, Kasen says. In 2004 a flare from one magnetar halfway across the Milky Way ionized the upper layers of Earth’s atmosphere. Astronomers know of around 30 of them in our galaxy so far.

“Magnetars are invoked to explain a lot of things we don’t understand,” says Brian Metzger of Columbia University, a theoretical astrophysicist who specializes in stellar-death transients. For instance, different transients might be different phases of a magnetar’s life. Magnetars might be born in the core collapse of the same massive stars as superluminous supernovae. A supernova might then condense into a pulsar and send out jets that are seen as gamma-ray bursts. Later, when the magnetar’s spin period has slowed from milliseconds to seconds, its flares may be seen as a fast radio burst. Magnetars might even explain FBOTs, Ho says, but so far FBOTS are too distant for scientists to be sure.

The stellar-death transients are dying in ways intrinsic to stars. But stars can also die because they’re just in the cosmically wrong place, in the nuclei of galaxies with supermassive black holes. These “nuclear transients,” the second overall category of transients, have turned up only in the past decade. They’re rare and barely understood.

One reason for that is that nuclear transients “are a minefield of contamination,” says Suvi Gezari of the University of Maryland, College Park. Astronomers must distinguish the flashes of nuclear transients from supermassive black holes whose behavior varies. One percent of supermassive black holes, the quasars, are furiously, actively accreting gas and shine so brightly they can be seen near the beginning of the universe. Most of the rest are inactive and just flickering; they have gravitationally cleared out much of the space around them, and their brightness varies by just 10 to 45 percent. And another, unknown fraction are not accreting at all; they’re completely black and invisible.

Nuclear transients are not active quasars, and they don’t flicker—they’re cosmic flash-bangs. One kind is a tidal disruption event such as AT2019qiz, a star trapped in a supermassive black hole’s gravitational field and torn to smithereens. Astronomers have found around 100 tidal disruption events, each visible for a few months in the x-ray, optical and ultraviolet ranges, each with its own small accretion disk that lasts for a few tens of years. Maybe one in 10 tidal disruption events do what AT2019qiz did and become the site of another kind of nuclear transient, the quasi-periodic eruption. In these cases, an errant star passes through the tidally disrupted star’s accretion disk and flares up in x-rays to the brightness of a billion suns. Such flares last minutes and repeat in hours to weeks.

Other nuclear transients may not involve stars at all and may reflect odd behavior of the black holes. One kind of transient discovered in the past decade is called a changing-look quasar (CLQ). It has the brightness of a normal quasar but rapidly changes its appearance in unexplainable ways. It should take thousands of years for a quasar to switch off and go from brilliantly active to quietly inactive. Yet astronomers have found dozens to hundreds of CLQs that change their looks by 200 percent in months—they change so much and so quickly that “they’re not theoretically explainable,” says astrophysicist Paul Green of the Center for Astrophysics | Harvard & Smithsonian. Maybe they’re the aftermath of a long-gone tidal disruption event, or maybe, he says, "we haven't watched long enough to see a change of state that's lasting."

As if CLQs weren't improbable enough, astronomers also find ambiguous nuclear transients (ANTs), whose problem is in their name: "They're ambiguous," says astrophysicist Philip Wiseman, who studies nuclear transients at the University of Southampton in England. They are a diagnosis of exclusion, a flash that isn't any other transient. ANTs are brighter than all transients except gamma-ray bursts. Their light rises slowly over months and lasts for two or more years. They've been found in data archives in numbers from a few to hundreds, depending on who's defining them. "We can find them, but we don't know what they are," says astronomer Matthew Graham of Caltech, another nuclear-transients specialist.

These events are flashes of inconceivable amounts of energy.

One ANT discovered in 2020 became famous: At first astronomers thought it was an actively feeding supermassive black hole in the center of a galaxy, but they couldn't find the galaxy. The lonely supermassive black hole, like a kind of negative island, is somewhere between 10 and 1,000 times the size of the one in the Milky Way. One of its names is ZTF20abrbeie; astronomers call it Scary Barbie.

ANTs could be outsize tidal disruption events—that is, instead of sun-size stars being torn apart by black holes with the mass of a million suns, they might be 10-solar-mass stars torn apart by black holes with the mass of a billion suns. Or they could be supermassive black holes moving from inactive flickering to active fiery accretion—black holes "turning on," Graham says. Researchers are still looking for Scary Barbie's galaxy. "We're guessing at half this stuff," Graham adds.

The obvious question is, Are some of these transients somehow aspects of the same thing? For stellar-death transients, the answer is not exactly no. Several of them may be related to one another or to magnetars; in general, they're a menu of the variables that determine how stars end their lives. For nuclear transients, the answer is unsatisfying: either a captured star or a black hole's accretion disk is brightening. For a better answer, astronomers need to collect many more nuclear transients.

Nor can stellar and nuclear transients be put together into a single grand unified theory. Such a picture should be based on their physics—specifically, the source of energy for their outbursts. "The holy grail is understanding what produced the transient," says Eliot Quataert of Princeton, a theoretical astrophysicist studying nuclear transients. Theorists want to be able to slot energy sources into a few categories, such as radioactive decay, shocks and gravity, although some transients don't seem to fit into any of these boxes.

To figure out the energy sources and maybe unify transients, astronomers need to compare what they see in different wavelengths, which each reflect different physical processes. In supernovae, for instance, ultraviolet light comes from shock breakouts, and x-rays and radio waves come from collisions between matter ejected in the explosion and the surrounding gas. Collecting every possible photon from every physical process allows astronomers to assemble a complete picture of the event.

Accordingly, telescopes now operating in optical, ultraviolet, x-ray, gamma-ray and radio-wave bands are about to be joined by a series of new telescopes in space. Among them are NASA's Nancy Grace Roman Space Telescope, which will launch by mid-2027 and observe in the infrared; the Einstein Probe in x-ray; and NASA's Ultraviolet Explorer, which will launch in 2030.

You might wonder whether this is a lot of telescopes and effort just to learn about 100,000 one-offs in a universe full of 10,000 billion

billion stars in 100 billion galaxies. Understanding transients is important partly for answering other astronomical questions. Supernovae are used as distance markers to enable calculations of the universe's acceleration. Both tidal disruption events and quasi-periodic eruptions hold evidence about supermassive black holes that are quiescent and therefore invisible, as well as about the all but theoretical class of black holes whose masses are between those of stellar black holes and supermassive ones. And fast radio bursts, because they are visible in the distant universe, can be used as searchlights to map the distribution of regular matter, of which only 10 percent is known.

But transients are also interesting for their own odd selves, for their ability to teach us what physics doesn't forbid. Kasen says they are "laboratories for fundamental physics and extreme conditions"; they are "physics at the extreme," Margutti says, "and I can't probe that on Earth." Transients show "the range of phenomena possible in the universe," Ravi says.

These events are flashes of inconceivable amounts of energy released in the time it takes to buy groceries, drink a glass of water or snap your fingers. A supernova shock breakout travels the distance from Baltimore to Western Australia in half an eyeblink. A magnetar passing 160,000 kilometers away could demagnetize every credit card on Earth. A neutron star compresses a massive star to the length of a leisurely two-hour walk. The study of transients is certifiable science, but if it weren't, it would still be reason for near-holy astonishment.

**Editor's Note (12/18/25): This sentence was edited after posting to correct the date at which the Einstein Probe began collecting data.*

Ann Finkbeiner is a science writer based in Baltimore. She specializes in writing about astronomy and cosmology, grief, women in science, and the intersection of science and national security. She is co-proprietor of the science blog The Last Word on Nothing.

https://www.scientificamerican.com/article/mysterious-bright-flashes-in-the-night-sky-baffle-astronomers

Meet Your Future Robot Servants, Caregivers and Explorers

Robots are poised to play a much bigger role in daily life at home, at work and in the world

By Ben Guarino edited by Clara Moskowitz

Bed making is one household task that could eventually be outsourced to robots such as TidyBot, a project led by Stanford University computer scientist Jeannette Bohg.
Christie Hemm Klok

In the future, a caregiving machine might gently lift an elderly person out of bed in the morning and help them get dressed. A cleaning bot could trundle through a child's room, picking up scattered objects, depositing toys on shelves and tucking away dirty laundry. And in a factory, mechanical hands may assemble a next-generation smartphone from its first fragile component to the finishing touch.

These are glimpses of a possible time when humans and robots will live and work side by side. Some of these machines already exist as prototypes, and some are still theoretical. In situations where people experience friction, inconvenience or wasted effort, engineers see opportunity—for robots to perform chores, do tasks we are unable to do or go places where we cannot.

Realizing such a future poses immense difficulties, however, not the least of which is us. Human beings are wild and unpredictable. Robots, beholden as they are to the rules of their programming, do not handle chaos well. Any robot collaborating or even coexisting with humans must be flexible. It must navigate messes and handle sudden changes in the environment. It must operate safely around excitable small children or delicate older people. Its limbs or manipulators must be sturdy, dexterous and attached to a stable body chassis that provides a source of power. And to truly become a part of our daily lives, these mechanical helpers will need to be affordable. All told, it's a steep challenge.

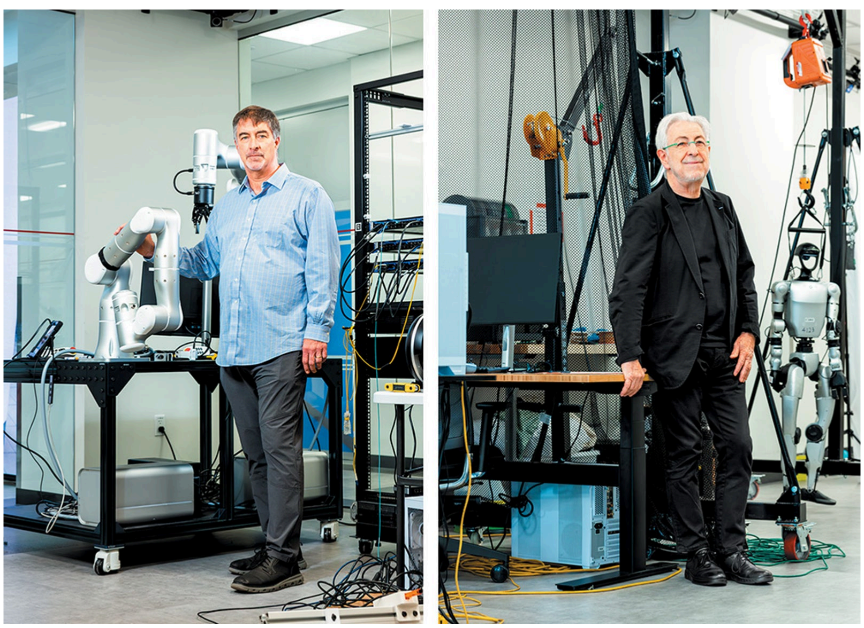
But not necessarily an insurmountable one. To see how close we're getting to this vision, I visit the Stanford Robotics Center, which has 3,000 square feet for experiments and opened in November 2024 at Stanford University. There I am greeted by Steve Cousins, the center's executive director and founder of the company now known as Relay Robotics, which supplies delivery robots to hospitals and hotels. He believes robots will become indispensable to modern life—especially in areas such as caregiving, which will need more workers as the world's population ages. "Robotics is about helping people," he says.

In some roles, robots' abilities can surpass those of the flesh and blood. Yet it's also true that there are certain jobs only humans ever could or should do. The Stanford Robotics Center is one attempt to probe that boundary and find out just how many tasks of daily life—at home, at work, in medicine and even underwater—are best offloaded to metal and plastic assistants.

One skill in particular is a significant stumbling block for robots. "The biggest challenge in robotics is contact," says Oussama Khatib, director of the center. Lots of robots have humanlike hands

—but hands are more complex than they seem. Our articulated fingers belong to an appendage built of 27 bones and more than 30 muscles that work in concert. Our sense of touch is actually a synthesis of many senses, relying on cellular receptors that detect pressure and temperature and on proprioception, or our knowledge of our body's location and motion. Touch and dexterity enable humans to outperform current robots at many tasks: although children often master tying their shoes between the ages of five and seven years, for instance, only machines designed specifically to tie shoelaces can do so at all. Many robots rely not on hands but on "jaw grippers" that bring two opposing fingers toward each other to hold an object in place.

Impressive demonstrations of robotic hands, such as when Tesla's humanoid Optimus robot was recorded snatching a tennis ball out of the air in 2024, often rely on teleoperation, or remote control. Without a technician guiding Optimus off-screen, playing catch would be out of the question for the robot.



Stanford Robotics Center executive director Steve Cousins (*left*) and director Oussama Khatib (*right*) pose with some of the robots being developed in November 2025.
Christie Hemm Klok

In the early 1960s the first industrial robot arm—a bulky, 3,000-pound machine—was installed in a General Motors plant in

Trenton, N.J. Named Unimate, it was designed for “programmed article transfer,” as its patent describes. In practice, this meant the robot used its gripper to grab and lift hot metal casts from an assembly line. Unimate’s proprioception was crude. A handler had to physically move the arm to put it through any desired motion. It could carry out basic tasks, including hitting a golf ball and pouring a beverage from an open can—which a Unimate robot demonstrated for Johnny Carson on the *Tonight Show* in 1963.

Yet Carson gave the machine’s business end a wide berth. Maintaining a respectful distance from robot arms is, after all, a long-standing norm, part of the structured environments that have helped manufacturing robots succeed for the past 60 years. Moving them out of such orderly domains, as the roboticists at Stanford are trying to do, is hard. Khatib says he and his colleagues are “taking robots to a world that is uncertain—where you don’t know where you’re going exactly and where, when you touch things, you [might] break them.” He seeks inspiration from what he calls human “compliance,” or the way we adapt to our environment by touch and feel. Guided by these principles, he developed a pair of cooperative robot arms equipped with grippers, named Romeo and Juliet.

I spy Romeo in Khatib’s lab, powered down and alone; Juliet has recently been shipped back from a museum in Munich and is still boxed up. Khatib recalls becoming nervous when a wealthy computing pioneer visited the university in the 1990s and approached the arms because he “wanted to dance” with the robots. The visitor wasn’t hurt, luckily, but that wasn’t a guaranteed outcome. “This is our work: trying to discover human strategies,” he says, and then applying them to robots that must operate in a world that includes variables such as spontaneous dancers.

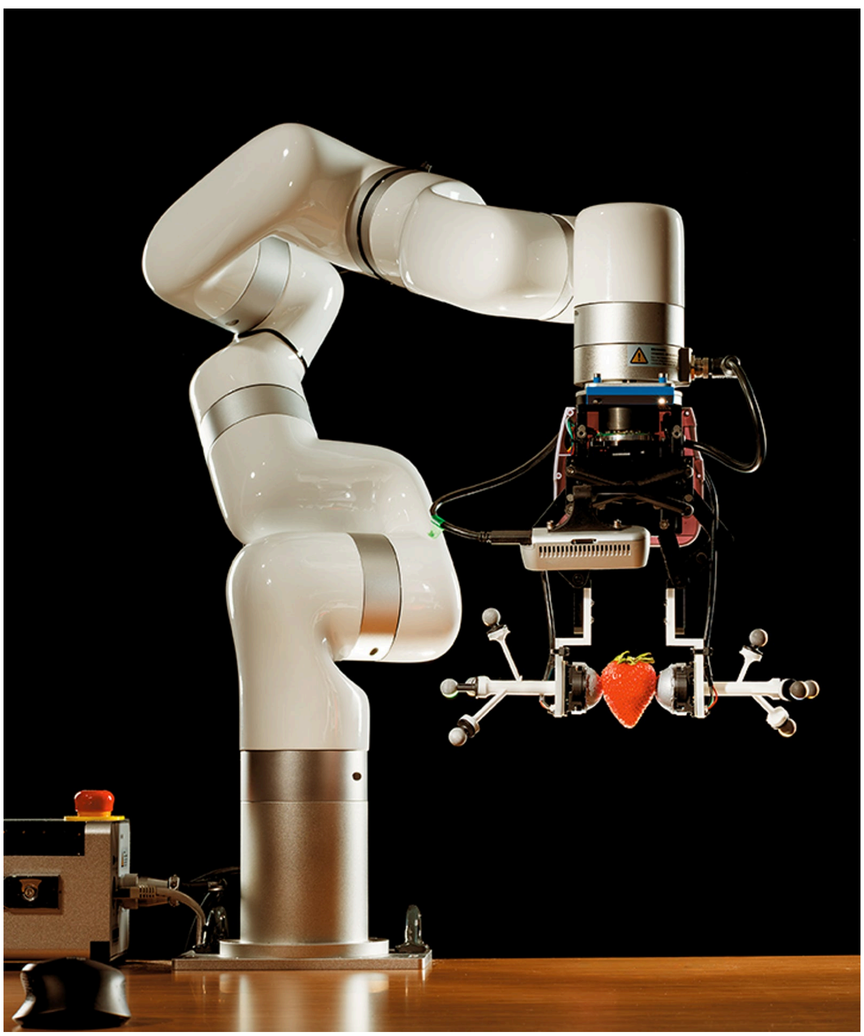
To help robots better feel their way through the world, Monroe Kennedy III, an assistant professor of mechanical engineering at Stanford, is developing a sensor called DenseTact. The device improves standard grippers by equipping them with a translucent silicone gel tip. When the tip presses against something, the object leaves an imprint in the gel. A camera in the sensor then detects light, produced by an LED embedded in the sensor, reflecting off the interior surface of the silicone. The robot uses the changing light intensity to make a mathematical representation of the surface of the object. In other words, DenseTact enables a robot to “see” what it’s touching. One of Kennedy’s robots can rub a sheet between two fingers and tell whether the fabric contains one, two or three layers of silk with greater than 98 percent accuracy.

Scientists at the Massachusetts Institute of Technology created a similar system named GelSight. Sandra Liu, as a doctoral student in mechanical engineering there, has shown that GelSight can identify by touch the tiny letters spelling out LEGO on the stud of a toy brick. In a departure from other designs for robot hands, which tend to emphasize fingers, Liu inserted a GelSight sensor into a rubber palm. Palms are underappreciated in robotics, Liu says. “When I grab something large, for example, I’m actually grasping more with my palm than I am with my fingers,” she explains. Liu and her thesis adviser tested robots with various finger-and-palm configurations by having them grasp plastic Fisher-Price toys slathered in paint. A robotic palm that was bendable and covered in compliant gel afforded the best grip on the toys, they found.

Although palms seem promising, Liu acknowledges that the optimal robotic hand might not need to mimic our own anatomy at all. “There’s a lot of philosophical debate about whether we’re so hung up on the idea of making humanlike robotic hands that we’ve lost sight of what’s actually important,” she says, “which is just a robotic hand that can do a bunch of different tasks.”

To descend into the Stanford Robotics Center is to enter what must be among the nicest basements of any university engineering schools. Bright artificial light beams from fake skylights in its white ceiling, which ripples as if to suggest waves. The rooms, partitioned by glass walls, are themed around domestic, recreational and workplace environments. There's a kitchen where a robot has stir-fried shrimp and put away dishes. In a medical suite, a see-through replica head is threaded with tubes filled with red liquid à la human veins. The idea, Cousins says, is that tiny robots could be guided by magnets through the vasculature to, for instance, remove a blood clot. Outside in the hallway, a quadruped robot rests like a sleeping dog at the end of a sofa. "I think they're teaching it to jump on the couch," Cousins says.

There is also a dance studio, complete with a wood floor and large mirrors. Here scientists record the movements of human dancers to train virtual robots. "Robots move in the world," Cousins says. "Who understands how to move in the world more innately than dancers and choreographers?"



The DenseTact Optical Tactile Sensor delicately grips a ripe strawberry.

Next door, in a bedroom styled with IKEA furniture, two roboticists are testing TidyBot. The one-armed machine uses a parallel jaw gripper to clean up the space. Cameras that ring the ceiling help it determine which object among those scattered around is nearest. Using its onboard camera, TidyBot categorizes each item as, say, a toy, a piece of clothing or a hat. Then it decides where that thing belongs; roboticists determined that TidyBot can put an object in its proper place about 85 percent of the time (better than my human children).

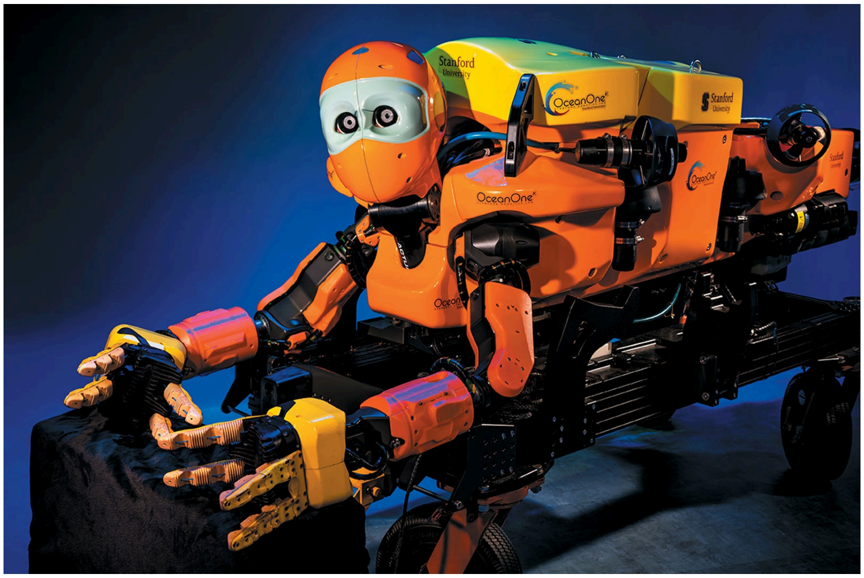
As I watch, the robot deposits a shirt in a laundry basket. Then it finds a hat, grabs it, wheels across the room to a bureau, places the hat on the ground, opens a drawer by gripping its handle, picks up the hat, sets it inside and closes the drawer. Next it turns around, spies a plastic banana, picks it up and sets it on a shelf. In other tests, TidyBot has, with varying levels of success, wiped down a countertop, loaded a dishwasher, closed a refrigerator and watered a plant.

If robots are to truly partner with humans, they will need to master skills that are more ambitious than tending to ficuses. I follow the Stanford Robotics Center's ceiling ripples down a passage that leads to a large pool, still under construction, that will host the merperson-shaped robot OceanOne.

The 500-pound underwater machine has two arms and an anthropomorphic face, which Khatib says is designed to appear reassuring to human divers in murky water, and it tapers into a fishlike rear that sprouts omnidirectional thrusters. Its hands have rubbery fingers that give slightly when squeezed. It's designed to venture deeper into the ocean than scuba divers typically dare. "It is the only [robot] in the world capable of reaching the seabed" and sensing it with haptic feedback, Khatib says.

OceanOne has already navigated the world’s deepest swimming pool, in Dubai, where Khatib used it to play chess against a diver. Near the coast of Corsica it explored a sunken Roman ship dating to the second century C.E. There Khatib, onboard a research ship at the surface, remotely piloted the robot’s soft fingers to pluck a delicate oil lamp from the ancient wreck. He and his colleagues are working on an upgraded version named OceanOneK, which will be able to dive to a depth of 1,000 meters (almost 3,300 feet).

When OceanOne is diving, its hands are controlled via a tether that links it to a control system and a pilot who wears 3D glasses to see the robot’s view. Outside his office, Khatib leads me to a set of similar controls. The apparatus is akin to a pair of parallel video-game joysticks but sleeker and with more degrees of freedom. I grab one in each hand. A scene appears on a computer screen in front of me, showing a ball atop a slab of what looks like gelatin. Khatib asks me to roll the ball across the gel. I move the controller forward, and the ball responds. What feels smooth and instantaneous to me requires hefty computing power. “This is really difficult because we are simulating in real time the deformable membrane, but at the same time you are touching it and feeling it physically,” he says. “Go to the middle and push hard—hard!” I follow his instructions, and the simulated membrane breaks as I drive the ball downward. The response through the haptic feedback is uncanny: it’s exactly how I imagine it would feel to press a billiard ball into a tray of Jell-O.



The OceanOne robot’s anthropomorphic face is designed to reassure human divers underwater.
Christie Hemm Klok

Khatib’s dream is to put more controllers like this one, attached to more robots like OceanOne, in the hands of many other scientists. He would submerge those robots at various points on the ocean floor to create a submarine fleet scattered around the world. The program would operate similarly to space observatories, where experts from many institutions can visit to take measurements with specialized sensors and return home with their data. “Imagine what you can do,” he says, “for the coral reefs, for plastic, for the environment, for the sea.”

Charmed though I am by such visions, I have an admission: I have a hard time picturing myself using robots in daily life (as much as I’d love a cheerfully beeping R2-D2-style helper). Perhaps it’s because my only relationship with a household robot, an automated dinner-plate-size vacuum, ended in disaster. A well-meaning houseguest turned on the robot before she left, unaware of the prep required to robot-proof the apartment. The bot ran over my cat’s food bowl and partially ingested some salmon pâté; by the time I arrived at home it had smeared the rest in a brown slug trail across my rug and floors. I was already unsure whether the device was saving me any cleaning time, and after the cat food fiasco, I retired the robot to a closet and never turned it on again.

And there are still issues to work out in the machines at Stanford, as impressive as they are. In one test I observed, TidyBot was supposed to put away a yellow LEGO brick but failed to find it when it was obscured behind a bed. During another demonstration in the center's kitchen, the dishwashing robot, which had previously been working normally, glitched. The reason, after some investigation, was that it got confused by the unusually large number of people watching it that day—its surroundings were so crowded that the machine could no longer detect where to place dishes. The robot is trained through machine learning, so Cousins says one solution might be to train it more frequently to perform with an audience.

Near the end of my tour, a few doors down from the kitchen, in the Field Robotics Bay, a staff roboticist launches a small, cylindrical drone named the Firefly. It lifts off vertically with a sound like a hair dryer set to max. Unusually for a drone, it has only one spinning blade and relies on self-stabilizing systems to remain oriented upright. Cousins pokes the monocopter in the side, and the flying robot wavers and automatically rights itself. His next nudge, though, is a touch too hard. The drone tilts sideways, then shoots off and crunches into a wall.

Cousins pauses. "It should probably turn itself off if it goes horizontal," he says. The staff roboticist who's been operating the drone appears unfazed as he picks up the scattered pieces of plastic; such are the benefits of housing an experimental robot in a replaceable 3D-printed shell. The crash, though minor, is a reminder of two central truths: robotics is complicated, and, to robots, people are complications. We'll have to wait to see whether humans are a problem that can ever be solved.

Ben Guarino is a freelance journalist with a soft spot for big ideas and tiny critters. He was formerly an associate technology editor at *Scientific American*. He wrote and edited stories about artificial intelligence, robotics and our relationship with our tools. Previously, he worked as a science editor at *Popular Science* and a staff writer at the *Washington Post*, where he covered the COVID pandemic, science policy and misinformation (and also dinosaur bones and water bears). He has a

degree in bioengineering from the University of Pennsylvania and a master's degree from New York University's Science, Health and Environmental Reporting Program.

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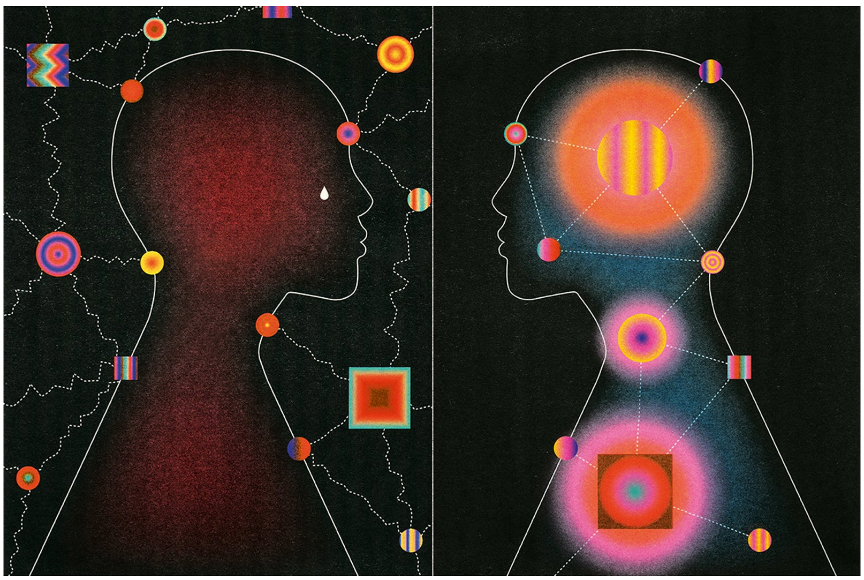
https://www.scientificamerican.com/article/meet-your-future-robot-servants-caregivers-and-explorers

| Section menu | Main menu |

A Distorted Mind-Body Connection May Explain Common Mental Illnesses

Disruptions in interoception may underlie anxiety, eating disorders, and other mental health ailments

By Diana Kwon edited by Jeanna Bryner



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By the time Maggie May, an Arkansas resident in her 30s, was admitted to a psychiatric clinic in 2024, she had been struggling for years with atypical anorexia nervosa, an eating disorder that leads to severe food restriction and profound disturbances in body image. (Her name has been changed for privacy.) She had already tried traditional interventions with a psychotherapist and a dietitian, but they had failed to improve her condition. So when May heard about a trial of a new and unconventional therapy, she jumped at the opportunity.

The treatment was unusual in that alongside talk therapy, May underwent several sessions in a sensory-deprivation chamber: a dark, soundproof room where she floated in a shallow pool of water heated to match the temperature of her skin and saturated with Epsom salts to make her more buoyant. The goal was to blunt May’s external senses, enabling her to feel from within—focusing on the steady thudding of her heart, the gentle flow of air in and out of her lungs, and other internal bodily signals.

The ability to connect with the body’s inner signals is called interoception. Some people are better at it than others, and one’s aptitude for it may change. Life events can also bolster or damage a person’s interoceptive skills. Sahib Khalsa, a psychiatrist and neuroscientist at the University of California, Los Angeles, and his colleagues think a disrupted interoception system might be one of the driving forces behind anorexia nervosa. So they decided to repurpose a decades-old therapy called flotation-REST (for “reduced environmental stimulation therapy”) and launched a trial with it in 2018. They hypothesized that in people with anorexia and some other disorders, an underreliance on internal signals may lead to an overreliance on external ones, such as how one looks in the mirror, that ultimately causes distorted body image, one of the key factors underlying these conditions. “When they’re in the float environment, they experience internal signals more strongly,” Khalsa says. “And having that experience may then confer a different understanding of the brain-body relationship that they have.”

Studies have implicated problems with this inner sense in a wide variety of conditions, including anxiety disorders, post-traumatic stress disorder and borderline personality disorder. Some researchers and clinicians now think that problems in interoception might contribute to many mental illnesses. Alongside this research, which itself is complicated by challenges in testing design and by a less than clear understanding of interoception, other groups are also developing therapies that aim to target this inner sense and boost psychological well-being.

This work is circling in on a central message: the body and mind are inextricably intertwined. “We have always thought about [mental health conditions] as being in the brain or the mind,” says Camilla Nord, a professor of cognitive neuroscience at the University of Cambridge. But clinicians have long noted that people with mental illness frequently report physical symptoms such as abnormalities in heartbeats, breathing and appetite, she adds.

The idea that the body can influence the mind dates back centuries. In the 1800s two psychologists on opposite ends of the globe independently proposed a then novel idea: emotions are the result of bodily reactions to a specific event. Called the James-Lange theory after its founders, American psychologist William James and Danish doctor Carl Lange, this view ran counter to the long-dominant belief that emotions were the cause, not a consequence, of corresponding physiological changes.

Although this notion has garnered critics, it inspired a slew of studies. The 1980s saw a surge of interest in the role of physiological signals in panic disorders. Researchers discovered that they could bring on panic attacks by asking people to inhale carbon dioxide–enriched air, which can increase breathing rates, or by injecting them with isoproterenol, a drug that increases heart rate.

> Breathing rate can affect how someone perceives the intensity and unpleasantness of pain.

These findings led some psychologists to suggest that physical sensations were the primary trigger of panic attacks. In the early 1990s Anke Ehlers, a psychologist then at the University of Göttingen in Germany, and her team examined dozens of people with panic disorders and reported that these patients were better able to perceive their heartbeats than healthy individuals—and that this greater awareness was linked to more severe symptoms. On top of that, a small, preliminary study by Ehlers of 17 patients revealed that those who were more skilled at this task were more likely to relapse and start having panic attacks again. These observations hinted at a two-way dynamic: not only could physical sensations within the body cause psychological effects, but the ability to perceive and interpret those signals—in other words, one's interoceptive ability—could have a profound influence on mental health.

Over the years a growing body of evidence has indicated that interoception plays an important role in shaping both emotions and psychological health. A large chunk of this work has focused on the heart. With every heartbeat, blood rushes into the arteries and triggers sensors known as baroreceptors, which shoot off messages to the brain conveying information about how strongly and rapidly the heart is beating.

In one pivotal 2014 study, Hugo Critchley, a neuropsychiatrist at Brighton and Sussex Medical School in England, and his team reported that this process can affect a person's sensitivity to fear. By monitoring volunteers' heartbeats while they viewed fearful or neutral faces, they found that people detected fearful faces more easily and judged them as more intense when their heart was pumping out blood than when it was relaxing and refilling. But participants with higher levels of anxiety often perceived fear even when their hearts relaxed.

Researchers have also demonstrated that bodily signals such as breathing patterns and gut rhythms can influence emotional reactions. People are quicker to react to fearful faces while breathing in than while breathing out, and breathing rate can affect how someone perceives the intensity and unpleasantness of pain.

In more recent work, some neuroscientists have turned their attention to the gastrointestinal system. In 2021 Nord and her colleagues discovered that people given a dose of an antinausea drug that affects gut rhythms—processes within the stomach that help digestion—were less likely to look away from pictures of feces than they normally would have been. These disgust-related visceral signals, Nord speculates, may be relevant to eating disorders. “It’s possible that some of these signals contribute to feeling aversion to signals of satiety, making satiety very uncomfortable, a feeling you don’t want to feel,” she says.

But how, exactly, do disruptions in interoception come about? Many researchers suspect it may have to do with our brain’s predictions going awry. Interoception, like our other senses, feeds information to the brain, which some neuroscientists suggest is a prediction machine: it constantly uses our prior knowledge of the world to make inferences about incoming signals. In the case of interoception, the brain attempts to decode the cause of internal sensations. If its interpretations are incorrect, they may lead to negative psychological effects—for example, if a person erroneously assumes their heart rate is elevated, they may begin to feel anxious in the absence of a threat. And if a person has learned to associate pangs of hunger with disgust, they might severely restrict how much food they consume.

Inner signals can be much more ambiguous than the external input from other senses such as sight and hearing. So the brain’s prior information about these internal signals becomes especially important, says André Schulz, a professor of psychology at the University of Luxembourg.

To better understand and assess potential mismatches in subjective and objective measures of our bodily signals, researchers have developed a framework that captures the different dimensions in which interoceptive processing occurs. In 2015 Sarah Garfinkel, then a postdoctoral researcher in Critchley’s group at Brighton and Sussex, and her colleagues proposed a model to clearly differentiate three categories of interoceptive processing: interoceptive accuracy (how well someone performs, objectively, on relevant tasks such as heartbeat detection), interoceptive sensibility (a person's subjective evaluation of their interoceptive abilities), and interoceptive awareness (how well that self-assessment matches their actual abilities).

Along with their collaborators, Garfinkel, now at University College London, and Critchley have found that in autistic adults there is a link between anxiety and a poor ability to predict one's interoceptive skill—in this case, one's sensitivity to heartbeat. In a study of 40 people (20 of whom had autism), they and their colleagues discovered that individuals with autism performed worse on a heartbeat-detection task and were more likely to overestimate their interoceptive abilities than those without autism. This disconnect was more pronounced in people with higher levels of anxiety, suggesting that errors in the ability to predict bodily signals may contribute to feelings of anxiety, Critchley says.

In recent years the list of psychiatric conditions linked to interoceptive dysfunctions has grown. Some, such as panic and anxiety disorders, are associated with heightened attention to one's internal processes; others, such as borderline personality disorder and schizophrenia, may be tied to a blunting of one's ability to connect with these signals. In a review of interoception research, published in 2021, Nord and her colleagues examined 33 studies that collectively involved more than 1,200 participants. They found that people with a range of psychiatric disorders, including anxiety disorders and schizophrenia, shared similar alterations in the insula, a key brain region linked with interoception during body-sensing-related tasks.

Overall, though, studies show mixed results. "If you look across the literature, [however many] studies have found an association with, say, anxiety, [a roughly] equal amount will have not found a relationship or found it in the other direction," says Jennifer Murphy, a psychologist at the University of Surrey in England.

The varying results could stem from the challenges associated with studying interoception, which can be difficult to both manipulate and measure. Take cardiac interoception. In most early studies in this domain, participants counted their pulses, but this test may measure people's estimate of their heart rate rather than how well they can feel their heartbeat. This flaw was perhaps most clearly demonstrated in a 1999 study in which people with pacemakers reported their heart rates while experimenters (with the participants' consent) secretly tuned their pacemakers' timing up or down. Participants' self-reported heart rates didn't follow the shifts in the actual pulses; their beliefs about how their heart rates should be changing had a much stronger influence.

To address these limitations, scientists have been devising better study methods. Micah Allen, a neuroscientist at Aarhus University in Denmark, and his team have developed a heart-rate-discrimination task in which people are asked to report whether a series of tones is faster or slower than their current pulse, allowing researchers to quantify how sensitive an individual is to their heartbeats. Allen and his colleagues are now testing breath interoception in a similar way. Using a computer-controlled device, the researchers can make precise changes to the air resistance someone feels when they inhale through a tube. By doing so, they can quantify how well the person can detect changes in their breathing.

Using these new techniques, Allen's team has learned that an individual's interoceptive chops don't translate across all domains. In a recent preprint study of 241 people, they found that a person's ability to perceive their heart rate wasn't correlated to their performance in a breathing-resistance task.

Researchers have also been combining these behavioral tests with measurements of brain activity. One example is the heartbeat-evoked potential, a spike in brain signaling that occurs each time the heart beats. Scientists have found that changes in these signals, which can be detected with noninvasive brain-imaging techniques such as electroencephalography, are linked to accuracy in heartbeat-detection tasks and to the ability to process emotions. Similar brain signals related to organs such as the gut and those of the respiratory system have been linked to the ability to perceive sensations within those organs.

These studies indicate that interoception abilities don't align across a person's bodily functions, from breathing to heart rate to gut rhythms. It's therefore difficult to know whether the conflicting findings about the role of interoception disruptions in mental disorders mean there is no meaningful relation to be found or whether the issue is that researchers have simply not been using the right task or studying the most relevant system or level of interoception, Murphy says. "It's very unlikely that every condition will have the same bit of interoception disrupted."

Untangling how, exactly, interoception is disrupted in people with mental illness remains an active area of investigation. Some experts say answers may come from treatment trials investigating whether interventions that target disturbances in this inner sense might boost mental health. Many such studies are currently underway.

"To understand what interoception is, we need to manipulate it," Allen says. "And to understand its role as a biomarker, as something that is related to mental health, we also need to manipulate it."

Jane Green knows stressful situations can have immediate effects on her body. For Green, who has autism, reading a piece of bad news or dealing with a face-to-face confrontation may set off a chain reaction in her body: a rush of adrenaline followed by a pounding heart, bloating and itchiness, among other physical reactions.

Such responses may be linked to an inability to read one's inner body. In 2019 she took part in a clinical trial in which Critchley, Garfinkel and their colleagues sought to test just that—how resolving a discrepancy between a person's perceived interoceptive abilities and reality could improve anxiety levels in adults with autism spectrum disorder. The intervention in the study focused on tasks that involved heartbeat detection.

After training and testing 121 participants (half of whom were randomly assigned to receive a noninteroception-based control task) across six sessions, the team reported in a 2021 paper that this treatment successfully reduced anxiety in their participants and that this effect persisted for at least three months.

Participating in the trial was a "real turning point" in Green's ability to deal with anxiety, she says. "I recognize now that when I'm stressed, whether I like it or not, my body reacts," she explains. Although she still experiences physical reactions to emotionally charged situations, they are often less severe than they were prior to the treatment. And her knowledge of what's happening in her body has made it easier to cope, she adds. Green is chair and founder of SEDSConnective, a charity dedicated to neurodivergent people with connective tissue disorders such as Ehlers-Danlos syndromes. These conditions tend to overlap with anxiety disorders, and Green is now advocating for interoception-based therapies to help affected people.

> A person's interoceptive capabilities might be especially malleable during early childhood or adolescence.

For May, who participated in the flotation-REST trial, what she learned from being cut off from the external world helped her to get through an inpatient stay at an eating-disorder clinic where she was being forced to eat—and, as a result, gain weight. "You're working on the things that drove you to come in the first place, but at the same time, your distress with your body is getting worse and worse," she says. When she was in the flotation chamber, however, May's awareness of her physical body would slip away, reducing some of the negative feelings she had about herself and quieting the worries that swirled in her mind. "You can't tell where your body stops and the water begins," May says. "Because you're completely buoyant, you also have no sense of the ways that your body distresses you."

Flotation-REST shows promise: in a clinical trial of 68 people hospitalized for anorexia nervosa who were randomly assigned to the therapy or a placebo, Khalsa's team found that six months after treatment, those who received therapy reported less body dissatisfaction than those who did not. The researchers have also created a version of this therapy for anxiety and depression. In early-stage clinical trials, this intervention appeared to reduce the symptoms of those disorders. Now they are investigating whether this therapy might also benefit people with amphetamine use disorder.

Other interoception-based treatments are also under investigation. At Emory University, a group led by clinical psychologist Negar Fani has been examining the effects of combining a mindfulness-based intervention with a wearable device that delivers vibrations corresponding to a person's breaths. In a group of trauma-exposed individuals, this intervention increased the participants' confidence in their bodily signals more than the mindfulness-based intervention alone. Even long after these sessions, people report being able to recall the feeling of breath-synced vibrations, Fani says. "It helps to ground them, brings them back into the present moment. They can access their body signals and figure out what they want to do with them." The team is now conducting a follow-up study to see whether this treatment can improve mental well-being in people who have experienced trauma.

In yet another ongoing trial, Nord is collaborating with Garfinkel on a series of studies aimed at understanding in which body systems—and in which of the three dimensions (accuracy, sensibility and awareness)—interoception is altered in people with various mental disorders, among them anxiety and depression. As part of that effort, the researchers are testing interventions, including interoceptive training, mindfulness therapy—to help improve the mind-body connection—and stimulation of the insula with focused ultrasound.

Scientists still have plenty of questions to answer about interoception. One major open question is how differences in interoception arise. Some of our interoceptive abilities may begin taking shape during early infanthood. Scientists have discovered that babies as young as three months show differences in the amount of time they spend looking at colored shapes moving either in or out of sync with their heartbeats—a finding that suggests our ability to sense heart rhythms is present at this young age.

Interactions with caregivers during one's first years may play a crucial role in determining how in tune a person becomes with their body. The way a parent responds to an infant's cues about being hungry, tired or in pain, for instance, may shape how well the child is able to interpret those signals later in life. Although direct evidence for this hypothesis is still lacking, studies have shown that an individual's early caregiving environment can shape how their body responds to stress.

Other factors such as a person's sex or various environmental conditions, including adversity in early life, may also influence how interoception develops. Some research suggests that adverse experiences, especially chronic, interpersonal trauma early in life, may be key contributors. Clinicians have long observed that traumatic events can lead people to detach or "dissociate" from the body, and some researchers have proposed that this disconnect can disrupt interoceptive processes over time. For a subset of people, these alterations might be linked to an increased likelihood of self-harm and suicide: one 2020 study, for example, found that people with a history of suicide attempts and a diagnosed mental illness, such as anxiety, PTSD or depression, were worse at an interoceptive heartbeat-detection task than those who had the same ailments but had not attempted to take their own life.

A person's interoceptive abilities may change over time. Interoceptive capabilities might be especially malleable during certain life stages: periods such as early childhood, when a person is just learning how to interpret their bodily signals, or adolescence, when puberty is creating a whirlwind of physical changes. It might be one mechanism, among many, that explains why "these times tend to be risk periods for the development of mental illness," Murphy says.

The boundaries of interoception are also only beginning to be understood. In recent years some scientists have become interested in probing the links between the immune system and the brain, which are in constant conversation. An emerging body of work suggests that the brain both keeps tabs on and influences what happens in the immune system, and the immune system can in turn affect the brain. Studies have linked dysfunction in the immune system—namely, inflammation—to mental illnesses such as depression, psychosis and trauma-related disorders. The immune system may affect our mental states over much longer time scales than, say, the heart, which can influence our emotional experiences in real time.

Understanding the mysteries of interoception may lead to better therapies for illnesses of the mind—and the body. Some researchers believe that understanding interoception may ultimately be helpful for treating physical symptoms as well. Schulz and his team, for instance, are currently evaluating interoception-based treatments for chronic fatigue syndrome (also known as myalgic encephalomyelitis), a complicated disorder that causes a range of symptoms, including severe tiredness. "Interoception has so much relevance to health in general," Fani says. "We can't ignore it anymore."

IF YOU NEED HELP

If you or someone you know is struggling or having thoughts of suicide, help is available. Call or text the 988 Suicide & Crisis Lifeline at 988 or use the online Lifeline Chat at chat.988lifeline.org.

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https://www.scientificamerican.com/article/interoception-is-our-sixth-sense-and-it-may-be-key-to-mental-health

| Section menu | Main menu |

Rising Temperatures Could Trigger a Reptile Sexpocalypse

The sex of many turtles, crocodilians, and other reptiles is determined by the temperature at which their eggs incubate. Global warming could doom them

By Elizabeth Preston edited by Kate Wong

The tuatara, a reptile found only on small islands in New Zealand, is facing a dangerous combination of habitat restriction and skewed sex ratio.
Melinda Mackenzie/iStock/Getty Images Plus

Under no light but the stars, a green sea turtle hauls herself out of the surf and onto the familiar sand of Alagadi Beach on the northern coast of Cyprus. She doesn't notice any predators as she makes her way up the beach; tonight will be the night.

When the turtle reaches a satisfactory spot, she nestles into the warm sand and begins excavating a deep pit. Nothing can distract her; she's gone into a kind of trance. She pushes out 100 wet, leathery eggs into the pit. The turtle won't move until she has completed her task, even if humans creep close to measure her shell and tuck a temperature logger in among her eggs. She finishes laying in about 20 minutes, but her work isn't done. Still focused, she spends another few hours laboriously scooping the sand over her eggs. Then she turns around and crawls back into the ocean.

In about two months her babies will emerge from that sand and make a mad dash to the water. They'll have to fend for themselves—their mother is done caring for them. She'll never know the curious fate that befalls her offspring: nearly all of the hatchlings will be female.

Many reptiles differ from typical vertebrates in that their sex is not determined by their genes. They lack sex chromosomes such as the X and Y inside human cells. Instead the temperature of their nest pushes them toward becoming male or female.

For green sea turtles, if the temperature is about 29 degrees Celsius (84 degrees Fahrenheit) during a critical mid-incubation window, the babies will hatch as a half-and-half mix of females and males. But the hotter the nest, the more they will skew female. In the dark sand of Alagadi Beach, the eggs incubate at a toasty 33 or 34 degrees C, resulting in broods that are overwhelmingly female.

The reptiles that have temperature-dependent sex determination—most turtles, as well as all crocodilians (crocodiles, alligators and their kin), some lizards, and a unique creature from New Zealand called the tuatara—belong to lineages that have survived Earth's climatic ups and downs for millions or even hundreds of millions of years. Yet the present day brings a confluence of problems they haven't ever encountered in their long history, including anthropogenic habitat loss and a planetary thermostat gone haywire.

> How in the world reptile biology came to rely on temperature to decide the sex of babies is largely a mystery.

Global warming will affect various kinds of reptiles in different ways. Whereas hotter temperatures turn developing turtles female, they have the opposite effect on crocodilians, producing more male hatchlings. Scientists have predicted nearly single-sex generations of alligators by the year 2100.

If rising temperatures mean entire generations of sexually reproducing reptiles will be dramatically skewed male or female, it’s not hard to see how they could doom species: mating opportunities will decline; populations might become inbred. Surviving members of a species that’s already dwindling from other pressures might not be able to find a partner with whom to make babies. Some species seem to be adapting to the shifting conditions by altering their nesting behaviors. But as climate change accelerates, their continued survival may depend on whether they can keep up.

Temperature-based sex determination is an admittedly strange phenomenon—one that scientists have struggled to explain. Consider the American alligator. Around the summer solstice the alligator mother shoves vegetation from her wetland habitat into a pile to create a nest. She then deposits her eggs in this “glorified compost heap,” as Benjamin Parrott, an ecologist at the University of Georgia, calls it. The eggs are warmed by the slowly decomposing pile. If they incubate at a little below 32 degrees C, they’ll hatch as an even mix of males and females. If they incubate above this so-called pivotal temperature, more hatchlings will be male, although if the temperature gets hot enough, the ratio will skew back toward females. “A couple of degrees Celsius makes all the difference,” Parrott says.

How in the world reptile biology came to rely on temperature to decide the sex of babies is largely a mystery. Some of Parrott’s research suggests that this type of system can evolve in a species if one sex survives better at warmer temperatures. Sex determination based on temperature has evolved in some fishes, too.

It makes sense for parents to use information about their environment to give their kids an edge. But unlike, for example, the Atlantic silverside—a fish with temperature-based sex determination whose offspring grow up within a year—reptiles such as alligators and turtles mature very slowly. American alligators in South Carolina, for instance, won't start laying eggs until they are 16 years old. Sea turtles might take as long as 40 years to mature. Why should one warm summer dictate the fate of your offspring when they'll need to survive another 16 summers or more before they reproduce? "It's hard to wrap your head around," says Rachel Bowden, an ecological physiologist at Illinois State University who studies freshwater turtles.

Nor do researchers understand why incubating eggs at their pivotal temperature produces a mix of males and females, because all the eggs have experienced the same conditions. Bowden is investigating the hormones and other molecules that might turn differences of a few degrees into ovaries or testes.

Newly hatched green sea turtles climb across the sand at Alagadi Beach on the island of Cyprus. The high temperatures of the turtle nests there produce broods that are almost entirely female.
Laura Boushnak/AFP via Getty Images

Further complicating the research is the fact that even experts can't always tell whether a baby gator or turtle is a girl or boy. "There's no easy way to sex them," Parrott says. An alligator's external genitalia won’t start to look distinctive for about six months. In the laboratory, scientists have euthanized hatchlings and examined them internally to learn that certain steady incubation temperatures produce certain ratios of males to females. But they usually have to estimate the sex ratios of hatchlings that emerge from nests in the wild under naturally fluctuating temperatures.

Sex determination is even more complex in lizards. Among the several thousand lizard species on Earth, some have temperature-dependent sex determination, whereas others rely on genes. But even in species with sex chromosomes, temperature can influence whether offspring develop into males or females. In the snow skink, a little copper-colored lizard that lives in Tasmania and bears live young, populations that dwell at high altitude have genetically determined sex, whereas low-altitude populations depend on temperature. In the central bearded dragon, native to Australia, warm temperatures can turn chromosomally male lizards into females.

Against this backdrop of unknowns, researchers are racing to learn just how flexible reptiles can be in their nesting habits. During their many millions of years on Earth, reptiles have survived dramatic climate shifts, living through ice ages and intense heat. Alligators and their relatives, for example, managed at least in part by migrating to more favorable climes: The fossil record shows that they moved toward the equator when it was cooler and toward the poles when things heated up. At one point, crocodilians lived in Alaska. But in our human-dominated world, Parrot says, migration might not be a feasible solution. “I don’t think people in D.C. are going to tolerate gators in the Potomac,” he says.

In theory, today’s reptiles might be able to keep their eggs cool and their sex ratios steady by nesting earlier in the year or in shadier places or by digging deeper in the ground. But that would depend on the animals perceiving the temperature shift—and having the capacity to do things differently.

During the summer nesting season, Sophie Davey becomes nocturnal. She leads the sea turtle monitoring project for the Society for the Protection of Turtles. Nearly every night of the week, she goes to Alagadi Beach at about 7:30 in the evening. Every 10 minutes a team member will walk up and down this beach to check for laying turtles. Both loggerheads and green sea turtles nest here, and this past summer “they’ve been coming thick and fast,” Davey says, especially the greens.

To avoid disturbing the nesting mothers, the team members do as much as they can in the dark. They use a red light if they need it for something like entering data in a form. Otherwise they have learned to rely on their other senses.

The scent of freshly dug sand is often their first clue that a green sea turtle has arrived. “As soon as that wind hits you and you smell earth, it’s like, okay, there’s a turtle on the beach somewhere,” Davey says. In contrast, loggerheads, with algae and barnacles clinging to their shells, have a seaweedy smell.

Sounds offer more hints to what’s happening in the dark. Fat plops of sand hitting the beach mean a turtle is using her big front flippers to carve out a depression for her body, whereas more delicate scoops indicate she’s using her flexible back flippers to dig the egg chamber.

During the turtles’ nesting rituals, the team members gather data. They measure the animals, give them identification tags and microchips, and take tissue samples that let them study genetics as well as where the turtles have been living and what they eat at sea. Afterward the workers cage the nest to keep predators away.

As part of its mission, the project is helping to answer questions about how turtles might adapt as the world gets hotter. Since the 1990s green sea turtles have been laying their first nests at Alagadi Beach almost one day earlier each year. Marine conservation biologist Annette Broderick of the University of Exeter in England, who is one of the scientific advisers of the turtle-monitoring project in Cyprus, says the older and more experienced females, who lay multiple clutches in a nesting season, are driving the trend. Nests that are laid earlier stay cooler throughout their incubation. Loggerheads exhibit a similar trend, with experienced loggerhead moms arriving about half a day earlier each year.

In other words, the sea turtles seem to be adjusting their habits in response to warming. “But that can happen only to a point,” Broderick says. The seagrass that the turtles eat, hundreds of kilometers away, may not be available early enough in the year for them to fill up on before heading to the nesting beach.

The nesting beaches themselves may pose their own constraints. Even though the mothers who nest at Alagadi Beach are arriving earlier and earlier, their offspring continue to be almost all females. With its dark, hot sand (and, Davey points out, a constant influx of potentially heat-retaining plastic trash), Alagadi Beach just might not be able to maintain temperatures cool enough to produce males no matter how early the mothers arrive to lay their eggs. Elsewhere on Cyprus there are cleaner beaches with deep, white sand, where a few more males might hatch. Still, all the island’s beaches skew highly female.

In any case, a 50–50 ratio of females to males in a brood isn’t necessarily the goal. Sea turtles seem to naturally have female-biased nests, Broderick says. Things may balance out because a female will lay eggs only every two to four years, whereas a male can mate every year. In the near term, then, temperatures that produce extra females could actually help sea turtle populations grow.

Baby American alligators bask in Florida’s Big Cypress National Preserve. Scientists have predicted that entire generations of alligators could be nearly single-sex by 2100.
Troy Harrison/Getty Images

“Undoubtedly, there will be some positive effects,” Broderick says. “But there will also be some negatives.” Besides producing more female turtles, warm temperatures tend to make reptiles grow faster—so those females might be ready to reproduce sooner. But hot enough nesting temperatures, in addition to leaving those females with almost no potential mates, could make entire clutches fail to hatch.

Ocean-dwelling turtles aren’t the only ones changing their habits as the climate warms. Freshwater turtle mothers seem to be adapting their behavior, too. Populations of several different North American turtles have shifted their nesting earlier in recent decades. Slider turtles in Illinois nest more than three weeks earlier in the spring than they did in the 1990s.

In one study, Jeanine Refsnider, an evolutionary ecologist at the University of Toledo, brought wild painted turtles from New Mexico, Illinois, Nebraska, Iowa and Washington State to research ponds in Iowa. All of the turtles were pregnant females. They could have sought the ideal nesting conditions for their home climates: females from hot New Mexico choosing shade, those from chilly Washington looking for relatively warm spots, and so on. Yet in Iowa everyone acted the same. The mothers chose similarly shady conditions to build their nests, and their offspring hatched with essentially the same sex ratios.

“They do seem to adjust their nesting behavior quite quickly in response to the current conditions they find themselves in,” Refsnider says. She notes, however, that “if they don’t have the habitat availability to express that kind of innate flexibility, then they’re in trouble.” In other words, it’s not enough for turtle moms to be perceptive and flexible; they also need better options for nesting.

Refsnider is now studying the nesting habits of endangered spotted turtles, which live in swamps and nest in damp, mossy mounds or rotten logs. If researchers can understand turtles’ preferences about nesting conditions, then humans can try to manage habitats to help the turtles: adding shade cover, for instance, or hauling in rotting logs so the turtles can maintain a healthy sex ratio as the climate warms. “I don’t think it’s hopeless,” Refsnider says of the fate of turtle populations on a warming planet. “But it is concerning.”

The situation is more acute for species that are also facing pressure on other fronts. The tuatara is a charismatic medium-size reptile with a Muppet-like face and a row of spines running down its back. It looks a lot like its closest living relatives, the lizards. But it’s actually the lone survivor of a separate order of vertebrates that split off from the lizards around 250 million years ago, before mammals had evolved from our reptilian ancestors, the therapsids.

Lately its survival hasn’t been easy. Predators introduced by waves of human settlers have eliminated tuatara in much of their original habitat, which once spanned all of mainland New Zealand. Today they live only on about 32 small islands, and climate change is threatening those scattered survivors. Tuatara share the sex-determination pattern of the crocodilians in that warmer temperatures create males, although unlike in crocodilians, no one has found an incubation temperature warm enough to shift the sex ratio of the developing tuatara young back toward female. Predicting how climate change will affect adult tuatara sex ratios is difficult because the reptiles mature so slowly, explains Alison Cree, an emeritus professor at the University of Otago in New Zealand, who has studied the biology and ecology of tuatara. Their eggs may stay in the ground for a year or longer. The adults don’t reproduce until age 13 or so.

But because the remaining tuatara populations all live on islands, it’s clear that their options for shifting their habitat or habits are limited. On a tiny, treeless bit of land called North Brother Island, the population is becoming increasingly male. Researchers warn that the combination of habitat restriction and skewed sex ratio is setting up the North Brother Island tuatara for a downward spiral known as an extinction vortex that will be very difficult, if not impossible, to escape.

It doesn’t help that tuatara tend to return to the same nesting sites they’ve used before—that behavior is ingrained. But they may be more flexible when it comes to timing. A study at another site, on Stephens Island, found that tuatara nested earlier in years with warmer springs. That shift could help keep their eggs cooler, as it does for turtles. The authors of that study predicted that at least in the medium term, the reptiles could keep their female-to-male ratios steady.

If tuatara sex ratios reach a crisis, Cree suspects it will be a symptom of a larger emergency that's already underway. Once temperatures have climbed high enough to turn most tuatara male, the creatures will also be facing drought, flooding, and a rising sea eating away at their islands.

In that case, we will be losing far more than a charismatic species. Tuatara play significant roles in their ecosystems, Cree explains. If they went extinct, their unique quarter-billion-year-old lineage would disappear, too. "From a perspective of studying reptile evolution, that's a huge loss," she says. Tuatara are also culturally significant to the Maori, the Indigenous people of New Zealand. Commonly featured in Maori stories, tuatara may signify knowledge or warn of a coming calamity.

Still, next spring the tuatara will do what they always do. The pregnant females will gather in open, sunny areas. Each expectant mother in the shared rookery will use her strong limbs and claws to dig a burrow for her eggs, working across several nights. She'll lay a small clutch, only about 10 eggs. She'll cover her burrow with dirt and vegetation until it's undetectable. For another two weeks or so, the tuatara mother will stay and guard her nest. Then she'll walk away, having done everything she can.

Elizabeth Preston is a freelance science journalist and editor. Her book *The Creatures' Guide to Caring* will be published by Viking in May 2026.

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https://www.scientificamerican.com/article/global-warming-could-skew-reptile-sex-ratios-and-lead-to-extinctions

Heart and Kidney Diseases and Type 2 Diabetes May Be One Ailment

These three disorders could really be “CKM syndrome,” which can be treated with drugs like Ozempic

By Jyoti Madhusoodanan edited by Josh Fischman

Jennifer N. R. Smith

Amy Bies was recovering in the hospital from injuries inflicted during a car accident in May 2007 when routine laboratory tests showed that her blood glucose and cholesterol were both dangerously high. Doctors ultimately sent her home with prescriptions for two standard drugs, metformin for what turned out to be type 2 diabetes and a statin to control her cholesterol levels and the heart disease risk they posed.

The combo, however, didn’t prevent a heart attack in 2013. And by 2019 she was on 12 different prescriptions to manage her continued high cholesterol and her diabetes and to reduce her heart risk. The resulting cocktail left her feeling so terrible that she considered going on medical leave from work. “I couldn’t even get through my day. I was so nauseated,” she said. “I would come out to my car in my lunch hour and pray that I could just not do this anymore.”

Medical researchers now think Bies’s conditions were not unfortunate co-occurrences. Rather they stem from the same biological mechanisms. The medical problem frequently begins in fat cells and ends in a dangerous cycle that damages seemingly unrelated organs and body systems: the heart and blood vessels, the kidneys, and insulin regulation and the pancreas. Harm to one organ creates ailments that assault the other two, prompting further illnesses that circle back to damage the original body part.

Diseases of these three organs and systems are “tremendously interrelated,” says Chiadi Ndumele, a preventive cardiologist at Johns Hopkins University. The ties are so strong that in 2023 the American Heart Association grouped the conditions under one name: cardio-kidney-metabolic syndrome (CKM), with “metabolic syndrome” referring to diabetes and obesity.

The good news, says Ndumele, who led the heart association group that developed the CKM framework, is that CKM can be treated with new drugs. The wildly popular GLP-1 receptor agonists, such as Wegovy, Ozempic and Mounjaro, target common pathology underlying CKM. “The thing that has really moved the needle the most has been the advances in treatment,” says Sadiya Khan, a preventive cardiologist at Northwestern University. Although most of these drugs come only in injectable forms that can cost several hundred dollars a week, pill versions of some medications are up for approval, and people on Medicare could pay just $50 a month for them under a new White House pricing proposal. The appearance of these drugs on the scene is fortunate because researchers estimate that 90 percent of Americans have at least one risk factor for the syndrome.

More than a century before Bies entered the hospital, doctors had noticed that many of the conditions CKM syndrome comprises often occur together. They referred to the ensemble by terms such as “syndrome X.” People with diabetes, for instance, are two to four times more likely to develop heart disease than those without diabetes. Heart disease causes 40 to 50 percent of all deaths in people with advanced chronic kidney disease. And diabetes is one of the strongest risk factors for developing kidney conditions.

> At present, around 59 million adults worldwide have diabetes, about 64 million are diagnosed with heart failure, and approximately 700 million live with chronic kidney disease.

The first inkling of a connection among these disparate conditions came as far back as 1923, when several lines of research started to spot links among high blood sugar, high blood pressure and high levels of uric acid—a sign of kidney disease and gout.

Then, several decades ago, researchers identified the first step in these tangled disease pathways: dysfunction in fat cells. Until the 1940s, scientists thought fat cells were simply a stash for excess energy. The 1994 discovery of leptin, a hormone secreted by fat cells, showed researchers a profound way that fat could communicate with and affect different body parts.

Since then, researchers have learned that certain kinds of fat cells release a medley of inflammatory and oxidative compounds that can damage the heart, kidneys, muscles, and other organs. The inflammation they cause impairs cells’ ability to respond to the pancreatic hormone insulin, which helps cells absorb sugars to fuel their activities. In addition to depriving cells of their primary energy source, insulin resistance causes glucose to build up in the blood—the telltale symptom of diabetes—further harming blood vessels and the organs they support. The compounds also reduce the ability of kidneys to filter toxins from the blood.

Jennifer N. R. Smith

Insulin resistance and persistently high levels of glucose trigger a further cascade of events. Too much glucose harms mitochondria—tiny energy producers within cells—and nudges them to make unstable molecules known as reactive oxygen species that disrupt the functions of different enzymes and proteins. This process wrecks kidney and heart tissue, causing the heart to enlarge and blood vessels to become stiffer, impeding circulation and setting the stage for clots. Diabetes reduces levels of stem cells that help to fix this damage. High glucose levels also prod the kidneys to release more of the hormone renin, which sets off a hormonal cascade critical to controlling blood pressure and maintaining healthy electrolyte levels.

At the same time, cells that are resistant to insulin shift to digesting stored fats. This metabolic move releases other chemicals that cause lipid molecules such as cholesterol to clog blood vessels. The constriction leads to spikes in blood pressure and heightens a diabetic person's risk of heart disease.

The circular connections wind even tighter. Just as diabetes can lead to heart and kidney conditions, illnesses of those organs can increase a person's risk of developing diabetes. Disruption of the kidneys' renin-angiotensin system—named for the hormones involved, which regulate blood pressure—also interferes with insulin signaling. Adrenomedullin, a hormone that increases during obesity, can also block insulin signaling in the cells that line blood vessels and the heart in humans and mice. Early signs of heart disease such as constricted blood vessels can exhaust kidney cells, which rely on a strong circulatory system to filter waste effectively.

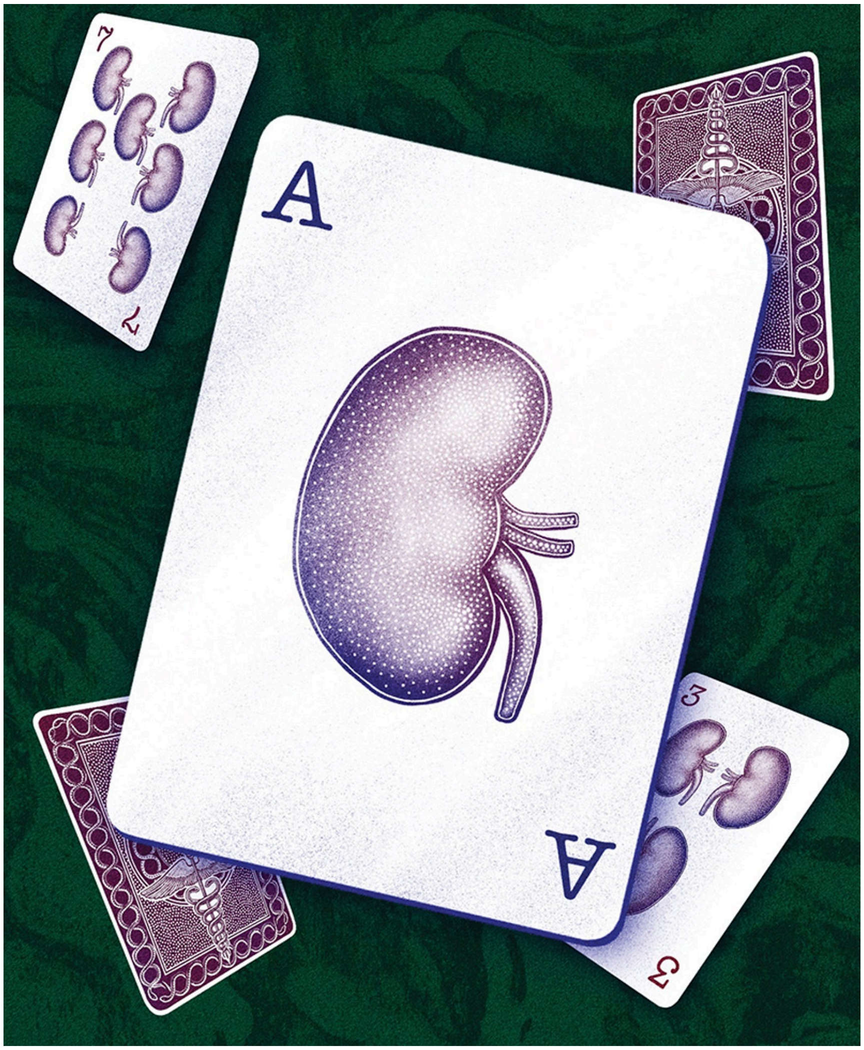
The year before Bies's car accident, when she was in her early 30s, her primary care doctor diagnosed her with prediabetes—part of metabolic syndrome—and recommended changes such as a healthier diet and more exercise. But at the time, the physician didn't mention that this illness also increased her risk of heart disease.

Not seeing these connections creates dangers for patients like Bies. "What we've done to date is really look individually across one or two organs to see abnormalities," says nephrologist Nisha Bansal of the University of Washington. And those narrow views have led doctors to treat the different elements of CKM as separate, isolated problems.

For instance, doctors have often used clinical algorithms to figure out a patient's risk of heart failure. But in a 2022 study, Bansal and her colleagues found that one common version of this tool does not work as well in people with kidney disease. As a result, those who had kidney disease—who are twice as likely to develop heart disease as are people with healthy kidneys—were less likely to be diagnosed and treated in a timely manner than those without kidney ailments.

In another study, researchers found that among people with type 2 diabetes—one in three of whom are likely to develop chronic kidney disease—fewer than one quarter were receiving the kidney disease screening recommended by the American Diabetes Association and KDIGO, a nonprofit group that provides guidelines for global improvements in kidney health.

At present, around 59 million adults worldwide have diabetes, about 64 million are diagnosed with heart failure, and approximately 700 million live with chronic kidney disease. Collectively, these illnesses are the leading cause of death in dozens of countries; the evidence for CKM indicates that the several epidemics may in fact be one.



Jennifer N. R. Smith

One of the first pushes for treating these diseases together came in the late 2000s. That’s when Cleveland Clinic cardiologist Steven Nissen was scouring a database from a pharmaceutical company that listed its drug tests, in search of clinical trials of a diabetes drug named rosiglitazone. Across 42 trials, Nissen found, the data revealed a clear increase in heart attacks with the use of the drug. If the drug reduced diabetes, accompanying heart trouble should have gone down, not up, he thought.

A Senate investigation followed this vein of evidence and led to a 2007 advisory panel convened by the U.S. Food and Drug Administration. The discussions brought about a transformational change in how diabetes drugs were approved: It was no longer enough to simply show an improvement in blood glucose. Pharmaceutical companies would also need to demonstrate that the drugs were not linked to increased chances of developing heart health issues. Clinical trials to test the drugs would need to include people at high risk of heart or blood vessel diseases, including older adults.

Nissen recalls immense opposition to the idea and concern that the bar had been set too high. Those fears were not unfounded—many large pharmaceutical companies "abandoned the search for diabetes drugs" because the trials would take longer to complete and cost more, according to endocrinologist Daniel Drucker of the Lunenfeld-Tanenbaum Research Institute in Toronto. "The pharma industry was 100 percent worried about this," Drucker says.

Drucker, who at the time was studying a promising new group of drugs for diabetes, was concerned about the extra time and expense, too. But in preliminary experiments, the scrutiny for additional conditions began to pay off. In 2008, at about the same time the fda updated its guidance on diabetes drugs, Drucker and other researchers discovered that the new molecules they were investigating seemed to protect mice and rats from heart disease.

> "There's not going to be a one-size-fits-all approach to all of this." —Nisha Bansal, *nephrologist*

The new drugs mimicked a small protein named GLP-1, which normally regulates blood sugar and digestion. Small studies suggested it had wider benefits and might protect heart function in people who were hospitalized after a heart attack and angioplasty. At the time, these GLP-1 mimics were being used only as diabetes treatments. But studies in animals suggested they could do more, and subsequent trials in people showed the drugs also protected heart and kidney function. "We might not have discovered these actions of GLP-1 for some time if we hadn't been directed by the fda to really study this," Drucker says. "In hindsight, it worked out very well."

The regulations ended up leading to very successful multifaceted drugs. In 2013, the year that Bies had her heart attack, the fda approved the first of a group of medications that act to block a receptor known as SGLT2 in the kidneys. These so-called SGLT2 inhibitors are “almost a wonder drug,” says nephrologist Dominic Raj of George Washington University.

In a series of stunning, large trials, researchers established that these drugs lowered blood glucose, delayed the worsening of kidney disease, and were strongly correlated with reduced risk of several cardiac conditions. These studies also confirmed that cardiac, kidney and metabolic diseases are “more closely linked than we anticipated,” Bansal says. “The SGLT2 trials were really a landmark in this.”

GLP-1-mimicking drugs such as Wegovy have been similar changemakers. A clinical trial of GLP-1 medications was stopped early because the benefits were so overwhelming that it was unethical to continue giving a placebo to patients in a comparison group. In 2024 researchers compared one drug with a placebo in more than 3,500 participants with type 2 diabetes and chronic kidney disease. But instead of looking only at diabetes improvement, they examined kidney and heart conditions as well. The scientists found an 18 to 20 percent lower risk of death in those treated with the GLP-1 drug.

Although the GLP-1 medicines do have side effects (nausea and vomiting are some), within a few short years clinicians found that they had therapies that were designed to protect one organ but also treated others. “Now we have excellent evidence to say that not only will you have better control of your diabetes, and not only will these medicines help you lose weight, but they will prevent or attenuate the risk of developing serious heart disease and serious kidney disease,” Drucker says.

Jennifer N. R. Smith

Bies’s physician prescribed her the GLP-1 receptor agonist drug Ozempic in 2024. Two months after she began the treatment, her blood glucose levels dipped below the diabetic range. Her heart is healthier, too. Doctors are “very happy with where my numbers are,” she says. And with fewer drugs in her system, Bies feels much better overall.

Not everyone is convinced that the CKM syndrome framework is necessary. Nissen, for one, says it is “a rebranding of a very old concept.” The symptoms and health risks linked to CKM overlap significantly with those of metabolic syndrome, an older term used to describe a similar constellation of health risks, he says.

Ndumele, however, disagrees with that characterization. “Although they are clearly related, CKM syndrome and metabolic syndrome have some very important differences," he says. For one, the CKM framework encompasses more disease states. And clinicians can use the concept to identify different stages of risk: very early warning signs followed by clinical conditions—including but not limited to metabolic syndrome—and ultimately late stages of CKM, which include full-blown heart and kidney disease. "This is meant to better support prevention across the life course," Ndumele says. Ongoing studies are testing new ways to identify those at risk of CKM early on and help with preventive care.

Patients such as Bies agree that combining care for the diseases that make up CKM could save lives. For decades she and countless other patients have struggled to manage different aspects of their health. Bies remembers that although all her doctors were affiliated with the same hospital, they didn't communicate with one another or see others' notes about her prescriptions.

A few years ago Bies joined an American Heart Association advisory committee on CKM to inform clinicians and advocate for others who deal with this complex illness, in hopes that speaking up about her own traumatic journey might help others so that "somebody else won't have to wait 10 to 12 years to advocate for themselves," she says.

At the University of Washington, Bansal and her colleagues are testing an integrated care model in which patients meet with multiple specialists at the same time to chart out their care. It is, she says, a work in progress. "How do we actually improve the rates of screening and disease recognition and get more people who are eligible on therapies to treat CKM disease?" Bansal says. "Although there have been a lot of exciting advances, we're only at the beginning. Integrating care is always a challenge."

Such integrations are critical to help with early diagnosis—a crucial step in squelching the rise of CKM around the world, according to Ndumele. In the future, even more specialties may need to coordinate. New research already hints at the involvement of other organs and organ systems. Cardiologist Faiez Zannad of the University of Lorraine in France suspects that as researchers glean a clearer picture, CKM syndrome will further expand to include liver disease. Zannad is investigating liver damage in heart patients because it is another common fallout of the same disease mechanisms.

Researchers and patients caution, however, that the move to group different diseases into CKM should not hinder efforts to understand each condition. Each person's course of disease—their initial diagnosis, the complications they are at greatest risk of developing and how best to treat them—can vary. "It's a very broad syndrome, and there will be nuances in terms of understanding subgroups, what the mechanisms are, and how we diagnose and treat patients," Bansal says. "There's not going to be a one-size-fits-all approach to all of this."

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https://www.scientificamerican.com/article/heart-and-kidney-diseases-plus-type-2-diabetes-may-be-one-illness-treatable

Animals

- **How Animals Form Unlikely Alliances to Keep Predators Away**
  Cross-species “defense pacts” help animals keep tabs on parasites and predators
- **This Bat Recorded Itself Catching and Eating a Songbird in Midair**
  Scientists suspected that Europe’s largest bats snack on migrating songbirds when they can, but a stunning newly published observation proves it
- **Chimpanzee Metacognition Allows Humanlike Belief Revision**
  Are we the only rational thinkers? New research on our primate cousins suggests otherwise
- **Static Electricity Helps Parasitic Nematodes Leap onto Insects**
  For microscopic worms, physical laws we seldom notice take on life-or-death importance

How Animals Form Unlikely Alliances to Keep Predators Away

Cross-species "defense pacts" help animals keep tabs on parasites and predators

By Jesse Greenspan edited by Sarah Lewin Frasier

Parasitic cuckoos are many birds' common enemy.
Bebedi/Getty Images

When danger approaches, many creatures seem to follow the ancient proverb that "the enemy of my enemy is my friend." Researchers have recently been finding subtle ways that animals communicate with other species in this kind of cooperative defense pact.

For example, a recent study in *Nature Ecology & Evolution* documented more than 20 bird species on four continents that emit virtually identical "whining" calls when they spot brood parasites such as cuckoos. That call is essentially "the word for 'cuckoo,'" says study co-lead author James Kennerley, an ornithologist at Cornell University. "And it's recruiting individuals to come together [against] this common enemy."

Brood parasites lay eggs in other birds' nests, manipulating the host parents into raising their chicks for them. At a field site in Australia, Kennerley has witnessed individuals from a dozen or more species mob a cuckoo in response to a chorus of whining calls. These mobs can be so ferocious that Kennerley and his colleagues need to cage the taxidermy cuckoo used in their experiments to protect it. Otherwise the attacking birds would have "just completely shredded it to pieces," Kennerley says.

Many birds also share a common vocabulary for predators. Research by wildlife ecologist Erick Greene, an emeritus professor at the University of Montana, and others shows that various songbirds—and even red squirrels—produce recognizable "seet" calls to warn of a raptor in flight. The calls are too high-pitched for raptors to hear well, so the predators remain oblivious as info about their arrival shoots through the forest. If the raptor perches, songbirds switch to "mobbing" calls, a distinct vocalization that, as Greene puts it, "draws in the troops [to] drive that raptor out of Dodge."

Monkeys, lemurs and chipmunks also recognize other species' alarm calls. And in coral reefs, unrelated fish seem to swap visual and chemical cues as protection against dangers such as hungry barracudas. But cooperative defense is not the only reason for cross-species communication. Among other things, it may help birds migrate and enhance food intake among mixed-species monkey troops and dolphin pods. A recent study in the *Proceedings of the National Academy of Sciences USA* found that when seabirds with good vision, such as black-browed albatrosses, forage with seabirds with strong senses of smell, such as white-chinned petrels, they both have far greater success at catching krill. Unlike with the seet and whining calls, however, it's unclear whether they're deliberately signaling to one another or "just randomly following other birds," says study lead author Jesse Granger, an organismal biophysicist at Duke University.

But clearly, “very complex multispecies communication networks are pervasive,” Greene says. “It really behooves [animals] to pay attention to one another,” he adds. “It can save their lives.”

Jesse Greenspan is a San Francisco Bay Area–based freelance journalist who writes about history and the environment.

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https://www.scientificamerican.com/article/how-animals-form-unlikely-alliances-to-keep-predators-away

This Bat Recorded Itself Catching and Eating a Songbird in Midair

Scientists suspected that Europe's largest bats snack on migrating songbirds when they can, but a stunning newly published observation proves it

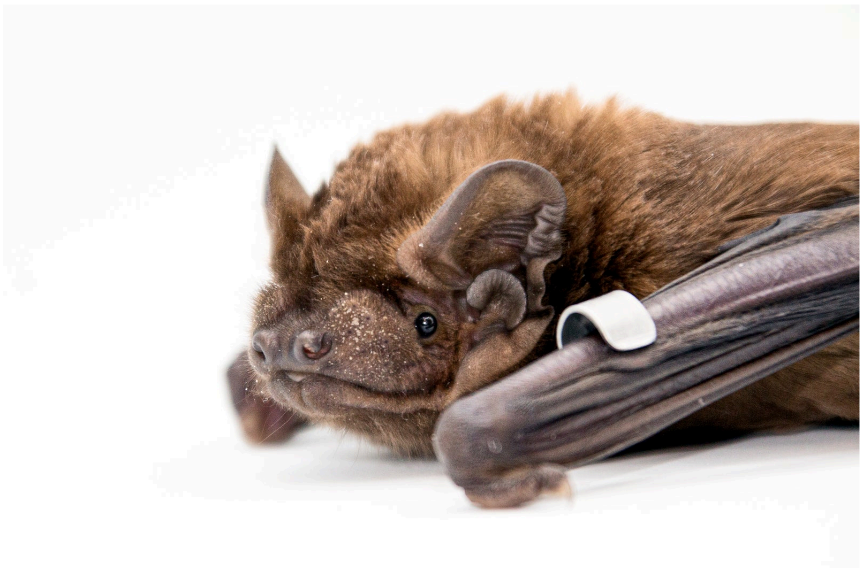
By Meghan Bartels edited by Andrea Thompson & Sarah Lewin Frasier

A greater noctule is caught with a feather in its mouth.
Jorge Sereno

For the nearly three-year-old female bat soaring into the Spanish sky in March 2023, it was just another night of striving to feed itself. But the bat's overnight exploits were about to become the stuff that scientists' dreams are made of.

The greater noctule bat (*Nyctalus lasiopterus*) wore a high-tech tag recording its behavior. From that recording, researchers reconstructed a dramatic, and scientifically valuable, exploit: the bat pursued, killed and proceeded to eat a migrating European robin (*Erithacus rubecula*) in midair while echolocating to navigate.

“There was this crazy noise and movement and a lot of echolocation, and I thought, ‘I’ve never heard this before on any recording,’” says Laura Stidsholt, a biologist at Aarhus University in Denmark and co-author of a paper about the observation, recently published in *Science*. “It was quite magical.”



Elena Tena

Greater noctules are among the largest and most endangered bats in Europe. Their usual fare is substantial insects such as beetles and moths. But in previous work, scientists analyzing the DNA in bat poop had been surprised to find evidence of greater noctules feasting on songbirds, too, during spring and fall migrations, when the birds are active at night rather than during the day.

The bats are typically difficult to study. But scientists at Doñana Biological Station, an outpost of the Spanish National Research Council, microchipped local individuals and outfitted 14 of them with cutting-edge recording tags that captured altitude, movement and sound over two spring seasons, gathering incredible reports of the furry mammals’ adventures. “It’s like flying with the greater noctule bat,” says Elena Tena, a conservation biologist at Doñana Biological Station and co-author on the study.


A great noctule bat equipped with a small device recording sound, altitude and movement.
Elena Tena

The researchers reconstructed quite a flight from that startling recording: The female bat soared to an altitude of three quarters of a mile, searching for prey. Then it apparently locked in on a migrating songbird, made contact and dove steeply, emitting echolocation calls amid the sounds of an ongoing tussle between the two animals. As the bat approached the ground, the bird let out a string of panicked cheeps before ominously falling silent.

And then—for an incredible 23 minutes—the bat's echolocation squeaks were punctuated by chewing and crunching even as the bat kept flying. "They're basically screaming with their mouths full," Stidsholt says, noting that proportional to the bat's body size, the species' calls are among the loudest noises known to scientists.

The researchers compared the bird's distress calls with existing songbird recordings gathered by other scientists whose work requires catching the birds in nearly invisible "mist nets." The cries from the unlucky bird on the bat's recording matched those of the European robin.

The researchers also gathered torn-off bird wings found on the ground in known greater noctule hunting areas. DNA testing confirmed the presence of saliva from these bats on the wings—

supporting scientific hypotheses that the animals bite off and discard the wings after killing a songbird as they do with insects, most likely to reduce the weight they carry while snacking.

Elena Tena

This aspect of the finding is particularly interesting to University of Wyoming bat biologist Riley Bernard, who was not involved in the study. Although the bats eat primarily insects, “they have this behavioral plasticity to be able to tap into resources when they’re available,” she says. Bernard admits to some envy of the European researchers, noting that North America’s bats are all much smaller than the greater noctule—too small to carry the tags used in this experiment.

Danilo Russo, an ecologist at the University of Naples Federico II in Italy who was also not involved in the study, would love to fit a small bat with this type of technology. “Now we have this amazing means of penetrating the darkness and their hidden world,” he says. “I think it would be a complete game changer, just like in this case.”

Meghan Bartels is a science journalist based in New York City. She joined *Scientific American* in 2023 and is now a senior reporter there. Previously, she spent more than four years as a writer and editor at Space.com, as well as nearly a year as a science reporter at *Newsweek*, where she focused on space and Earth science. Her writing has also appeared in *Audubon*, *Nautilus*, *Astronomy* and *Smithsonian*, among other publications. She attended Georgetown University and earned a master’s

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https://www.scientificamerican.com/article/this-bat-recorded-itself-catching-and-eating-a-songbird-in-midair

Chimps Can Weigh Evidence and Update Their Beliefs Like Humans Do

Are we the only rational thinkers? New research on our primate cousins suggests otherwise

By Cody Cottier edited by Sarah Lewin Frasier

Chimpanzees show the capacity to revise their beliefs when presented with new evidence. Innocent Ampeire/Ngamba Island Chimpanzee Sanctuary

You generally have reasons, good or bad, for your beliefs. You can reflect on those reasons: “Why do I think there’s a serial killer in the attic? It’s because the floor creaked.” And, paragon of rationality that you are, you can also adjust your beliefs when additional evidence demands it: “Having scoured the attic, baseball bat in hand, I must conclude that it’s just an old, creaky house.”

This cognitive skill is known as belief revision. It’s long been considered a hallmark of human rationality that distinguishes us from other animals. It relies on a reflective awareness of our own thought processes—thinking *about* thinking, or metacognition—

that other species don't obviously possess. But a recent study in *Science* shows that one of our closest evolutionary relatives also reasons in surprisingly sophisticated ways.

In a series of experiments, researchers tested chimpanzees at the Ngamba Island Chimpanzee Sanctuary in Uganda to see how the animals juggled different sources of evidence. Each experiment revolved around food hidden in one of several boxes: The chimps would pick the box they thought was most promising based on an initial clue. Then they'd get another clue that sometimes conflicted with the first. Given the chance to update their decision, they almost always chose the box predicted by a rational-choice model and changed their mind only when the new information was stronger than what they already knew. "The chimps knocked it out of the park," says Brian Hare, an evolutionary anthropologist at Duke University, who was not involved in the study. "It's obvious this is so easy for them."

Most impressive, the animals even accounted for clues that undermined earlier evidence. If they heard something bouncing around inside box 1, given previous experience they would assume at first that it was an apple—but then the experimenter would pull out a stone. Realizing they had been misled, the chimps would immediately opt for box 2 even though it had appeared uninspiring a moment before. "None of us thought they could do it because it's just so complex," says study co-author Jan Engelmann, a comparative psychologist at the University of California, Berkeley.

Of course, lots of animals obey reason without reflecting on it; an amoeba is acting rationally, in some sense, when it follows chemical signals toward food. This "unreflective responsiveness to evidence," as it's been called, is a mere shadow of human rationality. But Engelmann argues that chimpanzees' ability to scrutinize evidence and gauge the certainty of their own knowledge comes much closer to the real thing. "It's very hard to explain the chimps' behavior without appealing to some notion of reflection," he says.

Christopher Krupenye, who studies animal cognition at Johns Hopkins University and was not involved in the study, agrees. He's agnostic about the content of that reflection—without language, it's unclear how animals could mentally represent the propositions that make up human beliefs ("I hear rattling, so there's probably an apple in the box"). It's possible the chimps think primarily in pictures. Regardless, Krupenye says, "all of this suggests they're not just driven by simple, emotional responses. They have a rather complex awareness."

Clearly, however, there's still more to human rationality. Study co-author Hanna Schleihauf, a comparative psychologist at Utrecht University in the Netherlands, suggests that the crucial ingredient may be social interaction—we sharpen our beliefs through discussion. "This is really what makes humans so special," she says. "We give and ask for reasons." Indeed, some cognitive scientists think our reasoning skills evolved so that we could argue with one another.

This study reminds us that those skills evolved *from* somewhere—namely, from cognitive abilities that were already present in the common ancestor we share with chimps and bonobos. More than 150 years ago Charles Darwin predicted that our extraordinary mental powers would turn out to be extensions of capacities found throughout the animal kingdom. If chimpanzees are truly capable of reflection, the gap between us and our primate cousins narrows a bit further. As Hare puts it, there's no need to search the stars for intelligence akin to our own. "We already know we're not alone," he says. "There are beings here considering the world in a way that we think of as rational."

Cody Cottier is a freelance journalist based in Fort Collins, Colo.

https://www.scientificamerican.com/article/chimpanzee-metacognition-allows-humanlike-belief-revision

| Section menu | Main menu |

Watch These Parasitic Worms Use Static Electricity as a Tractor Beam

For microscopic worms, physical laws we seldom notice take on life-or-death importance

By Cody Cottier edited by Sarah Lewin Frasier

Flows of tracer particles show the attractive force of a positively charged fruit fly. Parasitic nematodes use this static charge to leap onto the insects.
Victor Ortega Jimenez/University of California, Berkeley

At first glance, it’s a wonder that jumping parasitic nematodes exist at all. To reproduce, these minuscule creatures—roughly the size of a pinpoint—hurl themselves up to 25 times their body length to land on a flying insect as it zooms overhead. Given that wind, gravity and air resistance all stand in the way of a bull’s-eye, the worms’ chances seem poor. But new research shows there’s a force working to their advantage: static electricity.

At human scale, static electricity is little more than a curiosity. You walk across the carpet, friction transfers electrons from the floor to your socks, and you receive a mild zap when the electrical imbalance rights itself by discharging to the first metal object you touch—ouch. But similar processes hold tremendous sway in the teensy world of insects. According to a recent study in the *Proceedings of the National Academy of Sciences USA*, the mere beating of insect wings generates enough positive charge to pull an oppositely charged, airborne nematode inexorably toward its unlucky host, whose decaying flesh will soon shelter the parasite’s eggs. The worms seem to have outsourced their accuracy to these electric tractor beams. “They don’t need to be precise” when they jump, says study co-author Víctor Ortega-Jiménez, a biologist at the University of California, Berkeley, “just close enough to be attracted.”

A nematode leaps and floats on the wind.
Victor Ortega Jimenez/University of California, Berkeley

This study is the latest in a line of experiments that, over the past decade, have illuminated the exotic physics that govern small animals’ lives. In 2013 researchers reported that bees can sense electric fields around flowers and use that information to guide their foraging decisions. Around the same time, Ortega-Jiménez and a colleague discovered that spiderwebs deform when positively charged insects fly by, bulging out to ensnare them. In 2023 a group of researchers in the U.K. found that ticks are passively attracted to furry hosts, whose fluffy coats accumulate electrons.

The 2023 study was co-led by Sam England, now a postdoc investigating sensory ecology at Berlin’s Natural History Museum. Given the precedent in ticks, he wasn’t surprised to learn from the new study that nematodes have also harnessed electricity for parasitic purposes. But whereas ticks sit around waiting, worms “actively input force into the attraction” by jumping, he notes, becoming agents of their own grisly destiny. England was also impressed by how Ortega-Jiménez and his colleagues integrated the effects of other forces, such as air resistance, with those of static electricity in the new research. The work “helps us better connect all of these new and exciting discoveries in electrostatic ecology with the wider physics of ecological interactions,” he says.

A nematode winds up for its leap.
Victor Ortega Jimenez/University of California, Berkeley

By adjusting the voltage sent through copper wire to living fruit flies—they don’t generate their own electricity unless they’re flying—Ortega-Jiménez tested the effect of static charge on airborne nematodes. The trend was clear: the higher a fly’s electric potential, the more likely nematodes were to latch on when they flung themselves into the air. Given zero static, they almost always missed; at higher voltages they latched on more than half the time. With the help of study co-author Ranjiangshang Ran, a postdoc studying fluid mechanics at Emory University, the team added hundreds of thousands more simulated jump trajectories and found that when the virtual voltage reached 800 V, the digital worms were almost unstoppable. In simulations with a gentle, buoyant breeze to keep them aloft long enough for static to take over, their overall success rate soared to more than 70 percent, including for launches that were in exactly the wrong direction.

Nematode launches and is pulled toward a charged fruit fly.
Victor Ortega Jimenez/University of California, Berkeley

For nematodes, a jump is no small feat. If they don’t stick the landing, these aerial hunters can quickly dry out, starve or become hunted themselves. So their odd survival strategy depends on static electricity—without its reassuring pull, they most likely would never have left the ground. “It wouldn’t make sense for them to evolve this jumping mechanism without the presence of electrostatics,” Ran says. Other animals may not be so fully reliant on this force. But England suspects that as the list of electrically sensitive species grows, we’ll find that electrostatic effects “play countless roles” throughout the natural world. “Their importance to ecosystems as a whole,” he says, “has probably been historically quite underestimated.”

Cody Cottier is a freelance journalist based in Fort Collins, Colo.

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https://www.scientificamerican.com/article/static-electricity-helps-parasitic-nematodes-leap-onto-insects

Arts

- ## Poem: ‘Large Hadron Collider,’ ‘Maxwell’s Demon’ and ‘Music for the Heat Death of the Universe’
  Science in meter and verse

Poem: ‘Large Hadron Collider,’ ‘Maxwell’s Demon’ and ‘Music for the Heat Death of the Universe’

Science in meter and verse

By Micháel McCormick edited by Dava Sobel & Clara Moskowitz

Masha Foya

LARGE HADRON COLLIDER

Lab coat voyeurs
collide
scatter

Protons bloom
one nanosecond
two

Lace webs sprout
charm quarks
like Cheshire cats

MAXWELL’S DEMON

Demon bars a door
    too tiny
for the likes of us to see

He lets fast atoms pass
    from B to A
Their slower cousins
    from A to B

Exclusion being
    so small a price
to pay for immortality

MUSIC FOR THE HEAT DEATH OF THE UNIVERSE

“There’s music in everything, even defeat.”
—Charles Bukowski

Last star ember
goes dark

Every atom freezes
absolute zero

A mournful oboe
lingers
    wavers

            stops

Micháel McCormick’s poems and short stories have appeared in more than 80 journals and anthologies. He holds a degree in mathematics and takes inspiration from math and science for much of his work. His debut novel, *Gods of Central Park*, will be published soon by Foundations Book Publishing.

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https://www.scientificamerican.com/article/poem-large-hadron-collider-maxwells-demon-and-music-for-the-heat-death-of

Astronomy

- **Asteroid ‘Families’ Reveal Solar System’s Secret History**
  Many asteroids are related, but their family trees can be hard to trace

Asteroid ‘Families’ Reveal Hidden Histories and Impact Risks across the Solar System

Many asteroids are related, but their family trees can be hard to trace

By Phil Plait edited by Lee Billings & Clara Moskowitz

This illustration shows the creation of an asteroid family. Ejected fragments from catastrophic collisions of asteroids between Mars and Jupiter tend to follow similar orbits around the sun, allowing astronomers to trace their lineage.
Luc Novovitch/Alamy Stock Photo

We’ve all seen this happen in a science-fiction movie: our plucky heroes jump into their ramshackle spaceship and escape the bad guys by flying through the treacherous asteroid belt, where huge rocks tumble and spin so close together that the crew has to constantly dodge, duck, dip and dive to avoid being smashed to atoms.

It’s exciting, but it’s wrong: asteroids so close together would grind one another to dust in short order, making it extremely unlikely that you’d ever find such a situation near a star. In our solar system, the odds are pretty good that you could stand on the surface of an asteroid and not even be able to see another one! Big ones tend to be many millions of kilometers apart.

Yet they *do* interact if they are given enough time. Even in the sprawling main asteroid belt between the orbits of Mars and Jupiter, collisions are inevitable. In fact, we've managed to see some small asteroid smashups; bigger rocks are far more rare, so larger collisions are proportionally less common. But they do still happen—spacecraft reconnaissance of large asteroids shows that they are riddled with ancient impact craters. And when two space rocks go "bump" in the main belt, their high orbital speeds mean they can have collision velocities far higher than that of a rifle bullet. Shrapnel is inevitable because big impacts blow lots of asteroidal real estate out into space.

What happens to that ejected debris? In many cases, these fragments stay on much the same orbital path as the parent asteroid, although they gradually separate from it because of slight velocity differences. After millennia the ejecta might be clear across the sun from its source. You might think this outcome must be problematic for anyone trying to track down different types of asteroids to figure out how they all fit together—and it is! But this problem of orbital mechanics provides its own solution.

> Asteroids are leftover rubble from the formation of the solar system itself, so studying them is quite literally studying our own family tree.

That's because the chaos of collisions scarcely seeps into some parts of an asteroid's orbit; two fragments from an asteroid may end up hundreds of millions of kilometers apart, but their distance from the sun and the shape and orientation of their orbits remain similar. One of their most important conserved characteristics is orbital inclination: changing the tilt of an object's orbit via impact is quite energy-intensive, so even after a big collision, the daughter asteroids that have been blasted into space retain a very similar inclination. Such enduring features are collectively called an asteroid's orbital elements, and they allow us to tease order out of the chaos.

Japanese astronomer Kiyotsugu Hirayama was the first to realize, in 1918, that many more asteroids seem to share orbital elements than would be expected as a result of random chance. He called such groupings asteroid "families," the term we still use today. Families are named after the largest asteroid in the group; Hirayama initially identified three such families, belonging to the asteroids Koronis, Eos and Themis.

Today we know of more than a million asteroids in the main belt, with more found all the time—the newly commissioned Vera C. Rubin Observatory discovered more than 2,000 asteroids in its first 10 hours of observing the sky! As our catalogs swell with newfound asteroids (and as the availability of requisite computing power grows), orbital patterns are getting easier to see, and more families can be flagged. Astronomers currently recognize a few dozen large asteroid families, but numerous smaller ones are known as well. In a paper published in August 2025 in the journal *Icarus*, a research team announced that its orbital-element number crunching had revealed an amazing 63 new families.

Finding asteroid families is a boon for planetary scientists seeking shortcuts to discovery: the properties of a small asteroid may be almost entirely unknown, for instance, but if that space rock belongs to a family with bigger, better-studied members, we can more easily make a good guess about what it looks like. Confirming those guesses—making sure the objects really are related—usually requires taking spectra, the time-consuming process of breaking an object's incoming light into individual colors to reveal its composition.

Care must be taken, though. Some very large asteroids are differentiated, which means that when they formed and were still molten, heavy metals and other dense materials sank toward the center while lighter, rocky material floated nearer to the surface. A large-enough impact could excavate an asteroid’s depths and shallows alike, creating a family with a mix of compositions; the Vesta family is one such example. (Vesta is the second-largest object in the main asteroid belt after Ceres, and both Vesta and Ceres are actually considered to be protoplanets by planetary astronomers.)

As a bonus, some meteorites on Earth have been identified as being from Vesta because they have very similar compositions; they probably made their way down to Earth when the gravitational effects of Jupiter dislodged them from the main belt. We can study them in detail in laboratories to gain even more insight into that family.

Another team of astronomers published a paper in August 2025 in the *Planetary Science Journal* on James Webb Space Telescope spectra of Polana, a 55-kilometer-wide asteroid in the main belt. The spectra show that it’s the likely parent of the near-Earth asteroids Ryugu and Bennu. If those two names ring a bell, it’s because both asteroids have been visited by spacecraft that gathered samples and delivered them to Earth for study.

Finding this particular branch of an asteroid family tree is more than a mere academic exercise: Both Ryugu (about one kilometer wide) and Bennu (0.5 kilometer wide) are potentially hazardous asteroids, meaning they could collide with Earth sometime in the distant future. If we know the parent bodies of such threatening asteroids, we can better understand how they find their way to the inner solar system from the main belt to pose threats in the first place, which in turn can help us defend our planet from future worrisome asteroids.

Of course, the scientific benefits to understanding asteroid families are worth the investigation, too. Asteroids are leftover rubble from the formation of the solar system itself, so studying them is quite literally studying our own family tree, with an occasional extra benefit of finding—and, we hope, avoiding—potentially apocalyptic space rocks.

Phil Plait is a professional astronomer and science communicator in Virginia. His column for *Scientific American*, The Universe, covers all things space. He writes the *Bad Astronomy Newsletter*. Follow him online.

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https://www.scientificamerican.com/article/asteroid-families-reveal-solar-systems-secret-history

Culture

Meet Your Plastic Pal

A new generation of household robots could change the way you live

By David M. Ewalt edited by Jeanna Bryner

Scientific American, January 2026

When Czech writer Karel Čapek coined the word “robot” in his 1920 play *R.U.R.*, he imagined tireless “artificial workers” liberating people from drudgery. The lead character dreams of destroying poverty by turning the whole of humankind into an aristocracy, an elite class of elevated beings “nourished by millions of mechanical slaves.”

You won’t be surprised to learn that the plan ends badly. Čapek’s initially emotionless robots develop into conscious, thinking beings and then violently revolt against their human creators. The finale is less aristocracy and more apocalypse.

In the 106 years since, humanity has remained captivated by the notion that machines could take over our daily work, as well as by the grim but entertaining idea that toiling automata will get murderously sick of picking up laundry. But even after a century of progress, neither scenario seems remotely close to fruition: our best household robots can barely vacuum a floor without smearing cat food across the rug, much less successfully execute a workers' revolution.

In this issue's cover story, journalist and former *Scientific American* editor Ben Guarino investigates why the dream of mechanical helpers has remained so stubbornly out of reach and what it will take to finally bring it home. I was particularly excited to read about Stanford University's TidyBot, a household robot that is currently part of a research project but could one day make my bed—although I admit I did briefly worry about the prospect of a rebellious bot imprisoning me by tucking the sheets in too tightly while I'm still under them.

If that thought makes you anxious, you might want to read journalist Diana Kwon's piece about interoception, our ability to detect and interpret the body's internal state. New research points to a link between how well we read the signals sent by our own bodies and a variety of psychological ailments. Findings suggest that unconventional therapies such as spending time in a sensory-deprivation chamber could help people improve their mental well-being.

Elsewhere in the issue, science writer Ann Finkbeiner dives into the fascinating topic of celestial transients. These astronomical objects appear suddenly from nowhere, shine with the light of entire galaxies and disappear soon after. New astronomical surveys are finding these seemingly improbable phenomena bursting to life all across the night sky at a rate of more than 20,000 a year and climbing, but astronomers are just beginning to understand what they are.

And make sure you join *Scientific American* multimedia editor Kelso Harper on a killer whale research expedition off the coast of Washington State around the San Juan Islands. Southern resident orcas have lived in the waters of the Pacific Northwest for thousands of years but are now on the brink of extinction. Harper joined a group of biologists who have studied the population for decades and discovered the research is at risk, too: government cutbacks threaten to stall or stop a swath of conservation studies at a crucial juncture for the species.

As you read that story, you might wonder what it looks and sounds like when Eba the orca hound gets on the scent of a hot killer whale scat sample in the Salish Sea. I'm happy to tell you that our entire multimedia team was on location in the salt and spray of the pursuit, and now you can experience it, too. Thanks to financial support from the Caplan Family Foundation, we're excited to share *The Protectors*, a new 25-minute documentary that brings you to the edge of the bow with Eba and the researchers who are striving to understand and conserve the southern residents. My sincere appreciation goes out to Amy Caplan for making this project possible and helping us tell the story of a group of remarkably dedicated scientists. You can watch *The Protectors* right now on the *Scientific American* YouTube channel.

David M. Ewalt is editor in chief of *Scientific American*.

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https://www.scientificamerican.com/article/meet-your-plastic-pal

Readers Respond to the September 2025 Issue

Letters to the editors for the September 2025 issue of Scientific American

By Aaron Shattuck

Scientific American, September 2025

SETI THE RECORD STRAIGHT

In “We Probably Aren’t Alone,” Sarah Scoles describes how Italian astronomer Giovanni Schiaparelli’s 1877 observation of apparent “channels” or “grooves” on Mars had led to a widespread belief that the planet was “home to canal-digging civilizations” thanks to a mistranslation. Scoles notes that this idea “began to lose its sparkle in 1909, when French astronomer Eugène Antoniadi” found that the lines Schiaparelli saw were an optical illusion.

The same finding as Antoniadi’s was made three decades earlier. In the February 2024 issue of the *Journal for the History of Astronomy*, I published an article on the history of astronomical observations made on the island of Madeira. In it, I point out that, in 1877, the same year as Schiaparelli's claim, amateur astronomer and professional artist Nathaniel Everett Green took advantage "of the transparency of the Madeira air" to observe Mars, as he wrote in the *Memoirs of the Royal Astronomical Society* in 1879. He noted that "it would be difficult to exaggerate the keen map-like appearance of the planet," which allowed him to conclude that "the remarkable dark canals ... of Professor Schiaparelli ... certainly were invisible at Madeira."

Green invoked an optical illusion as the reason for Schiaparelli's mistake. This account followed Green's earlier report of his observations in the prestigious *Monthly Notices of the Royal Astronomical Society* in 1877.

PEDRO AUGUSTO *PORTO, PORTUGAL*

Although Scoles's history of the search for extraterrestrial life is interesting, I believe she missed the most important reason for believing such life exists. It is one that is difficult for us mere humans to comprehend: infinity. If the universe is infinite, then there must be many other planets with life on them. The problem is that the laws of physics say we are all bound by the speed limit of the speed of light. This means that life exists on many worlds, in many galaxies, but it and we will never be able to find each other. Let's keep searching anyway; the pursuit of knowledge is unquenchable!

WES MOFFETT *VIA E-MAIL*

ANATOMICAL CONNECTIONS

Scientists themselves might benefit from reading *Scientific American*! In the July/August 2025 issue, there are two Advances articles reporting on findings that could be linked with those noted in previous issues.

“Wandering Mind,” by Nora Bradford [Advances; July/August 2025], concerns scientists studying how participants learn hidden patterns in tasks better when they let their mind wander. The researchers might consult “Speed Limit,” by Rachel Nuwer [Advances; March 2025], and note the described findings that the focused mind processes at about 10 bits per second, whereas the sensory systems do so at about a billion bits per second. This supports Queen’s University psychology researcher Jonathan Smallwood’s supposition in Bradford’s article that it’s the “particular state” in which mind wandering occurs, rather than the mind wandering itself, that causes people to learn such patterns: the lack of focus allows the body, working with those billion bits per second, to figure out the problem. I have experienced this myself for decades: when faced with any repetitive physical task, I immediately step back from thinking and let my body work out a process.

“Screaming Skin,” by Allison Parshall [Advances; July/August 2025], describes how Sun-Min Yu of the University of Massachusetts Amherst and her team found that epithelial cells make a signal when they are damaged that “may summon other cells to help rebuild the damaged spots.” Yu’s team might consult Martin Picard’s June 2025 article “The Social Lives of Mitochondria.” Picard shows how mitochondria, found in every cell of the body, communicate with one another, especially when they are in need of assistance. They do so between cells and by influencing multiple subsystems within each cell.

M. FOSQUE *HILLSBOROUGH, N.C.*

SLIME THAT HEALS?

In “Slime Attack” [Advances; July/August 2025], Elizabeth Anne Brown describes research on velvet worm slime, which can harden in seconds.

As someone who is taking various cardiovascular medications that result in thinned blood and profuse bleeding with the slightest scratch or scrape, I wonder whether this slime or similar substances might have application to staunch bleeding from a wound. (Besides people like me, it would be helpful for those with hemophilia.) The almost instant hardening might quickly form a barrier over the wound. And as noted in the article, the substance returns to a liquid state when soaked with water, so it could easily be washed off later.

GARY McKOWN *WEST CHESTER, PA.*

ICY APPRAISAL

In “Refreezing the Arctic” [June 2025], Alec Luhn reports on researchers who are trying to rebuild sea ice above the Arctic Circle to reflect the sun’s radiation and thus slow climate change. I hope you follow up by covering other means of Arctic ice-sheet restoration.

I am particularly interested in snow production because it seems to have several advantages over ice. For one, in addition to being more reflective than ice, snow is far superior as insulation, as Luhn notes. Thus, a layer of snow would keep the ice sheet colder than a layer of ice of the same mass—and for longer. Further, snow production would allow for much larger areas of coverage per pump station, reducing hardware costs.

NOEL KURTZ *VIA E-MAIL*

CLARIFICATION

“Closing In on a Cure,” by Tara Haelle [Innovations In Type 1 Diabetes; November 2025], noted Vertex Pharmaceuticals’ in-development drug Zimislecel. Breakthrough T1D did not fund trials for this drug. See more about its mechanism of action, intended recipients and trial results at www.scientificamerican.com/article/a-cure-for-type-1-diabetes-may-be-closer-than-you-think

ERRATA

“Bass Backlash,” by Martin J. Kernan [Advances; November 2025], should have clarified that the historical proliferation of smallmouth bass in Little Moose Lake resulted in native trout reaching only nine inches long at the time rather than to this day.

“Meteorite Heist,” by Dan Vergano [November 2025], should have said that, according to Nicholas Gessler, the Eli Ali object is being offered for sale in pieces at $200 a kilogram.

In “Organized Chaos,” by Aimee Lucido [Science Crossword; November 2025], the question for 16-Across should have specified a drum kit component.

Aaron Shattuck is a senior copy editor at *Scientific American*.

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https://www.scientificamerican.com/article/readers-respond-to-the-september-2025-issue

Earth

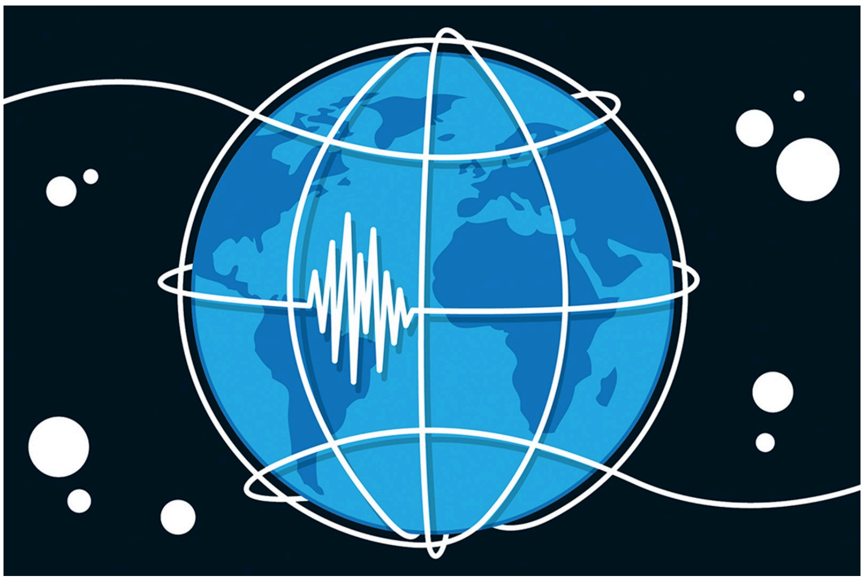
- **Telecom Fiber-Optic Cables Measured an Earthquake in Incredible Detail**
  Fiber optics that connect the world can detect its earthquakes, too

| Next section | Main menu | Previous section |

Telecom Cables Measured an Earthquake in Incredible Detail

Fiber optics that connect the world can detect its earthquakes, too

By Saugat Bolakhe edited by Sarah Lewin Frasier



Thomas Fuchs

The same optic fibers that pulse with the world's Internet traffic are now listening to the pulse of the planet, picking up earthquake tremors in better detail than traditional seismic networks do.

In a recent *Science* study, researchers used 15 kilometers of telecom fiber near Mendocino, Calif., to record the region's biggest earthquake in five years—capturing in fine detail how the magnitude 7 rupture started, slowed and sped up, accelerating even faster than the speed of sound.

"This is almost as if you look at Saturn and say, 'That's a star.' Then, you are given a new telescope and suddenly realize, 'Oh, my God, there's actually a ring around it!'" says Zhongwen Zhan, a geophysicist at the California Institute of Technology, who was not involved in the study.

Optical fiber, one of modern science's most remarkable inventions, is built to transmit light, which can carry encoded information with extreme efficiency. Even a small touch or bend can disrupt its flow, so telecom companies work hard to minimize environmental interference. "Yet what's noise to telecommunications is data to us," Zhan says.

The oil industry adopted this technology in the 1990s, deploying specialized fiber-optic cables to detect temperature, pressure and vibration during drilling. James Atterholt, a seismologist at the U.S. Geological Survey, hoped to adapt such observations to an actual earthquake. In May 2022 Atterholt and his team set up a device called an interrogator—"basically a big box with a laser and a computer," he says—to send beams of light through an unused fiber on a coastal telephone cable. Depending on ground vibrations, tiny imperfections in the fiber reflected the light back every few meters, turning the thread into 2,800 mini seismometers.

On December 5, 2024, when the quake struck Cape Mendocino, Atterholt's team was still monitoring the fiber-optic system. Its data revealed how the rupture moved eastward, slowed near a junction where three tectonic plates meet, and then accelerated to "supershear" speed, generating a sonic boom because it was traveling faster than the speed of sound. This was one of the clearest demonstrations of the complexity of a fault leading to supershear rupture, the researchers say. Recording comparable data with the existing seismometer network would require an even more enormous earthquake essentially right on top of the instruments.

Although this technology has been around for a while, "the actual demonstration of it in a proven case shows that it can improve earthquake early-warning systems," says Brad Lipovsky, a geophysicist at the University of Washington, who was not involved in the study. Such a system would be especially crucial for coastal cities vulnerable to offshore quakes and tsunamis. Lipovsky and Zhan both also highlight the technology's usefulness in extreme environments, such as Antarctica, where specially installed cable could monitor changing terrain and glaciers' response to climate change.

Saugat Bolakhe is a freelance science journalist. He studied zoology as an undergraduate in Nepal and received a master's degree from the Craig Newmark Graduate School of Journalism at the City University of New York. His work has appeared in *Scientific American*, *Nature*, *New Scientist*, *Quanta*, *Eos*, *Discover*, *Knowable* and other publications.

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https://www.scientificamerican.com/article/telecom-fiber-optic-cables-measured-an-earthquake-in-incredible-detail

| Section menu | Main menu |

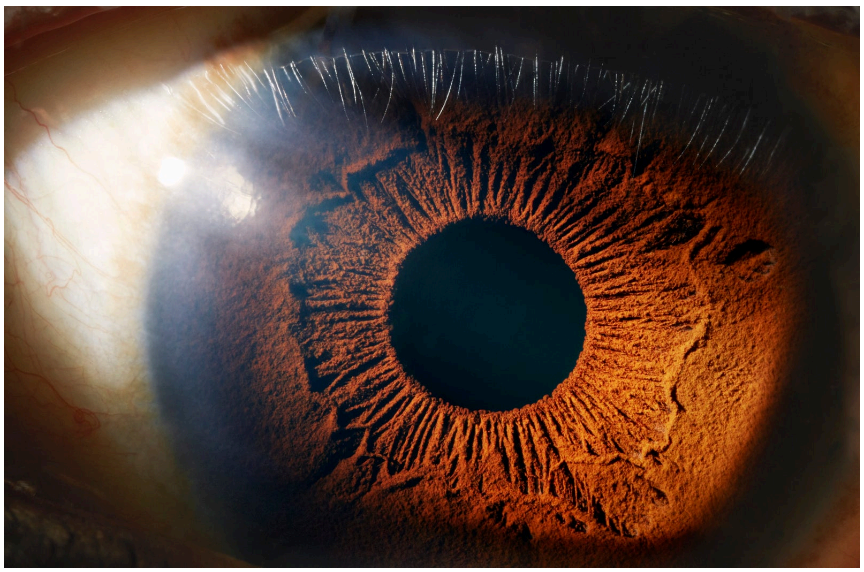
Electronics

- **Breakthrough in Digital Screens Takes Color Resolution to Incredibly Small Scale**
  These miniature displays can be the size of your pupil, with as many pixels as you have photoreceptors—opening the way to improved virtual reality

Breakthrough in Digital Screens Takes Color Resolution to Incredibly Small Scale

These miniature displays can be the size of your pupil, with as many pixels as you have photoreceptors—opening the way to improved virtual reality

By Simon Makin edited by Sarah Lewin Frasier



Peter Finch/Getty Images

Visual displays have steadily gotten smaller and held closer to our eyes as our viewing habits have shifted from cinema screens to TVs to computers, smartphones and virtual reality. This shift has required higher image resolution (usually through increased pixel counts) to provide enough detail. Conventional light-emitting pixels work poorly below a certain size: brightness drops, and colors bleed. The same isn’t true for reflective displays such as those used in many e-readers, whose pixels reflect ambient light rather than emitting their own—but creating those pixels typically requires larger components.

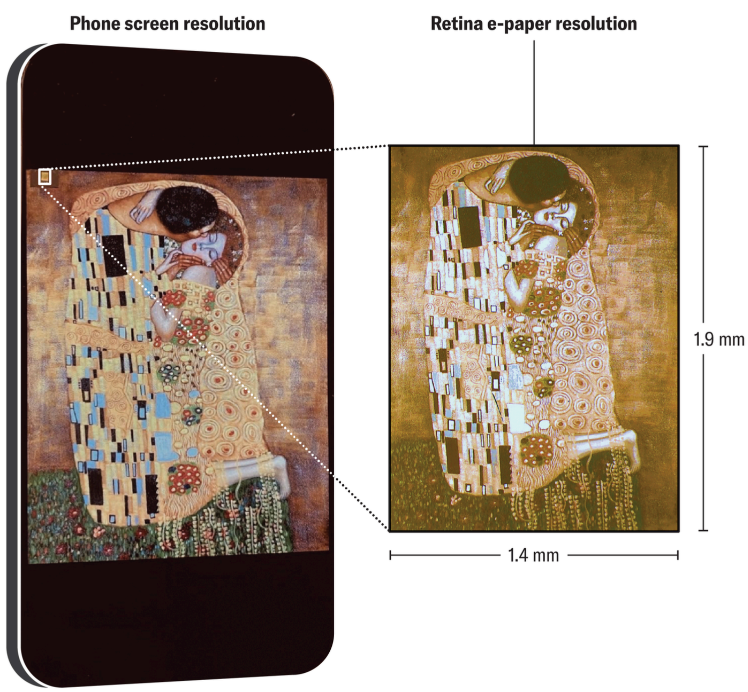
A new reflective display could shatter those restrictions with resolutions beyond the limit of human perception. In a recent study in *Nature*, scientists describe a reflective retina e-paper that can display color video on screens smaller than two square millimeters across.

The researchers used nanoparticles whose size and spacing affect how light is scattered, tuning them to create red, green and blue subpixels. The material is electrochromic, so its light absorption and reflection can be controlled with electrical signals. With this setup, "metapixels" consisting of the three subpixels can generate any color if you deliver appropriate signals.

Each pixel is only 560 nanometers wide, creating a resolution above 25,000 pixels per inch—more than 50 times that of current smartphones. "We can make displays a similar size as your pupil, with a similar number of pixels as photoreceptors in your eyes," says study co-author Kunli Xiong of Uppsala University in Sweden. "So we can create virtual worlds very close to reality."

Phone Screen vs. E-Paper

The screen area of the iPhone 15 (*left*) is 4,000 times larger than the area of the inset e-paper image (*enlarged at right*). These two iterations of Gustav Klimt's *The Kiss* show that the e-paper captures an impressive amount of detail but loses some of the color information visible on a typical phone screen.



Source: "Video-Rate Tunable Color Electronic Paper with Human Resolution," by Ade Satria Saloka Santosa et al., in *Nature,* Vol. 646; October 30, 2025; restyled by Amanda Montañez

E-paper screens also have relatively low energy requirements; the pixels retain their color for some time, so power is generally needed only when colors change. “It uses ultralow power,” Xiong says. “For very small devices, it is not easy to integrate large batteries, so that energy saving becomes even more important.”

The team demonstrated the technology with a version of *The Kiss* by Austrian painter Gustav Klimt and a three-dimensional butterfly image. “People have made these kinds of materials before, but usually they produce poor colors,” says Jeremy Baumberg, a nanotechnologist at the University of Cambridge, who studies how nanoscale materials interact with light. In comparison, the design of Xiong and his colleagues’ subpixels “generates colors that look more compelling than I’ve seen before,” Baumberg says.

These pixels can be rapidly controlled, enabling a reasonable refresh rate—but the necessary electronics for such a high resolution do not yet exist. Xiong and his colleagues anticipate that engineering companies will begin to develop such systems.

Meanwhile Xiong’s team plans to optimize other aspects of the technology such as its speed and lifetime. “Every time you switch [colors], the material’s structure changes, and eventually it crumbles,” Baumberg says—similar to how batteries decay. He estimates that it’ll be five to 10 years before we see commercially available devices.

Simon Makin is a freelance science journalist based in the U.K. His work has appeared in *New Scientist*, the *Economist*, *Scientific American* and *Nature*, among others. He covers the life sciences and specializes in neuroscience, psychology and mental health. Follow Makin on X (formerly Twitter) @SimonMakin

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https://www.scientificamerican.com/article/breakthrough-in-digital-screens-takes-color-resolution-to-incredibly-small

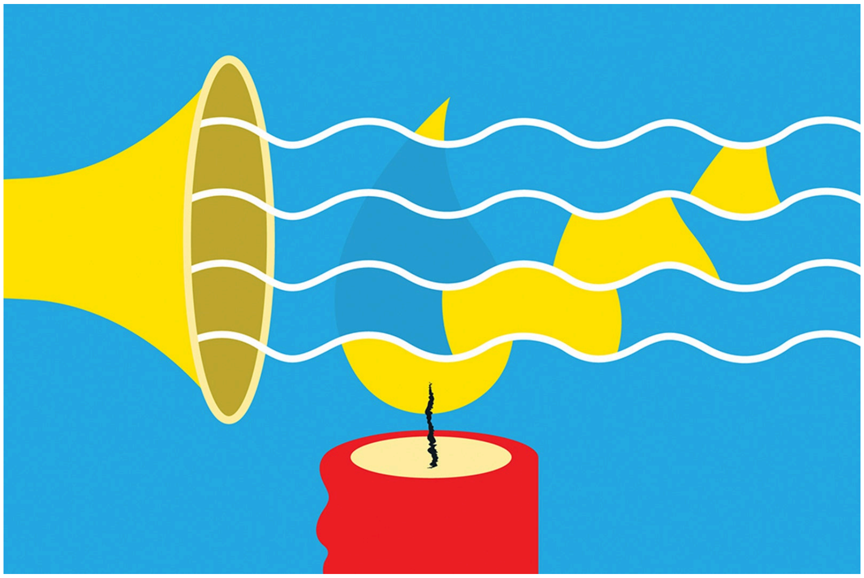
Engineering

- ## Infrasound Tech Silences Wildfires before They Spread
  A new sound-based system could squelch small fires before they grow into home-destroying blazes

How Sound Waves Can Fight Fires without Water

A new sound-based system could squelch small fires before they grow into home-destroying blazes

By Vanessa Bates Ramirez edited by Sarah Lewin Frasier



Thomas Fuchs

A wildfire burns in the hills of a Los Angeles suburb, leaping from one patch of dry brush to another as it approaches a cluster of homes. The landscaping at the first house burns, but the house itself stubbornly refuses to catch fire: any small flames that start along its walls or roof quickly die out. There’s no water in sight—the flames are being quenched by sound waves. This kind of acoustic fire suppression may soon play a vital role in fighting wildfires.

The key ingredients for a fire are heat, fuel and oxygen; take one of these away, and the flames are extinguished. Sound waves can stifle a fire by pushing oxygen molecules away from the fuel, preventing the fire from getting the air it needs to continue its combustion reaction.

Geoff Bruder, an aerospace engineer who researched thermal energy conversion at NASA, co-founded Sonic Fire Tech to build a sound-generating machine for this purpose. “It’s basically vibrating the oxygen faster than the fuel can use it, so you block the chemical reaction,” Bruder says. The company has demonstrated fire suppression from up to 25 feet away.

Using sound waves to fight fire isn’t a brand-new concept. The U.S. Defense Advanced Research Projects Agency studied the method from 2008 to 2011, and academic researchers explored the technique over the next decade (including a George Mason University team that built an extinguisher similar to a subwoofer in 2015).

“Acoustic influence on flames is well known in combustion,” says Albert Simeoni, head of the department of fire protection engineering at Worcester Polytechnic Institute in Massachusetts. “The challenge is to scale up the technology without creating disrupting or even damaging sound effects.”

Sonic solves this challenge by using infrasound. Whereas previous efforts used sound waves in the range of 30 to 60 hertz, which can be produced with simpler equipment, Sonic stays at or below 20 hertz. These waves are inaudible to people, and they travel farther than higher-frequency waves.

Homes often catch fire from embers accumulating in adjacent foliage or entering attic vents, Bruder says. Sonic’s system uses a piston pulsed by an electric motor to create sound waves, which travel through metallic ducts installed on a building’s roof and under its eaves. The system autoactivates when sensors detect a flame, creating a kind of force field of infrasound to extinguish it and prevent new ignition.

Acoustic waves can have a strong effect on fire, but they work only on small flames, says Arnaud Trouvé, chair of the University of

Maryland’s department of fire protection engineering. Nevertheless, homeowners and utilities are game to give it a try: Sonic is working with two California utilities to demonstrate its technology. Homeowners have also signed contracts with the company, which is aiming to have 50 pilot installations early in 2026.

Vanessa Bates Ramirez is a science and technology journalist focused on energy and climate tech, artificial intelligence and biotechnology. Her work has appeared in *Time* magazine, *Forbes*, AI Frontiers, *Scientific American* and SingularityHub, among other outlets. Follow Ramirez on X @vanessabramirez

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https://www.scientificamerican.com/article/infrasound-tech-silences-wildfires-before-they-spread

| Section menu | Main menu |

Health

- **The Hype behind Expensive Probiotic Supplements**
  Popular supplements with billions of “good” microbes really help only a few illnesses, research shows

| Next section | Main menu | Previous section |

The Hype behind Probiotics

Popular supplements with billions of "good" microbes really help only a few illnesses, research shows

By Lydia Denworth edited by Josh Fischman

Jay Bendt

This article was made possible by the support of Yakult and produced independently by Scientific American*'s board of editors.*

There are microbes living in medicine cabinets across the U.S., next to the aspirin and the Band-Aids. And people want them there. Indeed, consumers probably paid good money for them.

Probiotics are capsules or pills with live microorganisms—almost always bacteria or yeast—that are supposed to confer health benefits once people swallow them. Some of my friends, including a woman who was recently treated for cancer and a man with persistent digestive issues, bought the pills at the recommendation of doctors. Others, aware of a lot of new evidence about the ways microbes in our guts influence physical functioning, bought them on their own. Many hope the bacteria will improve their overall gut health, a desire reflected in bottle labels that say things like “improved digestion” and “clinically studied.”

But despite this popularity, evidence that probiotics help people is surprisingly limited. Medical organizations such as the American Gastroenterological Association (AGA) recommend only a few specific bacterial strains for a few well-defined conditions. “The average person likely doesn’t need probiotics and is unlikely to benefit from them for day-to-day use,” says gastroenterologist Omeed Alipour of the Santa Clara Health System in California, a spokesperson for the AGA.

That cautious perspective is widely shared across the medical and scientific community, says Yosra Helmy, a veterinarian and microbiologist at the University of Kentucky, who studies the intersection of human and animal health. “It’s not because probiotics lack promise but because the science remains uneven, highly strain-specific and difficult to generalize,” she says. “Clearly, the marketing is ahead of the reality,” says gastroenterologist Neil Stollman, an associate clinical professor at the University of California, San Francisco.

> “The average person likely doesn’t need probiotics and is unlikely to benefit from them for day-to-day use.” —Omeed Alipour, *gastroenterologist*

Another concern is that in the U.S., probiotics are dietary supplements, not medicines, and aren’t rigorously evaluated in the same way as pharmaceuticals.

Probiotics are attractive because our gastrointestinal systems naturally contain trillions of microbes, collectively called the gut microbiome. Much of this microbiota—mainly bacteria but also yeast, fungi and viruses—is beneficial. It keeps the gut’s microbial community in balance and supports protective intestine and stomach linings. It also produces metabolites such as short-chain fatty acids that nourish cells, regulate immune system and metabolic balance, and help to produce vitamins.

We regularly replenish our helpful gut bacteria when we eat yogurt and yogurt-based drinks, kefir, or other fermented foods such as kimchi, kombucha and miso. These are all natural sources of a wide variety of microorganisms. Fiber-rich diets provide fuel for the beneficial bugs once they are in our systems.

In a few situations, diet alone is not enough, and that is when probiotic supplements come into play. Some of the strongest evidence in favor of added probiotics is for two rare conditions. One is necrotizing enterocolitis, which kills intestinal tissue in premature infants and can kill the babies, too. The other is pouchitis, inflammation of the small pouch created as part of surgery for ulcerative colitis or Crohn's disease. Probiotics reduce the incidence of the first condition and ease the symptoms of the second one.

For the wider population, a prevalent evidence-based reason to take probiotics is to prevent or minimize diarrhea brought on by antibiotics. That's because antibiotics don't target just the bad bacteria that give people the runs; they tend to wipe out entire colonies of helpful bacteria as well. (Chemotherapy has similar indiscriminate effects.) Studies show that some *Lactobacillus* and *Bifidobacterium* species, as well as a yeast called *Saccharomyces boulardii*, can help with antibiotic-induced problems. "All three of those have reasonable evidence that they lower your risk with antibiotics," Stollman says. "You'll probably feel better, and it probably won't hurt you."

Studies have also found that probiotics reduce infections from the bacterium *Clostridioides difficile*, which can damage the colon. But the effect is small. Gastroenterologists recommend probiotics only for those at high risk of infection: people who are elderly, have had previous infections or are taking multiple antibiotics for long periods.

Sufferers of irritable bowel syndrome (IBS) would love to find a probiotic that reduces symptoms such as bloating, constipation and diarrhea. Recent studies have found that some strains bring improvement for some people, but gastroenterologists can't predict who will benefit and who will not. "It's such a subjective marker to report symptom improvement on IBS, which itself is so broad," Alipour says. As a result, there are no firm recommendations yet.

Newer studies of so-called next-generation probiotics are underway. "The goal is to move from a one-size-fits-all supplement model toward precision microbiome interventions, where specific strains are matched to specific health problems," Helmy says. These supplements might use a wider range of bacteria and improved encapsulation that is better able to withstand breakdown by the digestive system.

Until those products are available, experts recommend that anyone looking to improve gut health begin with nutrition. A diet rich in fiber and fermented foods is a better solution than going to a store and buying a bottle of pills, Stollman says.

For those who still want to try probiotics, the good news is that the risks are low overall. But their use should always be targeted and limited, Helmy says: try one for four to eight weeks and then reassess your symptoms. "They are not a universal solution," she says.

Lydia Denworth is an award-winning science journalist and contributing editor for *Scientific American*. She is author of *Friendship: The Evolution, Biology, and Extraordinary Power of Life's Fundamental Bond* (W. W. Norton, 2020) and several other books of popular science.

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https://www.scientificamerican.com/article/the-hype-behind-expensive-probiotic-supplements

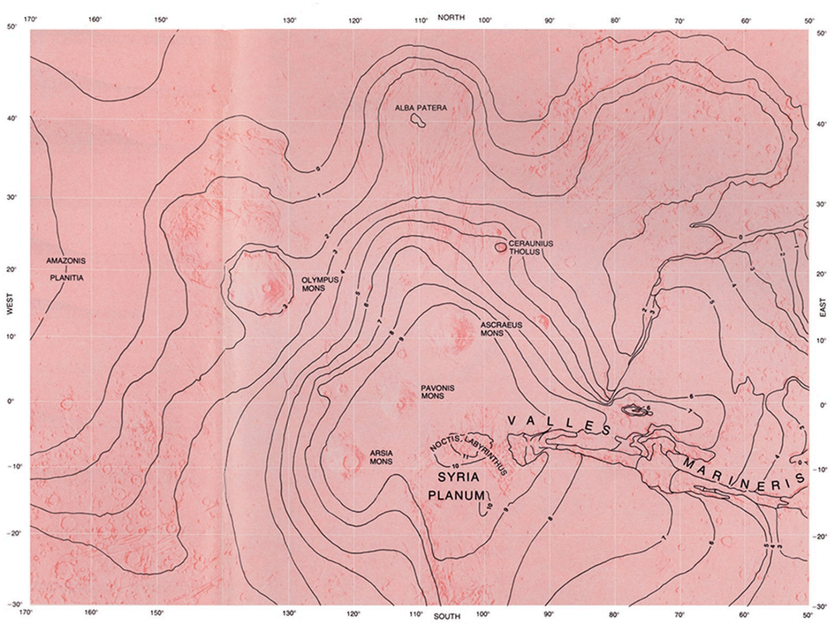
History

- **January 2026: Science History from 50, 100 and 150 Years Ago**
  Killer bees; Mars volcanoes

January 2026: Science History from 50, 100 and 150 Years Ago

Killer bees; Mars volcanoes

By Mark Fischetti edited by Jeanna Bryner



1976, Mars Volcanoes: “The Tharsis region is the most prominent volcanic region on Mars. This contour map, produced by the U.S. Geological Survey, outlines a broad bulge, informally called the Syria Rise, 5,000 kilometers across and seven kilometers high, on which the three shield volcanoes Ascraeus Mons, Pavonis Mons and Arsia Mons are located. Fractures radiate outward for several thousand kilometers.”
Scientific American, Vol. 234, No. 1; January 1976

1976

Killer Bees Won’t Invade

“Much attention has been given to the fact that honeybees of an African race (*Apis mellifera adansonii*) were accidentally released in Brazil in the mid-1950s, where they have been cross-breeding with commercial honeybee populations and also have established their own wild colonies. The northward and southward expansion of the bees’ range, coupled with the African race’s tendency to pursue any disturber of the hive with unusual persistence, have led to predictions that the ‘killer bees’ might eventually spread a reign of terror throughout the Western Hemisphere. Roger A. Morse, professor of apiculture at Cornell University, dismisses the threat as being grossly exaggerated. Morse points out that the African bees’ reputation for aggressiveness is no worse than that of other honeybee races regularly raised by beekeepers. As for a possible U.S. invasion, Morse notes that *adansonii* are adapted to living under tropical and subtropical conditions. They are unable to survive the cold season in temperate climates as other honeybees do by forming winter clusters, and the Africanized hybrids share this handicap.”

1926

Pangaea Idea Is Absurd

“Professor Alfred L. Wegener at the University of Graz in Germany says that millions of years ago the two Americas, as well as Europe, Asia, Australia and Antarctica, were one continent centered around Africa. Tidal forces—the attraction of the sun and moon for the earth’s solid mass (not ocean tides)—broke this supercontinent up, and the pieces slowly dispersed in various directions, like the blocks of a great, flat cake of floating ice that is broken up by the waves. Some of these pieces are drifting still. This theory is startling. To many it seems absurd. It may prove to be erroneous. It may gain final acceptance among geologists. But there is something about it that seems to captivate the interest of scientists.”

Today scientists accept the idea that plate tectonics broke up Pangaea.

Start of Civilization

“Two factions of scientists are at odds. One faction says civilization started in one place in the world and spread from this center. They place it near Egypt. Sun worship, ear-piercing, tattooing, pyramids, irrigation, similarity of art and a long list of even more peculiar manners and customs argue for a common origin, they claim. The other faction says these similarities of manners and customs simply show that the human mind works about the same everywhere. Given two or several isolated peoples, as time goes on they will develop similar peculiarities because there is an inherent tendency in humans to develop culture by the same stages and in the same way. They call this tendency psychic unity."

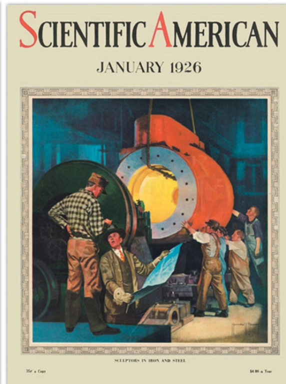
Chlorine Bombs Colds

"Two San Francisco chemists have perfected a chlorine gas bomb for the treatment of colds in the home, where the same results are obtained as with more elaborate apparatus. It eliminates the necessity of going to some central source for treatment, with possible exposure to bad weather and further lowering of body resistance. The bomb is made of glass and contains nothing but pure filtered chlorine gas. The patient takes the bomb in a closed room and breaks off the ends of the bomb, thus permitting the gas to mingle with the air in the room. The patient remains in this gas-filled room for one hour."

1876

Mysterious Jade

"A number of sales of Japanese and Chinese curiosities have recently taken place in New York City that included objects made of a material little seen in this part of the world, and about which little is here known. It is a precious stone, valuable not on account of its scarcity, because in China and Burma large mines of it exist, but for the great difficulty encountered in cutting and carving it, necessitating an amount of patience and manual dexterity rarely found. It is a silicate of alumina called jade. The true jade is hard enough to cut glass or quartz, and the most valuable pieces are of an intensely bright green hue, the ordinary material being pink and yellow.”



Mark Fischetti was a senior editor at *Scientific American* for nearly 20 years and covered sustainability issues, including climate, environment, energy, and more. He assigned and edited feature articles and news by journalists and scientists and also wrote in those formats. He was founding managing editor of two spin-off magazines: *Scientific American Mind* and *Scientific American Earth 3.0*. His 2001 article “Drowning New Orleans” predicted the widespread disaster that a storm like Hurricane Katrina would impose on the city. Fischetti has written as a freelancer for the *New York Times*, *Sports Illustrated*, *Smithsonian* and many other outlets. He co-authored the book *Weaving the Web* with Tim Berners-Lee, inventor of the World Wide Web, which tells the real story of how the Web was created. He also co-authored *The New Killer Diseases* with microbiologist Elinor Levy. Fischetti has a physics degree and has twice served as Attaway Fellow in Civic Culture at Centenary College of Louisiana, which awarded him an honorary doctorate. In 2021 he received the American Geophysical Union’s Robert C. Cowen Award for Sustained Achievement in Science Journalism. He has appeared on NBC’s *Meet the Press*, CNN, the History Channel, NPR News and many radio stations.

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https://www.scientificamerican.com/article/january-2026-science-history-from-50-100-and-150-years-ago

| Section menu | Main menu |

Language

- **Science Crossword: Pointing South**
  Play this crossword inspired by the January 2026 issue of Scientific American

Science Crossword: Pointing South

By Aimee Lucido

This crossword is inspired by the January 2026 issue of Scientific American. *Read it here.*

We'd love to hear from you! E-mail us at games@sciam.com to share your experience.

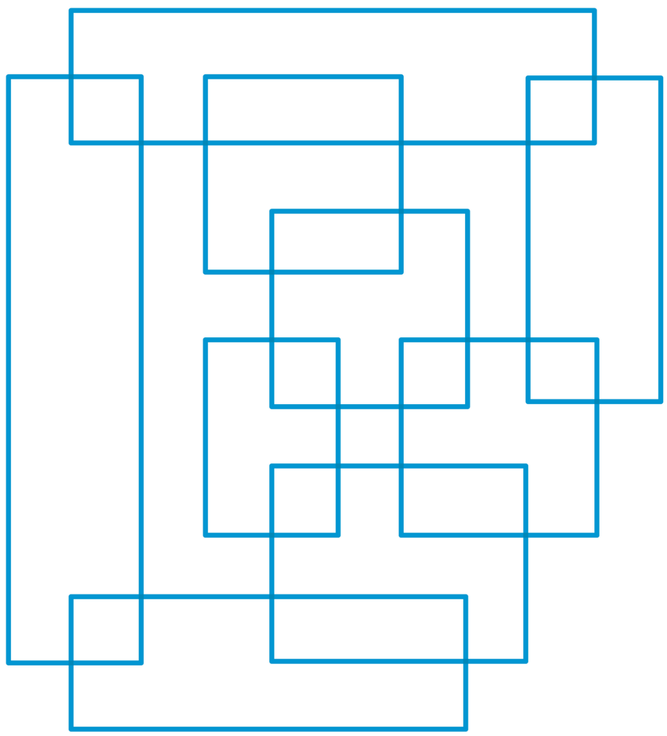
Aimee Lucido makes crosswords part-time for several outlets and writes trivia full-time for Bloomberg's news quiz, Pointed. She is also the author of several books for kids, including *Emmy in the Key of Code*, *Recipe for Disaster*, and *Pasta Pasta Lotsa Pasta*. Lucido lives with her husband, daughter and dog in New York.

https://www.scientificamerican.com/article/science-crossword-pointing-south

Mathematics

Math Puzzle: Wrangle the Rectangles

By Heinrich Hemme



The nine rectangles A, B, C, D, E, F, G, H and I overlap one another. Rectangle A intersects rectangles D and F; this relation can be written in shorthand as A\(D, F). Furthermore,

B\(F, G)

C\(G, H)

D\(A, H)

E\(H, I)

F\(A, B, I)

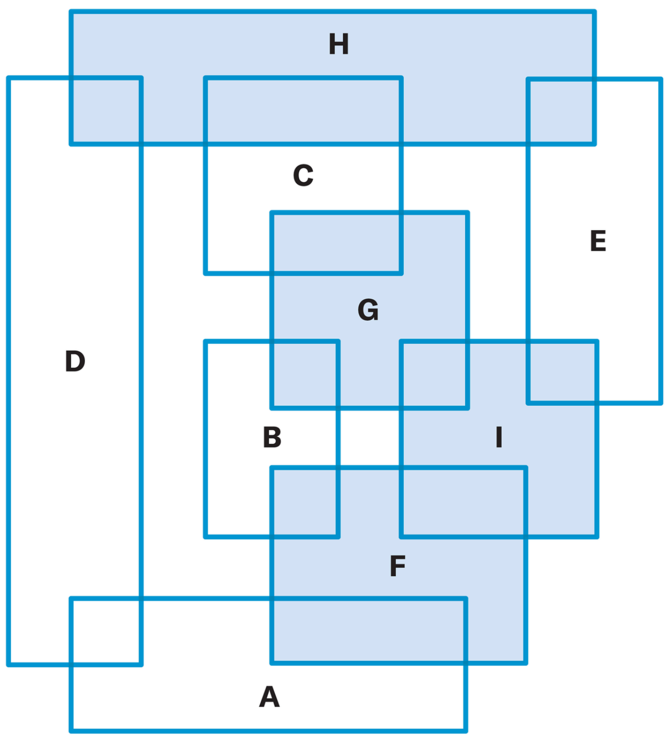
G\(B, C, I)

H\(C, D, E)

I\(E, F, G)

Label the rectangles correctly with the letters A to I.

Only the four blue-shaded rectangles below intersect three other rectangles, and therefore they must be F, G, H and I. H doesn't intersect F, G or I, whereas I intersects both F and G. Consequently, H is the topmost blue-shaded rectangle, and I is the third from the top. Because B\(F, G) and E\(H, I), the two rectangles B and E also can be identified. The rest is simple.



We'd love to hear from you! E-mail us at games@sciam.com to share your experience.

This puzzle originally appeared in Spektrum der Wissenschaft *and was reproduced with permission.*

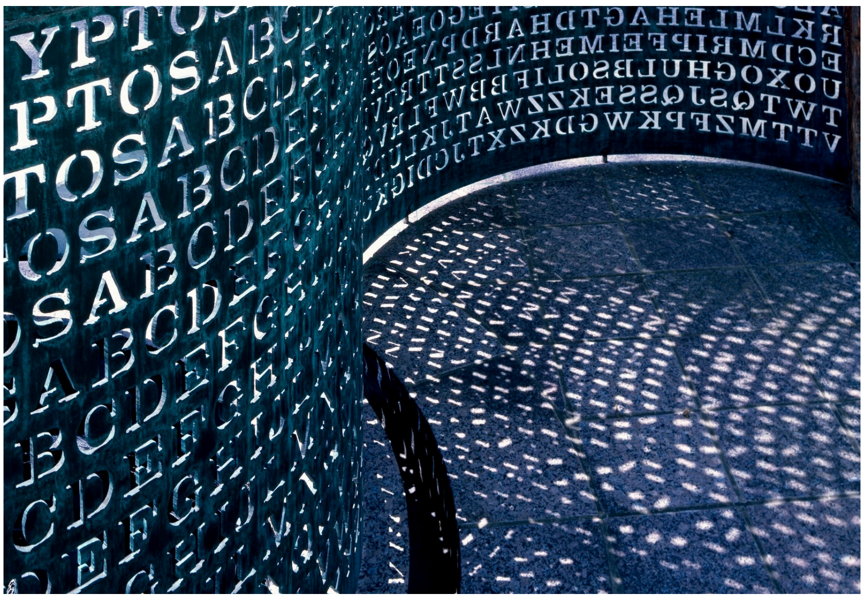
Heinrich Hemme is a physicist and a former university lecturer at FH Aachen–University of Applied Sciences in Germany.

https://www.scientificamerican.com/article/math-puzzle-wrangle-the-rectangles

How the World's Most Famous Code Was Cracked

Uncovering the CIA's Kryptos puzzle took three parts math and one part sleuthing

By Jack Murtagh edited by Jeanna Bryner



The Kryptos sculpture sits in front of the CIA headquarters in Virginia.
Carol M. Highsmith/Buyenlarge/Getty Images

The 35-year-old saga of *Kryptos*, an enigmatic sculpture containing four encrypted messages outside the headquarters of the U.S. Central Intelligence Agency, recently took a bizarre twist. Cryptographers had broken the first three passages in the 1990s, just a few years after artist Jim Sanborn erected the copper structure. But the fourth, known as K4, remained a 97-character fortress—that is, until last September, when journalists Jarett Kobek and Richard Byrne discovered the answer in the Smithsonian archives.

How does one crack the world's most famous code? The breakthroughs on *Kryptos* provide a guided tour of the cat-and-mouse game played by code makers and code breakers that has defined information security for millennia.

The core challenge of cryptography is to deliver a secret message securely in the presence of eavesdroppers. The strategy always involves the same ingredients: The message, called the plaintext, gets distorted (the encryption) so that anybody who intercepts it sees only garbled gibberish (the ciphertext). Ideally, only those with a secret key can decrypt it. If you share your secret key with the intended recipient and nobody else, then you can, in theory, communicate with them in code. Cryptography underlies everyday financial transactions and online communication, not just spy messages.

To understand *Kryptos*, we'll need to dig into early cryptosystems and why they failed. One of the simplest and oldest encryption methods dates back to a historical secret keeper: Julius Caesar. The Caesar cipher obscures messages by shifting every letter of the alphabet by some fixed amount. Here the key is a number between 1 and 25. Say we pick 5; the encryption of "hello" would be "mjqqt" because M is five letters after H, J is five letters after E, and so on. (If you reach the end of the alphabet, then wrap back around to the beginning.) In a more entertaining example, astute fans of the 1968 film *2001: A Space Odyssey* have noticed that the name of the rogue artificial intelligence called HAL is "IBM" with a Caesar-cipher shift of one letter backward. (Director Stanley Kubrick insisted that it was a coincidence.) Although Caesar trusted this method for his confidential correspondence, it's a lousy way to protect state secrets. If an adversary learns that you encrypt messages with a Caesar cipher, they need to try only 25 different keys to recover the original text.

A substitution cipher offers the most natural upgrade. Instead of merely shifting the alphabet, you scramble it. The letter A might become Q, B might become X, C might become D, and so on, with no consistent order. This *seems* far more secure. A Caesar cipher has only 25 possible keys, but a full substitution cipher has 403,291,461,126,605,635,584,000,000. (There are 26 factorial ways to mix up the alphabet, or 26 × 25 × 24 × 23 ... 3 × 2 × 1.) A brute-force search to check every key isn't feasible, yet substitution ciphers are still woefully insecure by today's standards. If you don't already know why, ask yourself how you would go about decoding a page of text encrypted in this way.

The flaw in a substitution cipher is that it leaves patterns in language intact. English has a distinct fingerprint. E accounts for more than 12 percent of all letters in English text, whereas Z crops up less than 0.1 percent of the time. If you intercept a page of gibberish encrypted with a substitution cipher and see that the letter J appears more often than any other letter, it's a good bet that J stands for E. The second most common letter is probably T. Furthermore, single letters almost certainly stand for A or I (the only frequently used one-letter English words), and common two- and three-letter words can give code breakers a foot in the door as well. Known as frequency analysis, this method is the subject of popular newspaper puzzles called cryptograms; it also played a critical role in deciphering the first three *Kryptos* passages.

To encrypt the first two *Kryptos* messages, K1 and K2—which contain 63 and 372 characters, respectively—Sanborn used the next level up: the Vigenère cipher. Invented in the 16th century and named after French cryptographer Blaise de Vigenère, it stood unbroken for 300 years, earning it the nickname "*le chiffre indéchiffrable*" (the indecipherable cipher). It works by applying several different Caesar ciphers to a single plaintext. For example, maybe we shift the first letter of the message forward by 19, the second letter forward by 16, the third letter forward by 25 and then repeat. (The fourth letter shifts by 19, the fifth by 16, the sixth by 25, and so on.) These shift amounts constitute the key, which is typically represented by a word corresponding to those locations in the alphabet. In this case, the key is SPY because S, P and Y are, respectively, the 19th, 16th and 25th letters.

The Vigenère cipher ingeniously defeats straightforward frequency analysis because not all E's, for example, will get mapped to the same letter. Imagine that the first two letters of a message are both E. We would shift the first by 19 to an X and the second by 16 to a U. But clever cryptanalysts can still break through. If you can guess the length of the key (for example, three for SPY), you can break the problem apart. You take the ciphertext's first, fourth, seventh and 10th letters, and so on, then put them in a pile. All of them were shifted according to the same key letter: S. Now you can conduct frequency analysis on just that pile. You do the same for all the letters shifted according to P: the second, fifth, eighth, and so on. The "unbreakable" cipher becomes three simple Caesar ciphers. Not sure of the length of the key? Careful scrutiny of the ciphertext can sometimes provide clues, but if all else fails, try all possible lengths. Too time-consuming? A computer program can help with the search.

Sanborn encrypted K1 and K2 with the keys "PALIMPSEST" and "ABSCISSA," respectively. The former, a poetic choice, refers to an object on which writing has been erased and something new has been written over it multiple times. An abscissa is the x value of an (x, y) coordinate pair. As is common practice in Vigenère ciphers, Sanborn also used a modified alphabet for the shifting: in this case, KRYPTOSABCDEFGHIJLMNQUVWXZ, which he etched into the sculpture.

Sanborn switched methods for K3, a 337-character ciphertext. Here he chose a transposition cipher in which he jumbled the letters in the message as though it were a massive anagram. The jumble in this type of cipher typically follows certain rules so that an intended recipient with a key can easily restore the letters to their rightful order. Cryptographers quickly suspected that K3 used this cipher. Why? You guessed it—frequency analysis. The letter distribution in the ciphertext matched what would be expected in typical English text, suggesting that letters had been shuffled, not substituted.

At least three independent efforts deciphered the first three *Kryptos* messages. Computer scientist Jim Gillogly announced that he had broken them with the aid of a computer in 1999. Only *then* did the CIA reveal that one of its analysts, David Stein, had solved all three by hand in 1998. And only then did the National Security Agency advertise that a small internal team had conquered them way back in 1992.

K4 resisted all attempts for 35 years. Perhaps Sanborn intentionally cranked up its complexity to reflect the strides made in cryptographic science since the days of Vigenère. Breaking full-fledged modern cryptography would amount to not merely a cleverer deployment of frequency analysis but a revolution in our understanding of math itself. That's because cutting-edge encryption shrouds information behind mathematical problems (such as factoring enormous numbers) that are conjectured to be unsolvable in any practical amount of time. To break the encryption, one would have to find a fast solution to these supposedly insurmountable problems, an act that would overturn a foundational assumption of modern math.

This past fall Sanborn was planning to auction off the solution to K4—an encrypted message that starts with "OBKR"—to relieve himself of the role of sole steward of its secrets. The auction announcement referenced original "coding charts" at the Smithsonian Institution. Rather than actually deciphering K4, journalists Kobek and Byrne requested access to the documents and found scraps of paper containing K4's plaintext. On September 3, 2025, the duo e-mailed Sanborn with the solution.

Journalists uncovering the answer to K4 in the Smithsonian archives perfectly exemplifies how hackers infiltrate 21st-century cryptography: through side doors. To the best of anyone's knowledge, the modern encryption that protects your e-mails and credit card purchases, when implemented correctly, works. Data breaches are rarely the result of hackers breaking an encryption;

rather people find some other weak link in the security chain. They run phishing scams to trick people into disclosing their log-in credentials. They exploit a bug in a website's code. That is, they target the flawed, forgetful and disorganized humans who use encryption. The discovery of K4's plaintext was akin to finding somebody's password scribbled on a sticky note in their office. Some find this climax disappointing, but we could also view it as a metaphor befitting of an art piece meant to honor cryptography through the ages.

The artist doesn't seem to share this perspective: Sanborn asked the journalists to sign nondisclosure agreements. (They refused but agreed to keep the plaintext a secret.) Those still longing for a puzzle are in luck because the public doesn't know what K4 says or how it was encrypted. Nobody fully understands the enigmatic messages that K1–K3 revealed. Sanborn also confirmed the existence of a K5 in an open letter published last August. Code breakers have plenty to look forward to in the next era of *Kryptos*.

Jack Murtagh is a freelance math writer and puzzle creator. He writes a column on mathematical curiosities for *Scientific American* and creates daily puzzles for the Morning Brew newsletter. He holds a Ph.D. in theoretical computer science from Harvard University. Follow him on X @JackPMurtagh

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https://www.scientificamerican.com/article/how-the-cias-kryptos-sculpture-gave-up-its-final-secret

Medicine

- ## Nobel Prize Winner Shimon Sakaguchi Reflects on How He Discovered Regulatory T Cells
  Nobel laureate Shimon Sakaguchi reflects on what role of regulatory T cells have in peripheral immune tolerance and how the cells could transform treatment for cancer, autoimmune disease and organ transplant rejection

Shimon Sakaguchi Reflects on How Hunting for a Mysterious T Cell Earned Him a Nobel Prize

Nobel laureate Shimon Sakaguchi reflects on what role of regulatory T cells have in peripheral immune tolerance and how the cells could transform treatment for cancer, autoimmune disease and organ transplant rejection

By Lauren J. Young edited by Tanya Lewis & Clara Moskowitz

Shideh Ghandeharizadeh

In 2006 immunologist Shimon Sakaguchi co-wrote an article in *Scientific American* that now feels prophetic. In the article, entitled "Peacekeepers of the Immune System," Sakaguchi and his co-author, Zoltan Fehervari, now a senior editor at *Nature*, traced a timeline of important studies that led to Sakaguchi's discovery of an elusive type of immune cell he called a regulatory T cell.

In the 1980s the field was not entirely convinced of the existence of such a class of cells, but Sakaguchi and other scientists proved that regulatory T cells, or Tregs, are the integral "peacekeepers" that prevent the immune system from overreacting and harming the body. That process, known as peripheral immune tolerance, stops the body's primary defense mechanism from entering a self-destruct mode known as autoimmunity.

The experiments Sakaguchi cataloged in *Scientific American* nearly 20 years ago were recognized in December at the 2025 Nobel award ceremony in Stockholm, where he and immunologists Mary E. Brunkow of the Institute for Systems Biology in Seattle and Fred Ramsdell of Sonoma Biotherapeutics in San Francisco shared the prize in physiology or medicine for their discoveries.

"I didn't expect it, and of course I was very much pleased," Sakaguchi says. "I'm happy to have this honor. But at the same time, I really appreciate the community of scientists who have worked together. The progress of this field is really due to the collective effort of many scientists and immunologists."

In an exclusive interview, *Scientific American* caught up with Sakaguchi on the day after the award announcement. He discussed the crucial findings that led to the discovery of regulatory T cells and the clinical trials that have harnessed these cells to potentially treat chronic infections, cancer and autoimmune diseases.

An edited transcript of the interview follows.

Shimon Sakaguchi, an immunologist and a distinguished professor of Osaka University, attends a press conference after winning the 2025 Nobel Prize in Medicine, in Suita, Osaka prefecture, Japan on October 6, 2025.
Paul Miller/AFP via Getty Images

What was your journey toward looking for cells that suppressed the immune system? What drew you to them?

I was very much interested in autoimmune diseases. Our immune system normally defends our cells from invading microbes—viruses and bacteria—but sometimes it's aggressive and destroys our body cells and causes autoimmune diseases such as rheumatoid arthritis and type 1 diabetes. So the immune system has two aspects: good and bad. What's the mechanism behind this? If we can understand that mechanism, we may be able to treat autoimmune diseases—or the opposite: make the immune system attack abnormal cells, such as cancer cells, arising in our body.

That was my interest when I was a student in medical school, and then I became a researcher to tackle this conundrum. At that time [in the 1980s], the only available approach to study autoimmunity was the mouse model. I happened to find that in newborn mice, if you remove the thymus [an organ in the chest that produces various types of T cells], they spontaneously develop autoimmunelike diseases. And then what was interesting was that if you inoculate the thymus-free mice with normal T cells from nonaffected adult mice, you can prevent disease development—meaning that in the normal collection of T cells in the thymus, there must be some cells that can prevent or suppress disease development. That was the start of my research career.

What convinced you that regulatory T cells existed when others abandoned the theory?

I was convinced that one could produce autoimmune diseases in healthy animals by just manipulating the immune system—removing certain T cells—similar to [the way they arise] in humans. That was always a very solid phenomenon for me. If other hypotheses or other ideas could explain what we saw, I would follow that concept or idea. I always compared what I believed with what other theories showed to find out which had better explanatory powers. Our results were not so bad—and were even better—so that was the reason that I continued my research on regulatory T cells.

> "It is really a key issue in modern immunology: How can we realize or understand why our immune system does not react with our body?" —Shimon Sakaguchi, *Osaka University*

For your 2006 *Scientific American* article "Peacekeepers of the Immune System," how did you come up with the name "peacekeepers" for the cells?

That was coined by my colleague and co-author of that article, Zoltan Fehervari. At that time, we talked about how we could name them and make them more relatable. And then he came up with that idea: "peacekeeper." It was a really nice name because, later on, we gradually realized that regulatory T cells not only are immunosuppressive but also have various other functions, such as promoting tissue repair. So they are peacekeepers for many things.

You essentially documented in the article, nearly two decades ago, how pivotal this work was. Did you think back then that your research would be recognized for a Nobel Prize?

Actually, I didn't. I really hoped that we could have a better understanding of immunological self-tolerance. It's a long-standing, important question in immunology. The 1960 Nobel Prize in medicine was awarded to Peter Medawar and Frank Macfarlane Burnet, who showed that immune tolerance is acquired, not innate. Well, that's really interesting, but how does it happen? There have been several theories, including clonal deletion: deleting the dangerous self-reactive clones of T cells. They are eliminated when they are immature and being produced in the immune system. But that couldn't explain how common autoimmune diseases happen—for example, type 1 diabetes or rheumatoid arthritis. So it is really a key issue in modern immunology: How can we realize or understand why our immune system does not react with our body?

Are any therapies based on or other applications of your work close to making it to the clinic?

What is fascinating about regulatory T cells is that they are specialized for immune suppression, which means that strengthening their functions or increasing their numbers could be a good way to treat autoimmunity or allergies or various other diseases. On the other hand, if you reduce the number of these cells or make their function weaker, then the immune response can be enhanced. That could be good for cancer immunity. My team and many others are pursuing both directions. There are many, many trials underway—at the Nobel announcement, the chairperson told us that more than 200 clinical trials are ongoing now.

Our approach is a bit challenging. For the cancer immunity, we're looking into how to increase the efficacy of current cancer immunotherapies. For example, current immune checkpoint blockade [a type of therapy that uses laboratory-made antibodies, or inhibitors, that block certain signals so the immune system can attack cancer cells] is maybe 20 to 30 percent effective and not curative. So our idea is: Regulatory T cells are really abundant in cancer tissue and are suppressing effective antitumor immune responses. How can we remove them in tumor tissue? Antibodies can be designed to remove Tregs. We could combine that with the current immune checkpoint blockade and maybe make the cancer immunotherapy more effective.

In the future, we could perhaps develop an oral drug of small molecules that may have a similar effect as the molecular antibodies against Tregs [molecules that are typically delivered intravenously in most trials]. Then we could improve cancer immunotherapy not only in developed countries but also in developing countries.

You mentioned that this approach could be the basis for cancer treatments. How about infections that suppress the immune system, such as HIV/AIDS?

So, increasing immune response could be good in a tumor-immunity setting and also for chronic infection. We still don't know whether it would work, but if we can strengthen the immune response by reducing Treg numbers, I think that's one idea for tackling chronic infections.

What advice would you like to give early-career scientists?

It's maybe a common one, but really what is important is this: If you are interested in something, in science or whatever, then pursue and continue working on that. Your interests may change along the course of your study or through your efforts, but you'll find something in the landscape. Someday you might realize that you are doing something different from others that's more fascinating than what you originally pursued. Nowadays you are expected to do something very, very soon and have a result. But it always takes time to arrive at something important.

Lauren J. Young is associate editor for health and medicine at *Scientific American*. She has edited and written stories that tackle a wide range of subjects, including the COVID pandemic, emerging diseases, evolutionary biology and health inequities. Young has nearly a decade of newsroom and science journalism experience. Before joining *Scientific American* in 2023, she was an associate editor at *Popular Science* and a digital producer at public radio's *Science Friday*. She has appeared as a guest on radio shows, podcasts and stage events. Young has also spoken on panels for the Asian American Journalists Association, American Library Association, NOVA Science Studio and the New York Botanical Garden. Her work has appeared in *Scholastic MATH*, *School Library Journal*, *IEEE Spectrum*, Atlas Obscura and *Smithsonian Magazine*. Young studied biology at California Polytechnic State University, San Luis Obispo, before pursuing a master's at New York University's Science, Health & Environmental Reporting Program.

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https://www.scientificamerican.com/article/nobel-prize-winner-shimon-sakaguchi-reflects-on-how-he-discovered-regulatory

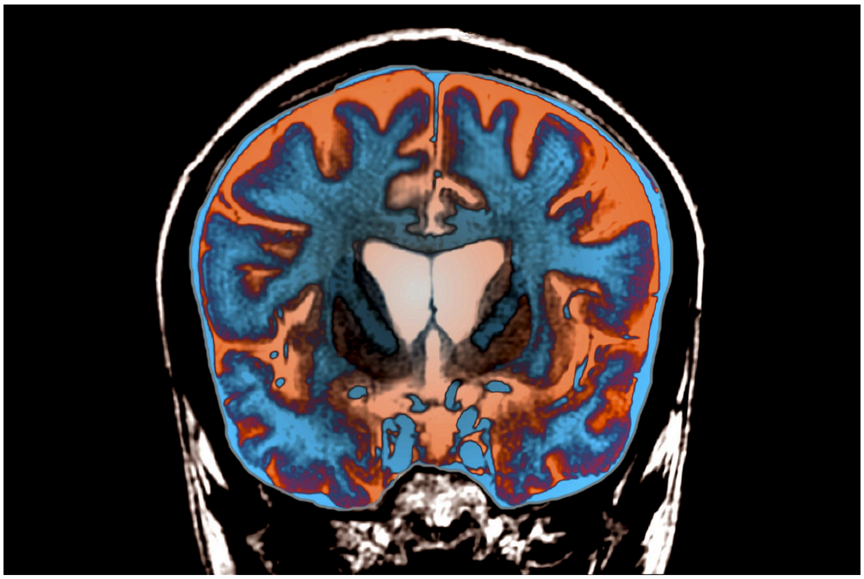
Neurology

- ## First Treatment That Slows Huntington’s Disease Comes after Years of Heartbreak
  After years of heartbreak, researchers have found an experimental treatment that can slow the progression of Huntington’s disease, according to early results from a small clinical trial

How Scientists Finally Found a Treatment That Slows Huntington’s Disease

After years of heartbreak, researchers have found an experimental treatment that can slow the progression of Huntington’s disease, according to early results from a small clinical trial

By Allison Parshall edited by Tanya Lewis & Sarah Lewin Frasier



This MRI shows Huntington’s signature brain atrophy, which a new treatment may slow.
Zephyr/Science Source

Every week neurologist Victor Sung sees people with Huntington’s disease, a rare and deadly neurodegenerative disorder, at his clinic at the University of Alabama at Birmingham. But a Wednesday in September 2025 was a day unlike any other. “I cried with every single patient,” Sung says. The results of crucial phase 1/2 clinical trials had finally been released: an experimental gene therapy drug was the first treatment that appeared to slow the progression of Huntington’s.

The treatment, known as AMT-130, is delivered deep into the brain during a surgery that lasts more than eight hours. The trials were small, with the three-year follow-up results including just 24 participants who received either a high or a low dose of treatment.

These results showed that a high dose reduced the rate of disease progression by 75 percent compared with rates in an external control group, according to the new therapy's developer, uniQure, which posted the results ahead of their review by the Food and Drug Administration. The company hopes to receive accelerated approval from the FDA, which, according to a uniQure spokesperson, could allow the drug to be approved by the end of 2026 without the need for phase 3 trials.

Sung's patients probably won't receive the drug anytime soon. But this early success has given the Huntington's community measured hope after years of disappointments. "We've had so many failures," Sung says, "and there's been a lot of heartbreak over many years in this community."

Other researchers also praised the development. "This news has really buoyed everyone's expectations of what might be possible," says Rachel Harding, a toxicologist at the University of Toronto. Harding, who wasn't involved in the trials, researches the underlying cause of Huntington's.

When someone is diagnosed with Huntington's, their treatment options are limited. Doctors can offer patients medications that address their symptoms, such as by reducing depression and involuntary, unpredictable muscle movements called chorea. But until now, nothing could slow or halt the progression of the disease itself. People usually exhibit their first symptoms between the ages of 30 and 50 and can expect to live another 10 to 30 years after that. Because the gene that causes Huntington's runs in families, people affected by the disease have often watched many loved ones struggle and die from it, too.

In some ways, Huntington's seems like it should be the easiest neurodegenerative condition to treat. Unlike the case with Parkinson's and Alzheimer's, scientists know exactly what causes the illness: a mutation of the *HTT* gene in which a short, three-letter DNA sequence is repeated many times, causing the gene to produce a faulty version of the huntingtin protein. These faulty proteins damage neurons in a deep brain structure called the striatum and cause uncontrollable muscle movements, cognitive decline, and other symptoms that worsen over time.

Researchers have traditionally focused on treatments that can lower the levels of abnormal huntingtin protein in the brain. For years the most promising treatments were antisense oligonucleotides (ASOs), which are delivered by recurring injections into a patient's spinal canal. These drugs contain small pieces of genetic material that bind to and "silence" the messenger RNA molecules carrying instructions to build the mutant huntingtin protein.

But in 2021 clinical trials of three ASOs were halted, two in phase 1/2 trials. One phase 3 trial of a drug produced by Roche called tominersen was stopped because participants in the trial's treatment group showed no improvement in their condition compared with those who received a placebo. In some cases, it appeared to exacerbate symptoms—an outcome a neurologist called "the saddest possible result."

Although this setback was devastating at the time, Sung sees it as an inevitable part of the scientific process. Developers of new therapies targeting genes often try to tackle Huntington's first because of its straightforward genetic cause—meaning it's the site of both failure and innovation. "Sometimes the first generation of the thing doesn't work out, and we move to the next," he says.

Unlike ASOs, AMT-130 is a one-time treatment, but it involves a lengthy and invasive brain surgery. Physicians insert catheters into deep parts of the brain where they can deliver the drug directly into the neurons most severely affected by the abnormal huntingtin protein. The medication is transported through "shuttles" called adeno-associated viruses—noninfectious viral shells that can carry genetic material. Once inside neurons, the payload continuously produces tiny pieces of genetic material called microRNA. These microRNA target and degrade messenger RNA carrying the instructions to build more huntingtin protein.

Patients in the clinical trial were given either a high or a low dose of the drug. Three of the participants who received high doses of AMT-130 experienced serious neurological side effects, such as swelling and severe headache. The trial was paused as a result, but it resumed after the participants recovered and the data were reviewed. From then until the end time point for the data released so far, no serious adverse events were reported. Most minor adverse events were related to the initial surgery, uniQure said, and those all eventually resolved.

It is not clear at this stage how much the treatment will cost if it is approved or how it would be paid for, but experts say it will almost certainly be very expensive. This, in addition to its invasive nature, means it likely won't be available to most people around the world who have Huntington's or carry the faulty *HTT* gene. "What it does is give us hope that perhaps huntingtin-lowering is a really viable therapeutic strategy," Harding says.

Other huntingtin-lowering therapies are currently in clinical trials—two given in pill form and two delivered via spinal tap, including Roche's tominersen for a more restricted group of people. Along with the AMT-130 results, this competitive field brings Harding hope. "I don't think it's that the others haven't succeeded," she says. "They just might not have succeeded yet."

Allison Parshall is associate editor for mind and brain at *Scientific American* and she writes the weekly online Science Quizzes. As a multimedia journalist, she contributes to *Scientific American*'s podcast *Science Quickly*. Parshall's work has also appeared in *Quanta Magazine* and Inverse. She graduated from New York University's Arthur L. Carter Journalism Institute with a master's degree in

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https://www.scientificamerican.com/article/first-treatment-that-slows-huntingtons-disease-comes-after-years-of

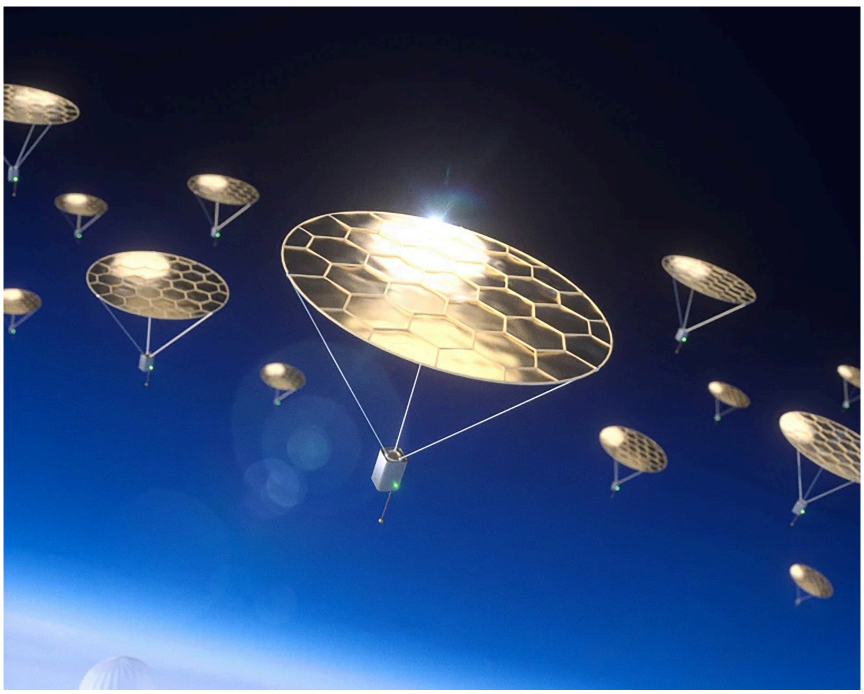
Planetary Science

- **Tiny Probes Can Surf Sunlight to Explore Earth's Mesosphere and Mars**
  With no fuel or engines, tiny explorers will surf sun-warmed air alone to explore high in the skies of Earth and Mars
- **JWST Spots Signs of Exomoon Birth in Alien Planet's Disk**
  Scientists found evidence of a distant planet's moon system forming

These Tiny Disks Will Sail on Sunlight into Earth's Mysterious 'Ignorosphere'

With no fuel or engines, tiny explorers will surf sun-warmed air alone to explore high in the skies of Earth and Mars

By Payal Dhar edited by Lee Billings & Sarah Lewin Frasier



Artist's impression of fliers carrying payloads.
"Photophoretic Flight of Perforated Structures in Near-Space Conditions," by Benjamin C. Schafer et al., in *Nature*, Vol. 644; August 14, 2025

Scientists have devised tiny featherweight disks that could float freely in Earth's mesosphere or the thin air of Mars, theoretically even while carrying payloads. Our mesosphere, which extends about 50 to 85 kilometers above the planet's surface, is sometimes called the "ignorosphere"—it's too high for aircraft and weather balloons to reach but too low for access by satellites, making it one of Earth's least-studied regions. Versions of the researchers' light-powered fliers could potentially carry sensors through this zone.

The new centimeter-wide prototype disks are made from two thin, perforated membranes of aluminum oxide connected by minuscule vertical supports. They are kept aloft by a force called photophoresis: the light-induced movement of small particles at very low atmospheric pressures. In laboratory experiments described in *Nature* simulating mesospheric air pressure and illumination, the researchers showed that their devices could float passively without any power source.

Gas molecules bounce more forcefully off the light-warmed side of an object than they do off the cooler one, creating airflow. In this case, the research team coated the bottom of each disk with chromium so it would absorb light and heat up more than the top. Thus, gas molecules pinging off the lower part gained more momentum than those at the top, generating lift, similar to the way a rocket's jet produces upward thrust. Carefully calibrated holes in the disk's structure increased this thrust, using an effect called thermal transpiration to passively channel the air from cooler to warmer regions.

"The air is not only moving around the sides of the structure—it moves *through* the structure, too, creating these little jets," says materials scientist Benjamin C. Schafer, co-lead author of the paper. This enhancement boosted the disks' performance enough to surpass that of previous photophoretic fliers demonstrated by other groups, which had required illumination several times brighter than that of sunlight.

Photophoresis was first demonstrated in the 1870s by English physicist William Crookes. He developed what came to be known as a Crookes radiometer, a toylike device that spins outstretched fins when exposed to sunlight. But because photophoresis works only at very low pressures and generates a very weak force, the phenomenon was long seen as a mere novelty. That began to change a couple of decades ago, Schafer says, as advances in nanofabrication let researchers make devices light enough to levitate with the meager force of photophoresis alone.

Using a laser to mimic sunlight, Schafer and his colleagues demonstrated photophoretic levitation on their centimeter-scale structures in a low-pressure chamber. They also designed a six-centimeter-wide version of the disk to carry a 10-milligram payload—which, in theory, would be enough to power a small communications system with a radio-frequency antenna, a solar cell and integrated circuits. The team calculates that this larger version of the disk could stay aloft at the rarefied altitude of 75 kilometers during daytime; in summertime at polar latitudes it could even fly continuously in the mesosphere.

Ruth Lieberman, a heliophysicist who worked on earlier attempts at photophoretic technology, calls it a brilliant design. “As long as the sun is shining, these things will work,” she says. “They are also made out of very inexpensive materials. Once you get past the prototype phase and can figure out how to manufacture [at scale], it strikes me as a really potentially fantastic solution for observing the atmosphere at very low cost in a way that gets you very good spatial temporal coverage.”

Schafer envisions a future in which swarms of these structures collect atmospheric data and relay telecommunications not only in Earth’s mesosphere but also in the tenuous atmosphere of Mars, which exhibits similarly low pressures. Schafer has co-founded a company that is developing new versions of the disks, and he hopes to launch payload-free atmospheric test flights soon.

Actually creating the larger disks that can carry payloads in the mesosphere or beyond is a more formidable task—perhaps a five- to 10-year project, Schafer says: “I think it’s certainly doable, but it’s going to take a lot of time and work.”

Payal Dhar (she/they) is a freelance journalist who covers science, technology and society. They write about AI, robotics, biotech, space, online communities, games and any shiny new technology

that catches their eye.

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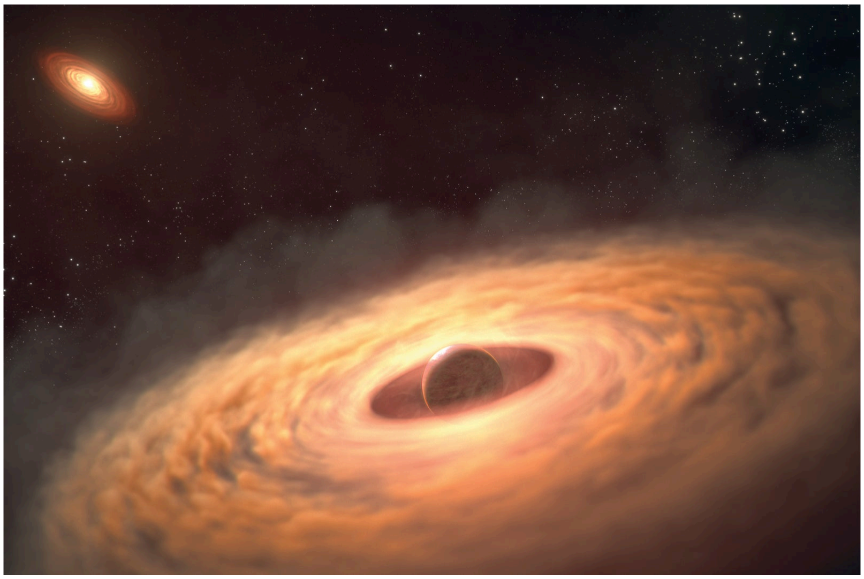
https://www.scientificamerican.com/article/tiny-probes-can-surf-sunlight-to-explore-earths-mesosphere-and-mars

| Section menu | Main menu |

James Webb Space Telescope Spots Swirling Cradle for Exomoons

Scientists found evidence of a distant planet's moon system forming

By Elise Cutts edited by Sarah Lewin Frasier



An illustrated moon-forming disk surrounds an alien planet.
NASA, ESA, CSA, STScI, Gabriele Cugno/University of Zürich, NCCR PlanetS, Sierra Grant/Carnegie Science, Joseph Olmsted/STScI, Leah Hustak/STScI

For the first time, scientists have directly detected molecules in a Frisbee of gas and dust swirling around an alien gas-giant planet. "I didn't think this was possible," says astronomer Sierra Grant of Carnegie Science in Washington, D.C. Typically such a faint signal would be invisible in the glare of a star. Grant and her co-author Gabriele Cugno of the University of Zürich, who published the results recently in the *Astrophysical Journal Letters*, think the carbon-rich disk is a lunar nursery and already have plans to observe several more; eventually researchers might be able to detect gaps carved in such disks by nascent moons.

Grant and Cugno used the James Webb Space Telescope (JWST) to pick out the infrared glow from the disk of gas and dust encircling a Goliath world called CT Cha b. Spotting light cast by a planet—let alone a disk around one—is like making out a firefly against a floodlight. It's easier if the firefly is enormous and far away from the light. CT Cha b weighs a whopping 14 to 24 Jupiter masses and orbits its star about 17 times farther out than Neptune does the sun.

Previous observations had hinted that CT Cha b was gobbling up material from a yet unseen disk, and Cugno aimed to disentangle this disk's glow of infrared heat from the star's bright gleam. Grant was skeptical it could be done, but Cugno wanted to test JWST's limits. "It was almost a game," he says.

Cugno ultimately pulled a "beautiful" light spectrum of the disk out of the data, in which Grant spotted clear chemical fingerprints of carbon-rich compounds such as hydrogen cyanide, acetylene and even molecules as complex as six-carbon benzene rings—substances absent from the material swirling directly around CT Cha b's star. The disk could be a moon-building zone around the planet.

"This might give us a hint about what material is available for the formation of exomoons," says astrophysicist Danny Gasman of the Max Planck Institute for Astronomy in Heidelberg, Germany, who wasn't involved in the study. She cautions, however, that although CT Cha b's size and extreme distance from its star make it a great target, they also mean that it might be more like a failed star than a typical gas giant.

Even in our own solar system, the origins of moons remain mysterious. Disks such as CT Cha b's offer a chance to understand not only moons of alien systems but also the moons in ours. "It's really hard to go back in time 4.5 billion years and imagine how they were created," Cugno says. "Now we can actually see this process."

Elise Cutts is a science writer based in Austria. She has written for *Scientific American, Quanta, National Geographic*, and other outlets.

https://www.scientificamerican.com/article/jwst-spots-signs-of-exomoon-birth-in-alien-planets-disk

Psychology

- ## Mondays Really Are More Stressful on the Brain and Body
  The start of the workweek can be a biologically measurable stressor, with consequences for long-term health that can stretch into retirement
- ## Why ‘Use Your Words’ Can Be Good for Kids’ Health
  Studies show that writing or expressing what we are feeling can help adults mentally and physically. Kids are no different

Mondays Really Are More Stressful on the Brain and Body

The start of the workweek can be a biologically measurable stressor, with consequences for long-term health that can stretch into retirement

By Tarani Chandola & Benjamin Becker edited by Daisy Yuhas & Allison Parshall

Oksana Stepova/Getty Images

For decades the term “Monday blues” has been shorthand for the collective groan that greets the start of each workweek. It’s also well documented in medical statistics. Mondays come with higher rates of anxiety, stress and even suicide compared with other days. Studies on the phenomenon across entire countries have found a 19 percent increase in the chance of sudden cardiac death from confirmed heart attacks and other cardiovascular events on Mondays, affecting both men and women across age groups.

It now turns out that the effect of Mondays can extend well beyond fleeting fluctuations in mood. One of us (Chandola) recently discovered that people who report feeling anxious on Mondays show evidence of heightened activity in the body's stress-response system over months. More surprising, this effect persisted among older adults who were no longer in the workforce, suggesting that, for some people, the stress of Mondays is a lifelong burden.

The biological underpinnings of the "Monday effect" have long been unclear, however. Is the type of stress and anxiety experienced on Monday biologically distinct? And could it be leaving a mark on the body even after people stop working?

To answer these questions, Chandola focused on the stress hormone cortisol. The hypothalamic-pituitary-adrenal axis, a central stress pathway linking brain and body, manages much of people's response to stress. When we experience a stressor—whether it's something psychological, such as a looming deadline, or physical, such as a biting cold morning—our brain triggers the release of cortisol. The hormone helps us manage short-term stress by mobilizing energy and sharpening focus. But chronically high levels of cortisol disrupt the brain and bodily systems, impairing immune function and increasing the risk of anxiety, depression, cardiovascular disease, diabetes and obesity.

Previous research had shown that cortisol levels can be higher on weekdays than weekends, but few studies had directly examined whether Mondays are uniquely stressful at a biological level. To investigate further, Chandola turned to the English Longitudinal Study of Aging, which follows more than 10,000 adults aged 50 years and older in England.

Chandola focused on a subset of these participants, asking them questions such as, "Overall, how anxious did you feel yesterday?" People also reported which day of the week "yesterday" was. To assess the long-term biological toll of stressful days, the study analyzed cortisol levels in participants' hair samples to measure cumulative cortisol production over the past two to three months.

Of the 3,511 participants, 281 people reported feeling anxious on a Monday and 1,080 on another day of the week. Some of these volunteers also provided a hair sample, which let Chandola compare cortisol levels between groups. Crucially, the study also considered whether participants were working or retired to see whether the Monday effect was tied to the all-too-real demands of starting the workweek.

The results were striking. Older adults who reported feeling anxious on Mondays had, on average, 23 percent higher levels of cortisol in their hair samples collected up to two months later, compared with those who felt anxious on other days. This association was strongest among those with the highest cortisol levels—a group at particular risk for health problems associated with chronic stress.

In contrast, anxiety reported on other days of the week did not predict higher cortisol levels. And the effect was not limited to those still working; retirees who felt anxious on Mondays also showed elevated cortisol. In other words, the biological impact of Monday anxiety appears to persist even after the regimen of the workweek fades from daily life.

One reason people show elevated cortisol on Mondays is that they feel more anxious on that day than on others. But that's not the full explanation. The data show that the effect of anxiety on cortisol is magnified on Mondays. In other words, feeling anxious on the first day of the workweek has a much larger effect on the body's stress hormones than feeling anxious on other days.

Why might Mondays in particular exert a powerful effect on the body? One possibility is that the transition from the weekend to the structured demands of the week is inherently stressful, and some people adapt to it better than others. Another is that Mondays present a higher level of uncertainty. Previous research from one of us (Becker) has indicated that anticipation and uncertainty represent key drivers of stress and anxiety. For those who don’t adapt to the weekly cycle, the repeated stress of Mondays may accumulate over the course of a lifetime, eventually leading to long-term problems in the body’s regulation of the stress system, which in turn can increase the risk of disease.

It is also possible that some people get anxious on Mondays so routinely that it becomes an automatic bodily response, one that persists even when the original trigger (such as a stressful job) is gone. This effect could reflect deeply ingrained habits of mind and body shaped by decades of routine.

Our findings indicate that, for some people, Monday blues are not a minor personal inconvenience but a persistent stressor with long-term—perhaps lifelong—detrimental effects on physical and mental health. The increased risk of heart attacks and other health events on Mondays is unlikely to be a random coincidence. Hospitals and clinics may need to plan for a surge in events at the start of the week, especially among older adults.

In addition, interventions aimed at helping people adapt to the start of the week might have long-term health benefits. The brain’s stress response is plastic, meaning it can change. Practices that support emotion regulation, including meditation, mindfulness, regular physical activity and good sleep hygiene, may help recondition the brain’s weekly cycle and attenuate stress-related health risks.

Finally, researchers will need to investigate why some people are resilient to Monday anxiety and others are not. That question could guide future studies and mental health strategies, opening the door to interventions that help people start the week not just with a groan but with greater resilience.

IF YOU NEED HELP

If you or someone you know is struggling or having thoughts of suicide, help is available. Call or text the 988 Suicide & Crisis Lifeline at 988 or use the online Lifeline Chat.

Are you a scientist who specializes in neuroscience, cognitive science or psychology? And have you read a recent peer-reviewed paper that you would like to write about for Mind Matters? Please send suggestions to Scientific American*'s Mind Matters editor Daisy Yuhas at* dyuhas@sciam.com.

Tarani Chandola is a chair professor of medical sociology at the University of Hong Kong. He investigates the social determinants of health, particularly the ways stressful living and working conditions can influence health in later life.

Benjamin Becker is a full professor of psychology and cognitive neuroscience at the University of Hong Kong. He studies how the brain constructs emotion and motivation and how such actions interact with mental health, neuropeptides and new technology, including artificial intelligence.

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https://www.scientificamerican.com/article/mondays-really-are-more-stressful-on-the-brain-and-body

Why ‘Use Your Words’ Can Be Good for Kids’ Health

Studies show that writing or expressing what we are feeling can help adults mentally and physically. Kids are no different

By J. David Creswell edited by Megha Satyanarayana

nadia_bormotova/Getty Images

In a desperate parenting moment after dinner, I told my six-year-old, who was mid-meltdown, “Use your words!” He had just started yelling and hitting his eight-year-old sister because she wasn’t sharing a stuffed animal he believed was his. Both kids froze for a second, giving me just enough of a pause to slow my own quickly rising emotions.

Looking back, I realize I never actually explained to my kids why words can help. But putting feelings into words is how we begin to name what’s happening inside us, and that naming can start to change the experience itself. Sometimes, as research shows, the words we choose to describe our lives can shape our mental health for months and years to come.

As a psychologist who has spent the better part of two decades studying stress and resilience in my Health and Human Performance Laboratory at Carnegie Mellon University, I explore how verbalizing our feelings can transform experience. It can help us manage heated moments and also supports healing from life's hardest situations. Research published over the past 40 years on expressive disclosure—literally, using your words—shows it can lead to significant health improvements, especially for those coping with stressful life events. After writing about a challenging situation, people report fewer doctor visits, reduced pain, stronger immune function, and better outcomes for conditions such as asthma and arthritis.

There are some rules of thumb we've learned from these studies with adults. First, writing about a difficult life event three or four times in close succession (such as on consecutive days) tends to be more effective than spreading the sessions out. Second, the sweet spot for the duration of each writing session seems to be at least 15 minutes; shorter sessions can even backfire, making health worse. Third, for those who don't like to write, talking through one's feelings works just as well. In fact, when one study directly compared talking and writing, talking came out ahead because people can express more in 15 minutes when speaking than when writing.

> Putting feelings into words is how we begin to name what's happening inside us, and that naming can start to change the experience itself.

One reason talk therapy can be so transformative is that it helps people put words to their experiences in a safe, structured way. In one study, psychologist Jonathan M. Adler of Olin College of Engineering in Needham, Mass., followed a group of adults who wrote narratives about themselves over 12 psychotherapy sessions. He found that as the participants began to describe themselves with a greater sense of agency—seeing themselves as active authors of their own lives—their mental health got better. He noticed that the change in the stories came first, followed by improvements in well-being. For parents, this observation is a reminder that helping kids tell their own stories with a sense of choice and authorship, whether about a playground conflict or a family move, can plant seeds of resilience.

One finding that surprised me is that translating our feelings into words can transform the feelings themselves. Neuroscience studies show that the act of naming one's emotional experience (for instance, as "angry") activates emotion regulation circuits in the brain's prefrontal cortex. In the scientific literature, this process is called affect labeling, and it has far-reaching clinical benefits. In one study, participants with a spider phobia who labeled their feelings during exposure therapy—while sitting next to a tarantula—had a reduced physiological stress response to spiders one week later relative to participants who used other strategies such as distraction.

Not only does taking a hot emotion and putting it into words have the potential to blunt its immediate force, but expressive disclosure also can reshape our emotional memories. When we narrate troubling experiences, whether by writing or by speaking, we aren't simply recalling a memory. We are pulling it up from long-term memory, reshaping it with our words and then putting it back into long-term storage as a new, altered memory. This process, known as memory reconsolidation, gives us a window of time to change how that memory is structured. When we describe painful or overwhelming events, we don't just relive them. We reorganize them. We add meaning, emotional context and resolution. In doing so, we can reduce the distress these memories trigger and make them easier to live with.

When I was a graduate student, I saw how powerful words could be. I spent one year reading and coding expressive essays from women who had survived breast cancer. What struck me was how often they talked about their sense of purpose, their close relationships and their personal values. These women were examining their emotional lives, reconsolidating their memories and experiences, and reaffirming what they cared most about.

Similar expressive writing programs are being explored with children and stem from research by psychologist John Gottman, now an emeritus professor at the University of Washington, who introduced a parenting approach called emotion coaching two decades ago. A recent review shows these newer expressive writing programs have small but meaningful effects on improving outcomes for emotional well-being among kids ages 10 to 18 years old. There's even some indication that these programs can enhance school achievement among kids who have significant emotional problems. Even for young kids, storytelling and drawing can help make sense of big emotions, especially when guided by a teacher or parent.

Of course, not every child is ready or able to use their words in the same way. Children with early speech delays or kids who are neurodivergent may find verbal expression especially hard in emotionally charged moments. For these children, emotion coaching might include pictures, physical prompts, or co-regulation through practicing a calm presence. My lab has been working on a new mindfulness meditation training app that can help parents develop calm-presence skills, with some of our initial clinical trials showing that learning these skills reduces biological markers of stress and boosts social connectivity. These skills develop gradually. The key is to be flexible and patient and to meet your child where they are.

"Use your words" is a tool, and like any tool, it takes practice for someone to use it effectively. If you've tried saying it to your child in the middle of a tantrum, you know it doesn't always work all that well. Big emotions often shut down a child's ability to think clearly, let alone speak. My family has learned that the most important changes often happen outside those intense moments. My wife and I try to talk with our kids when they're calm, helping them reflect on what strong emotions they might have had earlier that day and how they want to respond the next time they feel angry or overwhelmed. These conversations build emotional vocabulary and give our kids a sense of choice about how to act.

What else can parents do? Try a bedtime check-in with your child: "What was the hardest part of your day?" Gently explore it with them: "What were you feeling when that happened?" Parents can also model emotion language by saying something like, "I'm feeling frustrated right now, so I'm going to take a breath." These small moments can build a child's emotional vocabulary and can help foster a new family approach to relating to emotional lives. These techniques can work especially well when integrated into a daily rhythm, so the habit of naming feelings becomes a natural part of family life.

Sometimes we see it pay off. Our eight-year-old daughter now announces, "I'm so mad!" when she's frustrated—naming the feeling instead of acting on it. My six-year-old is trying new ways to ask his sister to share her toys, and sometimes it even works. When using their words helps them get what they want or helps them solve a problem, it creates its own reward loop. Over time these small moments of language aren't just about resolving conflicts; they help our kids start to see themselves as capable actors in their own stories, which, as research shows, is a foundation for lasting well-being.

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https://www.scientificamerican.com/article/why-use-your-words-can-be-good-for-kids-health

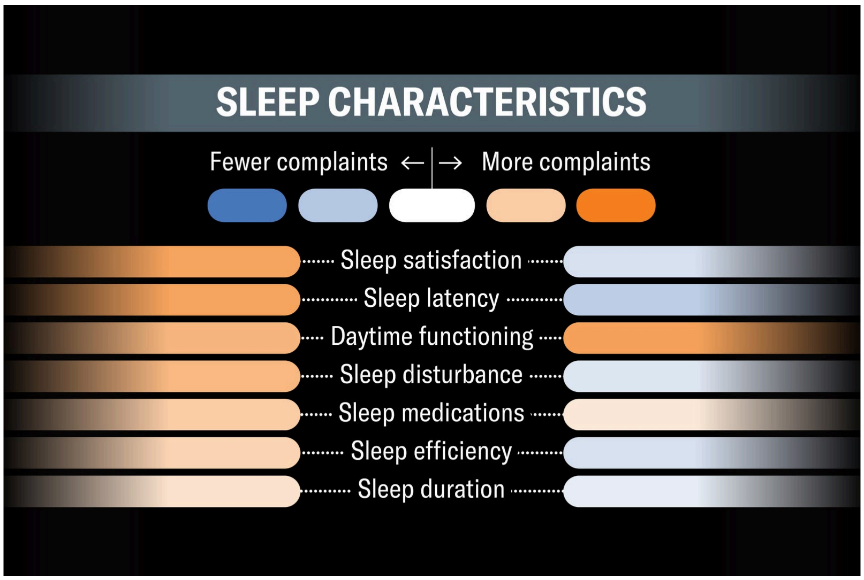
Sleep

- **What Your Sleep Profile Reveals about Your Health**
  Psychological data and brain scans show how sleep can improve our lives, our bodies and our relationships

Which Sleep Profile Are You? The Answer Shapes Your Health

Psychological data and brain scans show how sleep can improve our lives, our bodies and our relationships

By Clara Moskowitz edited by Jen Christiansen



Jen Christiansen

A night of solid rest can feel like a panacea. The quantity and quality of our sleep influence our physical health, our moods, our cognition and our ability to function in almost every aspect of life. Good sleep seems to improve all these measures, and bad sleep takes a significant toll. Yet sleep can't be divided into such a simplistic binary—researchers are coming to understand that it's more complicated.

In a recent study, scientists analyzed brain scans and data on how shuteye affects many different measures of health. The dataset is based on self-reports from 770 healthy young adults. The researchers used statistical analysis to show that the complex relation between sleep and health can be boiled down to five different profiles that describe how certain patterns of sleep are associated with changes in various aspects of our biological, physical and social lives. “You’re not either one or the other of these profiles,” says study co-author Valeria Kebets of Concordia University in Montreal. “We all express these profiles to a certain degree at some point in our lives.” The researchers also emphasized that causality goes both ways: sometimes bad sleep damages our health, but problems in our lives and bodies can also cause sleep cycles to suffer.

The profiles point to ways to improve sleep and health. Taking sleeping pills may hamper your memory, for instance, but could benefit your social relationships. And sleeping for at least six to seven hours a night might boost your cognitive performance and diminish your aggression. “Sleep is very individual,” Kebets says. “But there are some things that can definitely improve sleep.” These factors include going to bed at around the same time every night, following a set bedtime routine, and not consuming alcohol right before you try to sleep.

PROFILE 1: GENERALLY POOR SLEEP

This profile shows that worse sleep is related to worse mental health. People who take a long time to fall asleep, who wake up often and who don’t sleep for very long tend to be more anxious and more depressed and to have more intrusive thoughts.

PROFILE 2: SLEEP RESILIENCE

This profile applies to people who may have mental health concerns, especially issues with focusing and ADHD, but report no sleep complaints. It shows that psychological problems aren’t always associated with poor sleep.

PROFILE 3: SLEEP AIDS

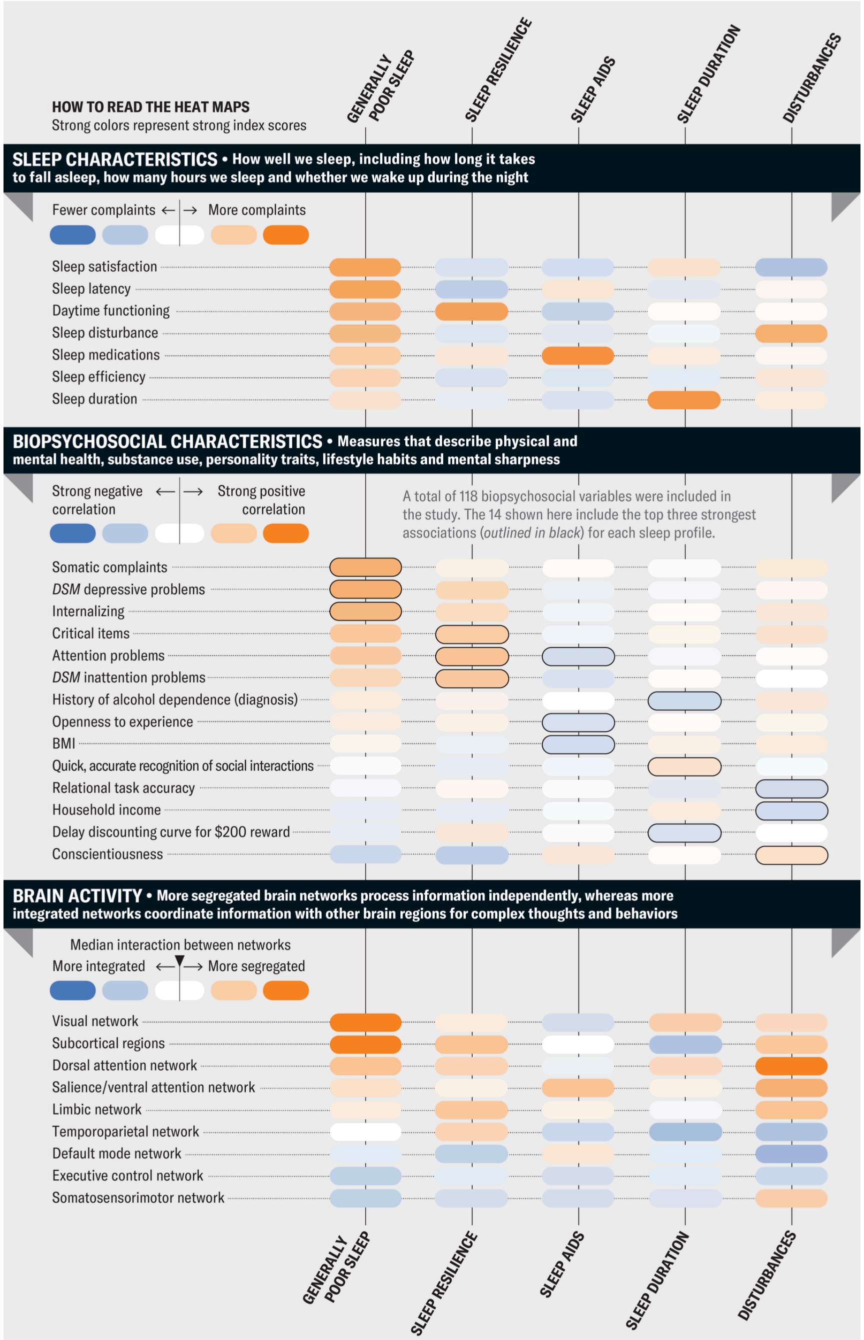
This association reveals that taking sleep aids, including prescription drugs, CBD, teas, or any other soporific, is related to worse episodic memory and emotional recognition. Interestingly, though, people who take sleep aids tend to feel more satisfied with their social relationships and support system.

PROFILE 4: SLEEP DURATION

A lack of sleep—specifically, getting less than six to seven hours a night—is linked to worse cognitive performance. People in this profile reported issues with problem-solving, emotional processing, language tasks and social cognition. They also felt less agreeable and more irritable.

PROFILE 5: DISTURBANCES

Those who report disturbed sleep, such as multiple awakenings, breathing issues and uncomfortable body temperatures, also say they experience mental health symptoms such as increased anxiety and depression, substance use and more aggressive behavior. They also have trouble with memory and language tasks.



Jen Christiansen; Source: "Identification of Five Sleep-Biopsychosocial Profiles with Specific Neural Signatures Linking Sleep Variability with Health, Cognition, and Lifestyle Factors," by Aurore A. Perrault et al., in *PLoS Biology*, Vol. 23; October 2025 (*data*)

Clara Moskowitz is chief of reporters at *Scientific American*, where she covers astronomy, space, physics and mathematics. She has been at *Scientific American* for more than a decade; previously she worked at Space.com. Moskowitz has reported live from rocket launches, space shuttle liftoffs and landings, suborbital spaceflight training, mountaintop observatories, and more. She has a bachelor's degree in astronomy and physics from Wesleyan University and a graduate degree in science communication from the University of California, Santa Cruz.

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The Sciences

- ## Science Carries On. Here Are Our Top Topics for 2026
  Whether space, health, technology or environment, here are the issues in science that the editors of Scientific American are focusing on for 2026

Science Carries On. Here Are Our Top Topics for 2026

Whether space, health, technology or environment, here are the issues in science that the editors of Scientific American are focusing on for 2026

By The Editors

NASA

The editors of *Scientific American* look to 2026 as a chance to peer into the future to see what science may be unfolding and what discoveries may lurk on the horizon. But the new year is also a chance to look back at recent turmoil and instability in federally funded scientific research, the wholesale dismissal of evidence in policymaking, and—in spite of these things—the perseverance of people working in the scientific enterprise. We celebrate the fact-checkers in the field of knowledge and you, our readers, who continue to trust us to bring you what's real, what's factual and what's amazing in our world. Here are some of the topics we are paying attention to in 2026.

Nuclear Energy

The coming year in the U.S. will be pivotal in the renewed push to use more nuclear power. This drive results largely from the energy requirements of the artificial-intelligence boom. Demand for nuclear power has largely been flat in this century, eclipsed by interest in wind, solar and natural gas. Moves in Congress—notably, a 2024 law streamlining reactor licensing—and actions by both the Biden and Trump administrations to push exports and arrange financing aim to reverse the trend. Advanced technology demonstrations supported by the U.S. Department of Energy may start to come to fruition. But loosened export regulations and favored technologies raise questions about safety, nuclear waste disposal and the risks of nuclear proliferation. Projections of spiraling energy demand for AI drive the nuclear push, despite warnings of an AI bubble that might burst, dragging down the entire economy.

In the meantime, the U.S. bombing of Iran's nuclear facilities in June 2025 put nuclear weapons back in the world's spotlight, returning an almost forgotten fear from the cold-war era to the geopolitical stage. The bombing killed Iran's already faltering agreement to not develop enriched uranium for nuclear weapons, and such efforts are already showing signs of renewal. President Donald Trump has made garbled calls, walked back by Secretary of Energy Chris Wright, to resume U.S. nuclear testing. The last time we tested nuclear weapons was in 1992. How these things play into the renewal of the weapons-limiting New START Treaty with Russia, which expires in February, will be one of the leading nuclear storylines of 2026.

Disaster Response

The Trump administration is trying to reduce the federal government's responsibility for disaster response by downsizing the Federal Emergency Management Agency and shifting the burden to states and local jurisdictions. To that end, government officials have fired or suspended multiple FEMA staffers, including ones who signed a letter to Congress decrying the cuts. They've also tried to halt federal grants for disaster preparedness and declined disaster declarations and funding for some places.

Any major disaster in 2026 will be a real test—even FEMA has struggled to handle disasters on the scale we have recently had to confront, and small towns will suffer disproportionately without needed federal assistance. FEMA had only just started putting more emphasis on preparation and disaster prevention, which are infinitely less expensive than response.

Space

The moon continues to be a hot destination for both public and private space exploration. NASA's Artemis II mission is set to launch as early as February, taking four astronauts on a 10-day journey around the moon in what would be the U.S.'s first crewed lunar mission in more than 50 years. In preparation for lunar landings later this decade, 2026 will see ongoing test flights of Space X's Starship vehicle, not to mention Firefly Aerospace's effort to deploy a lunar satellite for the European Space Agency and to deliver payloads to the far side of the moon.

Meanwhile NASA's Nancy Grace Roman Space Telescope is set to launch in autumn 2026. It will survey the cosmos for dark energy and dark matter while simultaneously honing its exoplanet-imaging skills.

Space exploration has truly become a global venture. We are watching efforts from India, China and Japan. China is set to launch Xuntian, a space telescope that will orbit with the country's space station, Tiangong. India's Gaganyaan orbital spacecraft is likely to conduct an uncrewed test mission in 2026. Japan's

Martian Moons eXploration mission will head to Phobos, one of Mars's moons, to collect samples to bring back to Earth.

Health and Medicine

We will be watching how the U.S. responds to health crises when it is in the dark about public health data. Cuts and layoffs at our public health agencies are already making it harder to detect major problems—foodborne-illness outbreaks, rates of severe illness from infectious diseases, deaths from drug overdoses and biosecurity threats from abroad.

Will the U.S. lose its measles-elimination designation? Canada lost its designation in late 2025, and we'll probably continue to see outbreaks of new and existing diseases such as COVID, whooping cough, bird flu and seasonal flu. With vaccination rates declining and trust in public health experts eroded by the current administration's health leadership and deep cuts to our public health infrastructure, vaccine-preventable diseases that have been eliminated from the U.S. for decades could come roaring back.

This year could also bring breakthroughs in new therapies for autoimmune diseases, transplants and cancer. The 2025 Nobel Prize in medicine honored advances in regulatory T cell (Treg) therapy, and the first Treg-based therapy could be approved by the U.S. Food and Drug Administration for blood cancers as early as this year. There's also ongoing progress in chimeric antigen receptor (CAR) T cell therapy and other immunotherapies for cancer, as well as in personalized cancer vaccines. We are curious about how lower drug pricing might affect the uptake of GLP-1 weight-loss drugs such as Wegovy.

Conservation

The federal government is trying to change the definition of the word “harm” in the Endangered Species Act to make it refer directly and only to animals and not to their habitats. If this change succeeds, it could make it easier to log, mine and build on lands that endangered species inhabit and need to survive. At the same time, the administration is trying to remove protections for gray wolves and wants to roll back parts of the Marine Mammal Protection Act. Since the act’s passing, not one marine mammal has gone extinct. We are watching to see how this situation might change.

In the meantime, misleading claims from Colossal Biosciences about reviving extinct species could harm conservation efforts. In 2025 the biotech company said it had “de-extincted” the dire wolf, and it has announced intentions to resurrect the thylacine (the Tasmanian tiger), the dodo and the flightless moa bird, not to mention its original claim to fame: an attempt to bring back the woolly mammoth. If people trust these pronouncements, they may question the necessity of protecting species that are currently imperiled at a time when public support for conservation is needed more than ever.

Artificial Intelligence and Technology

Will 2026 be the year the U.S. finally enacts comprehensive data-privacy laws? Technology companies are now stockpilers of global data, whether from wearable health-metric devices or smart-home voice recordings. State-by-state regulations will not be enough to manage users’ rights—the patchwork of laws will create too much confusion and too many loopholes.

It’s time for the American Privacy Rights Act, or similar legislation, to become the law of the land, and it’s time for holdouts in both major political parties to come together. This issue affects more than just consumers—responsible developers who do not opt to sell data on the global marketplace cannot compete easily with those who do. We need a law that sets clear limits on data collection, use and sharing. That law needs to have strong enforcement standards to challenge the powerful firms that will try to skirt their responsibilities. This law should also guarantee people the right to access, correct and delete their data. Other countries are taking this action. We should be, too.

Information Sciences

In 2026 we are expecting to see continued efforts to ban certain books. Since 2021 PEN America, which maintains an Index of School Book Bans, has counted more than 22,000 bans across 45 states. In an October 2025 interview, Kasey Meehan, director of PEN America's Freedom to Read program, told *Publisher's Weekly* that states such as Oregon and Massachusetts have been successful in fighting censorship. But the strength needed to combat these bans comes from large organizations such as Authors Against Book Bans, EveryLibrary, the American Library Association and Penguin Random House, as well as PEN, who are all already attempting to offer "pre-emptive protection against book banning" in schools and libraries, Meehan said.

While books are being censored, writers across genres are facing an existential threat from artificial intelligence. AI systems have often used copyrighted material without compensating the creator—a practice being challenged in multiple lawsuits. In addition, the use of AI to create works of art is leading people to question societal definitions of what it means to be an artist or a creator. In a 2025 report entitled *A.I. and the Writing Profession,* ghostwriting agency Gotham Ghostwriters states that 61 percent of surveyed authors across the writing profession said they use AI, yet only 7 percent have published AI-generated text. Those numbers could shift dramatically as the technology, backed by billion-dollar companies, continues to spread into the realms of education and even research and to impact common organizational tools.

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