ScienceNews

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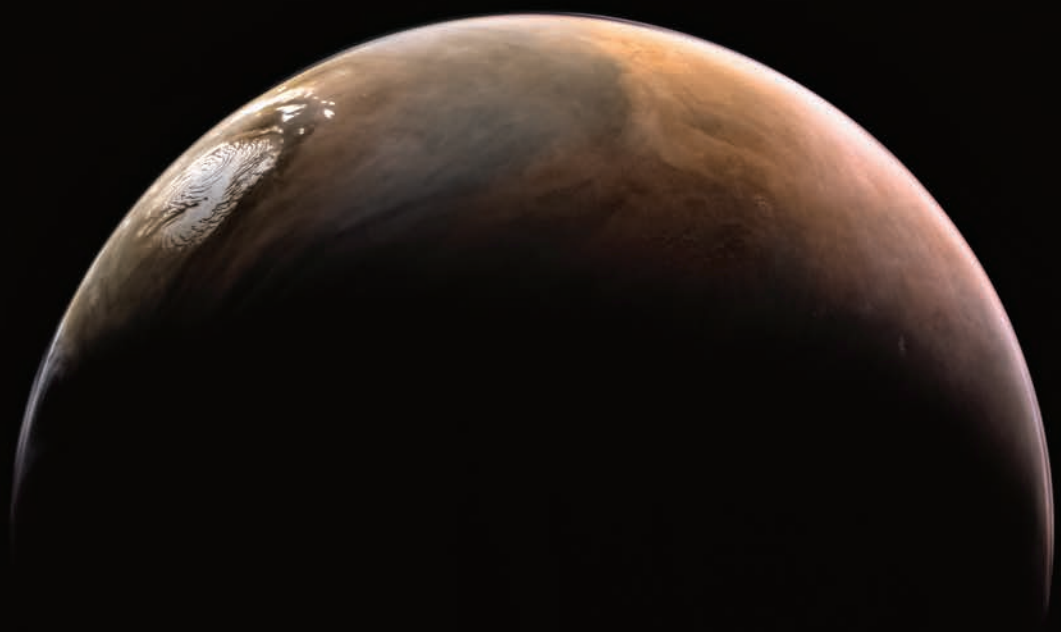
MARS IN LIMBO



Turmoil on Earth is confounding a decades-long quest to find Martian life

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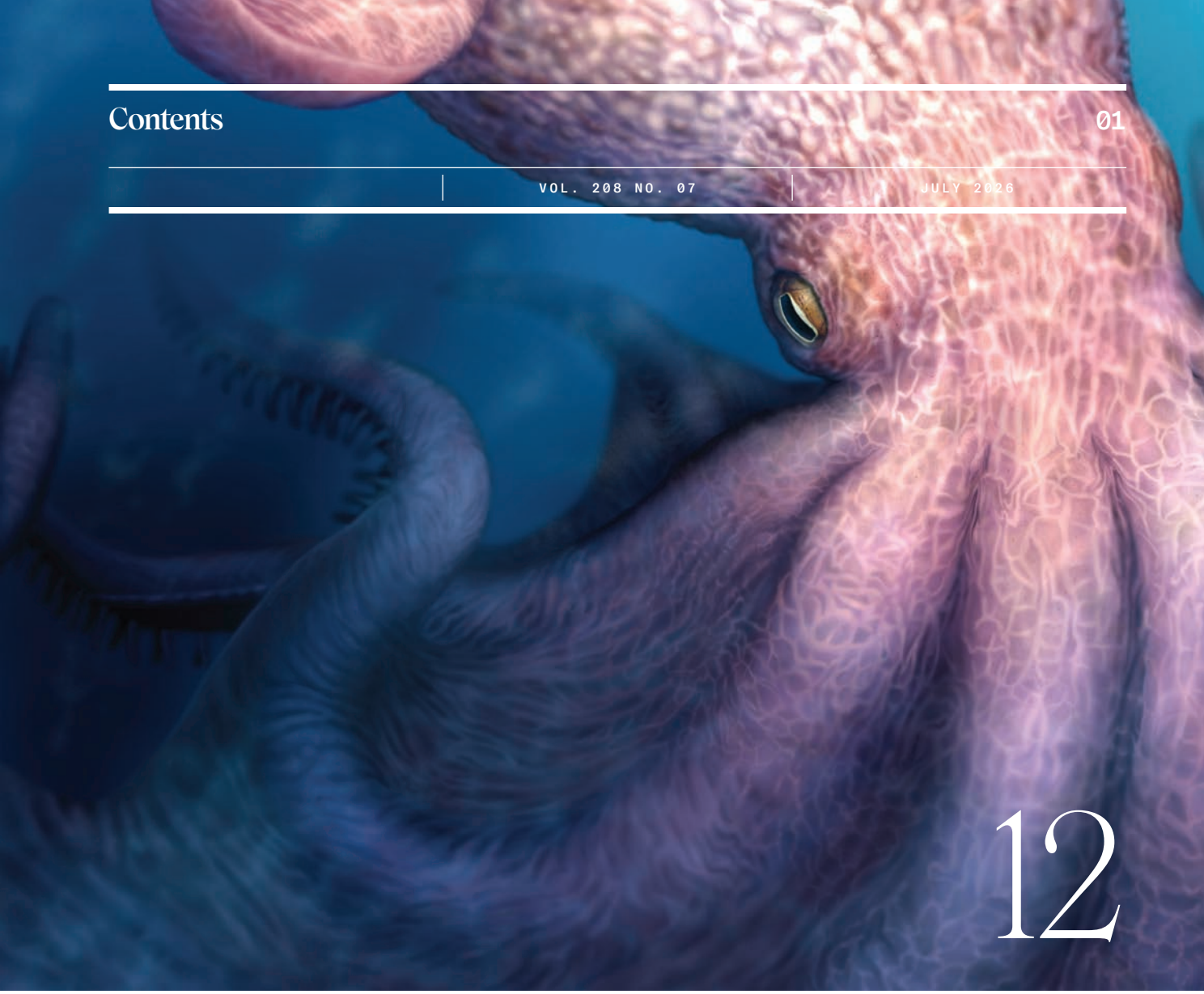

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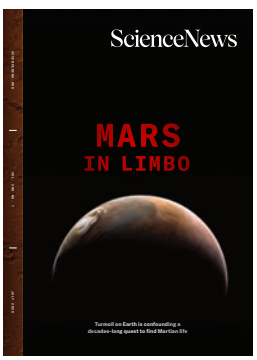
News



On the Cover

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YOHEI UTSUKI/DEPARTMENT OF EARTH AND PLANETARY SCIENCES/HOKKAIDO UNIV.

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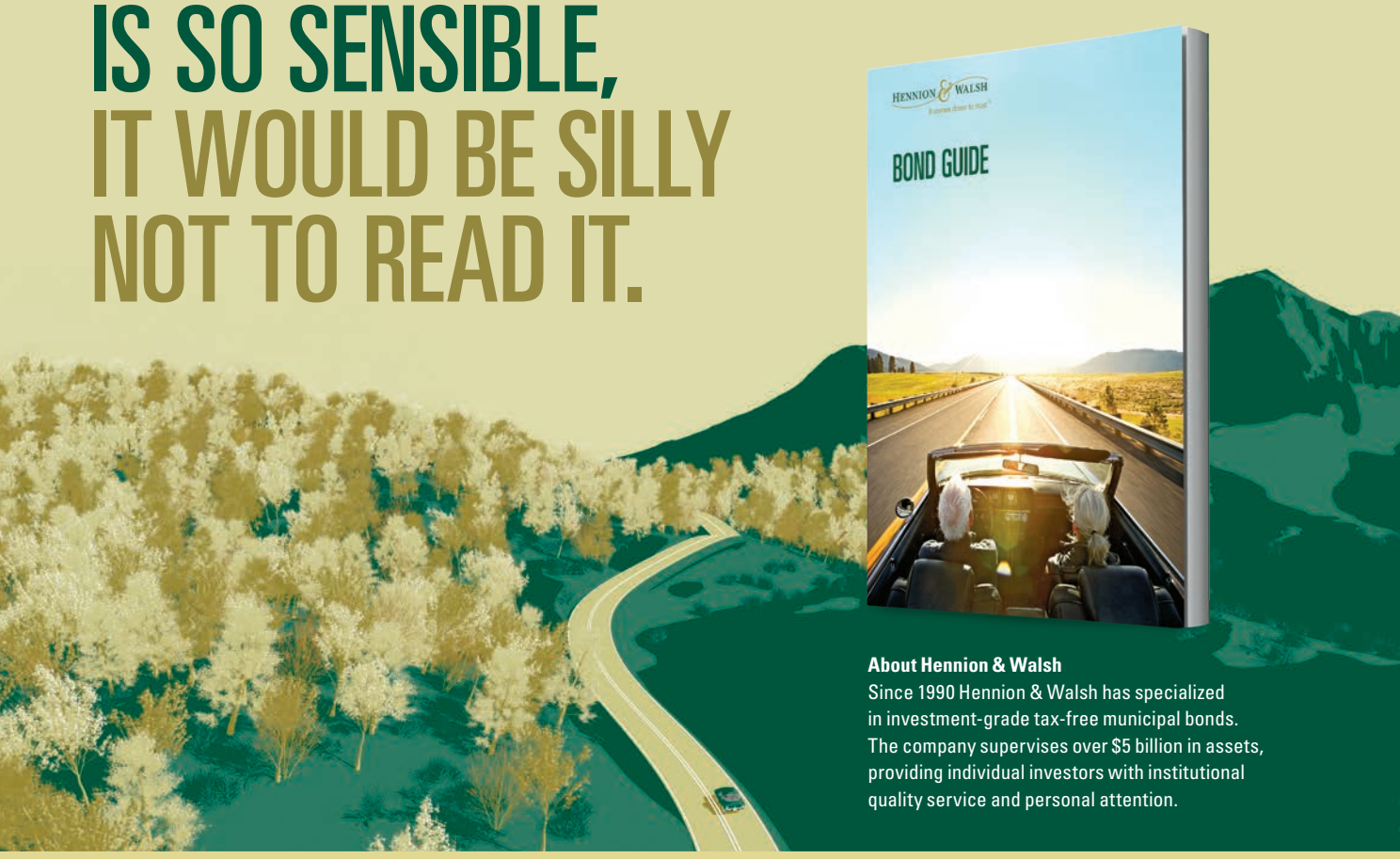

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Features

Curiosities

FROM TOP: CARLA THOMAS/NASA; ANDREEA DUMUTA

Is NASA falling out of love with Mars?

Earth may be our beloved home planet, but Mars exudes main character energy.

Earthlings have long yearned to travel to the Red Planet and check whether it harbors any kind of life. In July 1976, we used a robot to start looking: The Viking 1 spacecraft landed that month, followed by Viking 2 in September. The Viking twins started sending back photos and data from experiments designed to seek out life on Mars. One of the first lessons learned was that it's hard to run scientific experiments from 23 million kilometers away.

On the 50th anniversary of that historic landing, we look back at the failures and successes of Mars exploration since Viking (Page 40). Senior astronomy writer Lisa Grossman reports on the discoveries and setbacks that have steered the hunt for Martian life, including NASA's revised approach of looking for habitable conditions before directly seeking evidence of life. As Grossman writes, the wealth of information we now have about the Red Planet has reinvigorated scientists' excitement for finishing what Viking started.

The next step would be to bring samples to Earth for proper study. "The technology is either there or very close to there," Grossman told me. "NASA has been landing stuff on Mars now for a very long time and has gotten very good at it." The Perseverance rover, for example, has been collecting rock samples since 2021 and caching them for return to Earth.

But Congress cut funding for the Mars Sample Return mission in 2024, leaving the project at a standstill. Most of NASA's efforts are instead being directed toward the Trump administration's focus on sending people back to the moon. But Grossman notes that continued study of Mars is key to finding out if there really is, or ever was, life there — and to also learn what it would take to someday visit that intriguing red neighbor in person.

In this issue, we also explore life in the extreme environment of Earth's stratosphere (Page 30). The big news: Not only do microbes live 30 kilometers up, they shuttle between surface and sky and include common plant pathogens. Life on Mars, should it exist, might end up being a lot more familiar-looking than we expected.

Nancy E. Shute

Nancy Shute
Editor in Chief
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LISA GROSSMAN

SENIOR ASTRONOMY WRITER

● LISA GROSSMAN WAS IN 3RD GRADE. Her class had just learned about microorganisms and the solar system. The teacher connected the two lessons by talking about the possibility of life beyond Earth. "The idea that life — not aliens in sci-fi but real organisms that exist on Earth — could live on other planets just grabbed hold of me and never let go," Grossman says. Space (and life in space) became her prime obsession. For this issue's cover story, Grossman follows her lifelong passion and reports on the status of the search for life on Mars (Page 40). As she grew older, she learned how complex the question of life beyond Earth is. What do we mean by life? How would we recognize it? What kind of life? "There are so many more ways to attack the question than I knew about when I was 8," she says.

Jake Buehler
Freelance science writer Jake Buehler developed a passion for zoology from an early age. Growing up in rural areas of the U.S. Pacific Northwest, Buehler spent most of his time hiking and fishing. So it's no surprise that he became an evolutionary biologist and eventually a science writer who focuses on animals (Pages 12, 17, 19 and 23). Writing about cool critters is grounding when "there's a lot of doom and gloom," Buehler says. "Animals have been exhibiting cool phenomena for millions of years, regardless of our day-to-day lives. It reminds us of the shared evolutionary history."

Mićo Tatalović
More of an Art is a new column that explores the intersection of art and science (Page 60). For its debut, freelance science journalist Mićo Tatalović highlights a scientist and artists who teamed up to turn data into sounds to make music. Their aim? To engage people with space weather research. Initially, "the idea came across as wacky," Tatalović says. "I was first attracted by the space sounds, then I learned about the intriguing science. Finally, I explored the music and found it to be nice and relaxing," he says. "I imagine a reader could take a different journey depending on their interests and backgrounds."

Mandana Tadayon
To celebrate America turning 250 years old, the United States Botanic Garden has a new exhibit showcasing the official flowers of each state and territory. To complement *Science News*' review (Page 56), senior producer Mandana Tadayon has created TikTok videos featuring various flowers and scientific facts about them. "As a video person, I'm always attracted to visually attractive things," she says. "And flowers always make for good footage." Check out the videos on tiktok.com/@sciencenewsofficial and request to see your state's flower in the comments!

CLOCKWISE FROM TOP LEFT: LEISE JONES PHOTOGRAPHY; NICOLE BERRY; COURTESY OF M. TATALOVIĆ; M. TADAYON

LIFE

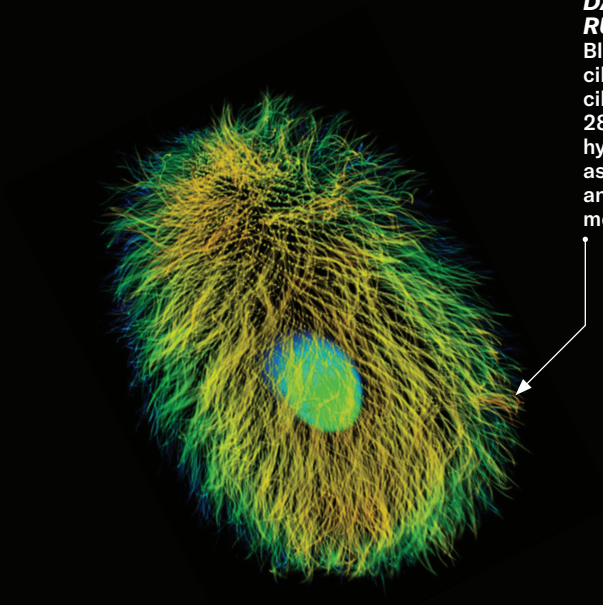
THE FUZZY MICROBES BEHIND COW BURPS

By Tina Hesman Saey

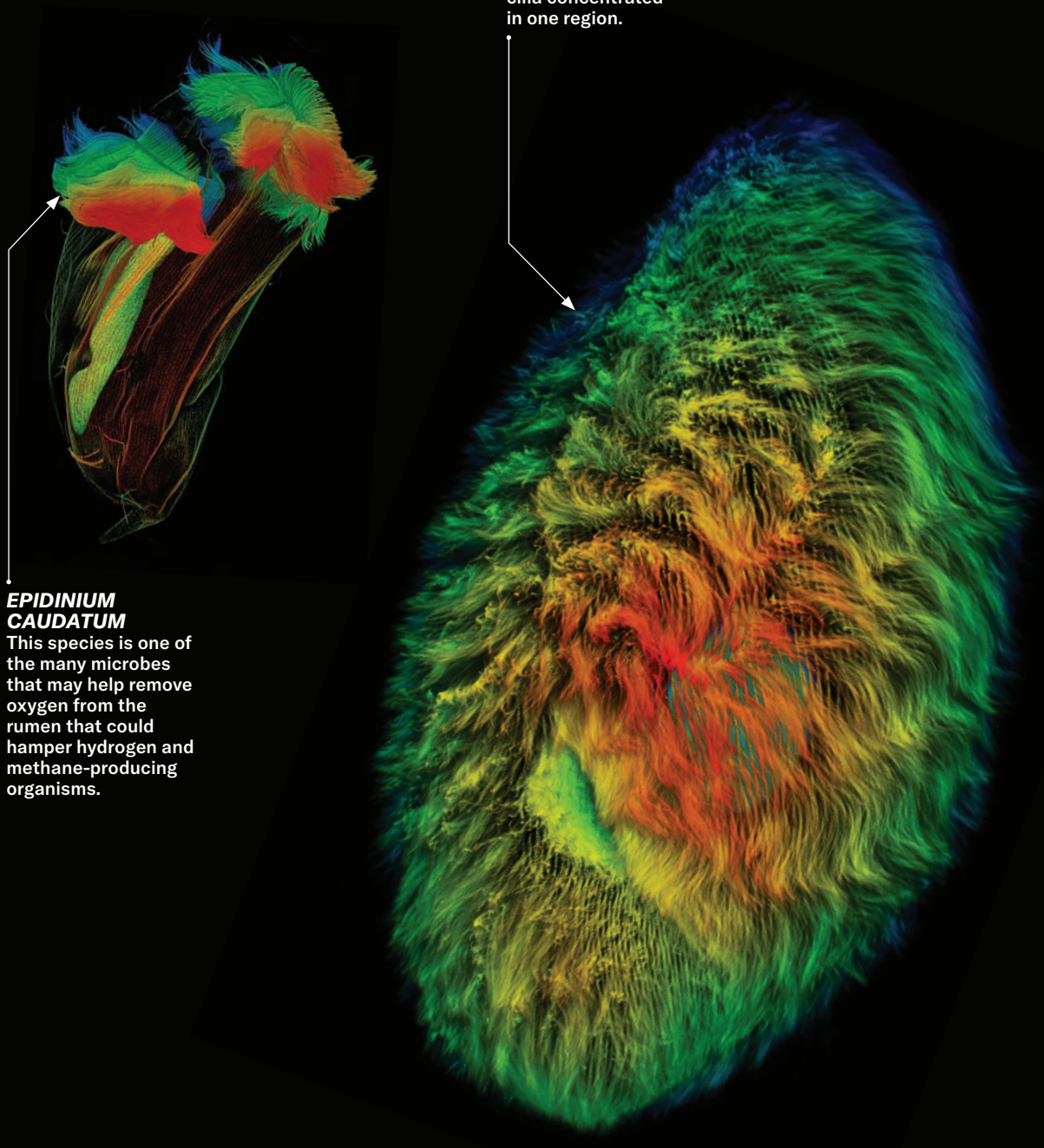
● A newly discovered organelle may hold the key to how much methane cattle burp out. The organelle doesn't belong to cows. It's part of fuzzy single-celled protozoa called ciliates that live in the bovine rumen. Dubbed a hydrogenobody, the organelle makes hydrogen, which stimulates other microbes in the rumen to produce the greenhouse gas methane, researchers report in *Science*. The discovery could point to new ways to control methane emissions from cud-chewing animals, which account for about 30 percent of methane from human activities. The images here show some of the 65 ciliate species the researchers cataloged, scaled to approximate relative size. Some are covered in hairlike cilia, while others have cilia concentrated in one part of the cell. The especially fuzzy species have more hydrogenobodies and stimulate more methane production, the researchers found. ✖

PHOTO CREDIT: CHUANQI JIANG AND CHE HU/INST. OF HYDROBIOLOGY/CHINESE ACADEMY OF SCIENCES, JINYING HE/JIANGHAN UNIV.

ENTODINIUM CAUDATUM
This species has cilia concentrated in one part of the cell. Ciliates in this genus have far fewer hydrogenobodies than the furrier *Dasytricha* ciliates.



DASYTRICHA RUMINANTIUM
Blanketed in cilia, *Dasytricha* ciliates have about 28 times as many hydrogenobodies as *Entodinium* and drive higher methane output.



ISOTRICHA PROSTOMA
The Koosh ball–like *I. prostoma* harbors more hydrogenobodies than species with cilia concentrated in one region.

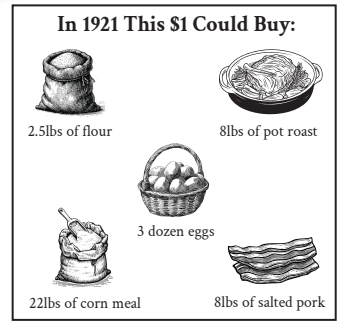
EPIDINIUM CAUDATUM
This species is one of the many microbes that may help remove oxygen from the rumen that could hamper hydrogen and methane-producing organisms.

JUST RELEASED!

Cache of 832 Last Year 1921 Morgan Silver Dollars Still Pristine As The Day They Were Struck

No coin embodies the spirit of America more than the Morgan Silver Dollar. From the Comstock Lode discovery that provided millions of ounces of silver to make them, to outlaws robbing stage coaches in the Wild West to pay for their bar tabs and brothel visits, the hefty Morgan Silver Dollar holds a special place in American history.

It's no wonder collectors and history buffs alike clamor to get their hands on them. That is, if they can get their hands on them.



Prized Last-Year Coins

Collectors love "lasts" as no collection is complete without the last coin struck. Last year coins are often hard to find and always in demand. Little did master engraver George T. Morgan know the legacy he was creating when he designed what has become known as "The King of Silver Dollars" but it came to an end 104 years ago with the last-year 1921 Morgan Silver Dollar, the most beloved coin in American history.

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Coin experts estimate that only 15%-20% of Morgans are still surviving today due to multiple mass-meltings over the years. The Pittman Act of 1918 melted over 270,000,000 coins, that's almost 50% of all coins produced at the time. Untold quantities were melted in the 1980s and 2000s when silver prices rose up to $50 per ounce.

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Like a living mood ring, this bee changes color as humidity fluctuates (see Page 19).

News

MIKE DAVIDSON/INATURALIST

PALEONTOLOGY

A REAL-LIFE KRAKEN MAY HAVE RULED THE ANCIENT DEEP OCEAN

BY JAKE BUEHLER

The kraken — a gigantic, tentacled sea monster capable of sinking ships — is a creature of Norwegian myth. But millions of years ago, a similar real-life animal lurked in the deep.

Fossilized jaws reveal that enormous octopuses possibly up to 19 meters long were top predators in the oceans during an era when dinosaurs ruled on land. These supersize cephalopods may have been the largest marine animals of the Cretaceous Period and may be the biggest invertebrates to ever live, researchers report in *Science*.

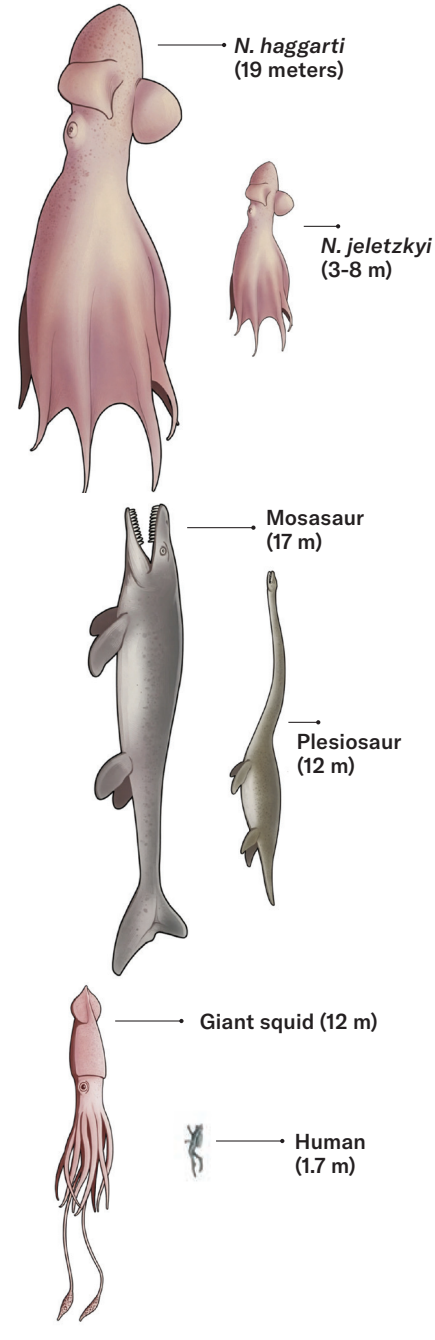
Ancient octopuses are difficult to study because their soft bodies often decompose before fossilization, says paleontologist Yasuhiro Iba of Hokkaido University in Sapporo, Japan. Precious few hard parts, such as beaklike jaws, are left behind to fossilize.

Some particularly large fossil jaws had been found by researchers in Japan and on Canada's Vancouver Island. These date to the Late Cretaceous Period — about 72 million to 100 million years ago, during the twilight of the age of dinosaurs. The jaws appeared to belong to octopus-like creatures, but their precise classification and any details on their size in life and possible role in the ecosystem remained mysterious, Iba says.

His team took a new look at 15 fossil cephalopod jaws to carefully measure them and compare them with those from other extinct and living octopus and squid species. The researchers also used a special technique to discover and document 12 more jaw fossils embedded in rocks found in Japan. The rocks were ground down layer by layer and photographed at each step. With the aid of artificial intelligence, the team created a detailed digital model of fossils too fragile to mine using traditional methods.

While these 27 cephalopods were initially thought to represent five extinct species, the researchers reassigned them to just two: *Nanaimoteuthis jeletzkyi* and the much larger *N. haggarti*. Based on comparisons with other cephalopod jaws, the creatures appear to be early finned octopuses. Today's finned octopuses, such as dumbo octopuses (*Grimpoteuthis* spp.), are deep-sea animals with webbed arms CONT. ON PAGE 14

YOHEI UTSUKI/DEPARTMENT OF EARTH AND PLANETARY SCIENCES/HOKKAIDO UNIV.; HOKKAIDO UNIV.



SIZING UP ANCIENT SEA MONSTERS

The extinct octopus *Nanaimoteuthis haggarti*, estimated to have been as long as 19 meters, may be the largest known invertebrate. See how the cephalopod sizes up to other Cretaceous creatures, including its relative *N. jeletzkyi* and a mosasaur and a plesiosaur, as well as a modern-day giant squid and a human.

CONT. FROM PAGE 12 at one end of the body and flapping fins at the other.

The largest lower jaw, belonging to *N. haggarti*, could cradle a grapefruit and was nearly twice as large as that of the giant squid (*Architeuthis dux*), one of the largest living cephalopods at about 12 meters long. Iba and colleagues estimate that *N. haggarti*'s billowing umbrella of arms could have made the creature between about seven meters and 19 meters long.

The animal "may have been among the largest invertebrates in Earth's history," Iba says.

N. haggarti might have rivaled or exceeded the size of the biggest marine predators at the time, including reptiles like mosasaurs (*Mosasaurus*) and long-necked plesiosaurs (*Styxosaurus*). And clues in the fossil jaws hint that *Nanaimoteuthis* competed with them for a spot high on the food chain. Consistent wear suggests the octopuses were voracious predators that used their powerful jaws to routinely bite shells and bones.

The discovery may mean that ancient marine ecosystems were more complex and had a wider range of predators than previously thought.

"For a long time, the top of the marine food web has been thought to be dominated by large vertebrates," Iba says. "Our study shows that ... octopuses also occupied that role in the Cretaceous."

Since the team had only fossil jaws to go off of, it's possible the newfound ancient octopuses were a bit smaller than Iba and colleagues estimate, says Christian Klug, a paleontologist at the University of Zurich. But "there is no doubt that these animals ranged among the top predators," Klug says. Future findings may help determine these beasts' precise ecological roles. ✖

NIGEL BUCHANAN

HEALTH & MEDICINE

People with stiff person syndrome might find relief in CAR T cell therapy

By Meghan Rosen

● **A living drug** could dial back the debilitating symptoms of stiff person syndrome.

After just a single infusion, patients with the autoimmune disorder saw meaningful improvements in mobility, stiffness and disability, neurologist Amanda Piquet reported in Chicago at the annual American Academy of Neurology meeting.

The drug, an experimental cell therapy called miv-cel, stands out from current treatment options for several reasons,

including how well it appears to work. "The results of this trial are truly remarkable," Piquet, of the University of Colorado Anschutz in Aurora, said at a news conference. "The magnitude and consistency of functional improvement observed is unprecedented."

Stiff person syndrome, or SPS, which may affect more than 5,000 people in the United States, is a mysterious disorder perhaps best known for afflicting singer Celine Dion. In people with SPS, their own antibodies can go rogue, attacking the brain and spinal cord. Symptoms include intense muscle contractions, chronic pain and spasms so strong they break bones. There are no cures for the disorder and no treatments approved by the U.S. Food and Drug Administration.

Current therapies include drugs to treat symptoms and immune therapies approved for diseases other than SPS. But these have limited benefits, Piquet said, and over time, patients often lose mobility, requiring walking aids or wheelchairs.

With the new therapy, developed by Kyverna Therapeutics, a biopharmaceutical company based in Emeryville, Calif., doctors looked beyond symptom relief and zeroed in on the root problem: rogue antibodies. Scientists borrowed a strategy from oncology called CAR T cell therapy, where patients' immune cells are genetically modified to attack a specific target. Miv-cel eliminates B cells, the body's antibody factories. Wiping out these cells gives the immune system a factory reset, Piquet said, ultimately clearing out harmful antibodies.

In a Phase II clinical trial with 26 patients to determine effectiveness, the strategy seemed successful. About four months after treatment, patients' walking speed improved, and eight of 12 people who had relied on a walking aid no longer needed one, Piquet reported. In a video presented during her talk, Piquet highlighted one patient's improvements. Before treatment, he was walking stiffly and slowly with a walker. After treatment, he was able to quickly stroll. "And at his last follow-up," she said, "he is running."

Stanford University neurologist Paul George called the results "very exciting." The work represents an advance in a disorder where no good treatment options exist, he said at the news conference.

The most common serious side effect Piquet's team reported was a low white blood cell count. And scientists don't yet know whether patients will need multiple infusions of the drug. "Obviously the hope and dream is once and done, right?" Piquet said. "We would love that."

Kyverna plans to request FDA approval for miv-cel this year. If approved, it would be the first CAR T cell therapy for an autoimmune disease. ✖

↖ Canadian singer Celine Dion has become the public face of stiff person syndrome.

ESA, NASA

QUANTUM PHYSICS

A SPACE-BASED CUBE MAPPED EARTH'S MAGNETIC FIELD

By Emily Conover

● An imperfect diamond is perfect for sensing Earth's magnetic field from space. A quantum device used a diamond's defects to map Earth's magnetic field from the International Space Station. OSCAR-QUBE collected data consistently over 10 months, and its measurements agreed with a previous estimate of the magnetic field, scientists report in *Physical Review Applied*.

Space-based measurements of Earth's magnetic field typically require bulky satellites. OSCAR-QUBE is just 10 centimeters on a side and has a lentil-sized diamond sensor. The diamond has defects in its lattice of carbon atoms, in which a carbon atom is missing and a neighboring carbon is replaced by a nitrogen. The defects act like quantum particles, with energy levels similar to an atom's. Magnetic fields alter the energy levels of the defects. That means variations in the strength of the Earth's magnetic field from place to place can be detected by measuring the light emitted when the diamond is hit with laser light and microwaves.

The cube didn't yet beat the most advanced conventional magnetometers. A future mission will use upgraded hardware and will place the cube outside the space station so internal fields can't interfere. ✖

ASTRONOMY

RECORD-BREAKING BLACK HOLES SHOOED STARS FROM A GALAXY

By Mara Johnson-Groh

● In a galaxy 4.4 billion light-years from Earth, scientists may have discovered the most massive pair of black holes yet found. Together, the behemoths weigh as much as some 60 billion suns. That's at least twice as heavy as the next most massive black hole duo.

The newfound pair, described in *Astrophysical Journal Letters*, lurks in the galaxy Abell 402-BCG in a region devoid of starlight. Researchers first identified this unusual dark spot in 2018 and theorized that a dust cloud was blocking light from the stars there. Now, observations from ground- and space-based telescopes reveal that the region is actually star-free.

Instead of a dust cloud, the void is probably home to two ultra-massive black holes spinning closer and closer together in a chaotic tango. The gravitational attraction between them is so strong that it sent nearby stars flying out of the cosmic ballroom, report MIT astronomer Michael McDonald and colleagues.

The scientists think Abell 402-BCG collided with another galaxy, which smooshed together all of their contents, including their central supermassive black holes. The pair has probably been together for only a few tens of millions of years, making the relationship relatively new, the team says. When the black holes eventually merge, they may form one of the largest known black holes in the universe. Individual black holes with masses exceeding 60 billion times that of the sun have been found just a few times before.

Both the black holes' masses and the stage of the merger make the sighting rare. Scientists hope to use the findings to better understand how often supermassive black hole mergers take place and how the mergers shape the galaxies around them. ✖

ANIMALS

SCIENTISTS RETHINK THE STORY OF PRIMATE SIZE EVOLUTION

BY JAKE BUEHLER

It's a game of monkey mean, monkey grew. Territorial tension may fuel the large size of some male primates.

In many primate species, males have evolved to be bigger than their female counterparts, a disparity typically attributed to competition among socially related males for access to females. But larger body size may be more about dissuading conflict with other males from rival groups, researchers report in *Biology Letters*.

"The traditional explanation is incomplete," says evolutionary anthropologist Cyril Grueter of the University of Oxford.

Many species in the primate order — which includes monkeys, apes and lemurs — have sexual size dimorphism, meaning an average size difference between the sexes. While some primates like gibbons show barely any size disparity, others such as baboons and gorillas can have males that are twice as massive as the females.

Most research on this pattern has centered on male-male competition for females within a social group, Grueter says. Bigger, stronger males can outfight or intimidate smaller males, giving them better access to mates.

"But primate groups are rarely isolated," Grueter says. Neighboring groups commonly interact. They overlap in territory and compete for resources such as food and mates.

During his Ph.D. research, Grueter found that leaf-eating monkeys with more contact between groups had especially large males compared with females. He and colleagues wanted to see if that relationship extended to other primates.

The team gathered data on 146 primate species from the scientific literature and compared female and male body mass against several measures of between-group contact. These included how much home ranges overlapped, how often groups met and how aggressive those encounters were, and each species' mating system. Not every measure was available for every species.

The more that territories overlapped and the more often that groups encountered each other, the bigger the males were compared with females, the team found. "Living in a

crowded social landscape with lots of interaction between groups seems to be linked to bigger males," Grueter says.

Being bigger may help males defend territory and resources from rival groups. This may be through physical fights, but Grueter says the persistent threat of altercations may be enough to supercharge size evolution in male primates via a kind of chronic cold war.

"Larger males may discourage escalation before fights even happen," Grueter says.

The mating system, a proxy for competition between in-group males for mates, didn't have much of an effect on the size split. But Grueter thinks male body size evolved due to multiple pressures, and competition between groups has just been underappreciated.

The findings may mean looking at the evolution of sexual body size differences through a new lens that accounts for broader social effects. The same evolutionary forces may be at work in other social or territorial mammals, producing similar size patterns, Grueter says.

Evolutionary biologist Catherine Sheard says the high variation in primate social interactions and the relative glut of data makes the clever mammals "a great place to start" studying the evolutionary impact of social traits.

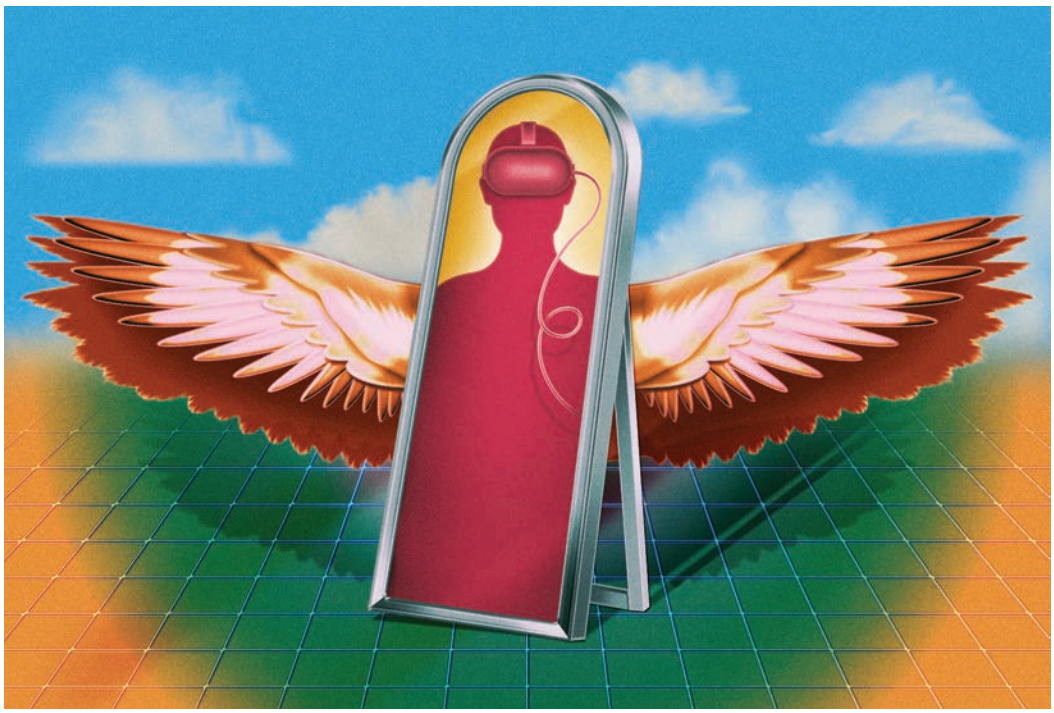
"I'm also wondering how these results would have changed if the researchers included solitary species in their analyses," says Sheard, of the University of Aberdeen in Scotland.

Grueter and colleagues had left out solitary species because the competitive dynamics between and within groups the team investigated don't easily apply to species that lack stable social groups.

The team wants to examine other traits linked to sexual evolutionary pressures in primates and other mammals, such as large canine teeth or physical or vocal displays, Grueter says. "It would be exciting to see whether the same pattern shows up." ✖

C. GRUETER

↓ **In black-and-white snub-nosed monkeys, males (right) dwarf females (left). Large body size in some male primates may be driven by conflict with rivals.**



NEUROSCIENCE

Flying like a bird in virtual reality changes human brain

By Yujia Huang

● **In *The X-Men*, Warren Worthington III sprouts huge wings** from his back and shoots into the sky. Scientists have yet to fully turn the comic book gift from fiction into fact, but virtual reality is offering hints of what it's like to learn to fly.

After training to use virtual wings, people's brains responded to wing images more similarly to how they respond to images of arms, making wings seem more like body parts, cognitive neuroscientist Yanchao Bi and colleagues report.

The study, published in *Cell Reports*, "nicely demonstrates how plastic the brain is," says Jane Aspell, a cognitive neuroscientist at Anglia Ruskin University in Cambridge, England. "If the brain can incorporate something as unhuman as a wing, it may also be able to incorporate many other kinds of limb enhancements."

↑ Learning to fly in virtual reality can reshape people's brains, making them treat wings more like human body parts.

Bi, of Peking University in Beijing, has long dreamed of flying on her own. "It would be amazing," she says. "Your whole world would become different." In 2023, she shared that wish over coffee with Kunlin Wei, who leads the university's motor control lab.

Wei's lab uses virtual reality, or VR, to study how people perceive movement. The conversation sparked questions: Could people learn to fly with wings in VR? And how would their brains change?

To answer those questions, the duo's colleague, neuroscientist Yiyang Cai, designed a weeklong training program based on the mechanics of bird flight. Wearing VR headsets and motion-tracking gear, 25 participants looked into a

AARON LOWELL DENTON

virtual mirror and saw themselves as birdlike figures with huge, rust-colored, feathered wings. When they rotated their wrists and flapped their arms, the wings moved too.

Across a series of tasks, the participants gradually learned to use their virtual wings. They flapped away falling green balls, stayed airborne over steep cliffs and even steered themselves through rings in the air.

"Some participants learned to fly on the first try, while others needed three or four sessions," says study coauthor Ziyi Xiong, a neuroscientist at Beijing Normal University. "But you could clearly see them improving."

Parts of the visual cortex, the brain region that normally responds to images of body parts, started responding more strongly to pictures of wings after the training. And the visual cortex's response to wings began to resemble its response to images of upper limbs, the team found.

"Participants began to see the wings as part of their own bodies," Bi says. That suggests the boundaries of brain plasticity, its ability to reorganize in response to learning and experience, may be broader than previously thought.

But the firsthand experience did more than reshape the brain. It transformed participants' understanding of flight in ways that abstract knowledge cannot, Wei says. The finding could apply to other technologies and artificial senses, letting people experience "reality" in ever more varied ways.

"In the future, we may spend a great deal of time in VR," Wei says. "We are very interested in what that could mean for the human brain." ✖

ANIMALS

HUMIDITY TURNS IRIDESCENT BEES GREEN

BY JAKE BUEHLER

When the weather gets muggy, iridescent bees shift their metallic hue.

The insects are a rich blue-green when ambient humidity is low. But as the amount of moisture in the air increases, the bees turn a coppery green, functional ecologist Madeleine Ostwald and colleagues report in *Biology Letters*. The reversible mood ring–like effect may be an overlooked phenomenon determining day-to-day color in bees and other insects.

Many bees have a shimmery exoskeleton. Some researchers working with specimens in museum collections have noted it can change color. For instance, the bees appear to dramatically shift color when placed in a high humidity chamber used to make them more flexible for mounting and imaging. "It can be a bit alarming when you're not expecting it," says Ostwald, of Queen Mary University of London. CONT. ON PAGE 20

A museum specimen of the fine striped sweat bee changes color as it goes from blue-green in dry air (left) to copper green in humid air (right). Most of the color change occurs in the first 24 hours. ↘

JORGE DE LA CRUZ

CONT. FROM PAGE 19 Ostwald was working in a lab at the University of California, Santa Barbara when undergraduate student Jorge De La Cruz noticed the color-changing effect while curating bee specimens. De La Cruz, Ostwald and their colleagues decided to investigate.

The researchers exposed two dozen museum specimens of fine-striped sweat bees (*Agapostemon subtilior*) to high and low humidity conditions for 55 hours each and then took photos of the bees. The team also gathered over 1,000 photos of living sweat bees from the citizen science app iNaturalist and noted the humidity at the times and places the images were taken. In dry conditions, under 10 percent humidity, the bees were blue-green. At 95 percent humidity, the insects turned a lighter, copper green.

Sweat bees' iridescence arises not from pigment, but from thin layers in the exoskeleton that reflect and scatter particular wavelengths of light. The researchers suspect that humidity causes the layers to swell, increasing the space between them and causing the exoskeleton to reflect longer, redder wavelengths.

"Because we saw redder bees in more humid conditions, this fits with that [scientific explanation]," Ostwald says.

Future work with high-powered microscopes might confirm this idea. The phenomenon may be widespread in insects that similarly produce color with microscopic structures, the team says.

"Color can be really dynamic and respond to the environment in ways we didn't expect," Ostwald says. "It's really important to study the color of the living organism in its natural environment, because as soon as we remove them from that context, the color changes." ✖

SPACE

Sunspots hasten falling space junk

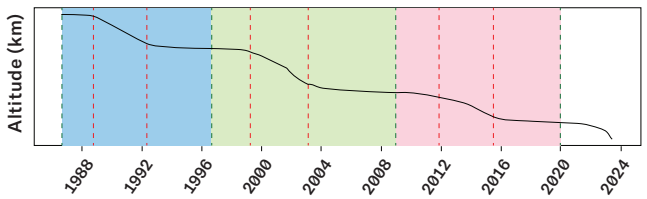
By Carolyn Gramling

● **Strong solar activity** can nudge space debris out of the sky. As solar cycles reach their peak — signaled by numbers of sunspots appearing on the sun's surface — satellites and other objects in low Earth orbit lose altitude more quickly, researchers report in *Frontiers in Astronomy and Space Sciences*.

By tracking the positions of 17 pieces of space debris in low Earth orbit over three consecutive solar cycles, astrophysicists in India found a threshold beyond which increases in solar activity impacted the objects. When sunspot numbers reached about 70 percent of their peak, orbital decay rates rose sharply.

The intensity of the sun's radiation waxes and wanes over an 11-year cycle. At its peak, sunspots bloom on the sun's surface. More intense radiation also streams toward Earth, heating and expanding an outer layer of atmosphere. Objects about 160 to 2,000 kilometers from the surface can find themselves in a denser atmosphere, increasing drag and slowing them down. Slowing down can mean they descend out of orbit sooner than they would have otherwise. That's exactly what happened to the tracked junk as each solar cycle rose to peak activity. Each time the cycle passed the sunspot threshold, the junk dropped a few kilometers in altitude. The pattern held from cycle to cycle, though where the threshold occurred and the magnitude of the altitude drop depended on a cycle's overall intensity. Understanding this pattern could be helpful for planning space mission launch windows to avoid collisions, the team says. ✖

FALLING DEBRIS



Space junk originally from a Delta 1 rocket (black line) shows a stepwise decrease in altitude through three solar cycles (shaded blue, green and red). Peak solar activity in each cycle (start and finish marked by dashed red lines) corresponds to a sharp decline in the object's altitude, after which the object's orbit levels out until the next peak.

A. M. ASHRUF *ET AL*./*FRONTIERS IN ASTRONOMY AND SPACE SCIENCES* 2026

THE HEALTH CHECKUP

NO, MASTIC GUM WON'T RESHAPE YOUR JAW

BY TYLER SANTORA

COURTESY OF T. SANTORA

On the island of Chios in the Aegean Sea, ancient Greeks gnawed on dried sap from the mastic tree to treat stomach upset. Greek philosopher and physician Hippocrates even used the resin as an herbal remedy for gastrointestinal disorders. Thousands of years later, social media creators are promoting mastic chewing gum as a way to boost gut and oral health and even chisel the jawline. But not all the claims are backed by science, experts warn, and there are risks to chewing mastic.

The companies that sell modern mastic gum, which has added ingredients like spearmint for flavor and calcium to boost enamel, promise health benefits shared by traditional cultures. Though the resin's health effects haven't been researched much in people, some small studies suggest that Hippocrates was onto something. Several common plant compounds found in the mastic tree have well-documented antibacterial and anti-inflammatory properties. Research indicates these compounds may fight the ulcer-causing bacteria *Helicobacter pylori* and ease symptoms of Crohn's disease, irritable bowel syndrome and dyspepsia — a type of chronic indigestion. The compounds have also been shown to reduce cholesterol and blood sugar levels.

However, few of the studies involved people actually chewing mastic gum. Participants typically took oil or powder supplements of concentrated plant extracts. "In gastrointestinal and metabolic conditions, chewing mastic gum does not have considerable efficacy," says pharmacologist Roja Rahimi of Tehran University of Medical Sciences in Iran.

But chewing mastic does have oral health benefits, such as reducing plaque buildup, helping prevent cavities and gum disease, and potentially fighting oral cancer, a review published in 2023 in the *Journal of Natural Medicines* found. Mastic compounds seem to limit the spread of cancerous cells and trigger their death, clinical research suggests.

Mastic's antibacterial properties might also make your breath smell better. Teenagers who used mastic toothpaste three times a day for two weeks lowered breath levels of stinky hydrogen sulfide, a by-product of bacterial fermentation, researchers reported in 2025 in the *Journal of Breath Research*.

When it comes to claims of mastic's aesthetic effects, the evidence takes a nosedive. Three out of five major mastic gum brands marketing on TikTok push the jaw-sharpening angle. But there's no research to back up these claims, says orofacial medicine specialist Anette Vistoso of the University of Southern California in Los Angeles.

Few scientists have looked into whether chewing mastic or everyday gum can change face shape. One study suggests it doesn't. Chewing typical gum three times a day for six months had no effect on the appearance of the jawline, researchers in Korea reported in 2024 in the *Journal of Oral Rehabilitation*.

Chewing firm gum can strengthen jaw muscles too much, Vistoso says. She has seen many gum-chomping patients develop jaw pain or clench so strongly that they grind through a night guard. Vistoso doesn't recommend chewing any sort of gum.

If you're keen on the gut and metabolic effects that mastic offers, Rahimi says, ask your doctor about oil or powder capsules. But she emphasizes that mastic isn't a panacea. "I do not recommend long-term use of herbal medicines for healthy individuals. The best strategy for them is lifestyle modification and eating healthy foods," Rahimi says. "However, in people who suffer from bad breath, dental and gingival problems, chewing mastic gum may help." ✖

PARTICLE PHYSICS

A MATHEMATICAL 'ROSETTA STONE' HELPS BLACK HOLE RESEARCH

BY EMILY CONOVER

Physicists have found a new way to investigate a black hole enigma using the mathematics of particle physics. They're trying to better understand the idea that black holes aren't entirely black. Instead, black holes emit a faint mist of particles called Hawking radiation, a concept central to major puzzles that swirl around black holes. But the radiation is so faint that it's not possible to observe directly.

Now, several teams of physicists have found a new angle on the phenomenon. They are taking advantage of a mathematical connection between two seemingly unrelated types of physics — a link known as the double copy.

Fundamental physics theories fall into two distinct camps. A theory called the standard model describes the physics of subatomic particles, while the general theory of relativity describes gravity. The double copy draws a mathematical connection between these two theories. That relationship can be used as a mathematical translation tool, switching a calculation from one "language" of physics to another. The swap can make calculations easier or reveal new insights.

The double copy says that many phenomena of general relativity are mathematically equivalent to those of certain particles in the standard model, with one difference: In general relativity, there are two copies of a particular part of the equation. Since this relationship was discovered in 2010 and developed in the years since, it has become a useful tool for understanding a variety of gravitational effects.

"It allows us to calculate things we've never been able to calculate before, just by recycling results in a clever way," says theoretical physicist Chris White of Queen Mary University of London.

Until now, scientists didn't have a standard model analog for Hawking radiation based on the double copy. Finding one "constitutes a major advance for these techniques," says theoretical physicist Cynthia Keeler of Arizona State University in Tempe. That's because Hawking radiation connects the large and the small, with enormous black holes emitting tiny particles. The discovery shows that the double copy can bridge both scales.

In a *Journal of High Energy Physics* paper, White and colleagues determined how Hawking radiation translates into the language of the standard model. In that language, the mathematical alter ego of Hawking radiation is a charged particle scattering off a spherical shell of charged matter collapsing in on itself. That's mathematically equivalent to the emission of a particle of Hawking radiation.

Two other teams came to similar conclusions, finding a mathematical

> *"It allows us to calculate things we've never been able to calculate before, just by recycling results in a clever way."*
>
> **— Chris White**

analog of Hawking radiation. Reported in *Physical Review Letters*, the pair of papers shows that physics intrinsic to black holes is contained in the standard model of particle physics, says Anton Ilderton, a theoretical physicist at the University of Edinburgh and a coauthor of one of the papers. "These papers have started to show how to extract that information from the standard model."

Scientists hope to explore even more inscrutable features of black holes in this way. For example, researchers would like to also find a standard model analog for a black hole's event horizon, the boundary beyond which nothing that enters can escape. "That's the big question that we would like to answer," says theoretical physicist Uri Kol of Harvard University. "These papers provide tools that can be used to address this question."

Hawking radiation alone is intriguing enough for further study. After physicist Stephen Hawking conceived of the radiation in 1974, physicists realized it implied a puzzle. As a black hole spews particles, it shrinks and eventually obliterates itself. Physicists don't understand what happens to the information in the matter that it previously swallowed. According to quantum physics, information can't be destroyed. Studying features of Hawking radiation translated into the language of the standard model may illuminate what's going on.

Hawking radiation is a "Rosetta stone" problem, says theoretical physicist John Joseph Carrasco of Northwestern University in Evanston, Ill., coauthor of one of the *Physical Review Letters* papers. By studying it, physicists could become more fluent with gravity's language. ✖

↗ Alston's singing mouse uses an inflatable sac in the airway to create dramatic, whistling songs.

ANIMALS

How some mice make sweet songs

By Jake Buehler

● **A musically inclined mouse** produces whistling tunes by inflating an air sac in the throat like a balloon, researchers report in *Proceedings of the Royal Society B*. Creating these rodential arias may be a unique use for air sacs in the animal kingdom.

Alston's singing mouse (*Scotinomys teguina*) lives up to its name. Males and females of the small species native to Mexico and Central America communicate with a train of high-pitched notes more complicated than those of any CONT. ON PAGE 24

CONT. FROM PAGE 23 other rodent. The 10-second songs, which appear to attract mates and warn rival males, consist of around 100 breaths and notes, says integrative biologist Samantha Smith of the University of Lausanne in Switzerland. This speed and song length is far more extreme than other rodents' calls, she says.

To figure out how the mouse makes melodies, Smith and colleagues removed the larynges of euthanized singing mice. Each larynx was then hooked to a hose with a microphone and camera pointing toward its top. When the scientists blew air through the hose, they could record how the larynx moved and produced sound.

Whenever the larynx produced sound in the right pitch range for the mouse's natural song, a pouch in the larynx was always inflated. When the team blocked this balloon with bits of wax or small metal balls, the larynx went silent. Cutting the sac had the same effect. The findings indicate that the air sac is crucial for making the song, though more work is needed to determine how tones are generated.

Other rodents have air sacs too, but don't appear to use them to sing like this. Rodents are "such a diverse group with such fascinating social, behavioral and ecological adaptions," says bioacoustician Raffaela Lesch of the University of Arkansas at Little Rock. "I'm excited to see our knowledge in their sound production mechanisms grow."

Inflatable sacs in airways have evolved multiple times across the animal kingdom. But in those cases, air sacs alter or amplify sound produced elsewhere in the respiratory tract. Studying how various features of rodent air sacs contribute to vocal output may shed light on how these itsy-bitsy serenades evolved. ✖

HEALTH & MEDICINE

STEM CELL PATCHES COULD TREAT SPINA BIFIDA IN UTERO

BY MEGHAN ROSEN

For the first time, doctors have used stem cells to try to repair the spinal cords of human fetuses in the womb.

The new technique attempts to heal nerve damage caused by spina bifida, a disabling birth defect. In this condition, the bony tissue of a fetus's spine doesn't knit together properly around the spinal cord. That can cause a kaleidoscope of medical issues, including lifelong paralysis.

Traditional fetal surgery to patch up the spine can limit the scope of these problems — but it does not repair nerve damage that has already occurred. Adding living stem cells to the procedure might.

At least, that's the goal of fetal surgeon Diana Farmer's team. So far, the approach appears to be safe, the researchers report in the *Lancet*. In six fetal patients with severe spina bifida, applying a stem cell–loaded patch to their exposed spinal cords did not cause infection nor tumor growth and did not interfere with healing. That's important because "no one knew what stem cells would do inside a fetus," says Farmer, of the University of California, Davis.

For now, whether the technique mends fetal spinal cords remains unanswered. The team is still performing follow-up assessments of the patients, who are now toddlers. At this stage, it's too early to say how well the surgery worked, and Farmer is careful not to speculate. "If we could get every kid to not be in a wheelchair," she says, "that would be fantastic." But the team won't know for a few years. Until then, Farmer says, she doesn't want to give people false hope.

In some ways, the study represents "a seismic shift" in the field, says Ramen Chmait, director of Los Angeles Fetal Surgery at the University of Southern California. If the technique pans out, it "could be a huge, important step in modern-day medicine," he says.

Maternal fetal medicine specialist Magdalena Sanz Cortes echoes the sentiment in a commentary accompanying the study. "We eagerly await follow-up results and definitive studies that might show benefit," writes Sanz Cortes, of Baylor College of Medicine in Houston. "Such results would herald a new era in fetal surgery."

But first, doctors will need to better understand the procedure's risks and benefits. At this point, Chmait says, Farmer's team has taken the "first step of a marathon."

In the United States, roughly 1 in every 2,800 babies are born with spina bifida. This abnormality leaves the delicate spinal cord exposed in the womb. Without bony vertebrae closing around and protecting the spinal nerves, tissue can bulge through the back, making the cord vulnerable to injury. Amniotic fluid washing over the bulge can degrade it. And as the baby grows, it rubs against the walls of the uterus, damaging unprotected nerves.

Beyond paralysis, this damage can cause fluid to build up in the brain. Some babies require a shunt surgically implanted after birth. That can be lifesaving, but it's also lifelong—a permanent implant that can malfunction or spur infection.

One way to avoid the shunt, and potentially some of the nerve damage accrued during pregnancy, is to surgically close the hole in the fetus's spine in the womb. But as well as it works, "there's a lot of room for improvement," Chmait says. Kids who undergo prenatal surgery can see gains in leg movement, but the ability to walk isn't guaranteed.

Farmer didn't just want to close the spinal defect, she sought to fix the damage that had already been done. She thought stem cells, which can renew themselves and repair tissue, might be the key. Hoping to tap their regenerative powers to restore dying nerve cells, Farmer sought out UC Davis bioengineer Aijun Wang. That kicked off a scientific odyssey that spanned more than a decade and took the researchers from experiments in sheep and bulldogs to, finally, humans.

Their work started with placental stem cells grown in a nutrient bath that Wang's lab engineered. The liquid prompts the cells to release a molecular concoction that protects neurons and stimulates growth.

The team tested the stem cells in fetal sheep with a hole in their spine. For the in utero repair surgery, doctors add hundreds of thousands of stem cells to a thin, flexible patch, Farmer says. Then, they use the patch to seal up the hole. The cells don't stay forever. "We want them to get in there, do their job, deliver their magic stem cell juice and repair that spinal cord," Farmer says.

And that's what they appeared to do. Sheep given the stem cells scored better on tests of their ability to walk, stand and move their hind legs compared with sheep given stem cell–free patches.

Other tests in bulldogs born with spina bifida and treated after birth illustrate the patch's promise, Chmait says. The dogs, Darla and Spanky, could walk and run just months after surgery, which he calls remarkable. Often, dogs with spina bifida can't control their hind legs.

The work has led to dramatic improvements and set the stage for the current trial in humans, says pediatric surgeon KuoJen Tsao of the University of Texas Health Science Center at Houston. Farmer's team is expanding the trial to include dozens more patients, who will be monitored through age 6. If the therapy works as well as it did in sheep, Farmer says, "we would be ecstatic."

Chmait doesn't currently work with stem cells himself, but if the trial's outcomes look good, he says he's ready to learn.

Tsao is already thinking ahead to technical issues that may arise. Stem cell work can be a complicated process, he says, and not every facility is capable of producing the patch. But he recognizes it will take years before doctors have to address such issues. Starting with a small group of patients, establishing safety and gathering evidence is the norm for even game-changing advances like this, Tsao says. "That's how most breakthroughs in medicine are." ✖

1 in 2,800

The U.S. incidence of babies born with spina bifida, a condition in which a portion of the spinal cord can remain exposed

↓ **Tobi Maginnis, born in 2022, received the new stem cell surgical treatment in utero. His mother says his physical and mental abilities are a miracle.**

COURTESY OF MAGINNIS FAMILY

HEALTH & MEDICINE

SUICIDE DEATHS FELL AFTER 988 LAUNCH

By Aimee Cunningham

● The 988 Suicide and Crisis Lifeline appears to be making a difference for U.S. teens and young adults in distress.

Since 988 replaced the ten digit lifeline, the suicide mortality of people ages 15 to 34 was 11 percent lower than predicted, suggesting an association between the shorter lifeline number and the decrease, researchers at Harvard Medical School report in *JAMA*.

The team analyzed suicide mortality data for teens and young adults from the National Vital Statistics System. From 988's launch in mid-2022 through 2024, there were about 35,500 suicides — fewer than the nearly 40,000 expected. Suicide is one of the leading causes of death for this age group.

The analysis doesn't account for other factors that could have contributed to the drop, such as changes to mental health services, the researchers note. But when they looked at mortality data for the same age group over the same time frame in England, which did not shorten its lifeline number, there was no similar decrease.

In the United States, budget cuts by the Trump administration may impact the lifeline's funding. And last year, the administration removed the 988 option to connect LGBTQ+ young people to specialized services, further endangering a population already at high risk for suicide. ✖

If you or someone you care about may be at risk of suicide, the 988 Suicide and Crisis Lifeline offers free, 24/7 support, information and local resources from trained counselors. Call or text 988 or chat at 988lifeline.org.

EARTH

Africa's 'necking' crust foretells a speedy breakup

By Katherine Kornei

● **It's a bit of a stretch,** but the analogy works: Sometimes Earth's tectonic plates pull apart from one another like taffy.

In eastern Africa, that taffy is already thin and weak, and the tugging forces are concentrated in certain spots. The Turkana Rift Zone, which straddles Kenya and Ethiopia, is undergoing "necking," a critical transition toward continental breakup that has never been observed before, geoscientist Christian Rowan of Columbia University and colleagues report in *Nature Communications*. The region may be closer to splitting, and doing so faster, than expected, the team says.

The researchers used a suite of archival data to look beneath the surface at a layer of metamorphic rocks. Those old, hard rocks form Earth's continental crust, with the stuff we think of as the ground merely piled on top. The team traced those rocks downward toward the mantle and found one region where the crust was just under 13 kilometers thick. "Typical crustal thicknesses are about 30 kilometers," Rowan says.

It was clear that Earth's crust had been stretched substantially and wasn't uniform — some spots have stretched more than the rest. The data match the necking stage of continental breakup in computer models of rifting. "It's kind of the point of no return," says geodynamicist Sascha Brune at the GFZ Helmholtz Centre for Geosciences in Germany. A handful of divergent plate boundaries elsewhere have already completed necking, but this process has never been observed in action.

To estimate how long the Turkana Rift Zone has been in this breakup stage, Rowan and colleagues traced how a layer of volcanic rock, once at Earth's surface, has been pulled downward over time as the crust stretched and sank. "The center of the rift has completely dropped out," Rowan says. The rift has been necking for roughly 4 million years, the data suggest.

If the Turkana Rift Zone continues necking, it could enter the final phase of continental rifting: oceanization. At that point, Earth's crust would tear and the underlying mantle would punch through, allowing magma to ooze across the surface. That magma would eventually cool and form new oceanic crust. Because oceanic crust is denser than continental crust, it tends to sink and collect water. Over millions of years, an ocean could develop that would separate parts of eastern Africa into a distinct landmass, Rowan says. "Eventually, eastern Africa will break apart." ✖

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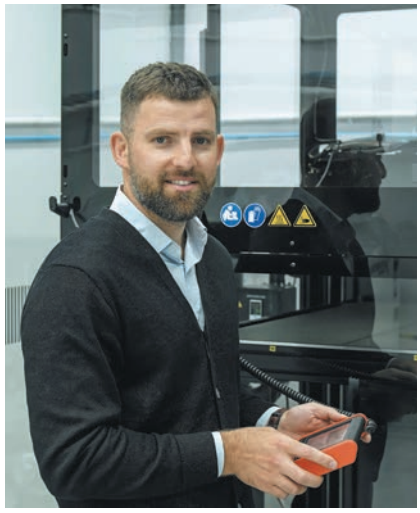
When buildings begin to feel: Lithuania's leap into smart, self-sensing structures

The modern construction industry faces a critical global challenge: buildings currently account for approximately 40% of global energy consumption and emit a similar share of CO_2. In a strategic response to this environmental crisis, Lithuania, through the Innovation Agency Lithuania, has launched pioneering projects to develop smart, climate-neutral structural solutions.



Dr. Arvydas Rimkus, Chief Research Fellow at VILNIUS TECH.

"Additive manufacturing, the technology behind 3D printing, is quietly reshaping how we build the world around us," says Dr. Arvydas Rimkus, Chief Research Fellow at VILNIUS TECH. "By replacing traditional cutting or casting with structures that grow layer by layer, forming complex geometries impossible to produce by conventional means, this technology opens the door to lighter, more efficient, and highly customised components."

Despite this potential, most materials used in 3D printing remain functionally simple – an obstacle Lithuanian researchers are working to overcome.

The Future of 3D Printing

VILNIUS TECH addresses this limitation by developing electrically conductive polymer composites suitable for 3D printing. The goal is to integrate these materials as sensors or conductive pathways within larger structures, rather than as primary load-bearing elements. The research team combines a common biodegradable polymer with precisely tuned metal and carbon-based nanoparticles. Silver particles form the main conductive paths, while carbon-based nanofillers link them at the microscopic scale. This resulting network conducts electricity while maintaining acceptable flexibility and printability.

Achieving this balance is a major scientific challenge. The researchers are developing methods to uniformly disperse nanoparticles throughout the polymer matrix, thereby ensuring stable and predictable electrical performance. They study how preparation techniques, surface treatments, and printing conditions influence uniformity and conductivity. "Structural, thermal, electrical, and mechanical tests reveal how microscopic structure governs macroscopic behavior – from filler distribution and processing stability to electrical efficiency and long-term mechanical integration," explains Dr. Rimkus.

Early results show these hybrid materials achieve electrical conductivity suitable for circuits or sensing networks printed directly within a component. This enables self-sensing structures that can monitor deformation or detect damage by detecting subtle changes in electrical resistance. Computational modelling predicts how printing parameters – such as temperature, deposition speed, and layer thickness – influence microstructure and conductivity, connecting laboratory insights with scalable manufacturing strategies.

The long-term vision is vast, promising to transform infrastructure and machine maintenance. Embedding sensing and conductivity into printed components could eventually enable structures such as bridges, aircraft wings, and automotive frames to become self-diagnostic, detecting fatigue or cracks in real time.. Buildings could use smart, 3D-printed components for continuous structural monitoring. In robotics, conductive polymers enable soft actuators and tactile sensors that mimic biological tissue. Energy systems and biomedical technologies also benefit from components that merge mechanical form with electrical responsiveness. As Dr. Rimkus notes, "By integrating sensing directly into materials, we move from structures that simply bear loads to ones that can feel, respond, and adapt."

Science-driven Missions

The Lithuanian Ministry of Economy and Innovation, and the Ministry of Education, Science, and Sport, with the support of Innovation Agency Lithuania, launched a €88.34 million mission-based initiative. Funded by the government and the European Recovery and Resilience Facility, the program targeted breakthroughs in health, cybersecurity, and climate neutrality. The expected results: three new competence centers, 20 R&D projects, and 20 spin-off companies to modernize the national economy.

VILNIUS TECH led the €31.5 million "Smart and Climate-Neutral Lithuania" mission, focusing on reducing emissions through sustainable construction and green hydrogen transport solutions.

Features

NASA

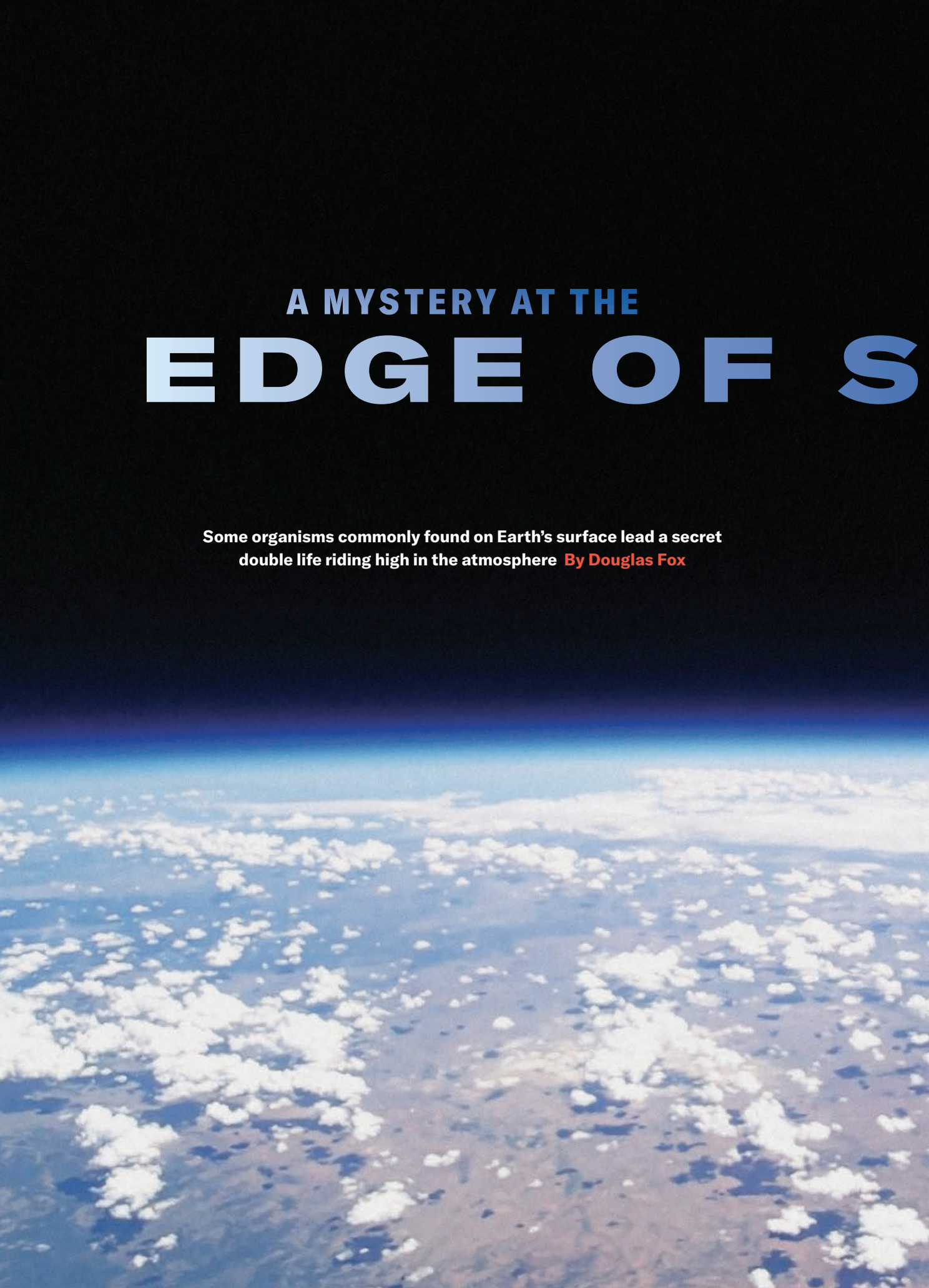
PLANETARY SCIENCE

MARS SAMPLE RETURN: SO CLOSE YET SO FAR

● NASA's Viking missions first landed on Mars 50 years ago. For astronomers like Carl Sagan, shown posing with a model of a Viking lander in Death Valley, Calif., the missions were the realization of a quest to find signs of life on other planets. Though the results of Viking's search were ambiguous, the missions kicked off an age of exploration on the Red Planet. Scientists have since found tantalizing clues hinting at ancient Martian life. But shifting political priorities have stalled plans to bring rock samples home for analysis (see Page 40). — *Cassie Martin*

A MYSTERY AT THE EDGE OF S

Some organisms commonly found on Earth's surface lead a secret double life riding high in the atmosphere By Douglas Fox



Seen from a scientific balloon 30 kilometers above New Mexico, the stratosphere is a gray zone between Earth and space. The air pressure at this height is one percent that at sea level and the ultraviolet radiation is intense. But scientists are learning that some microbes survive here, at least temporarily.

The stratosphere is both beautiful and hostile — a purgatory between Earth and space, between life and death.

Hover 30 kilometers above the ground, and you are nearly twice as high as any raincloud on Earth. The surface of the planet curves beneath you. A diaphanous film of blue stretches over that horizon, representing the disconcertingly thin layer of atmosphere that envelops all life as we know it. Above that, the sky resembles black interplanetary space.

You would quickly die here. The air pressure is one percent what it is at sea level. As you gasped for oxygen, your blood would boil inside you, causing your skin to welt like bubble wrap.

But the stratosphere holds plenty of life — tiny single-celled microbes that somehow navigate extreme dehydration, temperatures as low as

–60° Celsius and intense DNA-damaging ultraviolet radiation that would kill most life on Earth's surface.

"If you took a microbe from those altitudes and you put them on the surface of Mars, they wouldn't even know the difference," says microbiologist Brent Christner of the University of Florida in Gainesville.

When Christner and his team started looking for life high in the atmosphere over a decade ago, they intended to find the upper limits of Earth's habitable zone. They hoped that this, in turn, might show whether life could persist on the cold, radiation-pummeled surface of Mars, where the atmosphere is just as thin. But when Christner's graduate student Noelle Bryan sent sampling balloons to 38 kilometers above Earth's surface, she was utterly surprised by what they found: "We did not hit an altitude where we couldn't find something [alive]," says Bryan, who is now a senior research manager at Mass General Brigham in Boston.

In 2025, Christner's team revealed something even more surprising. The microbes the researchers found weren't the kind of extremophiles that you'd expect at the edge of space. They looked nothing like the exotic organisms that inhabit extreme habitats on Earth, such as boiling hot springs, deep subterranean rocks or pools of concentrated acid.

Instead, they turned out to be some of the same humdrum bugs that grow on our crops, our gardens, even our skin. These well-known critters may live a secret double life that few people imagined: flying around the world at two to three times the height of a commercial jetliner.

The atmosphere "is like a highway system," Christner says. It allows microbes "to move globally in periods of weeks," crossing oceans and settling in new habitats. This realization expands our view of the biosphere and evolution. It could reshape our understanding of how pathogens spread around Earth. And it could transform how we look for life on other worlds — on Mars (see Page 40), in the clouds of Venus and even on exoplanets light-years away.

HUNTING FOR MICROBES IN THE SKY

Scientists have wondered for a century what sort of life, if any, might exist high in the atmosphere. For decades, their explorations yielded only tantalizing hints.

In 1935, the U.S. Army Air Corps launched a helium balloon to a height of more than 22 kilometers over the Black Hills in South Dakota, setting a world record. Two pilots in a pressurized gondola recorded air temperatures, magnetic fields, radiation levels and dozens of other measurements. They also dropped a sterile sampling device designed to collect airborne microbes on its way down. After falling halfway, it closed and parachuted back to Earth with its sample sealed inside.

Scientists managed to grow 10 types of bacteria and fungi from the sample that were ostensibly collected during its fall through the lower stratosphere. But in this era before scientists knew about DNA, they never learned much more than the shapes of the cells and the temperatures and nutrients that they needed to grow. Much later, in 1974, Soviet scientists launched several rockets equipped with sticky microbe collectors 48 to 77 kilometers into the mesosphere — the atmospheric layer above the stratosphere, where conditions are even more extreme. The collectors parachuted back to the ground and arrived with a few living cells embedded in them, which scientists again managed to grow in the lab.

That Soviet work is widely cited, Christner says, "but there's just no way to know what they sampled" and whether it came from contamination at ground level. He doesn't believe that they actually found something alive at that altitude.

A new generation of high-altitude studies started in the early 2000s.

PREVIOUS SPREAD: ELVIS ANDRÉS AYALA/TRINIDAD SYSTEM

Clockwise from top: Noelle Bryan and colleagues launched a microbe collector to a height of 29 kilometers in August 2013; a much larger balloon allowed her to sample airborne microbes up to 38 kilometers; this NASA-LSU High Altitude Student Platform carried a handful of experiments to the stratosphere.

NASA was flying its ER-2 aircraft (a civilian version of the U-2 spy plane) 20 kilometers up in the stratosphere to collect cosmic dust that filters down from space and use it to study the history of the solar system. Microbiologist Dale Griffin, then with the U.S. Geological Survey in St. Petersburg, Fla., arranged to have sticky microbe catchers taken on several of those flights from 2003 to 2008.

Griffin grew several kinds of bacteria from those samples. And unlike his predecessors, he subjected them to a simple DNA analysis called genetic barcoding that used a short sequence from a single gene to get a general idea of which family or genus they belonged to. These bacteria were related to several that were known from remote islands and volcanic soils, Griffin found. He speculated that eruptions might have lofted them into the stratosphere.

Taken together, the U.S. and Soviet observations didn't reveal much. They depended on growing microbes in the lab, but scientists can't grow 99 percent of the microbes that exist in most environments because they can't re-create the proper growing conditions. As such, the findings didn't reveal how many living cells were present in the stratosphere. They often didn't identify the species. The scientists didn't test whether these microbes could survive the extreme cold, desiccation or UV radiation found in the stratosphere. And they never identified the lifestyles of these microbes on Earth's surface — whether the creatures lived on plants, slurped raw sewage or grew in the armpits of NFL linebackers.

Christner was at Louisiana State University in Baton Rouge when he and Bryan started their search for life in the stratosphere in 2008. They planned to start low and sample progressively higher. They would try to grow the cells they collected, as other people had previously done. But they would also count the total number of living cells, something no one had ever done before at that altitude.

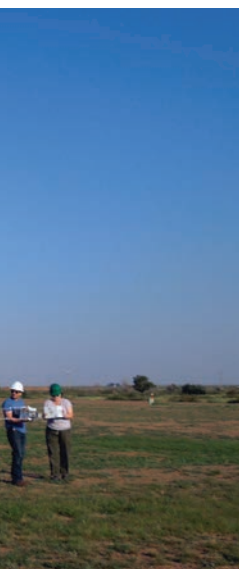
They expected that at some altitude, the number of living cells would drop to zero. This would define the outer limits of life on Earth — and hint at the possible limits of life on Mars.

Bryan spent three years building a series of microbe collectors, using Styrofoam and balsa wood purchased at Hobby Lobby and Home Depot. She launched these contraptions into the air dangling from helium balloons. During a dozen launches in Texas and Louisiana, she attempted to sample airborne microbes from as high as 25 kilometers. Each device included a control chamber that didn't open during the flight, allowing her to check whether the samples were contaminated with ground-level microbes. She gradually improved her design, bringing the levels of contamination down to almost zero.

By 2013, Bryan was using a more advanced system developed by LSU engineer T. Gregory Guzik. Its rugged circuits allowed it to reach even higher altitudes, where the thin air can cause electricity to arc from one wire to another, damaging a device. She and Guzik used this system in a pivotal series of balloon launches over Fort Sumner, N.M. These would be the last samples that she collected for her Ph.D. research, and they would transform the endeavor from a cool science project into a major discovery.

A SCIENTIFIC BALLOON BONANZA

The town of Fort Sumner crouches amid an arid plain of grass and yucca in eastern New Mexico. The 19th-century gunslinger Billy the Kid is buried in a cemetery at the south end of town. Just north of town is the airport, consisting of a corrugated steel hangar and cracked tarmac. The facility is occasionally used for launching scientific balloons, which benefit from the area's stable weather and flat, undeveloped terrain.



THIS SPREAD: FROM TOP, CLOCKWISE: LSU, NASA; N. BRYAN; N. BRYAN, ARIZONA STATE UNIV., NASA

On the morning of August 21, 2013, Bryan, Guzik and several other people wearing hard hats emerged from the hangar grasping the tether of a spherical white helium balloon the size of a small elephant. It bobbed and tugged impatiently as they walked it into an open field and let go. It surged upward, pulling its payload into the sky.

A downward-pointing camera captured video as it rose. The payload swung lazily as the desert shrank into a hazy, wrinkled mosaic. A large jet — perhaps a Boeing 737 — streaked by far below, tiny and silent. Later, the balloon was tossed by violent winds, marking its passage into the stratosphere.

When the balloon reached 18 kilometers, an electric motor whirred, opening a compartment and exposing a sticky collector to snag airborne cells. Minutes later, as the balloon passed 23 kilometers, the compartment door closed. An electric heating coil severed the balloon tether, sending the payload parachuting back to Earth.

Meanwhile, Bryan drove west on Highway 60 across empty rangeland while a fellow student tracked the balloon via GPS. She eventually veered off the road onto the dusty plain and after several miles found her germ catcher nestled between a yucca and a prickly pear cactus.

This was one of six balloons that Bryan, Guzik and colleagues launched during a three-week stint in 2013; some reached as high as 29 kilometers. A seventh launch on a larger NASA balloon reached 38 kilometers during that same period.

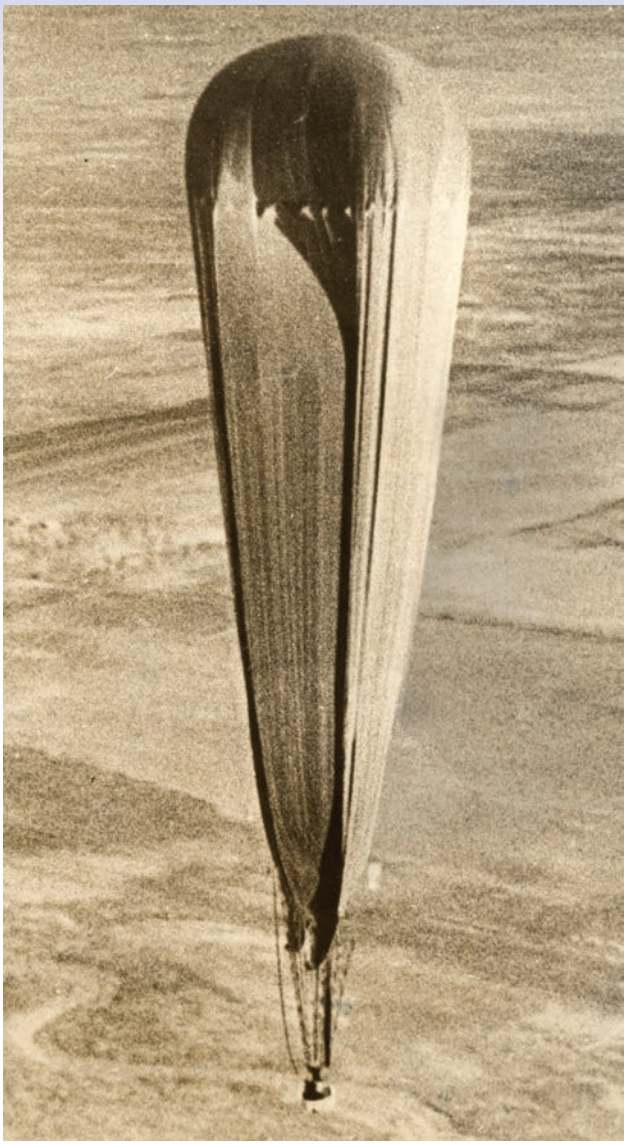
But in retrospect, the August 21 launch would loom especially large. That afternoon in the airport hangar, Bryan tested the sample for ATP, an energy molecule found in living cells. "I really thought everybody was going to be dead," she says. But test after test revealed the presence of ATP, prompting her to think, "Oh my God, they're alive."

Back at LSU, Bryan spent several months incubating her samples. The one from August 21 spawned a glistening orange bacterial colony, which she named L6-1. Samples from other launches spawned yellow, pink and black colonies. The colors probably indicated well-known pigments that protected the cells by blocking some UV radiation.

Bryan assumed that these still-unidentified microbes would turn out to be tough cookies — maybe belonging to a group called *Deinococcus* that can survive intense radiation, or to another group such as *Bacillus* that can compact itself into inanimate spores able to survive boiling. But as she isolated and barcoded their DNA repeatedly in 2013 and 2014, a very different picture emerged.

Only one out of a dozen or so bacteria turned out to be the sort of spore-former that Bryan expected. L6-1 and several others belonged to a genus called *Curtobacterium* that often lives on plants. Others belonged to groups that inhabit soil.

It "should have been nothing but spore-formers," Bryan says. It "should have been nothing but extremophiles." The fact that these critters appeared to be neither presented a mystery that she desperately wanted to solve. Fully unraveling it would take a decade of work.



The *Explorer II* balloon mission carried two pilots into the stratosphere in 1935. It set a world record, reaching just over 22 kilometers above South Dakota.

WIKIMEDIA COMMONS

PLANT PATHOGEN SUPERHIGHWAY

Bryan spent most of 2014 and 2015 doing work that was crucial to her Ph.D., including rigorous calculations and lab experiments to convert the cell counts from her balloons into estimates of how many live cells are floating around in the stratosphere.

These calculations would ultimately get published with Christner

> "Plant pathogens in the stratosphere — that was the furthest thing that we expected to run into."
>
> **— Brent Christner**

and Guzik in 2019 in the *ISME Journal*. The work suggested that at 24 kilometers high, the concentration of living cells was 100,000 per cubic meter. At 36 kilometers, the air still held nearly 8,000 cells per cubic meter.

In 2016, Bryan turned back to her mystery microbes for a new set of experiments. She tested their tolerance to UV-C radiation — an ultraviolet band that damages DNA and kills cells far more potently than the UV-A and UV-B bands that cause sunburns. UV-C is absent on Earth's surface because it's blocked by the ozone layer, but it's abundant in the mid-stratosphere.

Bryan compared her stratospheric germs to a bacterium called *Deinococcus radiodurans* that can survive roughly 1,000 times the radiation dose lethal for a human. *D. radiodurans* was long considered the toughest organism on Earth, after its accidental discovery in 1956. Scientists working with the U.S. military were trying to sterilize canned meat with gamma radiation. When they later opened the cans, they found the meat putrid, spoiled by these bacteria that had somehow survived.

D. radiodurans is also uniquely resistant to UV-C radiation. But when Bryan compared L6-1 to the supermicrobe, she was shocked at the results. Her dainty little germ, accustomed to the cool, shady canopies of plants, was just as tolerant to UV-C as *D. radiodurans*. And some of her other plant and soil bacteria weren't far behind.

"Clearly I [fudged] up," she remembers thinking — though using a spicier verb. But even as she repeated the experiments over a period of months, looking for potential errors, the results stayed the same.

This moment in 2016 was when the team's understanding "all sort of came together," Christner says. *Curtobacterium*, the plant- and dirt-dwelling genus that L6-1 belonged to, was "pretty abundant in the atmosphere," he says. "Almost every time we put up a balloon and collected samples, whether it's in the high troposphere or in the stratosphere, we are collecting something that is highly similar to this."

Discovering that L6-1 was resistant to radiation and drying hinted that it wasn't up there by accident. It suggested that these plant-dwelling bacteria, closely related to species that were well known, had a secret talent that no one suspected: surviving, at least briefly, at the edge of space.

This was the state of knowledge when Bryan finished her Ph.D. in 2017. Her discoveries had followed a path no one expected. But the story wasn't complete.

As Bryan began a postdoctoral fellowship at MIT, Christner moved from LSU to the University of Florida, where he began to examine another intriguing aspect of L6-1. Based on Bryan's earlier DNA barcoding, L6-1 and several of the other stratospheric bacteria were closely related to a notorious crop pathogen called *Curtobacterium flaccumfaciens*. It had plagued Midwestern farms from the 1920s to the 1970s, causing entire bean fields to brown and wilt. It had gradually faded before re-emerging around 2003.

Hoping to find out whether the stratospheric bacteria were also pathogens, Christner reached out to two plant pathologists in 2020, Brian Kvitko at the University of Georgia in Athens and Robert Harveson at the University of Nebraska in Scottsbluff. Sure enough, they found that L6-1 caused bean plants to yellow and wilt. So did two other *Curtobacterium* microbes Bryan had collected from as high as 29 kilometers.

That same year, Christner's new graduate student, Adam Ellington, sequenced the full genome of L6-1, revealing it as a new species, which they named *Curtobacterium aetherium*. It matched the DNA sequence of another unidentified pathogen that Harveson isolated from a diseased millet crop in Nebraska years before.

The discovery that *C. aetherium* was a plant pathogen was finally published in 2025 in *Microbiology Spectrum*. "Plant pathogens in the stratosphere — that was the furthest thing that we expected to run into," Christner says.

Harveson, a worldwide authority on *Curtobacterium*, had long believed that these pathogens spread on infected seeds. He was stunned to learn that at least some members of its genus could survive so high in the atmosphere. "I don't doubt that it can move that way," he says. "I'm just amazed that so many of these things survived."

"Brent [Christner] and his group are kind of the pioneers for this," Harveson now says. What they found could "change our thought processes about movement of diseases."

LIFE FINDS A WAY

The advantages of traveling long distances through the atmosphere could be huge. By surviving those journeys, a microbe could cross oceans and sprinkle down on new ecosystems, diversifying into countless niches. A pathogen like *C. aetherium* could escape regions where plants develop resistance and land on new hosts. Evidence has been building for some time that plant- and soil-dwelling microbes are well suited for making the jump.

Bacteria that live on leaves are known to experience frequent drying, which can damage their DNA in a manner similar to radiation. So some of them can already repair their DNA reasonably well. Leaf bacteria can also loft into the air with surprising ease. One landmark study published in 1982 found that during a warm day in a bean field, microbes levitated into the air — nearly 20 billion cells per hectare per hour — lifted by breezes, thermal updrafts or electric fields that coalesce around the drying leaves. Bacteria may even encourage this by clumping onto tiny leaf hairs where air currents can more easily lift them.

Once airborne, microbes probably have several ways of getting 10 or 20 kilometers into the air. Major thunderstorms, dust storms, hurricanes and volcanic eruptions can rapidly lift them. Smoke plumes from large wildfires can lift billions of live cells into the air, and in some cases can reach the stratosphere.

Ellington did work that suggests *C. aetherium* could have originated from a leaf-squatting, levitating ancestor, which then evolved new adaptations for surviving extreme altitudes as it got lofted higher.

In one experiment, Ellington looked at *C. flaccumfaciens*, the crop pathogen that's closely related to *C. aetherium* but has not been found high in the atmosphere. He found that it is already moderately tolerant to UV-C radiation. When he exposed it to 12 rounds of UV-C, its survival at high doses increased by another 20- to 80-fold. This bolsters the idea that some plant-dwelling bacteria have a natural flair for evolving extreme radiation protection if they're frequently lofted high into the atmosphere.

When Ellington examined the genes that *C. aetherium* turns on during UV-C exposure, he found three especially notable DNA repair enzymes — suggesting that its particular style of UV-C resistance may be well-suited for the high atmosphere.

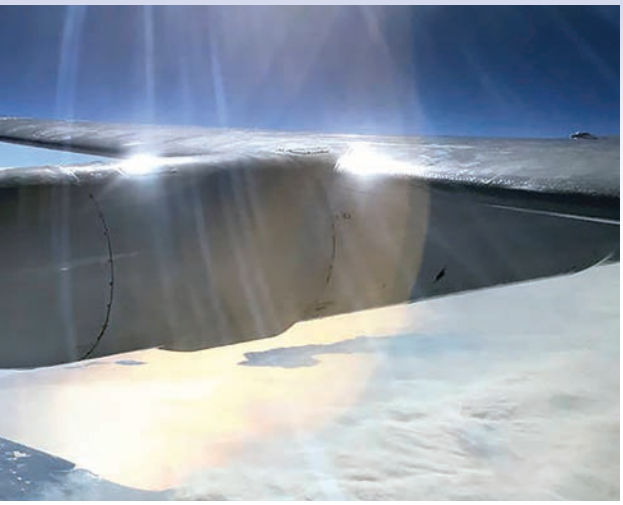
The "most intriguing" was an enzyme called spore photoproduct lyase, Ellington says. It repairs an unusual type of UV damage that occurs only when a cell is so dehydrated that its DNA re-arranges from the normal double helix into a tighter, crystalline form. A cell that's drifting in the stratosphere is "essentially in a desiccated state," Ellington says. So having this enzyme might allow it to repair a type of DNA damage that only happens in those conditions.

Ellington found that *C. aetherium* also uses two different photolyase enzymes. Unlike many other DNA repair proteins, these don't require food-derived energy to do their job.

Instead, they repair DNA using sunlight. This is a "huge advantage for an organism that's trying to survive" in the atmosphere, where food is scarce but sunlight is plentiful, Ellington says. He and colleagues published the findings in March 2025 in *Microorganisms*.

Food scarcity may represent a major challenge for microbes in the atmosphere. Some bacteria may have other strategies for coping with it. While sampling clouds drifting over remote Réunion Island in the Indian Ocean, aerobiologist Pierre Amato at the University

FROM TOP, CLOCKWISE: STU BROCE/NASA; CARLA THOMAS/NASA; NASA



NASA uses the ER-2 research aircraft (bottom right) to conduct experiments at altitudes up to 21 kilometers, such as this flight above California (top). Pilots must wear pressure suits (bottom left) because a loss of cabin pressure could cause them to lose consciousness within seconds and quickly die.

Clermont Auvergne in France found a strain of *Methylobacterium* that harnesses sunlight to produce the energy molecule ATP. This could allow it not only to repair its DNA without burning precious calories, but also to do countless other tasks, like manufacturing proteins.

Microbiologist Chris Greening of Monash University in Clayton, Australia, believes that airborne bacteria can also tap another hidden energy source. He has found that many bacteria living on trees, in soils and even drifting a few meters up in the air can oxidize hydrogen and carbon monoxide, which are trace gases in the atmosphere. He's recently found that some microbes can even burn hydrogen at –40° Celsius, a temperature similar to the stratosphere's. In addition to releasing energy, hydrogen oxidation actually produces water as its sole combustion product. "So, it is hydrating the cell," Greening says. "That might be just enough for some cells to avoid desiccation."

The work done so far has revealed a coherent story about how and why *C. aetherium* and some of its cousins could have evolved to survive high in the atmosphere. But many other stories may still hide among the thousands of other living cells that Bryan retrieved. She managed to grow only 12 or so species of bacteria from the stratosphere, but for every type of microbe that did grow in the lab, 100 to 1,000 others may have been present but didn't grow in the culturing conditions that she used. Some of them might even be more surprising.

"The next question would be to understand the whole community" up there, says Burak Erkorkmaz, a microbiologist at the University of Gothenburg in Sweden.

He envisions using a method in the stratosphere that he employed several years ago, sampling air at ground level in Israel. He sequenced DNA from all of the cells that he collected, identifying hundreds of species. Doing this in the stratosphere would provide a fuller picture of the species potentially present there. It would hint at whether they, like *C. aetherium*, carry genes for surviving at high altitudes and how that might fit into their evolutionary niche.

Scientists are already testing that approach. In 2018, NASA's C-20A jet sampled microbes from up to 12 kilometers over California, just below the stratosphere. Initial results showed DNA sequences for microbes that inhabit soil, rotting leaves and the anatomic nooks and crannies of humans or animals, likely derived from farmlands of the Central Valley, directly upwind.

Many questions remain. Although Bryan estimated that *C. aetherium* can hunker down for a few months or weeks at 20 to 36 kilometers, returning to Earth soon enough to survive the trip would still require some luck. For this reason, even *C. aetherium* probably makes most of it successful flights at lower altitudes, say 5 to 15 kilometers, where conditions are more mild — though still lethal for most microbes. But even so, simply finding that these bacteria can survive in the stratosphere has huge implications. It is spurring new thoughts about where life might survive in other worlds. Including ones that are hellishly hot.

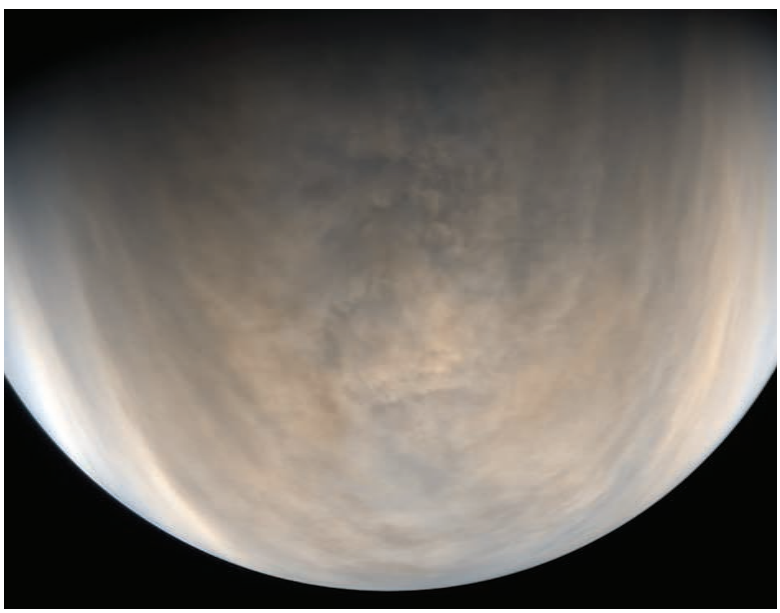
FROM EARTH TO EXOPLANETS

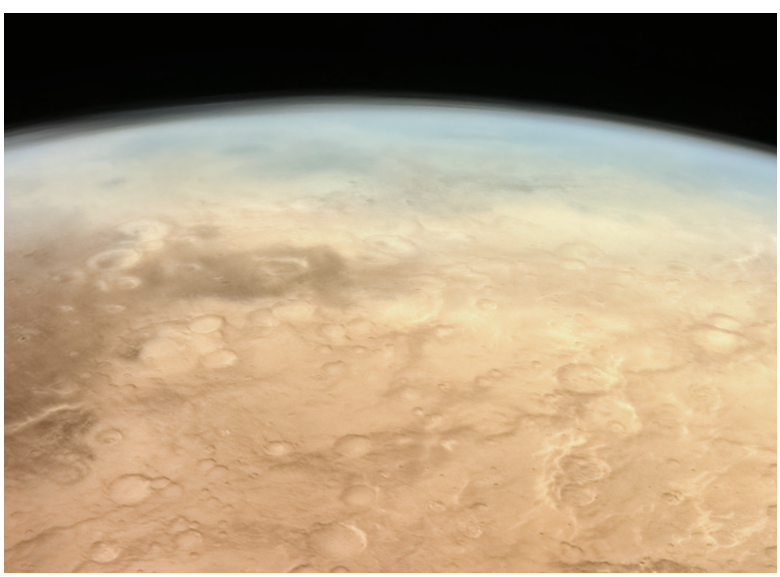
The lead-melting surface of Venus is inhospitable to life as we know it. But scientists have noticed some tantalizing chemical signatures in a cloud layer 48 to 60 kilometers above the surface, where temperatures and atmospheric pressures are similar to those at Earth's surface. Potential traces of several gases, including oxygen, methane, ammonia and

phosphine, have fueled speculation that Venusian microbes might inhabit those clouds, producing these gases through their metabolism.

If such cloud-dwelling microbes exist, they would have to survive periodic bouts of nastiness as they sank into lower, hotter layers of the atmosphere. In 2021, Bryan and Sara Seager, a planetary scientist at MIT, proposed in the journal *Astrobiology* that those Venusian microbes might survive the way *C. aetherium* seems to in Earth's atmosphere: by temporarily drying out and hunkering down, then re-awakening as they're swept back into cooler, wetter cloud layers.

Venus (top) and Mars (bottom) seem inhospitable to life as we know it for very different reasons. But the surprising abilities of microbes that thrive in Earth's stratosphere suggest new ways to look for miniscule life on both planets.





FROM TOP: JAXA/ISAS/DARTS/KEVIN M. GILL/FLICKR (CC BY 2.0); ©UAESA/MBRSC/HOPEMARSMISSION/EXI/ANDREALUCK/FLICKR (CC BY 2.0)

Bacteria that Bryan isolated from the stratosphere in 2013 could also guide the search for life in other solar systems that are light-years away.

For example, the critters grown in the lab produced those vivid pigments that are known to protect microbes from UV radiation. Last November, astrobiologist Lígia Coelho of Cornell University suggested that scientists could use this trait to identify distant planets with microbial life in their atmospheres.

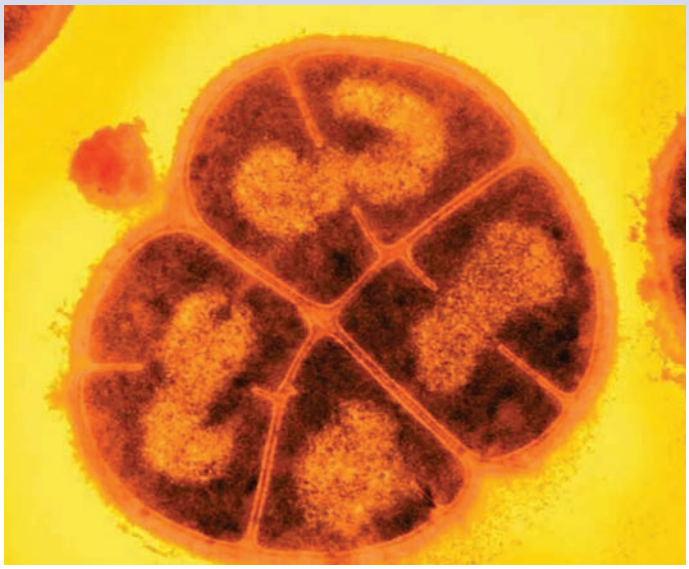
Such life might also have to protect itself from UV radiation. By analyzing pigments from Bryan's stratospheric bacteria, including *C. aetherium*, Coelho identified their specific patterns of absorbance and reflectance at certain wavelengths of light.

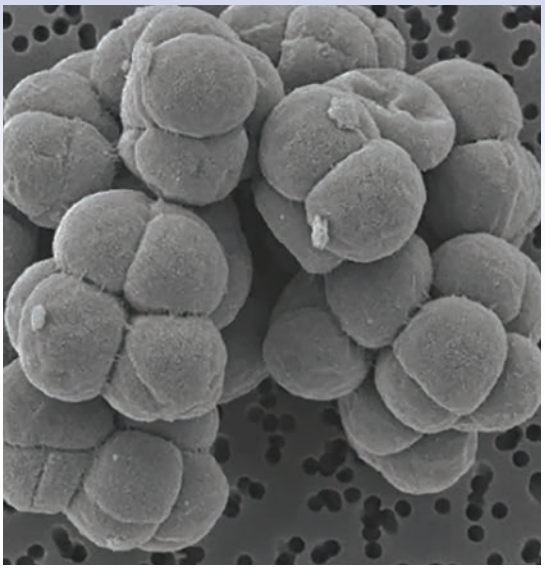
"We might be able to capture [these patterns] with future telescopes" looking at Earth-sized exoplanets, Coelho says. The initial candidates would be small planets orbiting nearby stars such as Proxima Centauri, which is about four light-years from Earth.

"This is opening a whole new paradigm" for looking for life on exoplanets, she says — especially on Earthlike planets with a lot of liquid water and clouds that might obscure the planetary surface.

But discovering *C. aetherium* in the stratosphere is probably most relevant for thinking about life on Mars. *C. aetherium* itself probably couldn't survive on Mars because it requires oxygen, which is largely absent there. But its sheer toughness suggests that other microscopic Earthlings probably could.

Astrobiologist Andrew Schuerger at the University of Florida in Gainesville has spent years looking for candidates. In 2025, he and Rachel Harris, an astrobiologist with Harvard and NASA, reported that a microbe called *Methanosarcina barkeri* comes surprisingly close.





Some of the microbes found living in the stratosphere are about as resistant to ultraviolet radiation as the hardy bacterium *Deinococcus radiodurans* (left). While none of the known stratospheric germs would likely survive on Mars because they need oxygen, the microbe *Methanosarcina barkeri* (right) found in sewage and landfills can tolerate Martian conditions in the lab.

M. barkeri normally lives in sewage, landfills, rice paddies and lake bottoms without oxygen. It obtains energy by converting carbon dioxide and hydrogen into methane.

Because *M. barkeri* often lives underground and underwater, one would hardly expect it to thrive in the extreme dryness and thin atmosphere on Mars. Still, Schuerger and Harris found that even at low, Marslike gas pressures — similar to Earth's stratosphere — it continues to produce methane.

For Mars enthusiasts, that's big news. Orbiters and rovers have repeatedly detected methane gas seeping into the planet's atmosphere, a potential byproduct of microbial life beneath the surface.

"For me it was space exploration. It was uncharted territory."

— Noelle Bryan

Due to the low pressure and dryness on the Martian surface, those methane-making critters might have to live kilometers underground, making them nearly impossible for a Mars rover to find.

But finding that *M. barkeri* is active at such low pressures "opens up the entire crust from the surface [downward]" as possible habitat on Mars, Schuerger says. If a Mars rover drilled 20 centimeters into the ground in the right place, it could potentially encounter tiny single-celled Martians — if they exist.

The niches where microbes could live just below the Martian surface might still be quite small, says astrobiologist Lynn Rothschild at NASA Ames Research Center in Mountain View, Calif. But Rothschild imagines Martian microbes using the surface of the planet the way *C. aetherium* seems to use Earth's atmosphere: as a hostile environment that can be tolerated for a period time to move from one place to another.

She imagines windstorms on Mars carrying not only dust, but also Martian microbes swept up with it. Microbes "would be floating around, just looking for a place to land [where] they can survive" and grow for a while, Rothschild says. If so, then a rover might find life the way a fence finds blowing leaves.

Years may pass before the lessons from Earth's stratosphere find their way into the search for life on Mars or Venus. But for Bryan, the excitement of it began years ago, even as she made her first tentative trips to Hobby Lobby, gathering materials that she would use to catch bacteria high up in the sky.

"For me it was space exploration," Bryan says. "It was uncharted territory." ✖

Douglas Fox is a freelance journalist based in Northern California.

FROM LEFT: MICHAEL DALY/USU; R.L. HARRIS AND A.C. SCHUERGER/*SCIENTIFIC REPORTS* 2025

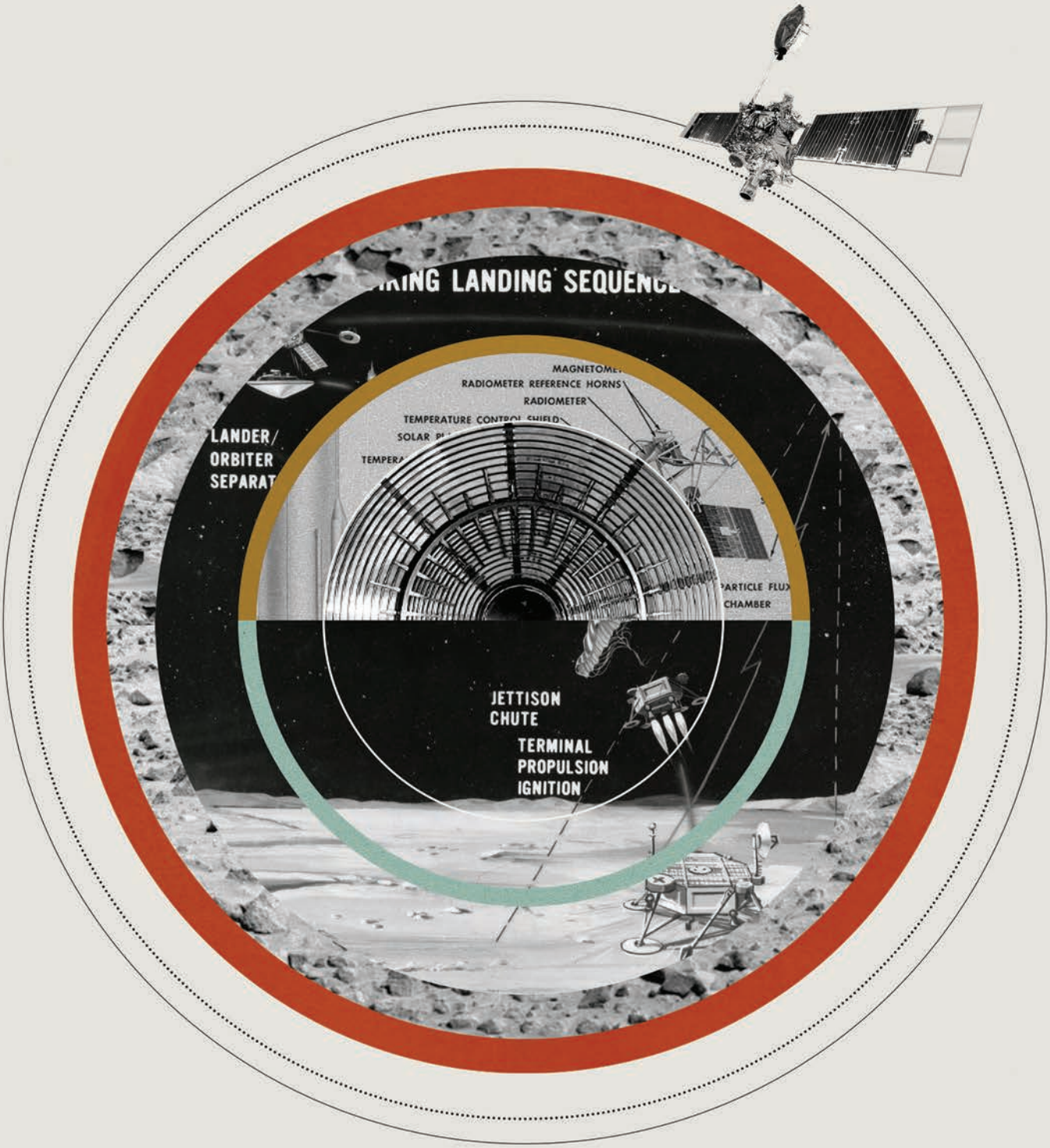


PHOTO-ILLUSTRATION BY VALERIE CHIANG

NASA's shifting priorities are putting a 50-year search for Martian life in limbo

BY LISA GROSSMAN

MARS DESCENDING

IT WAS AMERICA'S BICENTENNIAL, July 4, 1976, and NASA was hoping *not* to see fireworks. After a 10-month traverse through space, the Viking 1 lander was ready to become the first spacecraft to operate on Mars—if it didn't crash on the unexpectedly rugged ground first. More than two tense weeks passed while mission managers searched for a suitable landing site. Viking ultimately sank its footpads into Martian soil on July 20. The robot's twin, Viking 2, landed safely that September.

Together, the Viking landers had an ambitious goal, one that had never before been attempted on another planet: search directly for signs of life.

Shortly before the first landing, astronomers Carl Sagan and Joshua Lederberg wrote in the journal *Icarus*: "Large organisms, possibly detectable by the Viking lander cameras, are not only possible on Mars; they may be favored."

To Sagan, Lederberg and Mars dreamers like them, finding life elsewhere has been an existential quest. If life arose just once, it could be a fluke, a lucky alignment of vanishingly rare conditions. But if life also happened somewhere else, independent of Earth, it means we're not just a cosmic anomaly.

Our russet neighbor in particular has many Earthlike qualities, so if it ever hosted life, that would be a promising sign for it sprouting elsewhere across the galaxy.

The Viking experiments delivered ambiguous results. Most biologists saw them and gave up on Martian life, but some scientists never lost faith. The uncertainty kicked off a half century of ups and downs in NASA's relationship with the Red Planet. Now, after decades of methodically refining their understanding of Mars and how to study it, scientists are ready to finish what Viking started.

But the search for life on Mars keeps getting delayed by the complexities of life on Earth. NASA's efforts to bring Mars rocks back home are being knocked off course by political struggles in the United States. NASA and private space companies alike are shifting focus from exploring the solar system with robots to sending humans to the moon. And a European rover that aims to search for life on Mars has been delayed over and over by failure, plague and war.

Still, the sense that the answer to the great cosmic question could be nearer than ever has many holding out hope for the Red Planet, despite the frustrations.

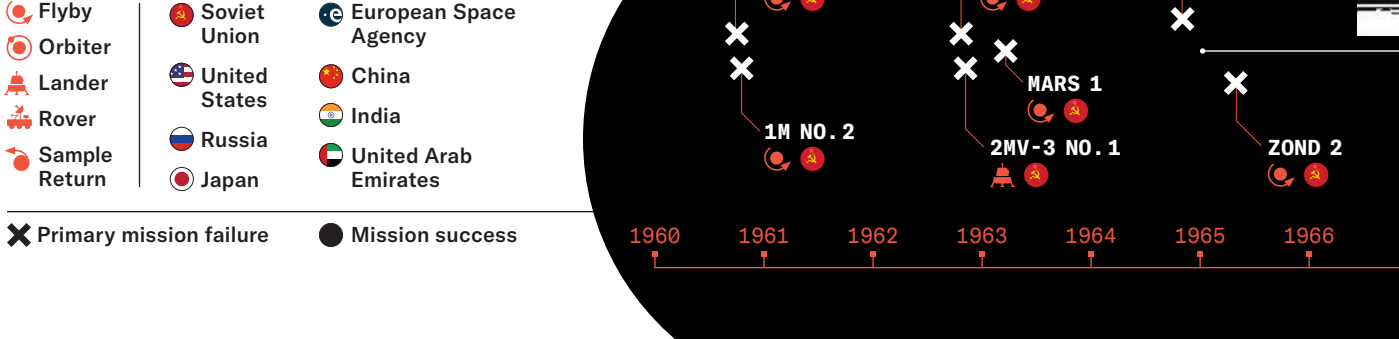
"Mars has always allured us, even when it's been disappointing," says Ashwin Vasavada, who has been one of the project scientists for

In July 1965, NASA's Mariner 4 spacecraft returned the first closeup image of Mars as it flew past the Red Planet. ↘

PREVIOUS SPREAD, FROM TOP: JPL-CALTECH/NASA; JPL/NASA, MSSS; NASA; NASA

REACHING FOR MARS

Humans have aimed robots at the Red Planet for almost 70 years.



NASA's Curiosity Mars rover since 2004. "The whole history of Mars exploration is a big roller coaster."

THE FIRST LOOK

Astronomers in the late 1800s saw signs of life everywhere they looked on Mars. Dark splotches that varied over the Martian year were interpreted as seasonal vegetation. Or else the dark patches were salty seas, and lines crisscrossing and connecting them were waterways built by a civilization complex enough to have engineered canals.

In 1971, NASA's Mariner 9 orbiter revealed the "vegetation" as dust in the atmosphere, and the canals as a mirage. Other measurements showed Mars was a frigid desert with low atmospheric pressure. The avenues for life narrowed considerably.

That was a setback for Mars hopefuls, but they rallied. Maybe they had to think smaller. Life on Earth can take minuscule forms, some of which thrive in environments akin to Martian conditions. If life on Mars couldn't be detected with telescopes and cameras, maybe it could be caught in an interplanetary test tube.

So the twin Viking landers were designed to look for microbial life. After transmitting photos of their surroundings, both landers extended their robotic arms, scooped up a bit of Martian soil and deposited it into three separate life detection experiments, plus others to assess the sample's chemistry and geology.

One experiment replaced Martian air with inert helium gas and added liquid nutrients to a soil sample, earning the instrument the nickname "chicken soup." The idea was that any microorganisms in the soil that could metabolize the nutrients would change the concentration of gases as they respired. The experiment could detect and measure those changes with a gas chromatograph.

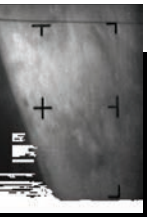
The second, called the labeled release experiment, added a dab of liquid nutrients tagged with radioactive carbon-14 isotopes to the soil. If anything metabolized those nutrients and emitted a carbon-containing gas as a by-product, the resulting gas would also contain the radioactive isotope. Similarly, the third experiment exposed dry soil to gas with carbon-14 isotopes and heated it to see if any organisms took in the tagged carbon.

Another experiment looked for organic molecules — the backbones of life on Earth — by heating soil samples to different temperatures and measuring the molecular weights of vaporized chemicals. If any organics were present, this gas chromatograph–mass spectrometer should have been able to find them.

Initial results looked promising. The chicken soup experiment did detect gases, although they could have been from

Viking 1 took the first photo from the Martian surface the day after the spacecraft landed in July 1976. →

FROM LEFT: PIOTR A. MASEK/JPL-CALTECH/NASA; JPL-CALTECH/NASA



unexpected chemistry in the soil rather than microbes. And the labeled release experiment detected radioactively labeled carbon dioxide. But surprisingly, the mass spectrometer found essentially no organic molecules at all. The only organics identified in the heated samples were chloromethane and dichloromethane, which the team thought were contaminants from cleaning fluids used back on Earth. Mars, apparently, had fewer organics than even the moon.

The biologists were flummoxed. Astrobiologist Ben Clark of the Space Science Institute in Boulder, Colo., who worked on one of the geology experiments on Viking, shared an office wall with the biology team. "Some of them thought they had discovered life and others thought they hadn't," Clark recalls. "We would sometimes hear loud arguments through the walls."

Ultimately, many scientists concluded that no organics meant no life. "Once [the biologists] got convinced that they didn't find life, they totally lost interest in Mars," Clark says.

But some scientists held on. The lead researcher on the labeled release experiment, Gilbert Levin, maintained until his death in 2021 that the experiment's results could be consistent with life. And even at the time, some scientists saw a glimmer of where the search was headed next.

"[T]he present Martian environment ... presents formidable challenges to any putative Martian organisms," biologist Peter Mazur of Oak Ridge National Laboratory in Tennessee and colleagues wrote in 1978 in *Space Science Reviews*. "The Martian environment in the past, on the other hand, appears to have been considerably less hostile."

JOURNEY TO THE PAST

The Viking landers continued working into the early 1980s. Still, NASA had more or less moved on. "After Viking, partly because we didn't discover life, it was decided to turn away from Mars and not do much of anything for about 20 years," Clark says.

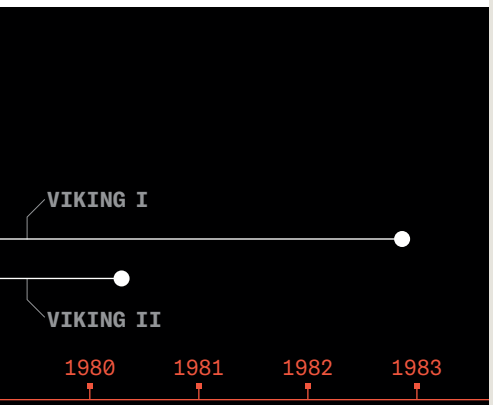
Some of the delay wasn't Mars's fault. NASA shifted focus to human spaceflight for a while, formally starting the space shuttle program in 1972. Then, in 1986, the space shuttle Challenger broke apart shortly after launch. The disaster halted shuttle launches for more than two years and delayed the launch of some planetary missions, including the next planned Mars mission. The $813 million Mars Observer launched in 1992, but lost contact with Earth just before it reached Mars orbit and was never heard from again.

Overall, it was a rough patch for NASA. At the same time, though, some started dreaming of sending humans deeper into space. In a July 20, 1989 speech, President George H.W. Bush called for sending humans back to the moon and eventually on to Mars. The sense that the Red Planet was becoming cool again was growing.

Mars scientists regrouped. Viking had made it clear that you can't land just anywhere and expect to pick up signs of life. But what if you looked somewhere else—or some*when* else?

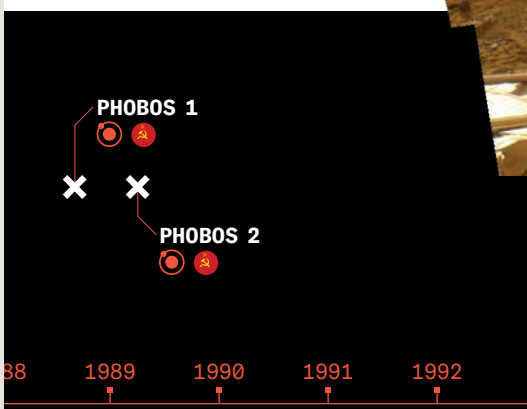
"They really went for it with Viking—the very first time you ever land, you try to detect life," Vasavada says. The thought was, "we're going to take a step back.... We're going to get to know Mars all over again."

By the early 1990s, a plan took shape. Send more spacecraft more often, ideally at launch opportunities every 26 months. Ask science questions that build on each other and build up the technical skills to eventually bring samples to Earth. After a rocky start, it worked. Today, there has been at least one



"After Viking, partly because we didn't discover life, it was decided to turn away from Mars and not do much of anything for about 20 years."

— BEN CLARK



NASA spacecraft orbiting, sitting or roving on Mars since 1997 with no gaps. "It really was a reboot after Viking," Vasavada says. "It's a golden age, in retrospect."

A successful string of rovers and orbiters that launched in the first two decades of the 21st century has transformed scientists' view of Mars. The planet today may be an arid icebox, but billions of years ago, it was a lot more like Earth. Liquid water pooled and flowed across the surface and seeped underground. Some of those wet environments may have had temperature and chemical conditions that could have made cozy homes for microbes.

In 2008, NASA's Phoenix lander provided an explanation for Viking's lack of organics: Mars' soil contains perchlorate salts, a class of oxidizing agents that are sometimes used in rocket fuel. Experiments on Earth published in 2010 showed that when heated with a Mars soil analog, a perchlorate salt can break down into chemicals that in turn break down organic compounds. The resulting molecules were chloromethane and dichloromethane, the same chemicals attributed to cleaning fluids on Viking. Maybe by heating the soil, Viking's instruments inadvertently destroyed the very thing they were looking for. In fact, there are organic molecules locked in Martian rocks; NASA's Curiosity rover finally found them in 2014.

"I think it's widely accepted that ancient Mars was capable of supporting life," says planetary geologist Katie Stack Morgan of NASA's Jet Propulsion Laboratory in Pasadena, Calif. "The question is, was it there? Did it happen?"

BUDGET CUTS AND LEOPARD SPOTS

Stack Morgan is closer to answering that question than almost anyone else in the world. She is a deputy project scientist for the latest Mars rover, Perseverance, which landed in an ancient river delta in 2021 and is still going. Part of its mission is to achieve the aspirations of the last 20 years of Mars science: cache samples of particularly interesting rocks for eventual return to Earth.

Mars scientists have been longing to get their hands on rock samples since before the Viking missions and have had some kind of "Mars sample return" in the strategic plan since the '90s. Earthly labs have better equipment than we can currently shrink down to fit on a rover. And caching samples on Earth means they can be studied with new techniques in the future.

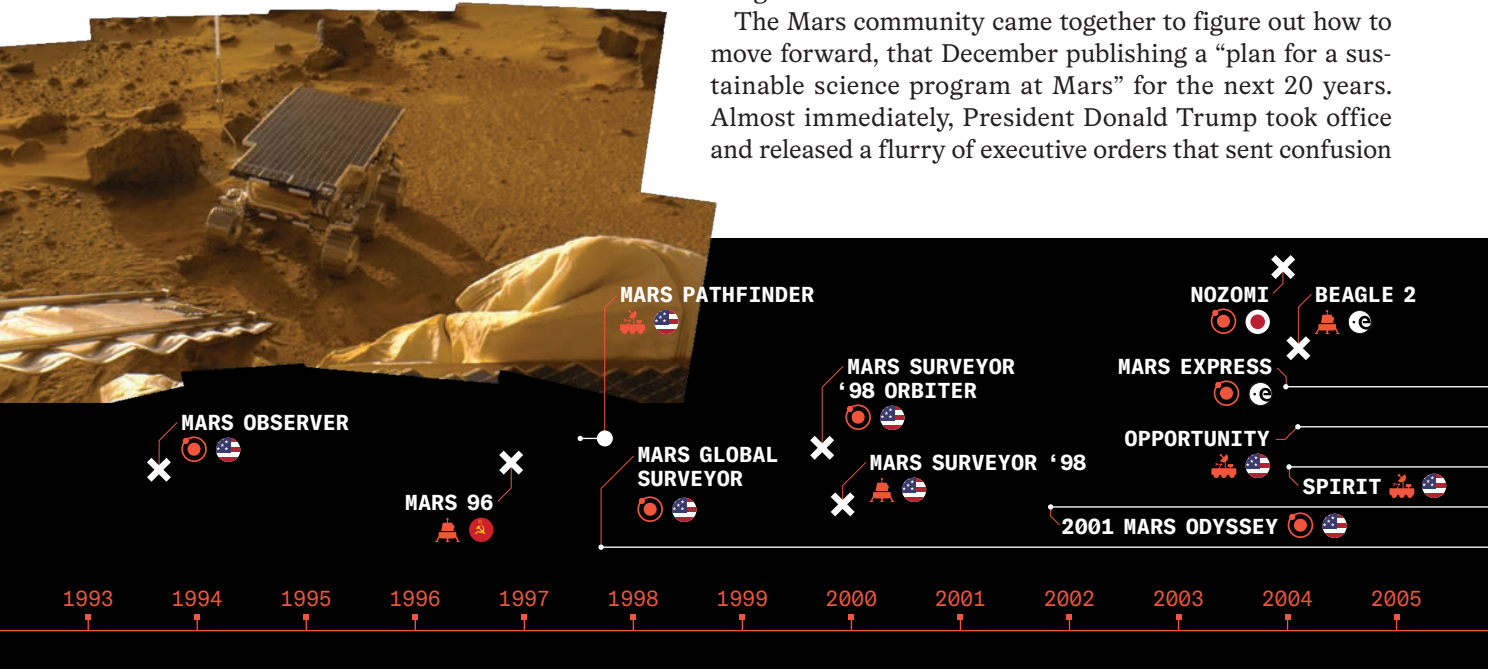
"When you do a space mission, it goes on for as long as the mission lasts and then maybe a few years after," says Clark, who has worked on each of NASA's landed Mars missions and on successful sample return missions that visited a comet and an asteroid. "With the samples, people keep inventing new ways to study them. It kind of never ends."

In the early 2020s, NASA and the European Space Agency were actively working on a Mars sample return campaign that would send another vehicle to collect Perseverance's samples. It was ambitious and exciting — until it fell victim to U.S. budget cuts in March 2024.

The Mars community came together to figure out how to move forward, that December publishing a "plan for a sustainable science program at Mars" for the next 20 years. Almost immediately, President Donald Trump took office and released a flurry of executive orders that sent confusion

JPL-CALTECH/NASA

In 1997, NASA's Pathfinder lander took this image of its companion, Sojourner, the first Mars rover. ↓



rippling through the federal government. Trump's first budget request cut almost half of NASA's science funding. Congress rejected that budget, but the bill that included NASA didn't pass until this past January, by which time the agency had already started making some of the president's requested cuts, according to a report released by House Democrats this April.

Amid this environment of uncertainty appeared the most biologically exciting Mars rock in decades. In July 2024, Stack Morgan and colleagues announced that Perseverance had drilled into a rock that might contain signs of ancient microbes on Mars. The rock, called Cheyava Falls, sports a pattern resembling leopard spots, with iron phosphate and iron sulfate molecules around their rims. Similar patterns in rocks on Earth result from chemical reactions associated with ancient microbial life. Stack Morgan and colleagues stop well short of claiming the rock pattern is a sign of life, but she's comfortable calling it a "potential biosignature." The only way to know for sure is to bring the rock home.

"We have not abandoned bringing samples from Perseverance back," Mars Exploration Program Director Tiffany Morgan of NASA Headquarters said at an April meeting of the Mars Exploration Program Analysis Group.

It's just not clear how, or when. NASA is once again looking away from Mars and toward crewed missions closer to Earth. The only proposed new NASA vehicles for Mars are a telecommunications orbiter and a nuclear propulsion tech demonstration called Space Reactor-1 Freedom. That spacecraft would carry Mars-exploring helicopters for a mission called Skyfall. But there's no guarantee that those helicopters will do any science, and no plan for how to determine what science they should do. In the United States, Mars is receding into the background — still a goal, but as distant as ever.

THE LITTLE ROVER THAT COULD

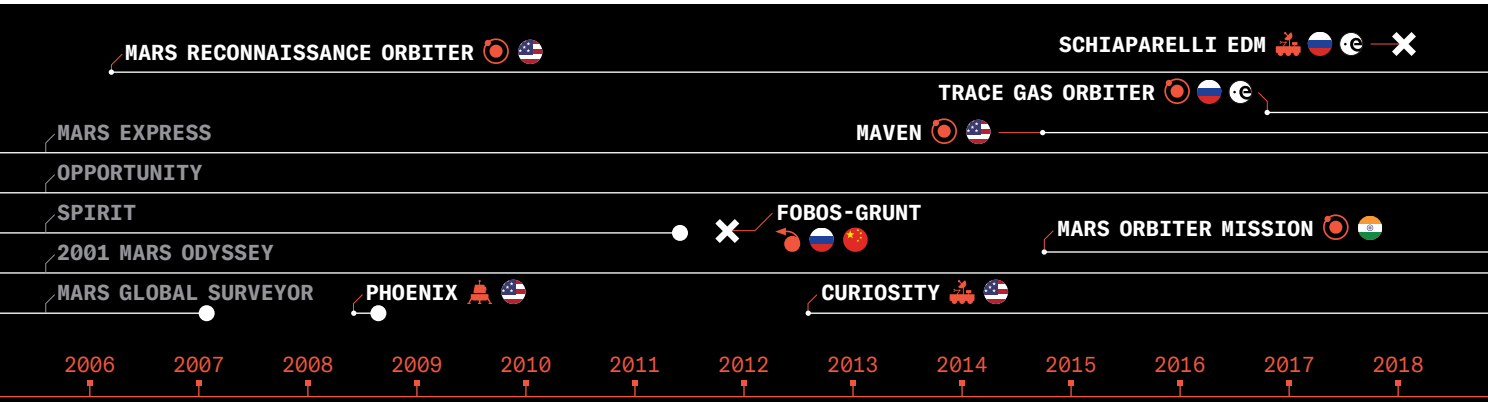
The history of Mars exploration is pretty much entirely a NASA story. But the future might not be. In recent years, China, India and the United Arab Emirates have all launched successful missions to the Red Planet. China plans to launch a Mars sample return mission of its own in 2028, due to return in 2031. And after a decade of delays, a rover from the European Space Agency, ExoMars, is preparing to launch in two years, aiming to make the first life detection measurements since Viking.

The ExoMars mission is no stranger to setbacks. It originally included NASA, but NASA pulled out in 2012, citing budget problems. The Russian space agency, Roscosmos, also collaborated on the mission, offering launch vehicles and its launchpad in Kazakhstan.

The mission had three parts: an orbiter and lander scheduled to launch in 2016, and a rover later named after DNA research pioneer Rosalind Franklin to follow in 2018.

The orbiter arrived on time and has been measuring trace amounts of methane and other gases in the Martian atmosphere and serving as a communications relay for various rovers. But the lander, called Schiaparelli EDM, crash landed on Mars. Meanwhile, technical issues delayed the rover's launch to 2020; the COVID-19 pandemic pushed it back to 2022. Launch opportunities to Mars come once every two years, so every setback was significant.

ExoMars project scientist Jorge Vago was giving a talk to high school students in Istanbul in February 2022. The team was one week away from bringing the rover to Kazakhstan to prepare for a September launch.



"We had packed the crates, we even had the celebration T-shirts and the wine bottles stacked," Vago says. "We were ready to go." Near the end of the talk, he noticed he had lost his audience's attention; everybody was looking at their phones. Russia had invaded Ukraine.

It soon became clear that partnership with Roscosmos on the mission could not continue. "It was traumatic at the time. It was a heavy blow," Vago says. "We didn't know if, after almost then 18 years of work, if this thing was the end."

Thankfully, it wasn't. NASA rejoined forces with ESA in 2024. President Trump's 2026 budget request threatened to pull the agency out again, but Congress rejected it and awarded the launch contract to SpaceX.

The Rosalind Franklin rover will take a longer-than-usual route to Mars to avoid landing during dust storm season. If all goes well, it will touch down in 2030 at a site called Oxia Planum, where the rocks are 4 billion years old and full of clays called phyllosilicates that form when organics are in prolonged contact with liquid water. "It's an amazing landing site," Vago says. "The hypothesis is that it could have been the coast of this very large ocean that some people think may have existed early in the history of Mars."

The team took lessons from every previous mission to Mars in developing its life-hunting instruments, Vago says. The most exciting one is the Mars Organic Molecule Analyzer, which has a laser that can extract organics from crushed rocks without activating the organic-wrecking perchlorate molecules that could have confounded Viking.

By now, scientists know that no single measurement will be enough to convince either themselves or the world that they've actually found life on Mars. The ExoMars science team designed a metric called the ExoMars Biosignature Score to help vet their findings. The score counts things such as the morphology of sedimentary structures, chemical biosignatures and geologic context.

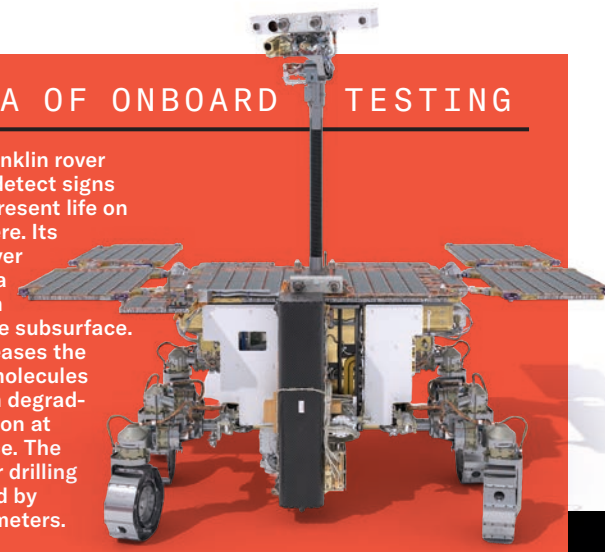
"We don't think that any one verified biosignature is sufficient," Vago says. He expects to work for at least two years after he gets the data before coming to any conclusions. "We need several independent lines of evidence that cannot be explained away by anything but biology."

A 2028 launch date means the Rosalind Franklin rover will launch alongside China's proposed sample return mission. Some might see the overlap as competition for scarce resources or national glory. But Vago doesn't feel like he's in a race. More Martian–life seekers could mean a more robust search. The quest doesn't have to stop when political circumstances change.

"I wish everybody well," Vago says. "In the end, we all want to learn things that are important for us as humankind." ✖

A NEW ERA OF ONBOARD TESTING

ESA's Rosalind Franklin rover should be able to detect signs of both past and present life on Mars, if they're there. Its chief advantage over previous rovers is a drill that can reach two meters into the subsurface. Digging deep increases the odds of catching molecules that have not been degraded by harsh radiation at the planet's surface. The previous record for drilling on Mars is still held by Viking, at 15 centimeters.



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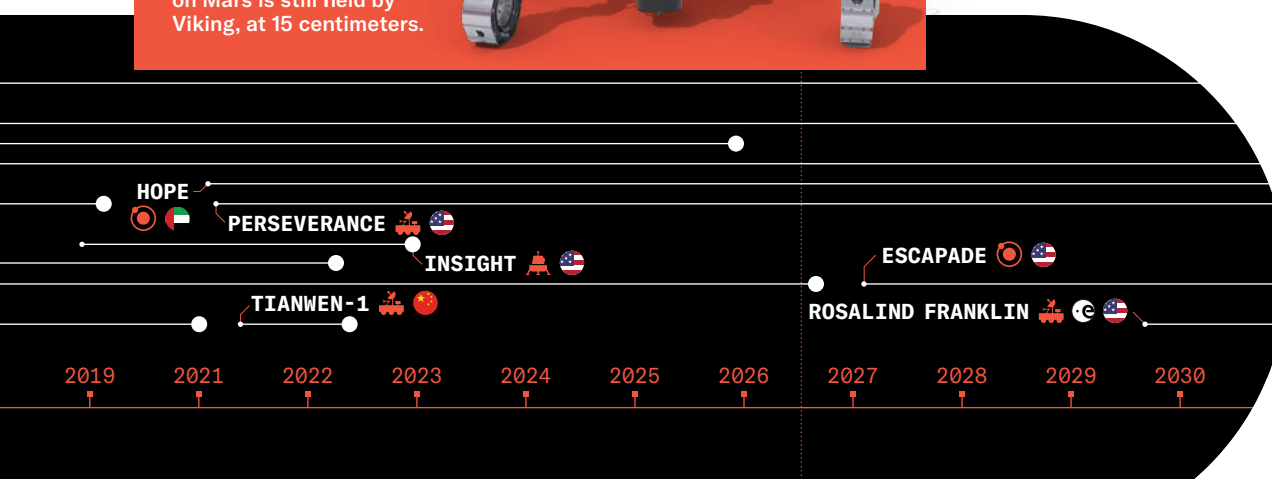


the truth about

Brain Rot

Emerging research suggests overusing digital devices can be harmful. But can this truly rot our brains?

By Kathryn Hulick
Illustration by Noah Verrier

Emma Lembke joined Instagram at age 12. Soon, she found herself "scrolling mindlessly for hours, addicted to gaining a certain number of likes, a certain number of comments." She often wanted to stop — but couldn't.

She's not alone. Most of us these days know the feeling of mindlessly scrolling through low-quality content. We call this sensation "brain rot." The term can also refer to the content being consumed. Tung Tung Tung Sahur, a personified wooden drum (see Page 48), is one in a slew of silly AI-generated characters deemed "Italian brain rot" because many of them have Italian-sounding names. Trendy among middle schoolers, these absurdist characters show up in memes, videos, Roblox games and more.

Brain rot is kind of a joke, but it also really isn't. A growing number of young people and their parents claim that spending too much time on social media, the spawning ground for brain rot, can mess with mental health. Thousands of cases accusing social media companies of harming young users with addictive features are now making their way through U.S. courts.

In May, the U.S. government released a Surgeon General's warning about the harms of screen use for young people, calling out social media as well as gaming, chatbots and more. "Policy makers and tech companies need to acknowledge the potential for harm and create frameworks to protect children to allow for healthy and joyful use," states the warning, which includes a disclaimer that the document was edited using the AI tool ChatGPT.

But the term "brain rot" evokes something more pernicious. Could browsing through stupid content actually make us stupid? This fear isn't new. Back in 2009, the former CEO of Google, Eric Schmidt, voiced concerns about how digital media was impacting young people's intelligence: "I worry that the level of interrupt, the sort of overwhelming rapidity of information ... is in fact affecting cognition," he said in an interview with talk show host Charlie Rose.

Scientific research is now emerging to support claims that overuse of digital devices in general — and social media in particular — can be harmful, especially to mental health. However, the evidence that any sort of technology use harms intelligence is still weak, says media psychologist Susanne Baumgartner at the University of Amsterdam. "It's so popular to have a statement that it ruins your brain if you use social media," she says. "But there are very few studies that really scientifically support this notion."

Still, you should probably think twice about how much time you and others are spending glued to your devices, Baumgartner says.

Brain rot is a lot like candy, says Kris Perry, the executive director of Children and Screens, a New York–based nonprofit that works to make the public aware of how digital media can affect kids. Like candy, a little brain rot now and again won't hurt you. But the more you partake, Perry says, the bigger a problem it can become.

Distractions in your pocket

Everything we do helps build or strengthen some brain pathways and trim back others. "What you do with your brain affects your brain," says neuroscientist Torkel

Klingberg at the Karolinska Institutet in Stockholm. This is called neuroplasticity.

A plastic brain allows us to learn and grow from experiences. It also allows those experiences to mold and change us. This is especially true for adolescents, whose brains undergo rapid change. Neurologically speaking, "adolescence" lasts into the early 30s, and our brains continue to adapt and change throughout our lives.

Many of our brain-molding experiences now take place on screens. A Pew Research Center survey conducted in 2025 found that 63 percent of U.S. adults ages 18 to 29 say they are online "almost constantly."

Of course, kids and adults alike can do creative or practical things on our devices. We can connect with faraway family and friends, make art or play educational games. These things can help develop a healthy brain.

But it's often far too easy to get distracted and sucked into brain rot.

Addicted to screens

Having a phone or tablet nearby offers up endless temptations. And you don't even have to be on your device to get distracted. One study found that just having your phone in the same room as you—available but not in use—can make it more difficult to think and process information.

Jason Nagata, a doctor who specializes in teen health and digital media at the University of California, San Francisco, led a study tracking which apps young people opened and used while in school. Spoiler alert: Educational tools were near the bottom of the list. Instead, Nagata says, "the top apps were social media, YouTube videos and video gaming."

These types of findings don't surprise Lembke. Now in her early 20s, Lembke used social media for five to six hours per day as a preteen. Back then, she says, "I felt much worse about myself ... I felt depressed. I felt more anxious."

However, Lembke felt trapped in the online world. "My social life was there, so I couldn't leave," she says. Now, she understands that her compulsive scrolling and checking wasn't really her fault. Social media apps and other similar technologies "are built to pull you in," Lembke says. "They are built to maximize attention at all costs."

This design can lead to symptoms similar to those seen with addiction to drugs or alcohol, Nagata says. In a 2021 study of almost 500 16- to 19-year-old students in India, more than one in three showed signs of addiction to their phones, including constantly checking for updates on social media or feeling pain in their wrists while using their phones. Addictive or at least habit-forming smartphone use also interferes with sleep, studying and friendships.

In March, a California jury found that Meta, the company behind Instagram, and Google, the company behind YouTube, had harmed a young user's mental health. That user, now 20, had been on social media compulsively since she was a child. She said this had triggered anxiety and depression, and the jury agreed, awarding $6 million in damages. When Lembke heard the news, she felt like she'd just won the Super Bowl. "I was tearing up," she says. "It felt like finally there was a legal path for accountability that was being charted."

Adults are at risk of problem-causing social media or phone use too. But the younger you are, the harder it tends to be to control your screen use, Klingberg says. That's because choosing to put down or ignore a tempting device requires using the prefrontal cortex, a brain area that, among other things, is involved with "self-management and impulse control," Perry says. But the prefrontal cortex is one of the last brain regions to fully mature.

The teen brain also responds strongly to rewards. Reward pathways in the brain activate when we do things such as eat chocolate or win money. Research has shown that getting likes on social media triggers these same pathways. This sensitivity normally decreases with age. But when young people checked social media constantly, one study found, their brains remained highly sensitive to rewards.

Despite all these obstacles, Lembke managed to take control and make a change. In ninth grade, she deleted the Instagram

Brain rot is kind of a joke, but it also really isn't.

app from her phone. “I felt really freed,” she says. In her senior year of high school, she founded the Log Off Movement, which empowers young people to think critically and make mindful decisions about how they engage with online content.

However, Lembke thinks her early compulsive social media use left “deep scars.” She has struggled with an eating disorder that she thinks is largely due to images and interactions she saw and experienced on Instagram as a young girl. She says the app’s content changed “the relationship I had with myself and my body.”

Cause and effect

Concerns about young people’s use of social media and other digital technologies have led researchers to dig deeper.

One important research project is known as the ABCD, short for Adolescent Brain Cognitive Development, study. It has been collecting data from more than 11,500 U.S. teens since 2016. At the beginning, participants were ages 9 or 10. Each year since then, researchers have assessed these young people’s health and screen use. And every other year, the participants have gone through medical tests, including brain scans.

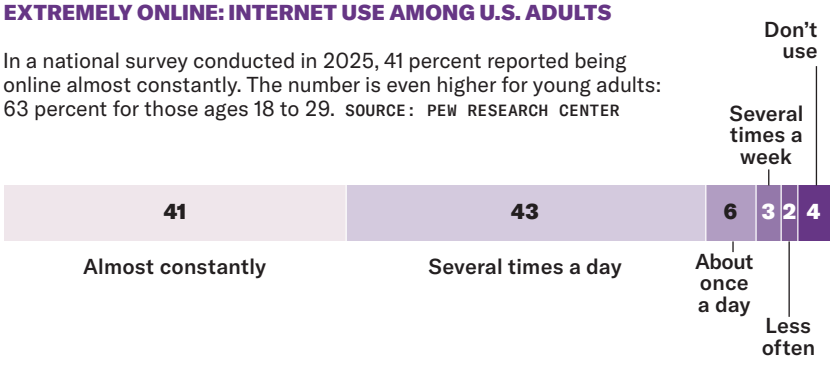
In 2025, Nagata and colleagues reviewed what scientists learned from the ABCD data. They linked higher amounts of screen time to a higher risk of health issues such as depression, attention-deficit/hyperactivity disorder and eating disorders.

It’s one thing to link health problems and screen time, but it’s far tougher to show one causes the other. Following the same young people over the course of several years helps. Researchers can study whether more screen time actually leads to health problems at some later date.

Nagata’s team used a subset of the ABCD data to see what happened to kids and teens with disordered patterns of phone and social media use. One year later, these young people were more likely than their peers to experience depression, attention issues, sleep problems and several other health issues, the team reported in February in the *American Journal of Preventive Medicine*.

EXTREMELY ONLINE: INTERNET USE AMONG U.S. ADULTS

In a national survey conducted in 2025, 41 percent reported being online almost constantly. The number is even higher for young adults: 63 percent for those ages 18 to 29. SOURCE: PEW RESEARCH CENTER



Klingberg, the neuroscientist at the Karolinska Institutet, was part of a team that analyzed four years’ worth of ABCD data. Rising social media use led to a greater likelihood of inattention symptoms over that time period, the team found. But the opposite was not true. Inattention symptoms did not lead to more social media use, the researchers reported in January in *Pediatrics Open Science*.

Klingberg’s group also looked at brain scans collected during the ABCD study. High social media use — around two hours or more per day — slightly stunted development of the cerebellum, the scans showed. Though the effect was very small, Klingberg says, “the trend was towards increasing changes.” If that trend continues over the next few years, he says, the effect would matter. The cerebellum has many roles. It’s important for body control, language and emotions and has been linked to attention, Klingberg says. So the cerebellum changes that his team found could help explain attention issues experienced by teens who increase their social media use.

Importantly, social media use was the only screen activity showing a negative impact on brain development in this study. Video games can actually help make kids smarter, Klingberg’s previous research has shown. But games might still pose some risks, he cautions, like “if you get so hooked that you can’t control the amount of gaming.”

Now, using AI to do work for you could be a new form of brain rot. Last year, researchers put this theory to the test in people ages 18 to 39. The team measured brain activity as groups of study participants wrote essays during several sessions over a four-month period. One group couldn’t use any online tools for help. Another group had access to Google search. The last group used ChatGPT.

Those using ChatGPT lagged behind the others in their level of brain activity and their ability to remember the essays they'd written, the researchers reported last June in a study posted at arXiv.org. That study has not gone through peer review. But one that has from October 2025 supports the arXiv paper's findings. Researchers compared how much people learn when using either Google search or an AI chatbot to research a topic. They found that those who used Google could explain their topic more deeply and thoroughly.

Tzipi Horowitz-Kraus is a neuroscientist at Technion–Israel Institute of Technology in Haifa who was not involved in either study but has done independent research in this area. When kids get an easy answer from AI, she says, they're "not developing the basic skills that [they] need in order to perform as an adult in this world."

Adapt and fight back

If everyone growing up now is gobbling brain rot, any problems it causes with thinking, attention or mental health could become an epidemic, Klingberg says. "If we have constant distractions in the entire population year after year, we will have long-term effects," he says.

That sounds scary. But don't expect a brain-rotted zombie apocalypse any time soon.

"Children adapt to new media quickly," Baumgartner says. Teens who use digital devices a lot while also doing other things will say they can't focus, her research finds. However, when they are not trying to multitask, they can still focus as well as their peers who report less multitasking. This suggests to her that screens impact kids' motivation to pay attention, not their ability. So, she concludes, brain rot "does not completely ruin your brain."

Still, Baumgartner says, brain rot can be a big problem if it replaces healthier things kids and adults could be doing with their time. When you're gazing into the glowing rectangle of your phone, you're not working, studying, playing sports, sleeping or spending quality time face to face with friends and family. So it's often not the brain rot itself that's harmful, but the loss of other activities you could have been doing.

Nagata agrees. "If you're using media in a way that's making you feel better about yourself so that you're learning, you're connecting with people, that's great," he says. "If you feel bad about the content that you've been seeing, then that is maybe a signal [to stop]."

In the end, though, it's not fair to put the responsibility for managing screen time entirely on us — and especially not on kids, since their brains haven't fully developed. Perry and Lembke argue that tech companies shouldn't be allowed to market products that harm kids' health. The lawsuits currently moving through U.S. courts will help decide this issue.

Lembke hopes that in the future, people will look back on today's social media the way we now look back on smoking in public places. Just a couple decades ago, "smoking was the status quo," she says. "Think about how much we have changed." She also hopes that the devices and apps we use to connect with each other will no longer spread brain rot. Rather, Lembke says, these tools should "give more power to the individual to shape their experiences." ✖

SIGNS OF PROBLEMS WITH SCREEN USE

In a survey of thousands of young people ages 10 to 14, significant percentages agreed with the following statements that indicate troubling levels of screen use. How many of these statements apply to you? SOURCE: J. NAGATA *ET AL/PEDIATRIC RESEARCH* 2022

47.5%
"I lose track of how much I am using my phone."

30.6%
"I interrupt whatever else I am doing whenever I am on my phone."

11.3%
"The thought of being without my phone makes me feel distressed."

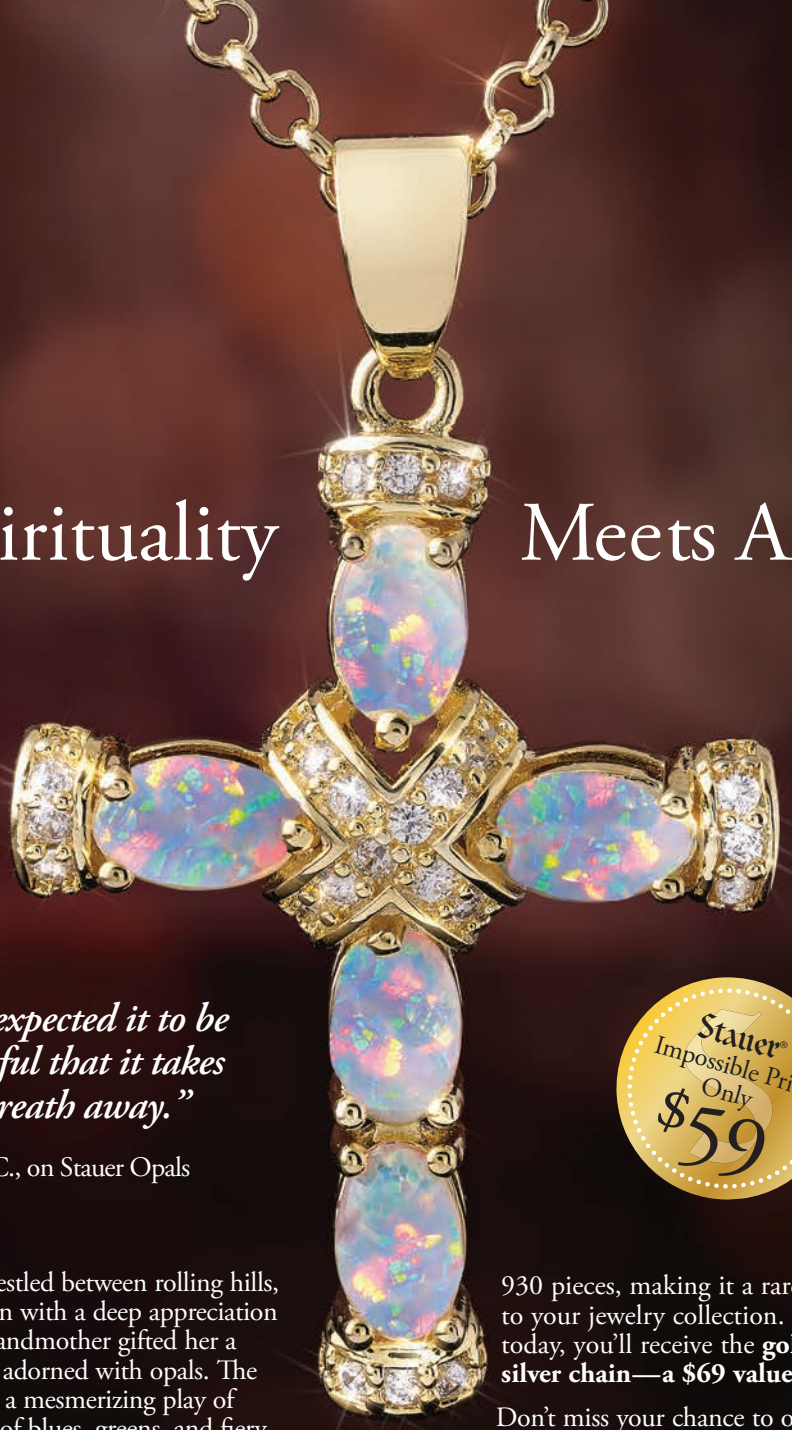
22.5%
"I spend a lot of time thinking about social media."

18.4%
"I use social media apps so I can forget about my problems."

15.5%
"I've tried to use my social media apps less but I can't."

Kathryn Hulick is author of *The UFO Files* and *Welcome to the Future,* and runs the Substack "Wow! Tech & Nature."

Spirituality Meets Artistry



"I never expected it to be so beautiful that it takes your breath away."

— Kaya C., on Stauer Opals

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In a quaint village, nestled between rolling hills, lived a young woman with a deep appreciation for gemstones. Her grandmother gifted her a delicate cross pendant adorned with opals. The opals shimmered with a mesmerizing play of colors, reflecting hues of blues, greens, and fiery oranges. Her grandmother shared the legend of the opals, believed to bring hope, purity, and luck to those who wore them.

Using this story as inspiration, Stauer brings you the **Opal Spirit Cross Pendant.** With over 2 total carats of Kyocera lab-created opals set in .925 sterling silver encased in yellow gold, this pendant is a radiant celebration of beauty and craftsmanship. Each opal captivates with a kaleidoscopic dance of fiery oranges blending into oceanic blues, streaked with flashes of vibrant green that seem to come alive with every movement. The shimmering opals are skillfully arranged to create an enchanting, otherworldly glow, embodying the spirit of hope and harmony.

This breathtaking combination of color and craftsmanship is available as a limited availability of only 930 pieces, making it a rare and treasured addition to your jewelry collection. Plus, when you order today, you'll receive the **gold-finished sterling silver chain—a $69 value—absolutely free!**

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JAMIE ANDERSON, BRITISH ANTARCTIC SURVEY

OCEANS

DAVID ATTENBOROUGH CHARGES AHEAD

● Sir David Attenborough is keeping busy. No, not the naturalist and broadcaster who turned 100 in May, but the British research vessel named after him. The R.R.S. *Sir David Attenborough* has been crisscrossing the globe to study Earth's polar regions and their ecosystems. Using the audio recorded aboard the ship — sounds of the Antarctic ocean, wind and animals such as seals, as well as of crew members doing science — a scientist has released a music album with the help of a composer and a multimedia artist (see Page 60). — *Karen Kwon*

CELEBRATE AMERICA'S 250TH BIRTHDAY AT A NEW STATE FLOWER EXHIBIT

By Cassie Martin

AMERICA'S STATE FLOWERS | United States Botanic Garden

America is turning the big 250 this year. To celebrate, the United States Botanic Garden in Washington, D.C., has a new exhibit of state flowers. Through October 12, visitors can go on a scavenger hunt in the glass-domed conservatory and outdoor gardens to find blooms representing all 50 states, the District of Columbia and U.S. territories. Whether you're a flower enthusiast or just a casual fan, the exhibit has something for everyone.

Science News had the opportunity to take a tour on opening day. Experts showed us over a dozen burgeoning blossoms and gave us their backstories.

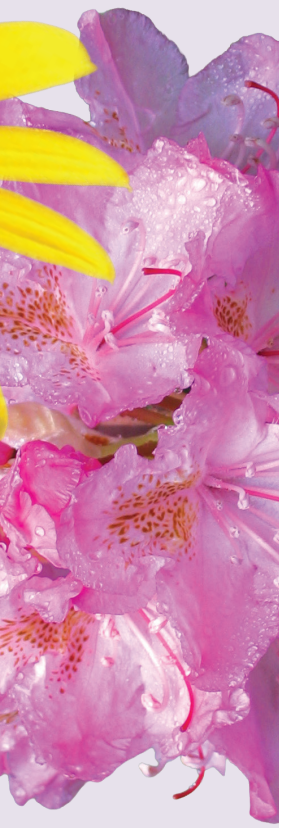
Consider Oregon's state flower, the Oregon grape (*Berberis aquifolium*). Not a true grape, it has roots and stems with medicinal properties. Compounds from the plant have been used to treat bleeding, arthritis and tuberculosis, says medicinal plant expert Lisa Philander, the garden's deputy executive director. Then there's Minnesota's state flower, the pink and white lady's slipper orchid (*Cypripedium reginae*). It's the only state flower that's an orchid, grows only where it gets supercold in winter and is illegal to pick.

"Probably the oddest selection of state and territory flowers is the state of Maine, which chose the white pine cone and tassel," says Susan Pell, the garden's executive director. "It doesn't actually have flowers at all but does definitely represent the state of Maine very well." Eastern white pine (*Pinus strobus*), the tallest conifer in the Northeastern United States, is ubiquitous across Maine and has been crucial to its economy since at least the 17th century. The state adopted the tree as its floral emblem in 1895, and today it appears on license plates. "It's something that's near and dear to Mainers' hearts," Pell says. "And I think Maine likes being a little bit weird."

Different flowers will bloom at different times over the exhibit's run. Missed your favorite? You can still see replicas of each one: A glass case in the conservatory lobby contains exquisite paper flowers made by D.C.–based artist Emily Paluska. And visitors can flip through books of dried specimens accompanying the doppelgängers.

Researchers collected the flora "to take a snapshot in time of what plants were occurring in a certain area," Pell says. The specimens "provide rich data for us to be able to understand

WIKIMEDIA COMMONS, ADAPTED BY J. HIRSHFELD



Whether you're a flower enthusiast or just a casual fan, the exhibit has something for everyone.

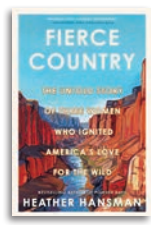
the impacts of climate change and other things, like development and invasive species, on the range of native plants."

Many plants in the United States are moving north as Earth's average temperature rises, Pell notes. "We're also seeing them move higher in elevation." In some states, if those plants can't move any higher, they die out, she says. If that happens to a state flower, it's possible a state could pick a new symbol.

"I will say that states are continuously changing their state flowers," Pell says. Just before the exhibit opened, Georgia updated its official flower from the Cherokee rose (*Rosa laevigata*), an introduced species from Asia, to a species native to the state, the sweetbay magnolia (*Magnolia virginiana*).

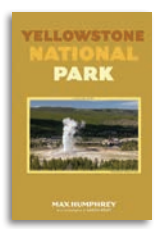
If you're visiting Washington, D.C., anytime soon, make some time to stop and smell these flowers before they're gone. ✖

BOOKS ON THE SHELF

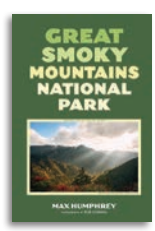


FIERCE COUNTRY | *Heather Hansman*
Hanover Square Press | $30.99
A journalist explores humankind's relationships with wilderness, ecology and climate change through the lives of three women who sparked America's obsession with the outdoors: Georgie White, Anne LaBastille and Dolores LaChapelle.

GRIZZLED | *Jason Bittel*
National Geographic | $28
This essay collection is an ode to some of North America's most misunderstood fauna, from opossums and yellow jackets to crows and lampreys. Science journalist Jason Bittel endears these animal neighbors to readers through a generous helping of humor and weird science facts as well as the stories of passionate conservationists.



YELLOWSTONE NATIONAL PARK | *Max Humphrey*
Gibbs Smith | $50
Author Max Humphrey brings an interior designer's eye to this travel guide that doubles as a coffee table book. Stunning photographs highlight the park's natural wonders and wildlife. Meanwhile, Humphrey's writing offers both historical context and practical tips that consider how visitors actually move through the park.



GREAT SMOKY MOUNTAINS NATIONAL PARK | *Max Humphrey*
Gibbs Smith | $50
Humphrey brings a similar touch to this Appalachian wonder. Structured like a road trip, the travel guide moves through the park stop by stop, pairing sweeping photos with information about popular sites, hidden gems and everything in between. ✖

Meet the World's Top Young Scientific Minds

Hikaru Kuribayashi (center in the photo above), 17, of Sapporo, Japan won first place and the $100,000 top award at the 2026 Regeneron International Science and Engineering Fair (ISEF). A program of Society for Science, Regeneron ISEF is the largest pre-collegiate STEM competition in the world. Hosted in Phoenix, Ariz., this past May, the competition brought together over 1,700 young scientists from nearly 70 countries, regions and territories. In total, the finalists were awarded more than $7 million in awards and scholarships.

In his research, Kuribayashi created a simulation program to understand complex folding, like in origami. Current methods for predicting folding can either only trace one path at a time or fail to test all the possibilities. Kuribayashi's simulation software samples many possible scenarios and uses those patterns to estimate the most probable answers. This program could help design devices that need to be packed into small spaces and unfolded later, such as solar sails for satellites, medical devices or emergency pop-up shelters.

Nikola Veselinov (left), 17, of Sofia, Bulgaria, and **Lakshmi Agrawal** (right), 18, of Bellevue, Wash., both received second-place Regeneron Young Scientist Awards of $75,000. Veselinov described a new theorem in mathematics that shows the conditions under which the equation $f(x) = a$ cannot be solved using basic math functions. Agrawal developed a sponge using natural materials that removes deadly pollutants and heavy metals from water. Compared with current alternatives, her solution required 85 percent less energy to produce and reduced costs by about 98 percent.

Regeneron ISEF finalists take part in a rigorous judging process, engaging with professional scientists, engineers and mathematicians. They also have the opportunity to connect with peers from around the world and share their passion for science.

Through Regeneron ISEF and other STEM programming, Regeneron and the Society are helping cultivate the next generation of STEM leaders working to solve some of the world's most pressing challenges.

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MAKING MUSIC FROM THE SOUND OF SCIENCE

BY MIĆO TATALOVIĆ

In the frozen vastness of Antarctica, a giant, spider-like antenna eavesdrops on radio waves pulsing around Earth via our planet's magnetic field. Triggered by solar winds and lightning, these waves can tell scientists about space. Scientists at the British Antarctic Survey use them to study space weather and its links to Earth's climate. But for one scientist, the waves are more than just data points — they're an artistic medium.

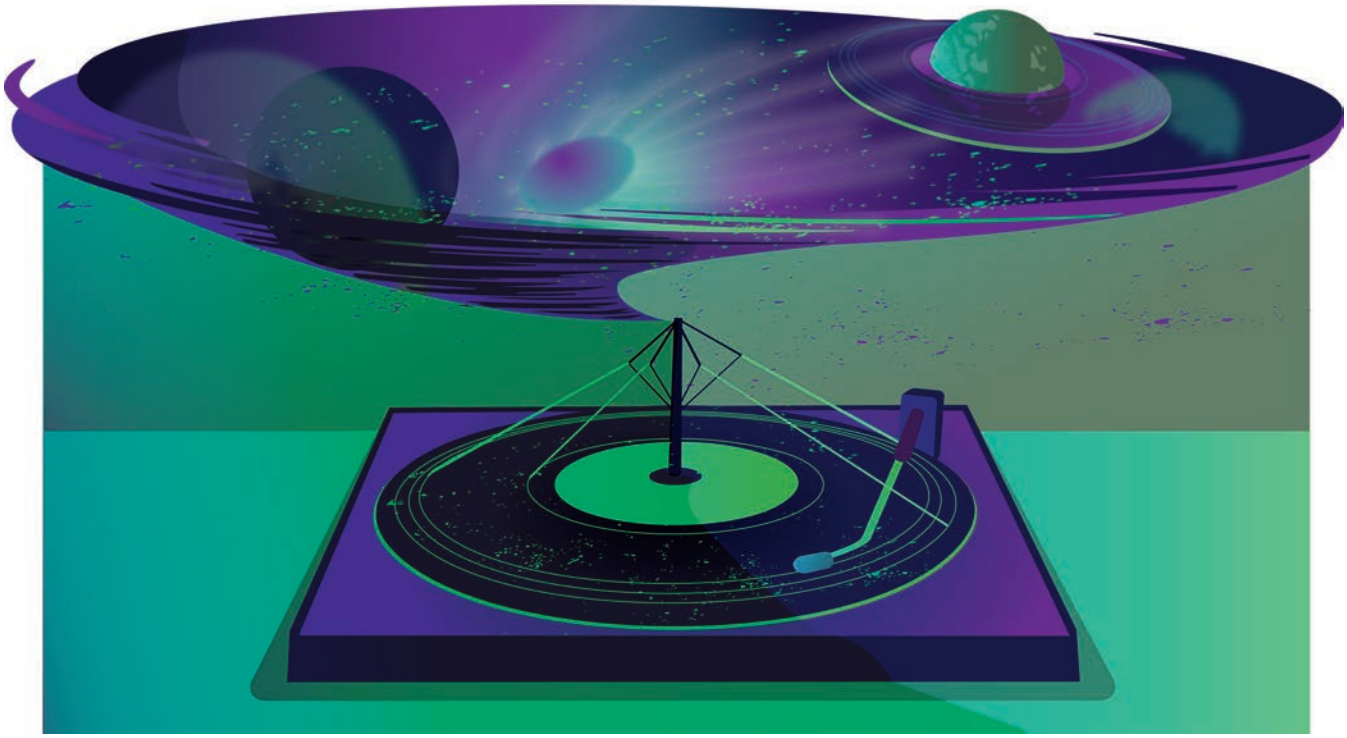
The radio waves, when converted to sound, make "weird and wonderful noises" that have a melodic quality to them, says research scientist Nigel Meredith of the BAS. That inspired him to team up with professional artists to transform the data into music.

In June, the team released *Infinitas Formas*, an album featuring sounds of Antarctica.

The project evolved from Meredith's realization of just how cool the data collected by the antenna at Antarctica's Halley Research Station sounded when played as audio. Many of the radio waves whizzing around our planet are in the audible frequency range, so they can be directly converted to sounds. And this is where the fun starts, because these sounds are literally out of this world but are also very familiar.

Sferics, short radio pulses generated by lightning, sound like crackly campfire. When they travel long distance, the pulses distort into ringing "tweaks" that sound like a quick-fire toy laser gun.

Chorus waves are reminiscent of



DALIA BIELIUNAITE

a dawn chorus of songbirds. These waves are generated when electrons driven by solar winds enter Earth's magnetosphere. (These electrons also trigger auroras.) And just like the birdsongs, the waves are the strongest at dawn.

Such sounds can help inspire the public to engage with space weather research and understand its importance, Meredith says. The chorus waves, for example, can accelerate electrons to very high energies, which then may threaten satellites and humans in space by damaging electronics and DNA.

After meeting Cambridge, U.K.–based multimedia artist Diana Scarborough at a science-meets-art event, the two struck up a partnership to form the Sounds of Space Project. Composer Kim Cunio, the head of the New Zealand School of Music at the Victoria University of Wellington, later joined. Over the last few years, they have worked on short films, dance performances, podcasts and publications, all featuring what the team calls a "unique combination" of science, music and the visual arts.

Since 2020, the trio have produced nine albums, which are free to stream on the project's Bandcamp page. The space sounds Meredith gathers inspire the artists: Cunio composes music and Scarborough designs an image for each track and a trailer video for some of the albums, often incorporating striking pictures of the research station and natural phenomena such as auroras. "We each bring our unique perspectives, skills and curiosity," Scarborough says. "We aim to evoke the beauty, wonder and vastness of space as emotional, experiential works while remaining grounded and inspired by the science."

The albums might appeal to anyone who loves classical, experimental or background music, or simply to people interested in space and visual art. They all come with a brief text explaining the science behind the sounds.

The team's new album is a bit more down to earth. It features field recordings from the R.R.S. *Sir David Attenborough*'s voyage to Antarctica in 2025 to study how climate change is affecting the release of nutrients from Earth's polar regions. Sounds of the sea, wind, penguins and seals, as well as the background sounds of the boat deck and researchers at work are all included.

The team continues to explore sounds from other planets and space bodies. Each has its own unique features depending on how and where radio waves were generated. For example, the solar particles hitting Jupiter's massive magnetic field sound like a giant ocean wave crashing onto the shore, as revealed in a 2016 recording by NASA's Juno spacecraft.

One striking aspect of the space sounds, the team says, is how similar they are to portrayals of space and aliens in popular culture: "It's a bit like entering the film set of a 1960's sci-fi movie," the trio writes in one of the album notes. Meredith wonders if producers of that era were inspired by early recordings of space radio waves — the earliest date to the 1880s and 1890s when the waves were first picked up by telephone and telegraph wires. Or, Cunio says, similarities could be caused by the same type of equipment being used to both convert the radio waves into sounds and create early sci-fi sound effects. "We have been thinking about it for some years," he says, but "no one knows exactly why they sound similar."

Meredith plans to explore a wider range of space weather data. This would involve sonifying more data that space weather researchers collect for their models and forecasts, such as electron intensities or solar wind speeds high above Earth. Those sounds would then inspire music, Meredith says, and be used to convey ever more complex and detailed science to the public. ✖

↖ The Sounds of Space team sonifies the galaxy, turning scientific data into music albums. ↑ The team has released nine albums, inspired by Antarctica (top album cover) and even outer space (bottom).

FROM TOP: D. SCARBOROUGH/BRITISH ANTARCTIC SURVEY ARCHIVES; D. SCARBOROUGH

BIOLOGY MAY HAVE INSPIRED CYCLOPES OF ANCIENT MYTHS

BY LILY BURTON

When Odysseus and his men reach Sicily on their 10-year voyage home, they find a formidable foe: a one-eyed giant with a taste for sailors. As told in Homer's *The Odyssey*, the Cyclops holds the men captive, eating them two-by-two, until he is outsmarted. Cyclopes may be the stuff of mythology (and now a live-action movie version of Odysseus' epic journey), but they have their roots in biology. Homer and the ancient Greeks, though, may have been more inspired by misinterpretations of fossils than by real-life one-eyed critters, which are far from towering — or terrifying.

Inspiration for Cyclopes might have come from the fossilized bones of prehistoric elephant ancestors. In the time of Homer, "nobody in Greece had ever seen a living elephant," says Adrienne Mayor, a historian of ancient science at Stanford University. Ancient peoples thought the immense bones of massive mammals belonged to giants, gods and mythical creatures. These elephant ancestors have a big opening in the center of the skull for the trunk, which may have evoked one big eye. "The eye sockets are really not very noticeable," she says.

For a true cyclops, look to the copepod. About a millimeter long, these tiny crustaceans make up a big portion of the base of the food chain in oceans and many bodies of water. A single, bright red eye peers from between two antennae on the heads of some species.

"They wouldn't have high resolution [sight] like we would," says Megan Porter, an evolutionary biologist who studies visual systems at the University of Hawaii at Manoa. These relatively simple eyes contain three cuplike structures that are sensitive to light, point in different directions and probably give the copepods a broad field of vision. It's good enough, Porter says, to guide ocean copepods to deeper waters during the day to evade predators.

Around 560 million years ago, an ancestor of humans and all other vertebrates also had a single eye — a median eye — on the top of its head that could detect light but couldn't resolve detailed images.

For this water-dwelling critter,

ANDREEA DUMUTA

going to one eye was an evolutionary innovation. *Its* ancestor had three eyes: one on each side of the head, plus the median eye, says George Kafetzis, an evolutionary neuroscientist at the University of Sussex in England. The pair of side eyes probably handled navigation while the median eye followed the daily rhythms of the sun.

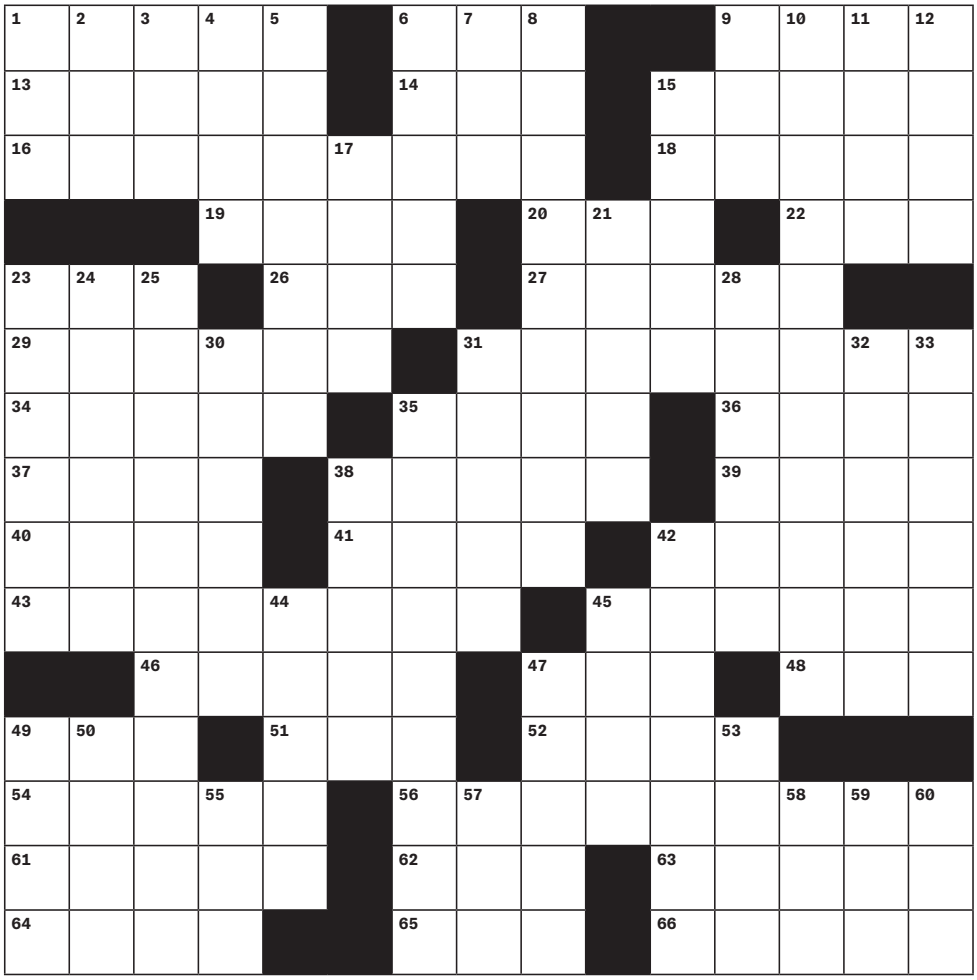
This ancestor might have lost its side eyes because it abandoned a free-swimming lifestyle for a sedentary burrowing one, says Kafetzis. "When you're partially burrowed, the steering eyes don't have much purpose to serve anymore," he says.

Over a few million years, lifestyles changed again, vertebrates evolved and three eyes again became better than one.

In humans, the cells that eventually become eyes begin as one cluster before splitting into two. In rare cases, genetics or environmental factors can cause cyclopia, a deadly disorder in which that cluster doesn't split, instead developing as one large eye. "Cyclopia is sort of the extreme end of a whole range of malformations," says Philip Beachy, a developmental molecular biologist at Stanford.

Our "third eye" descended into the brain to become the pineal gland, where it regulates our circadian rhythm based on information it receives from our seeing eyes. For some species of fish, reptiles and amphibians, a version of this median eye remains exposed on the top of the head and can still sense light directly.

"People of antiquity were always on the lookout for marvels," Mayor says. While today's one-eyed wonders are a world apart from the monsters of Greek mythology, they still inspire us to explore — and marvel at — our world. ✖



POWER PLAY

BY DEREK HINSEY

ACROSS

1 Cargo carrier in a canal
6 Muscles built with planks
9 Paresthesia-inducing video letters
13 "X is equal to X" or "A straight line may be drawn between any two points," e.g.
14 Set on fire
15 Excite, as interest
16 (Give a ring) × 10^{6}
18 Entertain
19 Diving bird with poor walking ability
20 Web portal that once was Internet Explorer's start page
22 Inquire
23 Once owned
26 Sorry state
27 Typical siding wood
29 Overjoyed
31 (Fender bender blemish) × 10^{1}
34 Knot-tying spot
35 Cutlass end that cuts less
36 What an integral calculates, geometrically
37 Unintended release of sensitive information
38 Marine mammals that wriggle on land
39 Desert that can get colder than −40° Celsius
40 If-___ statements (logical branching paths in code)
41 Darkens in the sun
42 City considered the epicenter of K-pop
43 (Winning chess move) × 10^{-1}
45 Snuggly settle
46 Like some digital purchases
47 Largest unit of geologic time
48 "What a pity"
49 Pollinating insect
51 Two days after Tue.
52 Longish skirt
54 "... forget it"
56 ("Piano," on a score) × 10^{-6}
61 Like specialized interests
62 Author Edgar Allen ___
63 Pizzazz
64 Consider
65 *T. rex* fossil named for its discoverer, paleontologist Hendrickson
66 Boat for commuters

DOWN

1 "Pow!"
2 Tool that can hew a yew
3 Gaming computer, in gamer lingo
4 Objective
5 Bestow authority to
6 Solo
7 Target for many a crumpled paper ball
8 Lab-cultured precursors to specialized tissue
9 Skill needed for archery
10 One for one and two for four, e.g.
11 Tousle
12 Smell really bad
15 Bear that uses its wrist bone as a "false thumb" to grip bamboo
17 Fume ___ (chemist's ventilated workspace)
21 Religious offshoots
23 Like a wound that's fully recovered
24 Null ___ (variant causing no functional gene product)
25 Field that involves mining and extraction
28 "Easy come, easy go" and "No pain, no gain"
30 Adopt, as a stray
31 Neuroscientist Lipscombe
32 Where a star is born, sometimes
33 Covertly followed
35 Devices that transfer thermal energy rather than generate it
38 Kind of infection
42 Retirement party, e.g.
44 Nonglossy photo finish
45 Film ___ (crime genre)
47 Show host
49 Result of many a charged interaction, in a chemistry lab?
50 Shallowest Great Lake
53 Great Britain, geographically
55 Impedance unit
57 Borrower's note
58 Rowboat propeller
59 Tree whose cones stand upright like candles
60 Take a shot at

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According to Bennet, in lieu of becoming a science teacher, donating to Society for Science is one of the best ways to help cultivate scientific thinking in future generations. Through science, we can understand the world and improve lives. That is why Bennet gives to the Society through his donor advised fund at Vanguard Charitable.

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>
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