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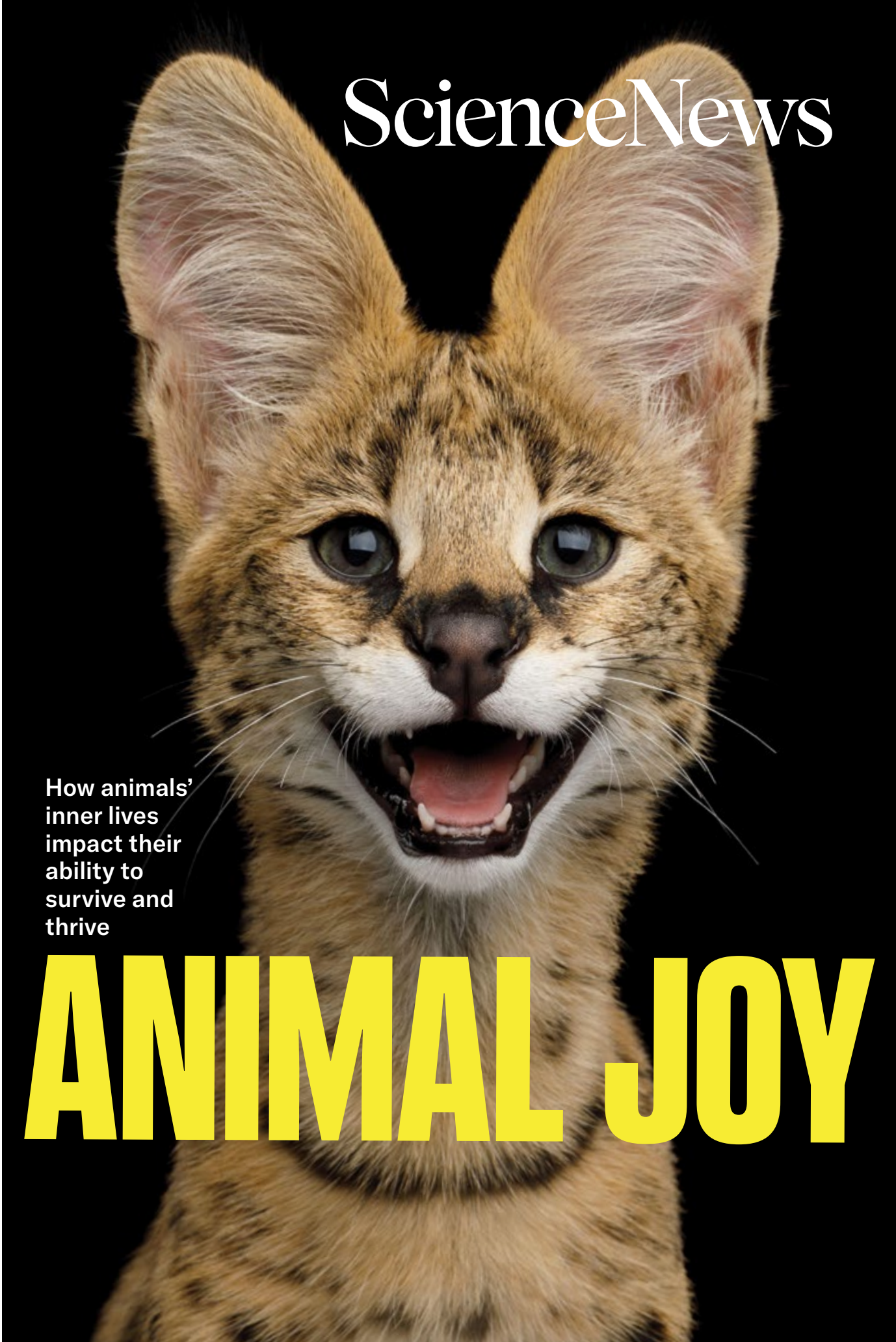
ScienceNews



How animals' inner lives impact their ability to survive and thrive

ANIMAL JOY

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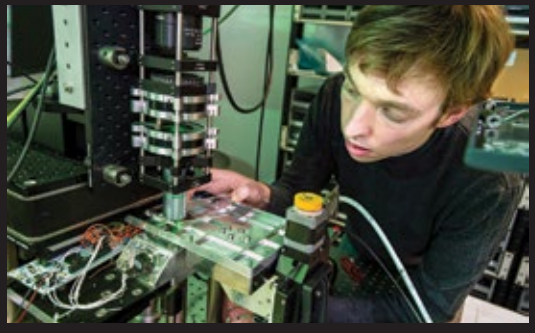


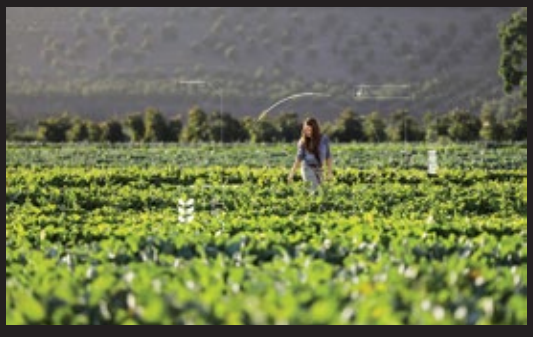



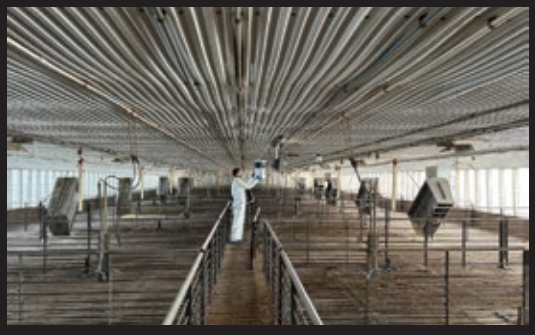


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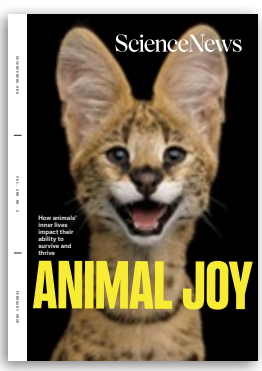

On the Cover

Photo by Sergey Taran/ Alamy

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FROM TOP: JASON RANSOM/U.S. NATIONAL PARK SERVICE; SPOOKY POOKA

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The inner lives of animals

A baby's first toy is often a soft stuffed bear. Soon, children may meet Winnie the Pooh and Paddington. They learn that these bears are kindhearted and polite with a good moral compass, cravings for honey notwithstanding. Bears also play major roles in folklore across cultures. But science has been surprisingly slow to illuminate the emotions and personalities of real-life bears.

One factor has been the fear of falling into the trap of anthropomorphism, and attributing human characteristics to animals. While there are necessary distinctions between human and animal behaviors, the lack of data on animal feelings and personalities makes it easy to fill in the gaps with assumptions. Anyone who believes real bears are friendly and kind might be in for a shock.

Research into a broad range of animal feelings has been held back by a 20th-century focus on limiting study to actions that scientists could objectively tally, such as physiologist Ivan Pavlov's work training dogs to salivate at the sound of a bell. Now, researchers are trying to objectively measure animals' inner lives.

In this issue, we report on the work of scientists around the world to study animals' positive experiences, including what we call joy (Page 32). Any pet owner will declare that their furry friends are clearly happy, but that impression could be influenced by the pleasure they bring to us. A group of scientists studying bonobos, dolphins and garrulous New Zealand parrots called keas is trying to develop a multispecies methodology for measuring joy. It's not easy. Some of the prompts that the scientists thought would spark joy induced distress instead.

This isn't just knowledge for knowledge's sake; an animal's personality can influence behavior, which in turn affects whether individual creatures thrive or perish in changing environments. As the research advances, conservationists are increasingly including animal personality in efforts to protect imperiled species (Page 40).

To round out our special report on animals, we take a trip to a hidden world where animals live beneath the snow: the subnivium (Page 48). Animal and plant life can survive harsh winters there because the snow acts like a down blanket trapping heat. But it's a fragile world, one that's being threatened by warmer winters caused by climate change. Scientists are racing to figure out how best to help this fairy-tale ecosystem survive on a changing planet.

Nancy E. Shute

Nancy Shute
Editor in Chief
nshute@sciencenews.org

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AMBER DANCE

FREELANCE SCIENCE JOURNALIST

● GROWING UP, Amber Dance always had pets. Her cats' cuddles especially brought delight to her childhood. But whether the pets themselves experienced happiness is a complicated question. In this issue's cover story, she explores the complex world of animal joy (Page 32). "It is interesting how challenging it is to tell if your pet's silly behavior means they are feeling joyful," Dance says. To measure animals' positive feelings, scientists are developing a "joy-o-meter." The researchers aim to use potential signs of joy, such as the noises animals make, to create standardized tests for happiness. Reporting the story was fun, Dance says, especially learning about quirky critters like Youssa, a cheeky chimp who enjoys hanging upside down. But she had just as much fun writing the piece. "If you're not smiling while reading this," she says, "I've done something very wrong."

Emily Conover
Seventy years ago, physicists Clyde Cowan and Frederick Reines proved neutrinos exist. To celebrate the anniversary, senior physics writer Emily Conover dives into the neutrinos' history (Page 60). Over the last seven decades, "we've certainly advanced our understanding of neutrinos a lot," says Conover, who studied the particles for her Ph.D. "But they're making us work for it." Neutrinos may have helped shape the universe. Yet they're likely the least understood subatomic particles. "There's this rich world that most people are unaware of," Conover says. "We wouldn't exist if it weren't for neutrinos."

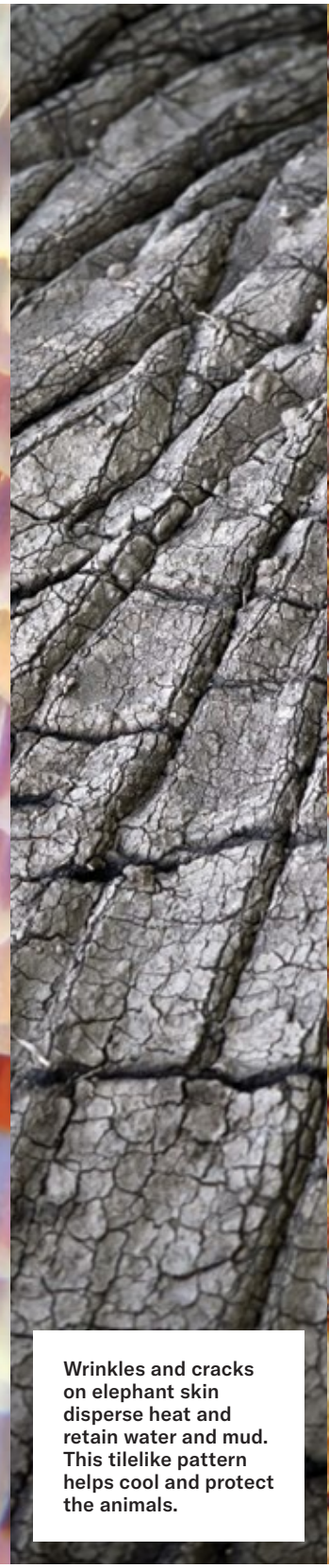
Nikk Ogasa
Staff writer Nikk Ogasa first encountered Martian "mini-lightning" four years ago as an intern at the now-defunct news site *Inside Science*. Back then, scientists theorized that dust storms on the Red Planet could create sparks of electricity. Now, Ogasa reports on the first proof of the flashes (Page 14). A Mars rover accidentally recorded a crackling sound on a microphone. At first, the small zapping noise underwhelmed Ogasa. But working on the story changed his mind. "It's crazy we can capture a sound on Mars and then listen to it here," he says. "And it's even more crazy that it's the sound of electricity."

Nicolle Fuller
Nicolle Fuller, the founder and CEO of science visualization firm SayoStudio, has been working with *Science News* for almost two decades. During those years, she has illustrated everything from spinning particles to a wasp covered in microbes. For this issue, Fuller depicts an under-the-snow ecosystem called the subnivium (Page 48). She studied scientific figures from journal papers to get the details just right. "I always wondered, where do all the animals go when it gets cold?" Fuller says. "It's fun to show people where they go and make it feel more tangible, so that the viewers can imagine that space."

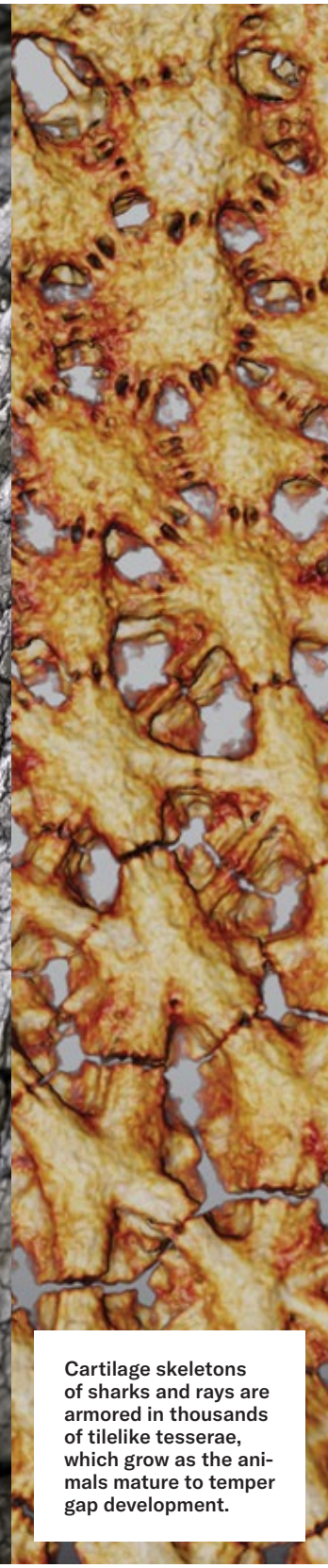
CLOCKWISE FROM TOP LEFT: KATIE WITT; SOCIETY FOR SCIENCE; LISA STRONG; SAYOSTUDIO

The compound eyes of the long-legged fly are made of closely packed mini-eyes. Each captures an image the brain compiles into one picture.

Butterfly wings are shingled with overlapping tiles, or scales, that give the wings color, repel water and reduce drag while flying.



Wrinkles and cracks on elephant skin disperse heat and retain water and mud. This tilelike pattern helps cool and protect the animals.



Cartilage skeletons of sharks and rays are armored in thousands of tilelike tesserae, which grow as the animals mature to temper gap development.

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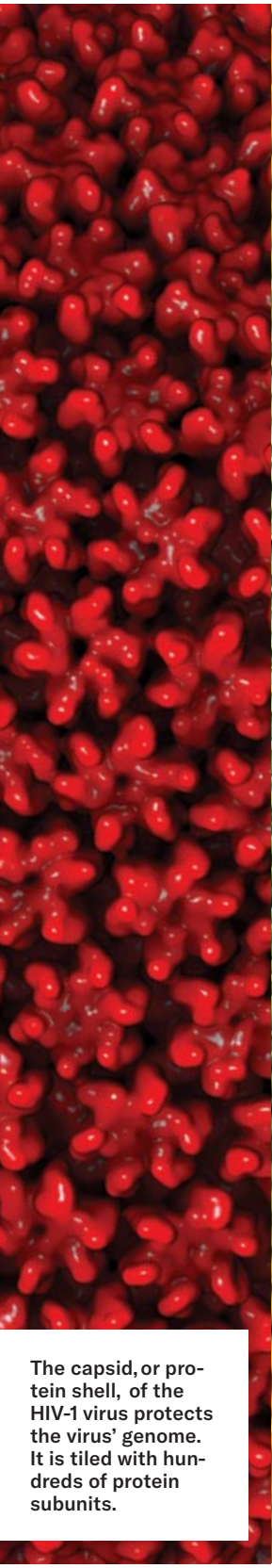
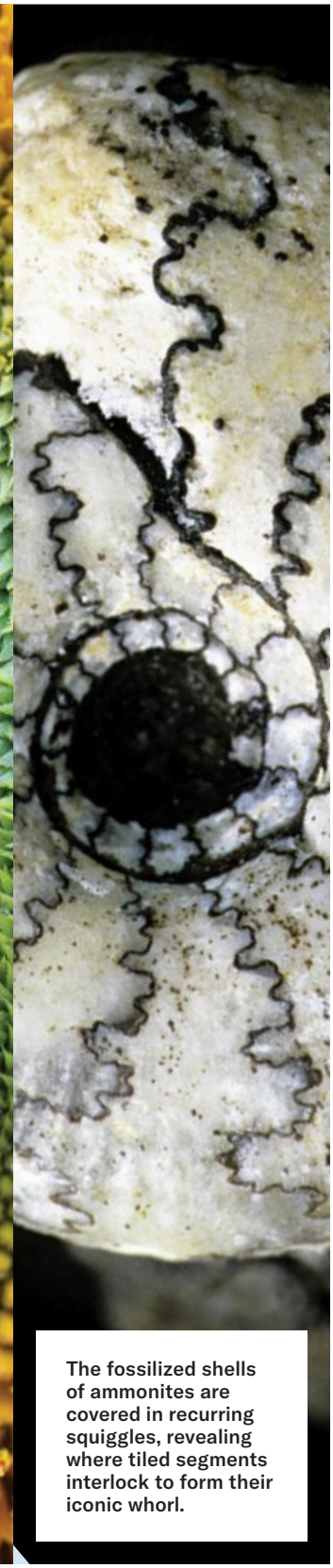


The capsid, or protein shell, of the HIV-1 virus protects the virus' genome. It is tiled with hundreds of protein subunits.

A sunflower's head is made of many tilelike flowers called florets. This structure packs many close together, boosting attractiveness to pollinators.



The fossilized shells of ammonites are covered in recurring squiggles, revealing where tiled segments interlock to form their iconic whorl.

MINT IMAGES/GETTY IMAGES; ED RESCHKE/GETTY IMAGES

LIFE

NATURE THRIVES ON TILED PATTERNS

By Nikk Ogasa

● **Mosaics can enchant** humans with gestalt beauty, but in nature, tiled patterns transcend aesthetics. Repeating, tilelike motifs adorn insect eyes, shark mouths, sunflower heads and many other organisms, providing diverse benefits, researchers report in *PNAS Nexus*.

"These surface designs exist on literally all scales," says biologist John Nyakatura of the Humboldt University of Berlin. Evolution, he notes, has arrived at tiled solutions many times independently.

Nyakatura's team cataloged 100 examples of biological tilings—surfaces made of repeating units separated by connective material, akin to tiles and grout. The patterns (some shown) span from virus protein shells to the plates on giant turtle shells and appear on plants, animals and microbes.

Often, these tilings provide protection without sacrificing flexibility. Studying such natural geometries, the researchers suggest, could inspire more adaptable and resilient surfaces for human-made structures. ✖

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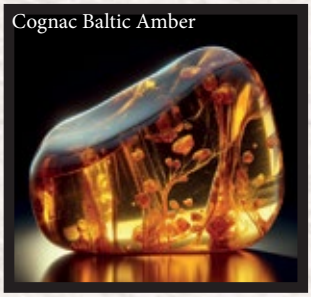

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News

What made a nearby star go supernova? The explosion's unusual shock wave, illustrated below, provides clues (see Page 22).

L. CALÇADA/ESO

PHYSICS

Twisted 2-D carbon stacks act as a weird superconductor

By Emily Conover

● **Stacks of graphene**, carefully twisted, gain a superpower: They become superconductors. Now scientists have new evidence that this "magic-angle" graphene is a member of a truly strange class of superconductor.

Unconventional superconductors transmit electricity without resistance when cooled, like all superconductors, but require less cooling than most. And there's no accepted theory that explains how they do it.

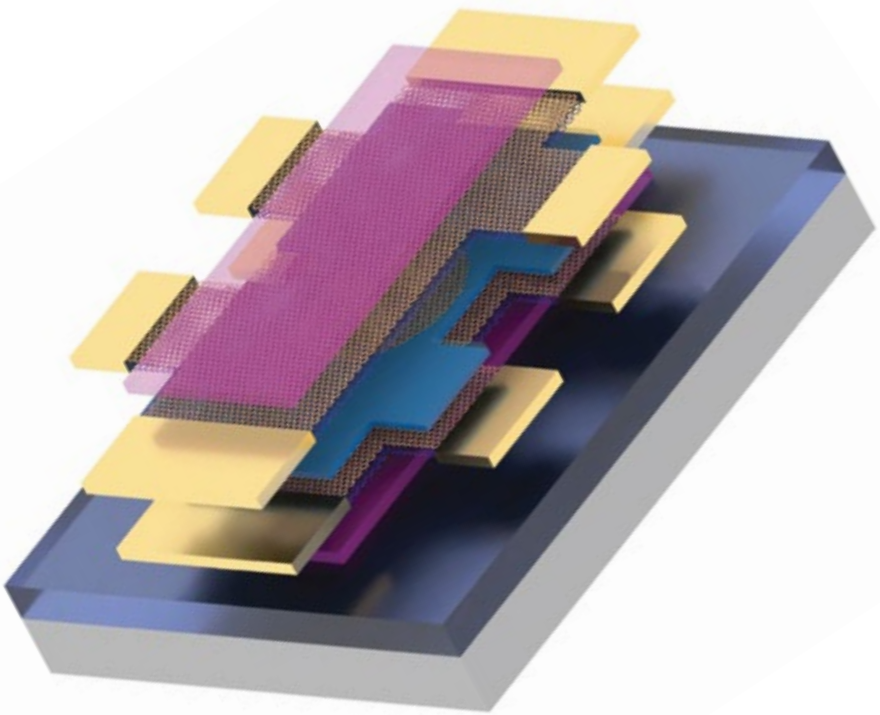
Clues could now come from 2-D sheets of carbon called graphene, stacked atop one another and twisted at a certain "magic angle" relative to one another. A triple layer of twisted graphene has a key hallmark of many unconventional superconductors, MIT physicist Pablo Jarillo-Herrero and colleagues report in *Science*.

That raises hopes that scientists can analyze the material to better understand unconventional superconductors and design new ones. Superconductors are useful for technological applications because the lack of resistance saves energy and makes it possible to build powerful magnets and quantum computers. Superconductors that work under warmer conditions, perhaps even room temperature, could greatly expand the possibilities.

In conventional superconductors, electrons pair up in a manner that eases their journey through the material. The electron pairs, known as Cooper pairs, also form in unconventional superconductors, but it's not fully understood what causes the electrons to buddy up in those materials. Scientists study magic-angle graphene because it is simpler and perhaps easier to understand than previously studied unconventional superconductors.

Much scrutiny has focused on what's called the superconducting gap. Splitting apart a superconductor's Cooper pairs takes a certain amount of energy. The superconducting gap is the amount of energy needed to free an electron, and it's a key identifying characteristic of superconductors.

In standard superconductors, that energy gap is usually a consistent size for any electron coursing through it. But in unconventional superconductors, the gap can



↖ **Two stacks of "magic-angle" graphene (gold), each composed of three layers, sandwich a material called hexagonal boron nitride (blue). Scientists used the device (illustrated) to probe the superconducting properties of the magic-angle graphene.**

P. JARILLO-HERRERO *ET AL*

depend on the momentum of the electrons. Electrons traveling in certain directions, called nodes, will not experience a gap at all. These nodes are a feature of many unconventional superconductors.

To look for this effect in magic-angle graphene, Jarillo-Herrero's team sandwiched an insulator called hexagonal boron nitride between two magic-angle graphene stacks, each consisting of three layers of graphene. The researchers measured how electrons from the magic-angle graphene could leap across the insulator, which indicated how much energy was needed to break apart the superconductor's electron pairs and thus revealed the energy gap of the material.

The gap behaved as expected for an unconventional superconductor, one with nodes in its energy gap. Simultaneously, the researchers showed that current flowed through the material without resistance. Adjusting the magnetic field and temperature also produced results that aligned with expectations for a superconductor with nodes.

In unconventional superconductors, the nodes mean that electrons traveling in certain directions don't participate in the Cooper pairs. "And this experiment shows very convincingly that that's what happens in these magic-angle twisted graphene systems," says physicist Allan MacDonald of the University of Texas at Austin.

Earlier studies also showed hints of this behavior. The growing consensus is adding to the excitement. "When the chorus comes together, it's very good," says physicist Ali Yazdani of Princeton University. "When everybody's singing the same hymn with many different experiments, that's when we have progress." ✖

ANTHROPOLOGY

FOOT FOSSILS SUGGEST A RELATIVE LIVED ALONGSIDE LUCY

BY JAY BENNETT

In 2009, Yohannes Haile-Selassie and his team were combing Burtele, a paleontological site in the Afar region of Ethiopia, when a team member found something remarkable: an ancient, humanlike foot bone. Searching on hands and knees, the team ultimately discovered eight pieces of a partial forefoot from about 3.4 million years ago. The researchers concluded that the fossils, called the Burtele foot, were not from *Australopithecus afarensis*, an early human relative from the same time, best known because of the famous fossil skeleton Lucy.

Now, Haile-Selassie, a paleoanthropologist at Arizona State University in Tempe, and his team have gathered additional fossils from the Afar Region, and they determined that the Burtele foot probably belonged to a distinct species, *Australopithecus deyiremeda*, the researchers report in *Nature*.

"This is the most conclusive evidence to show that multiple related species coexisted at the same time in our evolutionary history," Haile-Selassie says.

Paleoanthropologists long thought that *A. afarensis* was the only early human relative living in this part of Africa between about 3.8 million and 3 million years ago. The species has been viewed as "the ancestral species that gives rise to everything else, the mother of us all," says paleontologist Fred Spoor of the Natural History Museum in London.

A. deyiremeda was initially named by Haile-Selassie and coauthors in 2015 based on upper and lower jaw fragments found in the Afar Region, but at the time, the researchers did not think there was enough evidence to include the foot bones. Since then, they have discovered more fossils closer to where the foot was found that the researchers also attributed to *A. deyiremeda*. The close proximity convinced them that the foot must be from this species as well.

It is reasonable to assign the foot to *A. deyiremeda*, Spoor says. *A. deyiremeda* appears to have had more primitive features than *A. afarensis*, including a grasping big toe for climbing trees more easily. Chemical analysis of *A. deyiremeda*'s teeth suggests it primarily ate plants from wooded areas—a less diverse diet than the combination of foods from grasslands and forests that *A. afarensis* consumed.

CONT. ON PAGE 14

CONT. FROM PAGE 13 Rather than a unique species, *A. deyiremeda* may represent an intermediary stage between *A. afarensis* and the older *Australopithecus anamensis*, which lived between 4.2 million and 3.8 million years ago, says Leslea Hlusko, a paleoanthropologist at Spain's National Centre for Research on Human Evolution in Burgos. The dental features of the teeth attributed to *A. deyiremeda* show similarities to both *A. anamensis* and *A. afarensis*.

Hlusko also points out that the Burtele foot is incomplete. Considering that there is variation in the feet of *A. afarensis*, and there are no known foot fossils from the older *A. anamensis*, there is not enough evidence to say that the new bones come from a distinct species, she argues.

New species or not, experts agree that the picture of human evolution is far from complete. Until more fossils are found, researchers can glean only a partial picture of human evolution from the fragmented remains of the past. ✖

These 3.4-million-year-old fossil foot bones belonged to *Australopithecus deyiremeda*, an early human relative that challenges the traditional view of human evolution during this time. ↓

Y. HAILE-SELASSIE

PLANETARY SCIENCE

'Mini-lightning' crackles in Martian dust storms

By Nikk Ogasa

● **When it gusts on Mars,** electricity crackles through the air.

For the first time, scientists have detected electricity in the Red Planet's atmosphere. A microphone on NASA's Perseverance rover captured the sounds and electrical interference of dozens of electrical discharges generated by colliding dust grains, researchers report in *Nature*.

The jolts are relatively small, akin to the shock from touching a doorknob on a dry winter day. Nonetheless, they

MARK GARLICK/SCIENCE PHOTO LIBRARY/GETTY IMAGES

could pose a hazard for future astronauts and electronics and hamper the search for Martian life, if it ever existed, the researchers warn.

It's "like mini-lightning," says planetary scientist Baptiste Chide of the University of Toulouse in France. There are thousands of kilometers of dust storm fronts on Mars that can generate these jolts, he says, so "we think there are plenty of these small discharges happening en masse."

When airborne particles slide against or bump into each other, their surfaces can become charged like two balloons rubbed together. On Earth, countless such interactions occur within sandstorms and volcanic ash plumes, leading to the buildup of electrical fields that eventually discharge as arcs of electricity, called triboelectricity.

↖ **When Martian winds loft dust into the air (illustrated), interactions between the grains can generate electrical fields that eventually discharge electricity.**

For decades, lab experiments and computer simulations have suggested that triboelectricity also flashes within dust storms and dust devils on Mars. But no one had ever detected it.

Chide and his colleagues had previously attributed a loud clicking noise from sounds of a Martian dust devil to grains striking Perseverance's microphone. But after hearing scientists at a conference discuss Martian triboelectricity, Chide realized the click may have been a zap.

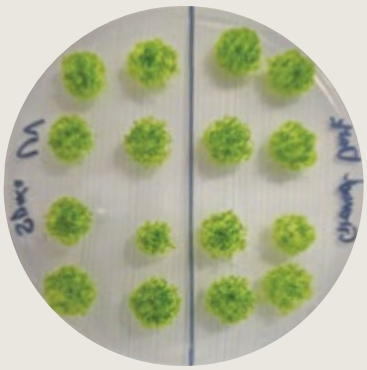
For confirmation, his team simulated the electrical interference the microphone would experience from a nearby discharge. Then they compared the results to the actual interference the microphone experienced. The signatures matched perfectly.

Excited, the researchers reviewed 28 hours of recordings taken over two Martian years. A total of 55 discharges occurred within about two meters of the microphone, they found. Most occurred in the windiest periods, with 16 during dust devil encounters and the largest packing an estimated 40 millijoules of energy. That's comparable to the zap of an electrical bug swatter, Chide says.

The jolts won't kill astronauts, Chide says, but they could degrade spacesuits over time and disrupt spacecraft electronics and instruments.

What's more, the zaps could obscure the search for evidence of Martian life. The discharges may spark a reaction that generates oxidants like hydrogen peroxide, which can destroy organic molecules, Chide says. The rock and soil samples taken and held inside Perseverance for later collection, he says, are probably protected by the rover's metal skeleton, which provides electric current a direct pathway to the ground. And the backup samples left on the ground are safe within sealed tubes, though they could have been zapped prior to sampling.

"This discovery calls for a next generation of instruments dedicated to measuring electric fields at the surface of Mars ... to better quantify this phenomenon," Chide says. ✖



PLANTS

MOSS CAN TOUGH IT OUT IN SPACE

By Jay Bennett

● In an extraordinary display of biological resilience, moss spores survived for nine months outside the International Space Station. The spores were then returned to Earth, where 86 percent germinated and began to grow, biologist Tomomichi Fujita of Hokkaido University in Sapporo, Japan, and colleagues report in *iScience*.

The research adds spores of *Physcomitrium patens* to the list of terrestrial organisms that can survive extended stays in space. This hardy group includes various species of bacteria, lichens, plant seeds and tardigrades.

The survival of dormant plant spores and seeds in space suggests that plants could potentially be transported to places including the moon or Mars and grown in facilities to provide astronaut life support, including oxygen, food and medicine.

For the *P. patens* spores, the next step is to assess the DNA damage incurred from cosmic and solar radiation in space and track how the plants repair that damage.

By studying how plants and other organisms recover from exposure to space, scientists can learn more about what it takes to survive beyond our planet's protective atmosphere. ✖

CHANG-HYUN MAENG AND MAIKA KOBAYASHI (CC BY-SA); MENDESBIO/ALAMY

HEALTH & MEDICINE

BATS MIGHT BE THE NEXT BIRD FLU WILD CARD

BY JANE QIU

Bats have become the latest mammals known to be susceptible to H5N1, a highly pathogenic avian influenza virus responsible for bird flu.

In Peru, over a dozen vampire bats have been found carrying H5N1 antibodies, indicating exposure to the virus, researchers report at bioRxiv.org. The finding is "very worrisome," says virus ecologist Vincent Munster of the U.S. National Institutes of Health's Rocky Mountain Laboratories in Hamilton, Mont., who was not involved in the study. Each time the virus jumps to a new mammalian host, he says, it gains opportunities to mutate and evolve, potentially bringing it closer to spreading among people.

And vampire bats may not be the only bat species at risk. Preliminary findings from Bangladesh indicate that 16 flying foxes, large bats with foxlike faces, appear to have died from H5N1 infection, says Munster, who is investigating those deaths.

Bats are hosts to several pathogens that pose serious risks to humans. If multiple bat species are

↑ Vampire bats (one shown) appear to be susceptible to H5N1 infection, raising the possibility that bats could help transmit the virus to other animals.

susceptible to H5N1, large colonies could act as reservoirs for the virus and help transmit it to other animals or even humans, says Gregory Gray, an infectious diseases epidemiologist at the University of Texas Medical Branch in Galveston, who was not involved in the bioRxiv.org study nor the Bangladesh study.

In October 2022, bird flu swept onto South America's Pacific coast, eventually killing at least 560,000 seabirds and 10,000 sea lions in Peru alone. Wildlife veterinarian I-Ting Tu of the University of Glasgow in Scotland wondered how Peru's vampire bats (*Desmodus rotundus*), known to feed on the blood of those creatures, would be affected by this animal equivalent of a pandemic.

Tu and colleagues collected samples from hundreds of vampire bats in three habitat types. Along the coast, the bats feed exclusively on marine animals such as pelicans and sea lions. In the Andes, they feed on livestock and occasionally humans. At mixed-diet sites, a few kilometers from the seafront, the bats feed on both marine and land-based species.

When the researchers analyzed the bats' blood meals by anesthetizing the animals and inserting a tube into their stomach, they found no H5N1 genetic material in the bats, probably due to delays in getting samples before bats had cleared the virus. But the team discovered that 14 bats, all of which had fed on marine animals during the outbreak, carried antibodies against H5N1, suggesting they had been infected.

Study coauthor Susana Cárdenas-Alayza, a conservation biologist at Cayetano Heredia University in Lima, wasn't surprised: They knew bats were feeding on H5N1-infected animals. During the 2022–2023 outbreak, she recalls, sick animals were everywhere, sea lions were coughing and pups were climbing over their dead parents.

Vampire bats — the only bat species that can walk and jump on land — could have been infected by the heavily contaminated coastal environment, Cárdenas-Alayza says. The bats use heat sensors in the nose to target parts of marine mammals where blood flows close to the skin, such as the eyes and anus. These areas are rich in mucosal secretions, which tend to shed viruses, she adds.

The findings could have serious implications, particularly at mixed-diet sites where vampire bats feeding on marine animals might acquire H5N1 and pass it to livestock or humans, says study coauthor Daniel Streicker, a disease ecologist at the University of Glasgow.

To assess the risks, key questions must be addressed, including how efficiently H5N1 can replicate in bats, transmit among them and spread to other species, says infectious diseases researcher Ariful Islam of Charles Sturt University in Wagga Wagga, Australia. He is part of the team that is investigating the flying fox die-offs in Bangladesh.

Tu's team found that H5N1 can attach to the upper respiratory tract of vampire bats and infect cells from various tissues, such as the lungs, kidneys and liver, in a petri dish. Transmission among bats, however, appears to be limited, as only those that foraged on marine animals carried H5N1 antibodies. Streicker suspects the virus may not be optimized to sustain a chain of infection. But the conclusion must be confirmed by further studies, he says, and a virus' ability to transmit is not fixed.

Marine animals along the Latin American coast continue to experience outbreaks of bird flu. Repeated jumps of H5N1 from sea life to vampire bats, Streicker says, could cause the virus to acquire new traits, possibly becoming more deadly or contagious.

Scientists also wonder what other avian influenza viruses bats may harbor. In 2017, a virus related to H9N2, another bird flu virus posing a public health threat, was discovered in flying foxes in Egypt. Probably a recent crossover from birds to bats, this virus exhibits traits from relatives capable of infecting either birds or mammals and can be transmitted between ferrets.

Gray suggests that future research should monitor the potential trajectory of avian influenza viruses from birds to bats. Given the frequent interactions between bats and livestock, he stresses the urgent need to strengthen surveillance to detect possible virus crossover into domestic animals. That's where we should "keep a pulse on," he says. ✖

560,000

Seabirds killed by H5N1 virus in Peru

10,000

Sea lions killed by H5N1 virus in Peru

ANIMALS

Lions have a second roar that no one noticed until now

By Elie Dolgin

● **The thunderous roar** of Hollywood's MGM lion has conditioned us to hear the big cat's call as a booming blast. But the real soundscape of a lion pride is far more intricate than that cinematic caricature.

By analyzing field audio recordings with machine learning techniques, scientists found that African lions (*Panthera leo*) produce two distinct types of roars: the guttural one that anchors a roaring bout — and carries vocal signatures unique to each animal — plus an overlooked intermediary roar. This newfound roar is shorter and lower-pitched than the full-throated version, the team reports in *Ecology and Evolution*.

The findings challenge long-held assumptions. Biologists knew that a lion's roar helps advertise territory, attract mates and locate pride members, and that roaring bouts begin with moans and end with grunts. Everything in the middle was treated as one undifferentiated roar.

Now, by decoding that roar into its component parts, and with AI trained to tell one lion's voice from the next, conservation groups may be able to count and track lions by sound alone. Such insights could prove valuable, considering lion populations are shrinking due to habitat loss and poaching, says study coauthor Jonathan Growcott, a conservation technologist at the University of Exeter in England.

Using pattern-recognition algorithms, Growcott's team analyzed recordings of over 3,000 roars from lions in Tanzania and Zimbabwe. Full-throated roars traced a clear arc, rising in pitch then falling. Intermediary roars were flatter and less elaborate.

Focusing on utterance length and pitch, the team built an algorithm that classifies each type of roar. Accuracy topped 91 percent in one population. By pulling out the full-throated call, the tool even identified which lion was roaring.

What the intermediary roar communicates is unclear because the recordings lacked behavioral context. "Unfortunately, we don't speak lion. There is no option of 'lion' on Duolingo," Growcott says, referring to the language-learning app.

Still, the work demonstrates that AI can reliably interpret mammal vocalizations, says computational ecologist Tanya Berger-Wolf of the Ohio State University in Columbus.

As for the MGM lion, his iconic roar contains no hidden intermediary for one simple reason: The roar actually belongs to a tiger. ✖

J. GROWCOTT

← The call of this lioness in Tanzania helped scientists uncover a second type of roar in the species' vocal repertoire.

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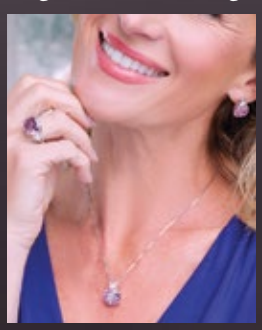

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HEALTH & MEDICINE

AN INSULIN CREAM FOR DIABETES SHOWS PROMISE IN EARLY TESTS

By Simon Makin

● A material that slips through skin might someday make needle-free insulin possible for people with diabetes.

In mice and mini pigs, attaching the permeating polymer to insulin and applying the resulting compound like a cream normalized blood glucose levels within one to two hours, comparable to injected insulin, scientists report in *Nature*. Levels stayed normal for 12 hours, much longer than the four hours for insulin delivered by needle. The approach could allow people to manage diabetes using patches rather than injections, which can be painful and cause skin complications, leading to poor compliance.

Patches are already used to deliver nicotine and other smaller molecules through the skin, but insulin is a large protein hormone and can't get through skin's complex structure. Microneedles, ultrasound or chemicals that liquefy parts of the skin's outer barrier layer can boost permeability, but these techniques compromise skin integrity, raising concerns about infection and safety.

The polymer, developed by bioengineer Youqing Shen of Zhejiang University in China and colleagues, travels through skin by adjusting its charge based on the pH of the different skin layers. With insulin in tow, the polymer makes its way to the bloodstream, where the combined molecule accumulates in tissues involved in regulating glucose.

"The polymer hasn't shown any side effects in mice or pigs, but humans use insulin for decades, so we need to investigate long-term toxicity," Shen says. The team is also working on giving just the right dose, since lowering blood glucose by too much can be dangerous. ✖

→ Small icy moons such as Saturn's Enceladus might harbor boiling oceans (illustrated), which could explain certain geologic features on the moons' surface.

ESA

PLANETARY SCIENCE

BOILING OCEANS MAY SCULPT SMALL ICY MOONS

BY MARA JOHNSON-GROH

Small icy moons might be boiling under their surface.

Many moons in the outer solar system are thought to harbor subsurface oceans beneath their icy crusts. New computer simulations, reported in *Nature Astronomy*, suggest that changes in the thickness of these icy shells can cause water in the underlying oceans to boil at low temperatures. This boiling may lead to geologic features, such as the ridgelike formations called coronae seen on Uranus' moon Miranda and the geysers on Saturn's moon Enceladus.

"The idea that a subsurface ocean on an icy world could actually reach boiling conditions is a really remarkable scenario," says study coauthor Max Rudolph, a planetary geophysicist at the University of California, Davis.

Moons are constantly squeezed by their planet's gravity,

which generates heat. The amount of heating can change over time as a moon's orbit changes, a common occurrence in multimoon systems, where satellites play gravitational tug-of-war as they pass one another.

Rudolph and colleagues calculated what would happen when the heating increases. They found that in some cases, a moon's icy shell will melt from underneath. As the shell thins, the pressure on the ocean below decreases. On small moons, this pressure drop can cause the water below to reach its triple point, where ice, liquid and vapor coexist. In the subsurface oceans of icy moons, this happens around zero degrees Celsius — allowing the frigid ocean to boil.

The gases released as the ocean boils might create cracks in the ice shell, potentially forming surface features visible from space, as seen on Miranda and Enceladus. However, if the ice shell is thick enough, these cracks might not appear. This might explain the geologic calm observed on Saturn's moon Mimas, another satellite thought to have a subsurface ocean.

"The overlying ice shell thickening and thinning over time might provide a means to explain how water could get through the ice shell from the ocean beneath to the surface," says planetary scientist Paul Byrne of Washington University in St. Louis. The release of gases from an ocean can help explain why icy moons look the way they do, Byrne says.

However, other researchers remain unconvinced by the findings. Planetary scientist Bill McKinnon, also at Washington University in St. Louis, thinks it's important to study the effects of melting. But he doesn't agree that such large-scale ocean boiling conditions would be reached in small moons, citing in part a differing view of geologic evidence, such as the lack of features on Mimas.

While the boiling of small moons is debated, larger moons almost certainly wouldn't boil. Rudolph's team found that only worlds smaller than about 600 kilometers across can have boiling oceans. That's because for larger bodies with higher gravity, such as Uranus' moon Titania, stresses on the icy surface would cause it to crack before the ocean reached its triple point. This cracking, Rudolph says, may account for features seen in images taken by the Voyager 2 spacecraft as it flew by Titania in 1986.

Beyond enhancing our understanding of small moons' geology, the findings may also inform the search for habitable conditions in the solar system.

"Looking at when these landforms developed ... could tell you something about when the ocean developed," Rudolph says. "And knowing that these icy worlds possess or have possessed a subsurface ocean through much of their geologic histories is really important in terms of thinking about the potential of those worlds to host life-forms." ✖

JUAN ALGAR/MOMENT/GETTY IMAGES PLUS

PHYSICS

WHY GOLF BALLS SOMETIMES GET LIPPY

By Emily Conover

● Nothing sinks a golfer's spirits like their ball zinging back out of the hole. Now, physics explains how it happens.

The anguish of a "lip out" occurs when a golfer putts a ball, and rather than the ball falling in, it swings around the rim of the hole, sometimes even descending into it, before escaping. The most common kind of lip out occurs when a golfer hits the ball too hard and it arrives slightly offset from the center of the hole. That situation sets up a competition between two different forms of angular momentum, the rotational oomph an object carries. For the putt to succeed, the angular momentum of the ball pitching into the hole must overcome the angular momentum of it rotating around the hole's rim, applied mathematician John Hogan and a colleague report in *Royal Society Open Science*.

In a rarer type of lip out, the ball partly descends into the hole then pops out. This can happen when the ball has some spin. That means the ball rotates about an axis that's perpendicular to the ground, or to the hole's wall once it falls in. As the ball descends, its potential energy can be converted into spin, which can then be converted back into potential energy, allowing the ball to pop out, says Hogan, of the University of Bristol in England.

As far as solutions go, Hogan is leaving that up to the pros. ✖

ASTRONOMY

A supernova's oblong shape hints at how the blasts ignite

By Mara Johnson-Groh

● **When one supernova** commenced, it looked like an olive — before it got shaken and stirred.

This insight, reported in *Science Advances*, comes from new observations taken in the wake of a massive star's death. As some of the most comprehensive views ever captured of a supernova's first moments, the findings give astronomers important clues about how these explosions begin.

On April 10, 2024, a supernova was detected in a nearby galaxy. Over the next 26 hours, an international collaboration of astronomers sprang into action to observe the explosion before it progressed too far. Their efforts produced the earliest look yet at the shape of any supernova — the explosive death of a massive star — and revealed its blast wave breaking through the stellar surface.

"It's a very important set of observations," says astrophysicist Adam Burrows of Princeton University, who was not involved with the study. "The modern theory of supernova explosions seems to be validated in broad outlines by these data."

For most of their lives, stars at least eight times as massive as the sun generate an outward pressure through the fusion of hydrogen and helium atoms in their core, counteracting gravity. But once these stars run out of fuel, that pressure disappears and the core collapses. The upper layers of the star follow suit, and as they hit the core, they create a rebounding shock wave. The shock wave splits the star's surface and releases an immense amount of energy and light, which we see as a supernova. How exactly the shock wave starts is a long-standing question.

Fortuitously, the shock wave's shape can reveal what initiated it. But this fleeting view must be captured before the shock wave is disrupted by the material surrounding the star, which can take just hours.

↑ **Astronomers used data on polarized light from a supernova's first moments to re-create the blast's early shape.**

ESO

Astronomers captured the snapshots with the European Southern Observatory's Very Large Telescope in Chile, which was able to look at the polarization, or orientation, of the supernova's light. Using a technique called spectropolarimetry, the researchers used the light's polarization to re-create the explosion's shape in its first moments. Their results showed that the light emanated not uniformly, like the light from a typical star, but in an elongated, olivelike shape.

"The very first [particles of light] and matter do not shoot out spherically from the star's surface," says study coauthor Yi Yang, an astronomer at Tsinghua University in Beijing. "Scientifically this is very important because the intrinsic shape of the shock breakout tells us a lot of how it was triggered at the heart of the star in the first place."

While the findings can't fully explain how this type of supernova is triggered, they do narrow the possibilities.

The observations support the theory that the shock wave is initiated by subatomic particles called neutrinos (see Page 60) being energized deep in the stellar interior, which heats the infalling upper layers like water boiling in a pot. Just as boiling water bubbles erratically, the star's material bubbles up in an irregular pattern, which averages out into an asymmetric shock wave. But specific details still need to be worked out, Burrows says. And that will require more observations.

Upcoming surveys will glimpse many, many more of these supernovas. If even a fraction can be observed with this type of precision, Burrows says, "I think we will see a new era of dialogue between theoretical study of these explosions and their observational validation." ✖

HEALTH & MEDICINE

SOME VETERANS FIND MIGRAINE RELIEF IN A LOW-GLUTAMATE DIET

BY LAURA SANDERS

A diet low in glutamate may ease migraines, a small study suggests. A month of staying away from foods rich in the amino acid led to fewer migraines in a group of 25 people with Gulf War Illness.

The specifics of these veterans' migraines, part of a collection of symptoms resulting from the Gulf War, may differ from those of other people who suffer from migraines. But if the underlying relationship between glutamate and migraines is similar, the diet could help the estimated 1 billion people worldwide who have migraines.

Current drugs for treating migraines can help, but they don't work for everyone, says neuroscientist Ian Meng of the University of New England in Biddeford, Maine. A dietary change could be a low-risk and accessible way to bring relief.

Glutamate is both a signal that excites nerve cells in the brain and an amino acid found in tomatoes, processed meats, aged cheese, mushrooms and monosodium glutamate, or MSG. For a month, 25 Gulf War veterans ate a low-glutamate diet full of whole fruits and veggies and avoided high-glutamate foods including soy sauce, mushrooms and ultraprocessed foods.

Before this diet, 64 percent of participants reported having a migraine in the previous week. After a month of a low-glutamate diet, that number dropped to about 12 percent, neuroscientist Ashley VanMeter of Georgetown University in Washington, D.C., reported at a meeting of the Society for Neuroscience. Eighty-eight percent of participants chose to remain on the diet after the study ended.

Brain scans showed that part of the visual system toward the back of the brain was thinner after the diet, suggesting that this neural change might be involved in the migraine reduction. Dietary glutamate doesn't usually reach the brain, as the blood-brain barrier holds the amino acid at bay. But for some people, this barrier can leak and let glutamate through, the team suspects. This influx of glutamate could be activating nerve cells in a way that leads to migraines.

While it's unclear whether a low-glutamate diet might help people with migraines who don't have Gulf War Illness, trying to cut down on glutamate might be worth a shot, Meng says. ✖

GENETICS

ANCIENT DNA TELLS A TALE OF TWO CATS IN CHINA

BY BETHANY BROOKSHIRE

The house cat (*Felis catus*) slunk into China in the seventh century. But long before that, the ancient Chinese were by no means catless.

A new genetic analysis offers evidence that between 5,400 and 1,900 years ago, it was the leopard cat (*Prionailurus bengalensis*) that pounced on the rats and mice of China, researchers report in *Cell Genomics*. The finding offers hints as to why some animals end up in our homes and hearts while others stay wild and free.

Modern house cats are descendants of the African wildcat (*Felis lybica*). Humans must have brought them to China, "but there were a lot of debates on when exactly this happened," says paleogeneticist He Yu of Peking University in China. Art and literature dating back to a few centuries B.C. reference "cats" and even include images of cats. But there are also people who argue that this cat may not be the domestic cat that we assume today, Yu says.

Yu's team examined the bones of 22 cats found in human settlements that date from around 5,400 years ago to as recently as the 20th century. The earliest of the house cats date to A.D. 730 during China's Tang Dynasty, when the feline species could have arrived via the Silk Road.

An analysis of the cats' mitochondrial DNA, passed from mothers to offspring, pointed to origins in the Middle East, suggesting the mothers of the cats were closely related to modern African wildcats from the same region.

DNA also provided clues to what that earliest house cat in China looked like, Yu says. Most likely, it had short fur and at least some white markings. Like elsewhere in the world, Chinese people throughout history have been into cat pictures, and paintings from the Tang Dynasty to the 20th century confirm that white cats or cats with white markings were popular — 85 percent of depicted cats had some white.

But when the scientists analyzed samples from before A.D. 200, the mitochondrial DNA didn't belong to house cats. It belonged to leopard cats, another cat local to China. It's unlikely these were as cuddly as house cats. "The leopard cats may have been more of what we call exploiters," living near humans but not in their homes, says evolutionary biologist Kathryn Lord of the University of Massachusetts Chan Medical School in Worcester.

The leopard cats could explain some of the archaeological remains from the Han Dynasty. A shallow bowl from around 168 B.C. has a cat image. But instead of stripes or patches, the cat is depicted with spots and a long, striped tail, much like a leopard cat, Yu notes.

The leopard cat disappeared from human sites after the Han Dynasty, around A.D. 200. It was a "chaotic period in Chinese history," with wars and economic and population declines, Yu says. Once stability and food abundance CONT. ON PAGE 26

↖ This artifact from the Han Dynasty shows a leopard cat–like animal. Now, DNA analyses suggest that leopard cats might have lived alongside people in China long before house cats did.

HUNAN MUSEUM COLLECTION DATABASE

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CONT. FROM PAGE 24 returned, along with small, tasty rodents in need of a predator, the leopard cat could have come back. But by then, Yu notes, the domestic cat had arrived. It filled the niche and won by a whisker because it was also more tame.

The leopard cat may not stay out of favor forever, though. Not only has it been bred with house cats to produce the now-popular Bengal cat breed, but ecologists are also finding wild leopard cats living in modern Chinese suburbs, Yu says. "A lot of leopard cats are living very close to humans even just in the suburbs in Beijing." People, their trash and rodents are still a draw.

The tale of two felines offers insight into why some animals end up in domestic relationships with people, while others don't, says vertebrate genomicist Elinor Karlsson of the Broad Institute of MIT and Harvard. "This paper shows that adapting to human environments is an evolutionary process like everything else."

Leopard cats exploited human environments when it worked for them and faded back into the forest when it didn't. "It's just amazing that animals can do this, and it's not humans making it happen," Karlsson says. ✖

The tale of two felines offers insight into why some animals end up in domestic relationships with people, while others don't.

—Elinor Karlsson

→ The nasal cavity of this Neandertal skull is similar to humans'.

C. BUZI/IPHES-CERCA

ANTHROPOLOGY

Neandertals' big noses weren't made for cold

By Tom Metcalfe

● **Proof that Neandertals** hadn't adapted to cold was right under their noses.

Unique video from the nasal cavity of a bizarrely well-preserved Neandertal skull confirms the hominid's enormous noses were not an adaptation to cold climates, as was proposed in the 19th century. Neandertal nasal cavities were much the same as those of our own *Homo sapiens* species, researchers report in *Proceedings of the National Academy of Sciences*. The research finally refutes an old idea that Neandertals' protruding faces were necessary to accommodate large noses that had supposedly evolved to warm and moisten cold and dry air before it reached their lungs.

"What we found is that, yes, Neandertals had bigger noses, but that the inner structure of their noses was not so different from our own," says paleoanthropologist Costantino Buzi of the University of Perugia in Italy. "They were simply larger and worked more efficiently."

The new study is based on the skull of Altamura Man, a Neandertal who lived between 172,000 and 130,000 years ago and whose skeleton was discovered in a cave in southern Italy in 1993. The skeleton seems intact, but it is covered by a

thick layer of calcite, also known as cave popcorn. Neandertal remains are rarely so well-preserved, and in other specimens the very fine bones at the rear of the nasal cavity have always been damaged or missing, Buzi says. But the fine nasal bones of Altamura Man are intact. Rather than risking damage to the skeleton by moving it, researchers have studied it within the cave.

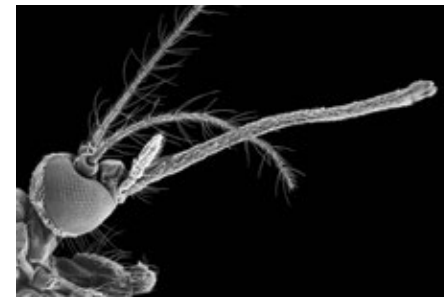
For their study, Buzi and colleagues used video footage, photos and specialized tiny cameras attached to thin tubes to create a digital 3-D reconstruction of the skull and nasal cavity — the first ever for the species.

Groups of modern humans that live in cold regions, such as the Arctic Inuit people, have nasal adaptations that allow them to better breathe cold air, Buzi says. "In cold climates, the nasal cavity gets taller and narrower."

But the researchers did not see any such signs inside the nasal cavity of Altamura Man. The finding is the first firm evidence that Neandertal noses did not feature a similar adaptation.

Neandertal bodies seem to have been better for cold climates than those of *H. sapiens*, says paleoanthropologist Bruce Hardy, who was not involved in the work. But the idea that Neandertal noses evolved for the cold has been debated for decades, perhaps in an effort to differentiate our species from the Neandertals we displaced or bred with.

"We finally have a fossil that preserves the internal nasal bony structures of a Neandertal," says Hardy, of Kenyon College in Gambier, Ohio. "The authors can actually observe the structure rather than speculate about it." ✖



DENNIS KUNKEL MICROSCOPY/SCIENCE SOURCE

↗ A mosquito uses its proboscis (seen in a scanning electron microscope image) to pierce skin. Scientists can use it for precision 3-D printing.

TECHNOLOGY

SCIENTISTS USE A MOSQUITO'S BLOOD SUCKER TO 3-D PRINT

BY PAYAL DHAR

The long, thin organ that mosquitoes use to pierce skin makes an excellent nozzle for intricate 3-D printing, researchers report in *Science Advances*. Or more specifically, 3-D necroprinting, the term for a field that uses parts of dead animals in high-tech machines.

Mechanical engineer Changhong Cao of McGill University in Montreal and colleagues used an *Aedes aegypti* proboscis as a nozzle to print lines about half the width of a human hair. This organ is relatively straight, has an inner diameter between 10 and 20 micrometers, and can withstand the pressure of ink being pushed through it. In a demo, the team printed a honeycomb shape, a maple leaf outline and a scaffold to hold biological cell samples with commercially available ink.

"This biological, nature-derived sample is much better than engineered material," says biomaterials engineer Jianyu Li of McGill. The best commercially available metal dispense tips have inner diameters of 35 to 40 micrometers. Glass tips can print finer lines than the proboscis but are easily breakable.

Dispense tips can be expensive and hard to build, says Daniel Preston, a mechanical engineer at Rice University in Houston who was not involved in the work. Using parts that nature has already created can help democratize 3-D printing, he says, "by lowering costs and removing barriers to entry." Preston says he's looking forward to "seeing other biotic materials incorporated in the 3-D printing process to enable new capabilities." ✖

RYAN SNOOK

ENVIRONMENT

Deep-sea mining might feed plankton a diet of junk food

By Carolyn Gramling

● **Mining the seafloor** for valuable metals could send dangerous ripples through ocean food webs.

Tiny floating plankton, the base of the food web, can accidentally ingest particles of sediment kicked up by deep-sea mining operations — forgoing more nutritious food of similar size, researchers report in *Nature Communications*. That could trigger a bottom-up starvation cascade, even up to large marine predators, the team says.

Researchers have long feared that seabed mining could cause irreparable harm to deep-sea ecosystems. Equipment scraping the seafloor some 4,000 meters deep can disrupt fragile microbial communities in the sediment for decades. It can also kick up sediment plumes that can clog the filtration systems of bottom-dwelling creatures.

But shallower depths are also at risk: Seabed mining can release sediment plumes into the water between around 1,000 and 1,500 meters. The new study suggests these plumes may be deadly to plankton.

In 2021 and 2022, oceanographer Michael Dowd of the University of Hawaii at Mānoa in Honolulu and colleagues journeyed to the Clarion-Clipperton Zone in the Pacific Ocean. There, the seafloor is littered with polymetallic nodules, chunks of rock enriched in metals such as cobalt, manganese and copper that are valuable for electronics.

During their first two trips, the scientists collected plankton and sediment particles using giant nets deployed at depths between 700 and 1,500 meters. The team analyzed the samples for particle size and chemical makeup — especially of the amino acids in the plankton and particles. By comparing the chemical forms, or isotopes, of nitrogen and carbon in those amino acids, the team determined that the plankton prefer to consume particles about 6 micrometers wide.

The team's third trip was alongside a pilot deep-sea mining operation conducted by the Canada-based Metals Company. This time, the researchers collected samples of particles from within a waste plume of sediment created by the mining activities. Analyses of those particles revealed a distressing fact: They were similar in size to, but far less nutritious than, the food many plankton usually eat.

"[The plume particles] were basically junk food," says biogeochemist Brian Popp, also of the University of Hawaii at Mānoa. "They had very, very low protein content."

That suggests a dangerous scenario, the team says, should deep-sea mining operations get under way in earnest. If more and more plankton are exposed to and consume these nutrient-poor particles, they might starve. And in turn, the creatures that feed on them would also suffer. ✖

THE HEALTH CHECKUP

‘PREHAB’ CAN BOOST SURGICAL RECOVERY

BY ANNA GIBBS

A. GIBBS

Major surgery is like running a marathon. Both take a big toll on the body. And both benefit from some prep before the event. The surgical equivalent of marathon training is called prehabilitation, a holistic approach that prepares the body for trauma through exercise, nutrition, cognitive training and lifestyle changes. You might already walk or swim to improve cardiovascular endurance, eat protein to support muscle repair or practice mindfulness to reduce anxiety. Research suggests that prioritizing these activities before surgery can prevent infections, shorten hospital stays and hasten recovery after surgery.

It may seem straightforward, but implementing prehab can be complex, says anesthesiologist Brice Gaudillière of Stanford University. It requires patients to adhere to strict regimens, often without much support. And programs that are more structured vary widely in design, largely because we still don’t understand how prehab works physiologically, Gaudillière says.

His recent study in *JAMA Surgery* investigates those potential mechanisms. Gaudillière and colleagues oversaw prehab programs for 54 adults undergoing major elective surgery. Half of the patients received a preset prehab regimen to follow for two to six weeks before surgery. The other half met remotely twice a week with specialists, who checked in on their progress and helped customize exercises, nutrition guidance and cognitive training. Researchers took blood samples from each patient before and after prehab and used an artificial intelligence model to map their immune systems. The maps revealed two specific cellular changes: A decrease of overreactive immune responses that can elevate risk of infection, and a reduction in the responses of combative T cells in the blood that have previously been linked to cognitive decline after surgery. The effect size was 40 percent larger in people who received the personalized regimen.

The influence of personalized prehab on the immune system was “surprisingly pronounced,” Gaudillière says, and without any side effects like medications for the same purpose might have. Untangling how prehab works can help justify investing in the resources needed to implement more comprehensive programs, he says.

Some medical centers already offer personalized prehab. At Washington University School of Medicine in St. Louis, patients who are older, have multiple health issues or are scheduled for particularly high-risk procedures are eligible for the center’s Surgical Prehabilitation and Readiness (SPAR) program, which started in 2021. Program coordinators meet with patients two weeks before surgery to guide them through physical therapy, nutrition plans, gratitude journaling and deep breathing training to strengthen their lungs.

The coordinators can tailor exercises and serve as motivation. “You have this patient who’s working on getting stronger, but they’re also being reminded that there’s someone else out there who really cares about them getting stronger because they want them to have a good outcome,” says pancreatic surgeon Dominic Sanford, who leads the program.

Prehab might not be necessary for everyone, though. The benefit to a patient largely depends on how difficult recovery is expected to be, Sanford says. SPAR is now among a handful of programs worldwide with online resources available to anyone interested in evidence-based lifestyle changes before surgery. Prehab might benefit a 30-year-old facing a straightforward operation, Sanford says. But the positive effect would likely be much stronger for, say, a 70-year-old undergoing a high-risk surgery. Still, it can’t hurt to tip the odds in your favor. ✖

Revolutionizing Urban Design: The Promise of Bioreceptive Concrete

In the pursuit of more sustainable urban environments, bioreceptive concrete has emerged as a transformative advancement in the architectural landscape. According to Dr. Ronaldas Jakubovskis, Chief Research Fellow at VILNIUS TECH University in Lithuania, this innovative material redefines building facades and our relationship with urban ecosystems.

Economic and Ecological Benefits

Bioreceptive concrete, unlike traditional structural concrete, is engineered to support the growth of organisms like bryophytes, algae, bacteria, and fungi on its surface, according to Dr. Jakubovskis.

"This design approach aims to cultivate living, self-sustaining micro-ecosystems that enhance a building's aesthetic appeal and its environmental functionality," he explains. "By optimizing both mechanical and biological properties, such as water retention capacity and pH levels, bioreceptive concrete promotes the growth of plant species, which transforms inert surfaces into dynamic ecosystems that actively regulate urban energy, water, and carbon cycles."

The implications of bioreceptive concrete are significant and far-reaching. Dr. Jakubovskis states that bioreceptive concrete facades offer substantial economic and ecological advantages over bare concrete, natural stone, or cement-based composite cladding. "They improve thermal comfort by minimizing surface and ambient temperatures, protecting vulnerable populations, and mitigating heat stress in densely populated areas."

Additionally, bioreceptive concrete enhances acoustic comfort, boosting high-frequency sound absorption up to 50%, benefiting cognitive performance and well-being in urban settings. It also improves air quality by capturing up to 30% more fine particles than bare cladding (concrete, stone, cement), aligning with the WHO's "Healthy Buildings" goals. Furthermore, it facilitates carbon sequestration, estimated at 10–20 grams per square meter annually.

Navigating Aesthetic Challenges

The aesthetic evolution of bioreceptive concrete does present challenges, like uncontrolled colonization by fungi and algae, causing undesirable discoloration. Dr. Jakubovskis suggests, "By employing specific surface geometries and managing water flow, architects can ensure facades remain attractive while promoting growth." He adds, "Current research advocates for a layered approach: an external bioreceptive layer acts as a host and aesthetic feature, while a robust internal layer ensures structural integrity."

To unlock full potential, Dr. Jakubovskis highlights the urgent need for comprehensive field studies across diverse climatic conditions. "Current methodologies prioritize short-term lab tests, which often fail to capture the complexities and long-term success of colonization. Advancements in non-destructive testing (like accessible, low-cost 3D mapping) could provide critical insights into colonisation dynamics and microorganism survivability."

Reimagining Urban Landscapes

Looking ahead, integrating bioreceptive concrete into urban landscapes prompts a major reimagining of city planning. These facades provide essential services like improved water retention and moderated temperatures, supporting the EU Biodiversity Strategy for 2030. Dr. Jakubovskis believes realizing this vision requires interdisciplinary research, uniting engineers, microbiologists, and architects.

Following this, Innovation Agency Lithuania, the Lithuanian Ministries of Economy and Innovation, and Education, Science and Sport launched the €88.34 million "Implementation of mission-based science and innovation programs". This initiative, funded by the European Recovery and Resilience Facility and Lithuania, will boost innovation in oncological/hereditary disease treatment, develop climate-neutral technologies/materials, and elevate cybersecurity.

Martynas Survilas, Director of the Innovation Development Department at the Innovation Agency Lithuania, notes this initiative expects significant results in 2026: 3 competence centres, over 20 R&D projects, 30 solutions, and 20 spin-off companies. These achievements will accelerate Lithuania's transition toward a knowledge-driven economy.

Features

ANGELA BOHLKE/NIKON COMEDY WILDLIFE

ECOSYSTEMS

A SECRET WINTER WONDERLAND

● This red fox (*Vulpes vulpes*) might look as if its stuck upside down in the snow—but looks can be deceiving. The cunning canid is hunting for a small vole keeping warm in the subnivium, an ecosystem that forms only underneath snowpack. Many critters, from other small mammals to birds to arthropods, along with lots of microbes, go about their busy lives here. Scientists working to understand this transient habitat are in a race against time as global warming threatens to wipe it out (see Page 48). —*Cassie Martin*

Animal Joy

Scientists have long focused on quantifying fear and other negative emotions in animals. Now they're trying to measure positive feelings—and it's a challenge.

By Amber Dance

Can animals experience *joy*?

Well, of course—just look at my tuxedo cat, Tango. He has an evening ritual: He waits atop the bed for his brother Teddy, a fat orange tabby with a remarkable resemblance to a loaf of French bread, to stroll by. Then Tango reaches out to snatch at Teddy's tail with apparent glee.

As animals ourselves, we think we see happiness in our fellow creatures all the time. Dogs romp in the park; squirrels chase each other up and down tree trunks; Tango purrs his head off at night while attempting to sleep on my face. Yet I know that it may not be glee because I can't be certain what emotions are felt by a creature that can't speak to me. Misinterpretation is possible. Sure, young squirrels could be playing, but adults are more likely to be chasing off a rival for their stored acorns or competing for a potential mate.

For decades, scientists have struggled to identify or measure true joy—or "positive affect," in sci-speak—in nonhuman animals, even though they've long assumed it exists. In the late 19th century, Charles Darwin wrote, "The lower animals, like man, manifestly feel pleasure and pain, happiness, and misery."

But in the 20th century, psychologists focused on strict behaviorism, which limited scientific study to actions that could be objectively tallied. Think Russian physiologist Ivan Pavlov and the dogs he conditioned to expect food when he rang a bell, giving him a measurable drooling response. Or American psychologist B.F. Skinner, who put rats and pigeons in "Skinner boxes" where they were trained to push levers and peck keys for rewards. That history left scientists wary of anthropomorphism and subjective topics like feelings.

That's true for positive feelings, at least—there has been loads of scientific attention on misery. In part, that's because researchers aimed to understand and relieve suffering, not just in animals but in people experiencing pain, depression or other clinical problems. It's also straightforward to measure a negative response, such as freezing in fear, compared to subtler signs of contentment.

All this history made the study of animal feelings largely taboo, a trend bucked on occasion by researchers like the late Jaak Panksepp, an Estonian neuroscientist and early leader in the study of emotions in the brain. In the early 2000s, when Panksepp reported that rats make a laughter-like sound when tickled, scientists were doubtful; the ultrasonic calls are inaudible to human ears.

"He had problems publishing it at all because people thought it was crazy," says Michael Brecht, a neurobiologist at Humboldt University of Berlin. Skeptical but curious, Brecht did research that found rats not just laughing, but also jumping for joy and playing hide-and-seek.

If scientists had better tools to measure positive emotions they'd be equipped to more deeply investigate the causes of happiness and how animals communicate it, with major implications for mental health among captive animals.

This need has inspired an audacious group effort to try to develop a "joy-o-meter"—or more likely, a set of happiness metrics—that could be used to better understand many critters, whether they are wild or captive, whether they walk, fly or swim.

"The overall goal of the project is to establish this serious, scientific approach to positive emotion in animals, which has been hugely overlooked," says Erica Cartmill, a member of the group and a cognitive scientist at Indiana University Bloomington. Cartmill studies great apes, but she knew that they wouldn't be enough to build a universal metric. So she joined up with investigators with interest in studying positive affect in dolphins and parrots.

Their work is part of a much-needed surge of interest in studying animal emotions, says Marc Bekoff, an ethologist and emeritus professor at the University of Colorado Boulder who studies canine play behavior. "For a long time, people wondered whether dogs and other nonhuman mammals experienced positive behaviors like happiness and joy, and of course they do." But, he adds, it is most likely different

PREVIOUS PAGE, CLOCKWISE FROM TOP LEFT: JURGEN & CHRISTINE SOHNS/IMAGEBROKER/GETTY IMAGES; JON STARLING/500PX PRIME/GETTY IMAGES; ANDREY NEKRASOV/IMAGEBROKER/GETTY IMAGES; VENTZ/ISTOCK/GETTY IMAGES PLUS; PAUL STAROSTA/STONE/GETTY IMAGES; CYRIL RUOSO/ALAMY

from human emotions.

In the joy-o-meter project, challenges quickly arose. It's not only tricky to measure happiness, it's also dicey to predict what event might induce that joyful state. "Studying emotions is actually really hard," says Colin Allen, a project lead and philosopher at the University of California, Santa Barbara who collaborates with Cartmill.

To keep it simple, Allen and his colleagues have focused on a strict definition of joy as an intense, brief, positive emotion triggered by some event, such as encountering a favorite food or a reunion with a friend. That kind of "woohoo!" moment seemed easier to assess than, say, ongoing mild contentment. Even with a strict definition, the researchers are contending with variations in joy triggers and responses from one animal to the next, including within the same species or group.

"You want to make sure that what you're putting out there is based on reality, as opposed to just guessing what is happening in the animal's mind," says Heidi Lyn, a comparative psychologist at the University of South Alabama in Mobile who is a co-leader of the project and is in charge of the dolphin studies as well as some of the ape work.

These efforts by Lyn and colleagues are important, says Gordon M. Burghardt, a biopsychologist and emeritus professor at the University of Tennessee, Knoxville.

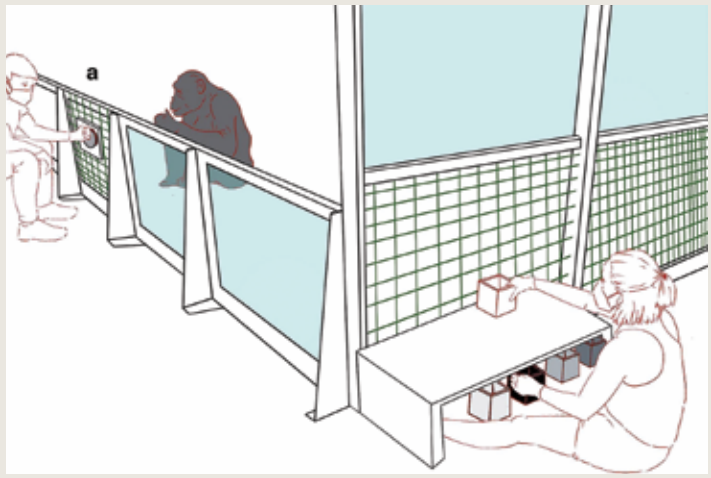
It's not only tricky to measure happiness, it's also dicey to predict what events might induce that joyful state.

He is not involved in the joy project, but has studied animal play for more than 40 years. In that work, Burghardt says, coming up with a definition with five criteria in 2004 made it possible to identify play in diverse creatures including mammals, birds, lizards, turtles, fish, octopuses and bumblebees.

"Positive affect is as much worthy of scientific study as studying pain and negative emotions," Burghardt says. Not only might scientists figure out how to better the lives of captive animals, they might get some clues to human happiness, too. "What is it that makes a good life?" he asks. "Those are the topics that are most worthwhile for us."

Do our nearest relatives feel joy?

The team began the work in apes because its funder, the Templeton World Charity Foundation, thought the odds of success were best in humankind's closest relatives. Bonobos are known for playful behavior, including frequent sex acts they use to create social bonds and resolve conflicts. Chimpanzees are considered more violent, though scientists have observed what are likely happy times in chimp troops. Cartmill's and Lyn's groups led the way, starting in 2022 with wild chimps at the Fongoli Savanna Chimpanzee Project in Senegal; zoo bonobos at ZOO Planckendael in Mechelen, Belgium; research bonobos at the Ape Initiative in Des Moines; and



Taking a chance on a surprise

Researchers trained bonobos to expect that a black box always contained a grape, while a white box never did. The apes chose to approach black boxes and ignore white ones. If they didn't like a box, they could touch a button (denoted "a," left) to cue up the next offering.

The scientists then played sound prior to a testing session: either the sound of a baby bonobo laughing or a windlike sound. Then they offered a novel gray box.

Bonobos who heard recorded laughter were more likely to take a chance and approach the gray box, which held a grape 50 percent of the time. They preferred darker gray boxes, perhaps because they were more like the black boxes that held grapes.

T. TRIPHAN *ET AL*./*CURRENT BIOLOGY* 2025

bonobos at the Jacksonville Zoo and Gardens in Florida.

Wild chimps don't have easy lives, says team primatologist Gal Badihi, who spent three months following a troop around Fongoli. They contend with dominance hierarchies, competitions and the ongoing search for food. Nonetheless, Badihi recorded potentially joyful moments. For example, chimps played with infants. A juvenile called Youssa proved to be quite the goofball, hanging upside down all the time. Other young chimps liked to drink from each other's mouths or roll around giggling. When reuniting with their fellows, chimps would embrace and kiss. "The joyous moments kind of stick out because they are quite rare," says Badihi.

She's currently focusing her analysis on a panting sound like unvoiced laughter that chimps often made during those apparently positive or social behaviors, as well as during situations where they wanted to communicate positive intent or de-escalate conflict. "It's really similar to how we use laughter and smiles across social context as people," Badhi says. (She now works at the German Primate Center in Göttingen.)

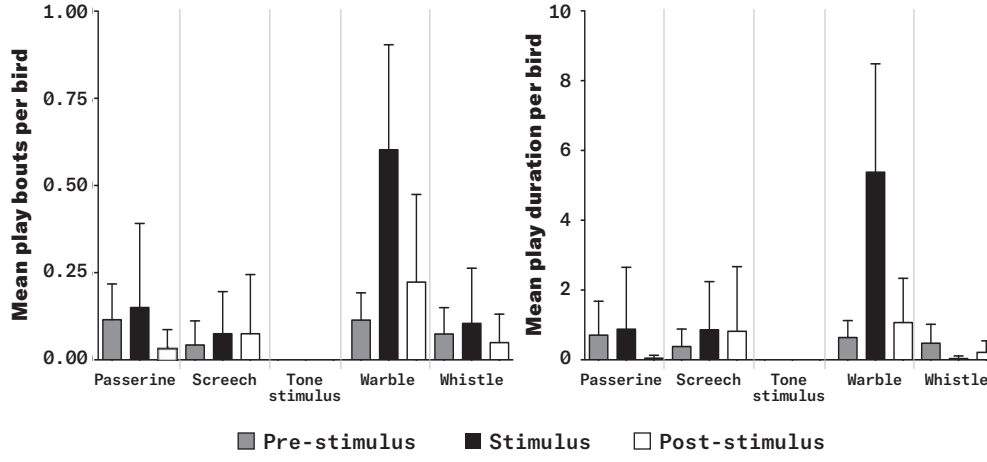
Badihi waited to observe potential moments of joy that occurred spontaneously, while another Cartmill team member, behavioral biologist Daan Laméris, tried to trigger possible joyful moments with the bonobo troop at ZOO Planckendael. His attempts to introduce novel toys to the bonobo enclosure illustrate how hard it is to predict what makes animals happy. Their favorites included a basketball, burlap sacks and T-shirts — the latter more for tearing than for wearing. But not all apes responded the same way to the joy triggers. Fewer bonobos liked the piles of sawdust Laméris hoped they would roll around in. And after he'd painstakingly cleaned hundreds of used tennis balls, only one individual bothered to collect them. The goal is to assess whether apes that play together tend to interact more later in the day, but Laméris isn't ready to finalize his conclusions.

> There was evidence that [bonobos] feel better after hearing laughter.
>
> — Sasha Winkler

Another member of the Cartmill group, primatologist Sasha Winkler, has succeeded both in inducing and measuring signs of joy with the bonobos at the Ape Initiative. Winkler set out to re-enact a test of feelings based on observations that depression in people can lead to pessimistic judgments. Scientists studying rats adopted the idea, first to study if rats in less-than-optimal living conditions are pessimistic, and later to find that rats that recently enjoyed a good tickle are more optimistic. Similar optimism tests have also been used with poultry to assess whether environmental improvements made the birds happier.

First, Winkler set up the measurement system. She trained four adult bonobos to approach a black box in expectation of a tasty grape, and to ignore a white box that held no such treat. The presumption was

A PARROT'S HAPPY WARBLE PROMPTS PLAY



Researchers played various sounds to wild keas, a type of parrot, and scored how the sounds affected the birds' behavior.

The kea warble call was the only sound that significantly increased playful behaviors such as chasing another bird, performing aerobatics with them or tossing an object in the air.

R. SCHWING *ET AL*/*CURRENT BIOLOGY* 2017

that if she then offered a gray box, an optimistic bonobo would be more likely to check it out in anticipation of a goody.

Then she brought in the happiness trigger: the sound of baby bonobo laughter. Winkler primed her subjects with an audio recording of either seven and a half minutes of laughter or a neutral windlike sound before bringing out the boxes. After hearing the laughter, the bonobos were more likely to approach the gray boxes, Winkler reported in 2025 in *Scientific Reports*. "That was evidence that they feel better after hearing laughter," says Winkler, who is now a postdoctoral fellow at Duke University in Durham, N.C.

JOHN DOWNER PRODUCTIONS/DIGITALVISION/GETTY IMAGES

Keas, large green parrots that live in New Zealand, appear to enjoy playing in sunny, snowy weather.

Another test the researchers are conducting in multiple species is a "windfall" experiment, offering a happy surprise as the joy trigger. Lyn tackled this test with bonobos at the Ape Initiative and the Florida zoo, using an unexpected bounty of treats as the trigger.

First, the experimenter showed a bonobo a grape, then hid it between two overturned bins. The researcher then revealed the grape for the ape to eat. So far, the treat was entirely expected. But after repeating this five times, the researcher performed a magic trick. Unnoticed by the bonobos, there was a third container underneath the other two. And sandwiched between that bottom box and the middle one were 10 grapes — jackpot!

That reveal was the windfall. In response, the Jacksonville bonobos made hooting sounds that are known to ape researchers as "food peeps." That alone wasn't much of a surprise, but further studies indicate the peeps may be about general happiness. The Des Moines bonobos nodded their heads instead, so that's another candidate joy signal, Lyn says.

The team also set up a social windfall. They arranged video calls between bonobos and their keepers on an iPad. The happy surprise was the appearance of a keeper the bonobo hadn't seen in a while. Again, the apes peeped or nodded, suggesting those behaviors might be about more than food. "Maybe they're just 'happy peeps,'" Lyn speculates.

Parrots that make snowballs

Once the ape research began to yield promising results, the Templeton Foundation began funding the parrot and dolphin studies in 2024.

The parrots under study are keas, big, smart birds found in the mountains and forests of New Zealand's South Island. Team investigator Ximena Nelson, a behavioral biologist at the University of Canterbury in Christchurch, New Zealand, already had plenty of reason to suspect the birds experience joy. In particular, she noticed they seem to love sunny, snowy weather. Nelson has seen them make snowballs and sled down the roofs of ski huts. "That is anthropomorphizing, there's no doubt about it," she says. "But I've spent a lot of time up in the mountains with these kea, and it's a thing, I'm sure of it."

Nelson's previous research on the curious, mischievous parrots revealed that they make playful "warble calls" that are contagious, like human giggle fits. Playing a warble recording to a wild kea, juvenile or adult, sets off a playful response. "It will start, like, tap-dancing," Nelson says. "They start playing, and they start warble calling."

Based on this finding, Nelson and zoologist Alex Grabham, a postdoc in her group, reasoned they could use the warble calls as an easy joy trigger for their experiments with a kea flock, sometimes called a "circus," at the Willowbank Wildlife Reserve in Christchurch. But they immediately hit a snag. Born and raised in captivity, these parrots had never heard a warble call — and they hated it. When the researchers played the tape, the birds flew around making distress calls. "They just went mental," Nelson says.

After some time back at the drawing board, Grabham returned to the circus with new

potential joy triggers.

One was a favorite food for the kea windfall experiment, a variation on what Lyn had done with the bonobos. First the keas got a carrot, which they consider "sort of a 'meh' food," Nelson says. Then another carrot, and another carrot. Then, the windfall: peanut butter!

For his part, Grabham hopes to use changes in keas' body temperature as a measure of joy. Body temperature changes with stress, so perhaps it does with happiness, too. He aimed an infrared camera at the area around the birds' eyes where there are no feathers to get in the way. The team is still analyzing the data, which came out noisy; the temperature seems to make more of a wobble, rather than go straight up or down.

Making measurements of biological markers, and not just behaviors, is important, says Sergio Pellis, an ethologist and animal play expert at the University of Lethbridge in Canada. "Just looking at the behavior from the outside may not be sufficient to make a judgment about how much the animals are enjoying this," says Pellis, who is not involved in the joy-o-meter project. "There may be situations when they're faking it."

For example, Pellis says, sometimes horses and dogs look like they're playing, but their levels of the stress hormone cortisol indicate they're not having a good time.

Grabham is also analyzing samples from a different experiment inspired by keas' love of snow. This time, the captive circus cooperated. Grabham dumped machine-made snow on the aviary's hillside in the hopes of triggering joy. He's pretty sure he succeeded. "The kea were all over it," he says. "My instinct is that they were having a good time." Some played alone; some held snow fights; one pushed a snowball toward a researcher.

To measure this possible joy more objectively, the researchers collected poop from playing parrots to measure levels of the bird versions of the hormones cortisol and oxytocin. To gather fecal samples, each of the 12 parrots was assigned a human researcher to follow the bird around with a spatula and test tubes. Grabham estimates each bird produced about five specimens in the one-day experiment, but one, called Plankton, offered up sizable samples every 20 minutes. Grabham is analyzing the hormone data now.

Again, Nelson expects the data to be noisy because hormone levels can be influenced by factors like the time of day, the animal's sex and whether it is molting. This variance in how joy may be expressed by individual animals has been an ongoing challenge.

And as with Laméris' apes, individual parrots had varying interest in joy triggers, too — and in whether they expressed interest in participating in the experiments at all. One adolescent kea, called Megatron and described by Grabham as "a little menace," eagerly bounded along behind the scientist as he headed for Megatron's testing platform. But another, Mystique, tended to ignore the scientist's calls; she'd rather push a leaf back and forth in the water.

That doesn't mean it's impossible to trigger and measure joyful behaviors, Grabham says. But "one experiment might not fit all."

While he continues analyzing data from the circus at the wildlife reserve, data from wild keas has shored up Nelson's beliefs about their happiness in sunny, snowy weather. She sent a student with a video camera to tramp up and down New Zealand's mountains and film the birds. In the resulting videos, the keas were four times more likely to warble if the sun shone.

"It is intriguing that keas make a warble song during play, and that it is four times more frequent when the sun is shining emphasizes the potential joyful aspect of the display," says Nicky Clayton, an expert in bird behavior and cognition at the University of Cambridge who was not involved in the study.

"Given the difficulties," says Nelson, "I think we've actually made quite a lot of progress."

Behind the dolphin's smile

Like keas in the sun, dolphins sure look like they're having fun, leaping through the bow waves of boats, blowing bubble rings or playing catch with bits of seaweed. But their characteristic "smile" is frozen in place and says nothing about their emotional state.

They have a few things in common with great apes: intelligence, yes, but other qualities too. Like bonobos, they're known for voracious sexual appetites. Like chimps, they can sometimes be violent, kidnapping females, occasionally killing baby dolphins and smacking around harbor porpoises. And sometimes their play objects are unfortunate sea turtles or seals.

Lyn's 2020 study with dolphins illustrates how valuable a joy-o-meter would be to monitor the well-being of captive animals. The Association of Zoos and Aquariums requires accredited facilities to provide enrichment, but not every toy provokes positive behaviors.

VALERY HACHE/AFP/GETTY IMAGES

Dolphins do things that look like fun, such as playing catch with seaweed, but scientists have struggled to figure out if these activities induce positive feelings. A "victory squeal" after being given a fish or while swimming with other dolphins may provide a clue.

In that study, the researchers provided novel items like bubble generators or barrels coated in artificial turf. The biggest response was to a 3-foot-long block of ice, and it wasn't a positive one — at least not at first. The two dolphins, Bo and Buster, initially fled, then returned to investigate. Overall, dolphins tended to avoid the novel objects — hardly a rousing endorsement for their potential to induce joy.

And as with apes and parrots, vocal calls may be the key to understanding dolphin joy. Other dolphin researchers have defined the "victory squeal" as a sound the animals make when they catch a fish or receive a fish prize from their trainers.

They suggest it reflects release of the reward chemical dopamine in the brain. Once trained, dolphins make the same sound after they complete a task but before they get the fish reward, or even in the open ocean where their trainers aren't nearby. It's as if it's a sort of "I did it!"

Lyn's team has observed similar squeals in other contexts, such as when dolphins receive a surprise treat, like a toy or bucket of ice. She hopes to perform windfall experiments to measure if the dolphins squeal more in the moments after they get an unexpected treat, like a favorite toy.

"While it is hard to know how animals experience emotions or how similar those impressions are to our own subjective emotional experiences, the cetacean victory squeal does seem to be associated with objectively positive events in a cetacean's life," says Jason Bruck, a behavioral biologist at Stephen F. Austin State University in Nacogdoches, Texas, who was not part of the study.

Dolphins' characteristic "smile" is actually frozen in place and does not reflect their emotional state.

Preliminary data indicate that squeals may have a social function, too. If their trainers are also screaming with joy, the dolphins seem to make bigger or more frequent squeals. And they do it when socializing with other dolphins, such as swimming together. "It seems to very much be this sort of communicative pattern," Lyn says.

While there's still plenty more work to do, the project researchers are excited about the progress they've made and what's to come. After scientists spent so many decades focusing on unhappy feelings in an effort to reduce negative experiences for animals in captivity, kea researcher Nelson says, "it's just nice to turn the tables and think about the positive." Her own reasons for studying animal happiness are even simpler than that: "Because it gives me joy." ✖

Amber Dance is a science journalist based in Los Angeles.


TAYASSU PECARI
SOCIABILITY
EXP

WILD PERSONALITIES

From bold foxes to gregarious birds, animals' personalities are increasingly being recognized as crucial to conservation efforts

BY DARREN INCORVAIA

PHOTO-ILLUSTRATION BY VALERIE CHIANG

Much like his ninja namesake, Naruto the white-lipped peccary was a bit of a loner.

Named after the titular character from a popular manga and anime, Naruto was the youngest male and one of the least social in his group of 17 peccaries, all of whom were born and raised in captivity at the Laboratory of Applied Ethology at the State University of Santa Cruz in Ilhéus, Brazil.

Destined for reintroduction into Brazil's Estação Veracel Private Natural Heritage Reserve and the Pau-Brasil Ecological Station, the peccaries were each given a personality test of sorts by lab researchers. The piglike mammals were video recorded as they went about their daily lives, resulting in 17 hours' worth of behavioral data. Their aggressive actions, friendly touches and moments of exploration were tallied so that the peccaries could be ranked in traits such as boldness and sociability.

The goal was to determine whether an individual peccary's behavioral traits influenced its survival when released into the wild. White-lipped peccaries (*Tayassu pecari*) are listed as vulnerable by the International Union for Conservation of Nature, or IUCN. In Brazil, the size of the species' historical range had plunged by 60 percent by 2020, and past efforts to reintroduce them had met limited success.

Around the globe, scientists are increasingly recognizing how a reintroduced animal's personality can impact how both individuals and groups fare in the wild. Such work is part of a growing trend to infuse the study of personality, and how it affects behavior, into conservation. When working with wild animals and tight budgets, personality tests may not always be possible. But understanding animal personality could help conservationists choose which individuals stand the best chance of surviving—helping to restore populations threatened with extinction.

For Naruto, his loner personality may have ultimately been his undoing.

Naruto's behavior stood out to Selene Nogueira, an ethologist at the university and leader of the lab's peccary project. "He was the last one to eat and then was thinner than the others," Nogueira says. "I think his personality was a little bit shy." Once the peccaries were released, Naruto continued his asocial ways. His wanderings helped the group disperse. But less than a year after the release, researchers found him limping with deep bite marks, probably from a jaguar or puma. He died three days later.

Peccaries are known to fend off predator attacks when in a group. Sure enough, the rest of the peccaries fared better, and now, after about two years, the group has welcomed 10 babies. From her study, Nogueira generally concluded that, for a released group of peccaries to be successful, they need a mixture of personality types—asocial adventurers to go off and nudge the group along, as Naruto did, and social butterflies that stick together.

For scientists working in the forests of Brazil in the 20th century, the mere idea of peccary personalities would have been laughable. But Nogueira's work is part of a wave of research in the last two decades showing that personalities aren't just the purview of peccaries—they're everywhere in the animal world.

PREVIOUS SPREAD, FROM LEFT: WRANGEL/GETTY IMAGES; WRANGEL/GETTY IMAGES; WIRESTOCK, INC./ALAMY; AMAZON-IMAGES/ALAMY; ALEJOMIRANDA/GETTY IMAGES. THIS PAGE: G&M THERIN-WEISE/GETTY IMAGES

A PLETHORA OF PERSONALITIES

For a long time, research into animal behavior was built on the view that individual differences are mostly raw material in the evolution of a species. Over time, natural selection should lead to animals that behave roughly the same, the thinking went, so that they make the best possible choices in every situation.

Then, in 2004, two influential papers — one led by Andrew Sih of the University of California, Davis, and the other led by Sasha R.X. Dall, then of the University of Cambridge — flipped that idea on its head. Rather than populations steadily evolving into behavioral monotony over time, the papers posed, variation between individual animals might itself be desirable for evolutionary success. The papers drew on recent studies of mammals, birds, reptiles and even invertebrates such as mollusks, as well as the principles of game theory, the mathematical modeling of optimal strategies. Combined, the data support the idea that evolution can lead to consistent behavioral differences between members of the same species. That is, evolution gives rise to personalities.

"That got folks really excited," says Kate Laskowski, a behavioral ecologist at UC Davis. Laskowski recalls an animal behavior conference in the early 2000s, in the wake of this revelation. "Every single talk was like, 'Oh, we found personality in this animal, we found personality in that animal,'" she says. "That's classic any time a new field starts."

Personality is a big part of animal behavior, so the idea that it matters to conservation comes as no surprise to Daniel Blumstein. As a child, he attended events on the first Earth Day in 1970, and he has long been interested in bringing together animal behavior and conservation. Now a behavioral ecologist at UCLA, Blumstein started his career studying how marmots in Pakistan's Khunjerab National Park avoid predators. He became involved with local conservation groups and communities during his time there. It has taken time for the broader field of conservation biology to catch up on the importance of behavior, he says. "A lot of mainstream conservation is still population biology, population modeling, what makes populations go up and down," Blumstein says. And "a lot of it is still genetics."

When species reintroductions go wrong, though, it's behavior that's often to blame.

In a paper published in 2020, Blumstein and colleagues scrutinized 293 case studies of animals being released into the wild; 27.6 percent of them reported problems with behavior. The most common issues were related to movement, with animals traversing into areas they weren't meant to go. When 12 endangered Hamilton's frogs in New Zealand were moved 50 meters away to start a new population, for example, some of them immediately tried to head back home, a common problem in amphibian and reptile releases.

Other behavioral troubles noted by conservationists involved mating, finding food and, in some cases, behaviors tied to personality.

Boldness, a commonly studied personality trait, can have mixed effects on population health. Such was the finding of a 2013 study on reintroductions for two species of fox, the swift fox (*Vulpes velox*) and the Santa Catalina Island fox

← White-lipped peccaries are listed as a vulnerable species. ↓ The pig-like mammals tend to fare better in groups, since they can better fend off predator attacks.

HANJO HELLMANN/ALAMY

↑ The black-fronted piping guan, a chickenlike bird native to South America, is among the animals showing how personality can influence conservation efforts.

JOSÉ MARÍA BARRES MANUEL/ALAMY

(*Urocyon littoralis catalinae*). When 31 captive-bred swift foxes were released onto the Blackfeet Indian Tribal Reservation in Montana, five of the 16 monitored foxes died. They were the boldest individuals, and they succumbed to dangers such as predators. By contrast, the reintroduced island foxes, with no natural predators, had more babies if they were bolder, and none of them died during the study period.

Similarly mixed benefits of boldness have been seen in released Blanding's turtles and Tasmanian devils, both of which survived longer if they were more adventurous. But in blue-fronted parrots, shyer birds lived 40 days longer on average than bold ones.

For Naruto the ill-fated peccary, being asocial might have at first helped him avoid conflict with a bigger, stronger male. With a predator around, though, it would have paid for him to switch his behavior and become friendlier to gain protection from the group. But Naruto wasn't keeping track of the optimal way to behave in every situation: He was just being himself. Because Naruto and the other peccaries can't do it all, the overall population can benefit from the mix of personalities that Nogueira identified — even if it means individuals make deadly mistakes.

HOW BRIDGES INFLUENCE BEHAVIORS

The study of animal personality has since matured and permeated fields such as evolution and community ecology. Behavior, including personality, is inseparable from conservation success any time it influences demographics, Blumstein says. Any behavior that affects an animal's ability to survive, mate, raise offspring, move from place to place, avoid death and more can be of interest to conservationists.

Carlos Ruiz-Miranda, a conservation biologist at the State University of Northern Rio de Janeiro, rigorously tests personality in a conservation effort he's involved in for a showy chickenlike bird called the black-fronted piping guan (*Pipile jacutinga*). Native to southeastern Brazil and parts of Paraguay and Argentina, these birds are classified as endangered by the IUCN due to habitat loss and illegal hunting.

"We use this test based on a human personality test," Ruiz-Miranda says. The birds are scored on their sociability, aggression, acceptance of new foods, overall activity and whether they prefer to stay on the ground or hang out in trees. Like their chicken relatives, they sometimes scrounge around on the ground for food.

"We don't want animals to do that a lot, because they're very vulnerable to predators," Ruiz-Miranda explains. He compared the testing process to a coach choosing a soccer or baseball player, when some attributes may be more important than others. For Ruiz-Miranda's guans, the most important traits are being social, recognizing predators and not being ground foragers.

Ruiz-Miranda started his career with a long-running project to reintroduce endangered golden lion tamarins (*Leontopithecus rosalia*) into their native Brazil (see Page 46). After a rough start in the 1980s, that program became a roaring success once the introduced tamarins started reproducing — the babies were much more adjusted to their wild habitat than their captive-raised parents.

Now, changes to the monkey's wild habitat are prompting the research team to take personality more seriously as a factor in their conservation.

The tamarin team recently built bridges to

help the monkeys cross sections of the forest that have been clear-cut for oil and gas pipelines. Tamarins view these open areas with caution, fearing exposure to predators. Ruiz-Miranda noticed that some tamarin families cross the bridges readily, while others are more hesitant.

"We started thinking about these bridges being a filter of personalities," he explains. So while the bridges allow tamarins to move around more easily, they may also be shaping the personality distribution of the entire population, which Ruiz-Miranda's team is now studying further. The well-meaning bridges could be acting as a sieve, restricting areas of the forest to those tamarins who are brave enough to cross, with potential consequences for the group's survival.

"Individuality is one of those domains that people are exploring in some conservation contexts, and could be important in some," Blumstein says. But, he cautioned, "just because behavior is important doesn't mean all of it's important to solve any given problem."

WHEN TESTING IS IMPOSSIBLE

Of course, it's not always possible to include detailed personality tests in reintroduction efforts. In December 2023, wildlife officials used darts to sedate 10 Oregon wolves from a helicopter hundreds of meters in the air, packed them up in crates and shipped them off to Colorado to start life anew.

"You try to isolate animals just based on how they respond to the helicopter, and you get what you can get," says Eric Odell, the wolf conservation program manager at Colorado Parks and Wildlife who is leading the canines' reintroduction into the state.

Personality has been studied in wolves before — at least as far back as 1972 — but mostly in captive individuals. Fully understanding the personalities of the Oregon wolves before capturing them would have taken intensive fieldwork. Figuring out how those personalities may influence the animals' success when reintroduced would have taken even more research.

Though lacking in-depth personality info for the wolves, Oregon wildlife officials had a good understanding of who was who in each pack,

A PECCARY PERSONALITY TEST

Using 17 hours' worth of video footage, researchers scored a group of white-lipped peccaries on behavioral patterns that tied them to certain personality traits. The data may then inform reintroduction efforts.

BEHAVIORAL DIMENSION	BEHAVIORAL PATTERN	DESCRIPTION
● AGGRESSIVENESS	*Threatening*	With a short distance (about 1 meter) between two animals, one quickly moves toward the other, mouth open and canines exposed.
	Pushing	One animal pushes the other with its head or the side of its body, pushing the opponent away.
	Chasing	One animal runs toward another, running regardless of the distance.
	Attacking	One animal attacks another aggressively (vocalizing, canines exposed and dorsal hair bristling), pushing the opponent with its head, exhaling air through its nostrils and then biting the attacked animal.
● EXPLORATION	*Foraging*	The animal moves slowly around its environment with its head lowered and its snout close to the ground, apparently looking for food.
	Investigating the ground	A stationary animal, standing with its head lowered, actively moves its snout, digging or sniffing the ground in the absence of food.
● SOCIABILITY	*Mutual rubbing*	Two animals stand sideways in opposite directions and rub each other with the side of their bodies, rubbing against their dorsal scent glands.
	Social grooming	One animal rubs the other's body with its snout, using its tongue and chewing.
	Olfactory investigation	One animal brings its snout close to another and sniffs it in various areas of its body.

C. J. T. CAVALCANTE NETO *ET AL*/*SCIENTIFIC REPORTS* 2025

← Golden lion tamarins once lived in Washington, D.C.'s Rock Creek Park as part of a long-running project to reintroduce the animals in Brazil.

SKIP BROWN/SMITHSONIAN'S NATIONAL ZOO

TAMARIN TOWN

Brazillian monkeys offer early lessons in conservation

● **The current work** to understand animal personalities builds on a previous push for conservationists to consider behavior in general. For a textbook example of how important behavior can be for conservation, Daniel Blumstein of UCLA points to golden lion tamarins.

If you were strolling through Rock Creek Park in Washington, D.C., in the early 1990s, you might have chanced upon a loose troop of monkeys with brilliant orange fur and long, twiggy fingers. The Smithsonian's National Zoo had released endangered golden lion tamarins (*Leontopithecus rosalia*) into a part of zoo grounds that connected to the park, making the world the primates' oyster.

"The tamarins had the opportunity to go anywhere they wanted in the city of Washington, D.C., or beyond," says Carlos Ruiz-Miranda, a conservation biologist at the State University of Northern Rio de Janeiro. "They could have gone all the way to Baltimore."

The tamarins released at the National Zoo and other zoos around the country weren't moving in permanently. They were in training to eventually be released back to their native Brazil as part of a long-running effort to save the species from extinction. The monkeys were outfitted with radio collars for easy tracking and were consistently monitored by zoo staff.

Golden lion tamarins hail from Brazil's Atlantic Forest, which has been subjected to clear-cutting and development since Portuguese colonizers first set sights on it in the year 1500. The late Brazilian biologist Adelmar Coimbra-Filho had realized that tamarins were in trouble in the 1960s after traveling around the Atlantic Forest and struggling to find them. He began trying to breed them in captivity in 1962, with the hopes of reintroducing them into the wild. But his and other early captive breeding efforts didn't fare well. Despite their undeniable charisma, wild golden lion tamarins were poorly studied — scientists simply didn't know enough about them to breed them successfully.

"For any reintroduction program, there's some basic things you need to know about the animal," says Ruiz-Miranda, who joined the National Zoo's tamarin project in 1992. "And tamarins were a big surprise to everybody at the beginning."

Most group-living primates are polygynous, meaning males mate with multiple females. But when male tamarins were housed with multiple unrelated females, the females spent more time fighting with each other

than they did mating with the male. It turns out golden lion tamarins are typically monogamous, with males and females pairing up exclusively.

"You have to keep them in pairs," Ruiz-Miranda says. Once researchers figured that out, the tamarins began breeding.

In 1984, captive-born tamarins were introduced in and around Poço das Antas Biological Reserve, a protected area established by Coimbra-Filho and fellow Brazilian ecologist Alceo Magnanini.

It didn't go very well. Fourteen tamarins were released in that first attempt, and only five monkeys remained after eight months.

The problem is that tamarins tend to live in traditional nuclear families of a mother, a father and their offspring. Both parents help raise the babies, including teaching the youngsters how to use their long fingers to fish tasty insects out of nooks and crannies. Learning is key: Tamarins aren't born knowing how to survive in the wild.

The stunning failure in 1984 prompted scientists to let tamarins roam free in the United States for a couple of months before making the trek to Brazil. More captive-born tamarins were brought to Brazil between 1984 and 2000, and two-thirds of them still died within two years. Some were snapped up by jungle cats. Some were bitten by snakes or stung by bees. Many starved.

It turned out that tamarins that had trained beforehand by roaming free in U.S. parks fared no better than tamarins that hadn't, which led researchers to conclude that the monkeys needed a longer training period before being put in the big leagues.

All this effort ultimately paid off. A 2023 census in Brazil found 4,800 wild tamarins, with more than 2,500 descended from the reintroduced pioneers.

Beyond bringing more tamarins into the world, the project has shown the importance of considering animal behavior when trying to save a species.

—Darren Incorvaia

MARIA MAGDALENA ARRELLAGA/*THE NEW YORK TIMES*/REDUX

← A forested overpass, seen under construction in 2020, helps tamarins cross a highway near Brazil's Poço das Antas Biological Reserve.

Odell says. In a second capture-and-release in early 2025, 15 wolves were taken from British Columbia to join the others in Colorado. They had never been studied in any capacity before, aside from GPS collars the relocation team had fastened to some of the canines a month prior.

The reintroduction has been a bit rocky — so far, 10 of the wolves released into Colorado from Oregon and British Columbia have perished.

While it can be challenging for wildlife managers to add behavior and personality to their already full plates, it is becoming more appreciated as a crucial component of conservation.

"Most wildlife managers, they think about populations primarily," says Stewart Breck, an ecologist at the U.S. Department of Agriculture National Wildlife Research Center in Fort Collins, Colo., who helps manage conflict between humans and carnivores like wolves and coyotes. "I think the recognition that behavior is important is definitely becoming more relevant."

Breck sees two main areas where personality can play a key role in conservation: when an animal population is really small and "every individual is really important," and when trying to mediate conflict between animals and people.

"Especially if you're thinking about nonlethal techniques, then animal personality becomes a really critical factor," Breck says. For example, fladry — ropes adorned with colorful flags that are hung around fences — are a popular tool for deterring wolves from preying on livestock. A bold wolf may not care about fabric flapping in the wind, while a shy wolf may be petrified.

Breck's words would be music to Blumstein's ears. In addition to working with conservationists throughout his career, he's now part of a team working on a website interface designed to easily bring the science of conservation behavior to wildlife managers, as well as other knowledge they may lack.

"You might not be trained on how to run a focus group, to manage people or understand the people in your area," Blumstein says. "You might not know how to identify stakeholders to figure out who should be consulted.... You might not know how to raise funds."

With his new project, he says, "we're really bringing the science and the social science and the management all together." ✖

Darren Incorvaia is a freelance journalist based in the western United States.

A pika peeks out from its winter home under the snowpack, a diverse ecosystem called the subnivium.

LIFE BENEATH THE SNOW

Nature's igloo helps animals and plants survive winter, but climate change is putting the subnivium at risk

By Bethany Brookshire

A soft, thick coat of snow makes a lot of the world seem to slow down or even stop — at least temporarily. The fluffy piles absorb sound and make the world quiet and still.

But deep underneath, in pockets between the snow and the ground, life goes on. This is the subnivium, a tiny ecosystem all its own.

Here under the white stuff, roots, small mammals, microbes, insects and even birds thrive. They use the subnivium to make the most of the winter months — hunting, breeding, breaking down leaves and more. All those cold-weather

ANDREI BEREZOVSKII/ISTOCK/GETTY IMAGES PLUS

activities help determine which plants and animals will thrive during the snow-free seasons.

But this seasonal ecosystem is in danger. Climate change is making winters warmer. Much of the precipitation that used to fall as snow now pours from the sky as rain. In the Northern Hemisphere, snow cover has decreased by 2.2 percent per decade from 1979 to 2012. Compared with 2016, 2020 had 2.5 fewer days of snow cover. No snow means no subnivium. And as it shrinks, a host of organisms might pay the price.

Their loss could change the way forests function year-round, not just in winter, scientists have found. Several groups are working to understand what is going on below the snow and how this ecosystem is responding to our warming world.

A NATURAL IGLOO

As snow falls, it can accumulate in layers that compress under their own weight, forming a snowpack. Once that snowpack gets deep enough — about 15 centimeters — the subnivium emerges, says community ecologist Jonathan Pauli of the University of Wisconsin–Madison. Shallow hollows just a few centimeters high collect around fallen trees and rocks and link up like a maze.

The thick snowpack acts like a natural igloo, insulating the labyrinth underneath, Pauli says. Above-snow temperatures might range anywhere from –20° to 4° Celsius. But when the snow is deep enough, it doesn't matter how cold the air is: The ground will remain a consistent 1° C, just above the freezing point of water.

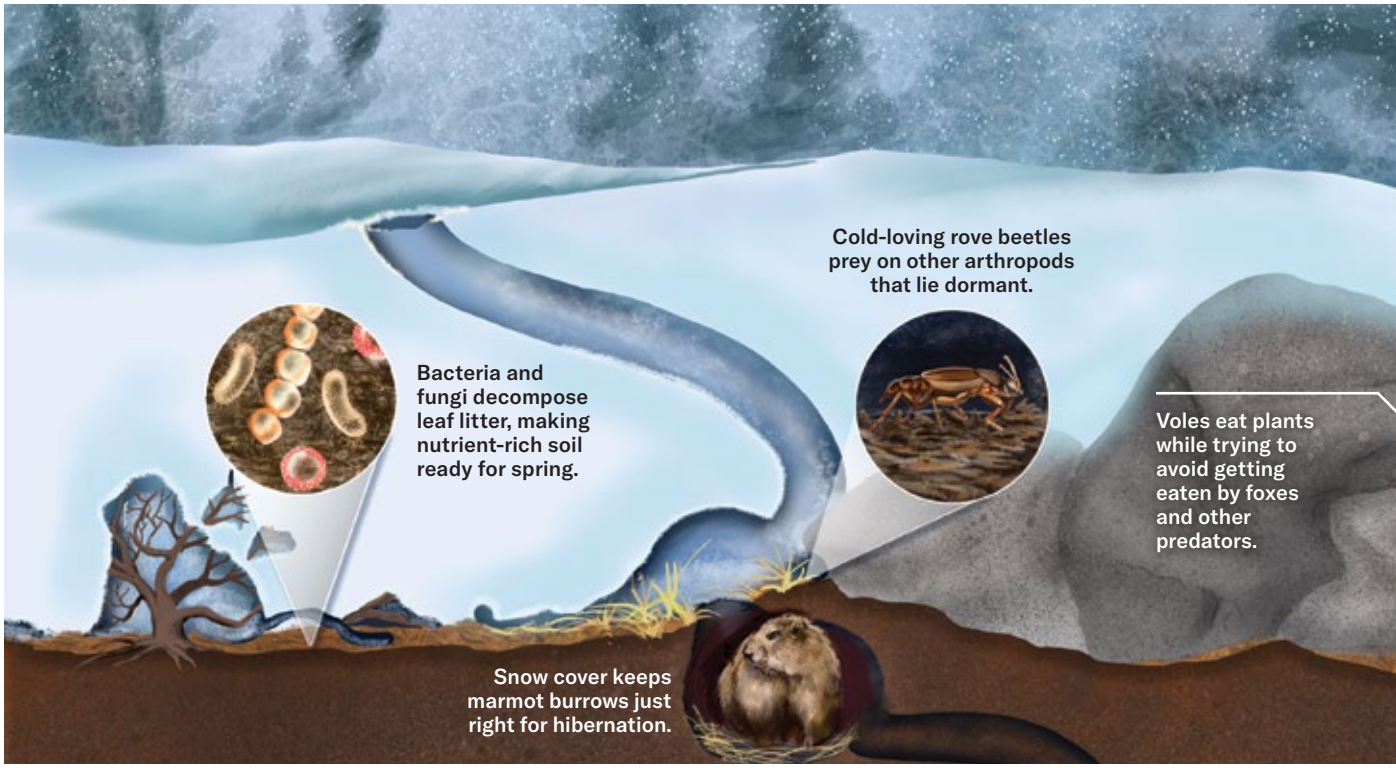
That one degree makes all the difference, says ecosystem ecologist Alix Contosta of the University of New Hampshire in Durham. It has changed the way scientists think about life in cold winter environments. When Contosta developed her fascination with the subnivium as a student in the late 1990s, winter was thought to be "a dormant season and there wasn't a whole lot happening," she says. But in the subnivium, where soil is warm enough for liquid water, life goes on.

DIVERSE DENIZENS

Bacteria and fungi that can stay comfortably unfrozen in the subnivium munch all winter on

SAYO STUDIO

WELCOME TO THE SUBNIVIUM



C. ZIADEH

Ecologist Chris Ziadeh checks a pitfall trap in the New Hampshire snow. Any arthropods that fall into the trap are preserved in the bright pink liquid.

dead plant material that accumulated in autumn. As these microbes eat, they breathe — taking up oxygen and pumping out carbon dioxide in a process called soil respiration. Some of the carbon from leaf litter gets stashed in the microbes' cells. "As long as those microbes stay alive, the carbon that's in their biomass is part of soil," Contosta says.

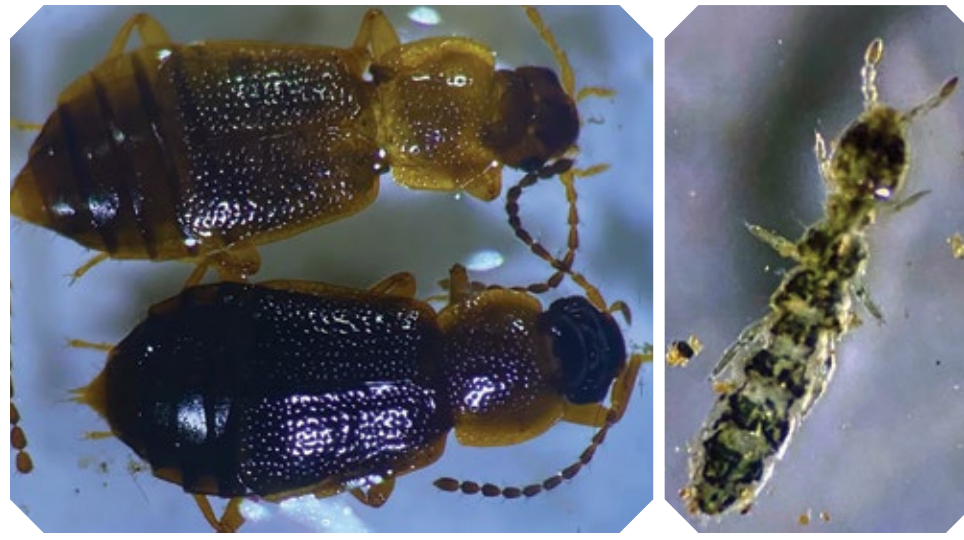
Snowpack depth seems to influence microbial populations and, in turn, soil respiration. Deeper snowpacks lead to larger, more diverse and more active populations, researchers in China reported in 2020 in *Scientific Reports*. More active microbes mean more respiration, which means more carbon-rich soil.

As the snow melts and spring arrives, the microbes die and release nutrients into the soil — right when plants start to resume growing. "All of these nutrients, all of these carbon molecules, it's ready for [plants] when they wake up," says soil scientist Kaizad Patel of Pacific Northwest National Lab in Richland, Wash. "In that sense, the microbes help regulate that [nutrient cycling]."

Meanwhile, hungry arthropods regulate the microbes. Springtails, centipedes, rove beetles and more are "down there feeding, moving around, searching for mates, breeding," says Chris Ziadeh, a New Hampshire–based ecologist with the U.S. Department of Agriculture Natural Resources Conservation Service.

Ziadeh and Contosta are part of a team

In winter, an array of life-forms seek refuge under the snow. Some go dormant while others keep going about their lives — hunting, eating, mating. Together, these creatures form a unique ecosystem: the subnivium.



Some arthropods, including rove beetles (left) and springtails (right), spend winters in the subnivium. The rove beetle species shown here is a subnivium specialist, thriving in winter and dormant in summer.

identifying exactly which arthropods call the subnivium home. The researchers set out pitfall traps, preservative-filled cups partially buried in the ground, over two winters and one summer in a forest in New Hampshire. Whatever wandered along fell in the traps.

Unsurprisingly, winter traps collected one-sixth as many arthropods as summer ones per day. But some species were found mostly or only in winter, including meshweaver spiders (*Cicurina brevis*) and three types of rove beetles (*Arpedium cribratum*, *Lesteva pallipes* and *Porrhodites inflatus*), the team reported in 2024 in *Environmental Entomology*. These subnivium specialists could have an impact on the ecosystem all year by putting nutrients back into the soil and keeping down certain pest populations, Ziadeh says.

What's more, the arthropods are important prey for larger animals that hide under the snow, such as lemmings (genus *Lemmus*). Those mammals, in turn, attract their own predators. Take American martens (*Martes americana*). About the size of a house cat, these fluffy, ferretlike predators "[slink] in and out of that subnivium space," Pauli says. "They'll find an opening, and they'll kind of go down and disappear and presumably hunt ... then pop up at another spot."

Even birds use the subnivium. Though ruffed grouse (*Bonasa umbellus*) and willow ptarmigans (*Lagopus lagopus*) live above the snow, they dig or even dive into drifts to roost. In New York's Adirondack Mountains, for instance, "grouse would kind of explode out of the snow," recalls climate change ecologist Benjamin Zuckerberg of the University of Wisconsin–Madison. "Just out of nowhere, this big bird suddenly appears!"

AN ECOSYSTEM AT RISK

Climate change, however, is coming for the subnivium.

Greenhouse gas emissions from human activities are driving up the average global temperature. At the current rate of warming, the presence of the subnivium worldwide is projected to drop from 126 days per year on average in 2014 to just 110 days by the end of this century, researchers reported in 2019 in *Nature Climate Change*. With less snow to insulate the ground, there would be 10 more days every winter where the ground is frozen.

That's bad news for subnivium dwellers. Plant roots can burst in frozen ground. Microbes can too. If they explode, they'll spill their nutrients into the soil months before the plants need it for their spring awakening.

Dying roots plus fewer nutrients add up to a "double whammy" for trees, Patel says. Weakened trees may grow poorly or be more vulnerable to diseases or insect pests.

Arthropods will suffer too. Subnivium specialists like the meshweaver spider and the rove beetles are "probably going to become locally extinct or just disappear altogether," Ziadeh says.

Even insects that normally lie dormant through the winter might be harmed. A warming of 5 degrees C relative to the current conditions would leave them exposed to killing cold. But if the planet warms 3 degrees C,

C. ZIADEH

computer models suggest that cold-hardy species might survive, the researchers reported in 2025 in *Diversity and Distributions*. Currently, the world is on track to warm 1.5 to 2 degrees C in the 21st century.

Larger animals that rely on the subnivium, such as pikas and marmots, could find their numbers plummeting too.

In the winter between 2014 and 2015, North Cascades National Park in Washington state experienced low snow and extremely dry weather. After the winter, the number of cold-loving pikas (*Ochotona princeps*) dropped at the lowest elevations, wildlife ecologist Aaron Johnston of the U.S. Geological Survey Northern Rocky Mountain Science Center in Bozeman, Mont. and colleagues reported in 2019 in *Ecology*. Those areas, stuck with no snow, left the rodents too cold. Less snow also meant less water for grasses that they rely on for food come springtime, and the underfed pikas reproduced less in response.

Unlike pikas, marmots hibernate underground in winter. But a lack of snow is stressful for them too, Johnston says. The subnivium and other snuggling marmots keep the animals' energy expenditure to a minimum. Without snow, temperatures may drop further in the burrow. At 0° C, the large ground squirrels would need to use four times as much energy to stay warm as they do at 5° C. After the winter of 2014–2015, the national park's marmot population, stressed from using extra energy to stay warm, dropped 74 percent in 2016 from the number in 2007, Johnston and colleagues reported in 2021 in *Ecology and Evolution*.

JASON RANSOM/U.S. NATIONAL PARK SERVICE

Marmots in Washington state's North Cascades rely on the subnivium to keep their dens warm as they hibernate. Without a snow blanket, the large ground squirrels need to use more energy to stay warm.

FINDING REFUGE FOR THE COLD

Saving the subnivium requires limiting climate change's impact enough to keep winters truly cold. "Fundamentally, at the end of the day, that requires reducing our carbon emissions to zero," says climate scientist Elizabeth Burakowski of the University of New Hampshire in Durham.

High areas, like the summit of New Hampshire's Mount Washington, give her hope. "It's not warming at the same rate as lower elevations," she says. "Rare alpine plants that live up there are a little bit more resilient to the changes of climate."

Burakowski is hunting for more climate refuges: "small pockets of really unique, protected climate zones that preserve snowpack," she says. These colder areas could be on the north slopes of mountains or behind large boulders, where there's less sunlight. By warming more slowly than other areas, they might allow patches of subnivium to persist, Burakowski says.

She's also interested in how we might alter forest management to make more patches where subnivium is safe. "At the end of the day, we are beholden to Mother Nature," Burakowski says. "More of that precipitation is going to fall as rain instead of snow."

But where there is snow, she says, "it would be great to keep it as long as we can, and to have it stick around." Burakowski is trying to understand what in a forest keeps snowpack present. The right number of trees in a forest seems to be key for snow buildup, for instance. "We think that there's this Goldilocks zone," she says. There needs to be "a thin enough forest canopy that more of the snow is reaching the forest floor, but thick enough that it's also shading the forest floor."

In some places, thinning forest canopy just a little might help snow build up, helping the fleeting subnivium — and its residents — stay just a little longer. ✖

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Abstract

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A bristlecone pine similar to this one has been around longer than Egypt's first pyramid. How does the tree and other long-lived plants endure? See Page 56.

Curiosities

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IN BOTANICAL TIME EXPLORES THE WAYS EARTH'S OLDEST PLANTS CHEAT DEATH

By Jude Coleman

IN BOTANICAL TIME | *Christopher Woods*
Chelsea Green Publishing | $40

In eastern California's mountains, a gnarled tree twists toward the sky. It is Methuselah, a Great Basin bristlecone pine and one of the world's oldest living trees. At over 4,800 years old, Methuselah germinated several hundred years before Imhotep began building ancient Egypt's first pyramid.

It's difficult to fathom such a long life span when humans live mere decades. But garden expert Christopher Woods' new book *In Botanical Time* helps readers do just that, telling the life stories of millennia-old plants and unpacking the science behind their longevity along the way.

One secret to longevity is slow growth, Woods writes. That has helped many ancient plants survive in less-than-ideal environments. For instance, growing about 2.5 centimeters per century enables Methuselah to focus its energy on surviving frigid temperatures, nutrient-poor soil and howling winds.

Other ancient plants take a different approach to cheating death: cloning. Woods describes one Norway spruce in Sweden that has cloned itself for 9,500 years, sprouting a new trunk every few centuries. Then there's Pando. This quaking aspen grove in Utah may appear as 47,000 distinct trees, but a look underground reveals the aspens are a single organism with a 14,000-year-old root system. New saplings that sprout from Pando's roots are genetically identical to the others. Even as single trees die, the organism continues to live on.

However, these ancient trees are babies compared with a meadow of Neptune grass off the coast of Spain. An analysis of its DNA and growth rate revealed the patch to be between 80,000 to 200,000 years old. It grows similarly to Pando, through rhizomes that send up genetically identical shoots.

Woods also regales readers with mythological tales. According to one Greek myth, dragon trees sprouted from the blood of the hundred-headed dragon slain by Hercules. Two species of dragon tree ooze bloodred sap, something so astounding that "it could only be ascribed to myth," Wood writes. The oldest known dragon tree, in the Canary Islands, may be as old as 1,000. But accurately dating these trees — and many other ancient plants — is difficult because they lack growth rings.

Though sometimes repetitive, Woods' cheeky prose and rich visuals make the book an easy, engaging read both for plant lovers and superlative seekers. At a time when longevity and wellness are trending topics, this book is a reminder that perhaps the best thing to do is live life a little slower. ✖

Cheeky prose and rich visuals make the book an easy, engaging read both for plant lovers and superlative seekers.

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Conversations with Maya

Maya Ajmera, President & CEO of Society for Science and Executive Publisher of Science News, spoke with Walter "Wally" Gilbert, Carl M. Loeb University Professor Emeritus and Emeritus Chair of the Society of Fellows at Harvard University. Gilbert had a long career at Harvard, first as a theoretical physicist, then as a molecular biologist. He discovered many aspects of protein synthesis and gene control. In 1976, he discovered a simple and rapid way to sequence DNA, and for this, in 1980, he was awarded a Nobel Prize in Chemistry (shared with Frederick Sanger and Paul Berg). He cofounded Biogen in 1978 and served as the company's CEO from 1981 to 1984. Then he cofounded Myriad Genetics in 1992. Today, Gilbert is an accomplished digital art photographer. Gilbert is an alumnus of the 1949 Science Talent Search (STS), a program of Society for Science.

DO YOU REMEMBER YOUR STS PROJECT? At that time, one submitted an essay, and my essay focused on a speculative idea, proposing that it might be possible to separate the elements zirconium and hafnium in one step, rather than through extensive fractional crystallization. For the next step of the competition, we had to display a project, and I thought that a hypothetical idea did not make an interesting display, so I showed off a camera-telescope I had made to photograph sunspots.

The competition was held at a hotel in Washington, D.C., where I lived. Although I didn't stay in the hotel with the other finalists, I remember hanging out with them. Nine of us went to Harvard together, including the mathematicians Henry Landau and Bob Blattner, so when I got there, I had a whole set of STS friends.

YOU STARTED YOUR CAREER AS A PHYSICIST. WHAT DREW YOU TO THE FIELD OF GENETICS? I went to college thinking I would become a chemist. I then became interested in theoretical physics and earned a Ph.D. in mathematics at the University of Cambridge in England. Later, I joined the faculty at Harvard as a theoretical physicist.

While at a party at Cambridge in April 1956, I met Jim Watson and we spent several hours talking, subsequently becoming friends. He came to Harvard that year as an assistant professor, while I returned to Harvard as a graduate student. In the late spring of 1960, Watson told me that exciting things were happening in his lab. They were trying to find messenger RNA and show that such a molecule existed in bacteria. I visited his lab and watched Watson and François Gros do an experiment. Watson gave me six papers to read; I came back the next day and joined in the experiments.

We proceeded to work together and published our paper on the discovery of messenger RNA mid-winter. I found myself happily doing experiments and learning biology by asking people how to do things.

IN 1980, YOU RECEIVED A NOBEL PRIZE FOR DEVELOPING METHODS TO SEQUENCE DNA. WHAT DO YOU REMEMBER MOST VIVIDLY ABOUT THAT PERIOD OF WORK? In the early 1970s, we set out to determine the sequence of bases that comprise a 24-base-long segment of DNA. We took two years to work out that sequence. It was one of the first DNA sequences published.

But at that rate, one would never be able to work out the thousands of bases that made up typical genes. Then, in the mid-1970s, the Russian molecular

biologist Andrei Mirzabekov convinced me to do an experiment that would show how the proteins called repressors contacted the DNA. The experiment's result was so clear that I not only discovered how the repressor touched certain G's and A's in the operator sequence, but I could also identify all of the positions of the G's and A's. We then developed a method that could sequence hundreds of bases in an afternoon, which was published in 1977. Fred Sanger in England simultaneously developed a different method.

Everybody began to sequence. They came to my laboratory to learn how to do it. By 1980, a million bases of DNA had been sequenced around the world. By 1985, 10 million bases of DNA had been sequenced. The rate has continued to increase by a factor of 10 every five years since then. The first human genome, 3 billion bases, was sequenced around 2000. Now machines can sequence a human genome in 30 minutes.

YOU WERE ONE OF THE FIRST MAJOR ACADEMIC SCIENTISTS TO STEP INTO WORLD OF BIOTECHNOLOGY, HELPING TO FOUND BIOGEN. WHAT WAS IT LIKE TO BUILD ONE OF THE FIRST BIOTECH COMPANIES AT A TIME WHEN THE INDUSTRY ITSELF BARELY EXISTED? I discovered that I have an entrepreneurial drive, which I didn't realize when I was a laboratory scientist. Small companies are a great deal of fun although they require total dedication. You may run the company, but you're also likely to sweep the floors because you can't afford a janitor. In a small company, speed is of the essence because you're burning through money.

Originally, Biogen's other cofounders and I didn't know what we were going to do. But soon we focused on interferon and the hepatitis B vaccine, which were developed to be the first products that went to market and became major sellers. Those successes really supported Biogen, although we didn't realize how long it was going to take to get anything to market. We started the company in 1978, and interferon entered the market in 1986.

YOU'VE ALSO INVESTED IN NUMEROUS START-UPS OVER THE YEARS. WHAT QUALITIES DO YOU LOOK FOR IN A YOUNG BIOTECH COMPANY OR IN ITS FOUNDERS? That's difficult to know. That said, I'm looking for quality of leadership and quality of focus. You can try to look at someone's idea, but companies often start out thinking they're going to do one thing and go on to do something else.

I characterize one aspect of being a CEO as this: it's not the role where one is going to make all the decisions, but one has to make sure the decisions happen. In science, in order to publish a good paper, we must wait until we have all the evidence accounted for. In business, you need to make decisions rapidly. The role of a CEO is to take the responsibility, so that people are free to make a decision quickly and not be punished if it turns out to be a wrong step.

HOW WOULD YOU CONTRAST YOUR APPROACHES TO INNOVATION AS A SCIENTIST VERSUS AN ARTIST? The underlying drive is very similar. As a scientist, I want to discover something new. I have the same impulse in art. I take photographs, superimpose them and fiddle with them, using a computer. The goal is to create a picture that I think is interesting, new and beautiful. The thirst to create something new is shared: in science, new and true, in art, new and beautiful.

WHAT ADVICE WOULD YOU GIVE TO YOUNG SCIENTISTS WHO WANT THEIR RIGOROUS RESEARCH TO HAVE REAL-WORLD IMPACT? In order to have an immediate impact, it's important to get involved in an applied science that could have immediate consequences. You know what the goal is, and you work on it. A medicine to cure human disease, for example.

There's another side of science that is curiosity-driven basic research. We want to find out something about a problem that no one understands, or even suspects. This research creates all the new ideas that shape the future of the world.

I occasionally describe it this way: We can build companies out of today's applied research discoveries. Those companies develop products that work today. Basic research, meanwhile, will lead to more discoveries, which will build tomorrow's companies. Tomorrow's companies will develop products that are undreamed of today.

WHAT ADVICE DO YOU HAVE FOR YOUNG SCIENTISTS TODAY? My basic advice is simple: Follow your curiosity.

THERE ARE MANY CHALLENGES FACING THE WORLD TODAY. WHAT IS KEEPING YOU UP AT NIGHT? We're living through a period in which American science is being willfully destroyed. Given the lack of funding here, young scientists may need to go abroad to find employment. The center of world science is moving away from America, which has chosen money over knowledge.

70 YEARS AFTER NEUTRINOS WERE DISCOVERED, THE GHOSTLY PARTICLES STILL HAVE SECRETS TO TELL

BY EMILY CONOVER

Neutrinos have been with us since the beginning. They existed alongside prehistoric humans, dinosaurs and the first scattered crumbs of life on Earth. The birth of the solar system, the formation of the cosmic web, the moments after the Big Bang — all were awash with the lightweight subatomic particles that we gave the name neutrino.

But only in the last 70 years have we known for certain they were there. In 1956, physicists Clyde Cowan and Frederick Reines unveiled the particles' existence.

And exist they do. Not in meek scarcity, either. They are the most abundant massive particle in the universe, outnumbering protons about a billion to one. Scientists are still grappling with what these particles are all about. And neutrinos are not just one type of particle, either, but a trio (electron neutrinos, muon neutrinos and tau neutrinos) and their antimatter counterparts, all of which physicists refer to collectively as neutrinos.

Other particles have their unknowns, but "for neutrinos, the list of questions is deeper and more fundamental," says physicist Diana Parno of Carnegie Mellon University in Pittsburgh. We don't know whether the particles are their own antiparticles, or whether additional types of neutrinos are in hiding. Some scientists wonder if neutrinos may explain why the universe is filled with more matter than antimatter.

Perhaps most glaringly, we don't know the particles' masses. We know that their masses must be incredibly tiny, but not zero. That makes them hard to measure.

To make matters more complicated, neutrinos have no electric charge and interact with other matter through a wimpy effect called the weak interaction. That forced Reines and Cowan to concoct inventive techniques to spot them. Their work set a precedent: To study the neutrino, ingenuity is indispensable.

Long before the Reines-Cowan experiment, in 1930, physicist Wolfgang Pauli proposed the existence of neutrinos to explain the energies of electrons emitted in radioactive decays. In those decays, one nucleus converts into another, emitting an electron. The conversion releases a fixed amount of energy. If only the electron were emitted, you'd expect a given decay to produce electrons with a specific energy. Instead, the electrons were observed with a range of energies.

The situation was so dire that some physicists considered dropping the concept of conservation of energy. Instead, Pauli proposed that an electrically neutral particle was also released, carrying some varying amount of the energy. He reportedly said, "I have done a terrible thing, I have postulated a particle that cannot be detected."

Pauli was wrong, but the particles did elude detection for a respectable quarter century. The Reines-Cowan experiment took place at a nuclear reactor in South Carolina. Because many radioactive decays happen at nuclear reactors, they would be a potent source of neutrinos if the particles existed. (Specifically, these particles would be antineutrinos.)

The trick to finding them was to measure back-to-back signals. When an antineutrino interacted with a proton in the detector, it produced a neutron and a positron — the electron's antimatter counterpart. The positron and an electron quickly annihilated one another, releasing gamma rays that could be detected in a scintillator, a liquid that lights up in response to radiation. The neutron loitered for a bit before a nucleus captured it, releasing more gamma rays and causing a delayed flash.

Cowan and Reines' detector had three scintillator layers separated by two layers of target material, which contained neutron-capturing cadmium chloride. A double flash, produced in adjacent layers, was an antineutrino hallmark — the conclusive lubb-dupp of its figurative heartbeat. Without that heartbeat to filter out spurious events, Reines and Cowan wouldn't have been able to detect antineutrinos at a reactor. This creative solution won Reines a Nobel Prize in physics in 1995. (Cowan died in 1974.)

Scientists have since detected neutrinos using the Antarctic ice sheet, the Mediterranean Sea and experiments deep underground. And they have spotted neutrinos produced in the atmosphere, in the sun and in an exploding star. Experiments revealed that the particles oscillate, or morph from one type to another. That phenomenon can happen only if neutrinos have mass, but it doesn't reveal how massive they are.

The discovery that neutrinos have mass means they clash with physicists' theory of particle physics, the standard model. The basic theory assumes that neutrinos have no mass.

"There is something else, outside of the standard model, that neutrinos bring to the table, and we're trying to figure out what that is," says physicist Enectali Figueroa-Feliciano of Northwestern University in Evanston, Ill. "We want to measure neutrinos in every way we can, because they don't always do what we expect them to do."

So physicists keep pushing detectors further. In lab experiments in 2017, scientists spotted neutrinos interacting with an entire nucleus for the first time. Such reactions are more common than interactions with single protons or neutrons, but detecting neutrinos' gentle nucleus-nudging demands highly sensitive sensors. Last year, nudges were spotted in nuclear reactors, which opens up possibilities to use the detectors to monitor reactors for weapons development.

To measure neutrino nudges even more precisely, Figueroa-Feliciano aims to detect the heat that recoiling nuclei generate with a transition edge sensor — essentially an extremely sensitive thermometer. If successful, the approach would offer a new way to test the standard model.

Meanwhile, a team in Italy is using transition edge sensors to get at neutrino masses. Its experiment uses sensors embedded with the radioactive element holmium-163. When the holmium decays, it emits a neutrino, causing the nucleus to recoil. Measuring the recoils can give insight into neutrinos' masses. This technique set a ceiling on the neutrino mass, the team reported in 2025.

Neutrino mass isn't just of theoretical interest. Neutrinos' masses helped shape the structures of galaxies. By observing galaxies, scientists can try to determine the maximum possible neutrino mass. But questions swirl around those numbers, too: There seems to be tension between experimental results and estimates based on the cosmos.

Neutrinos are a bit like the Mad Hatter's riddles. What's something that's crucial to the universe's structure but also imperceptible? How can you know a particle has mass without knowing its mass? How can you detect an undetectable particle?

At least Reines and Cowan bested the Mad Hatter on that one. ✖

Physicists Frederick Reines and Clyde Cowan monitor an experiment at a nuclear reactor in South Carolina. The 1956 experiment confirmed the existence of ghostly subatomic particles called neutrinos. ↓

DO OTHER UNIVERSES EXIST? PHYSICS SAYS MAYBE

BY MARIA TEMMING

Sci-fi loves a multiverse. Everyone from Rick and Morty to Spider-Man has stepped through a portal and met their alter egos. Screenwriters often deploy this trope to incite interdimensional team-ups or showdowns. But some physicists like the idea of a multiverse for another reason: The existence of many unobserved realms could answer deep questions about our universe. Two of the most popular multiverse theories come from cosmology and quantum mechanics.

Shortly after the Big Bang, our universe underwent a brief period of superfast expansion called inflation. During that growth spurt, tiny quantum fluctuations in the structure of the universe got stretched out to huge proportions. In parts of space close enough for light to reach Earth in the universe's lifetime, those fluctuations created variations in density that seeded the formation of galaxies.

At even larger scales — way beyond our cosmic horizon — quantum fluctuations could have created regions of space with radically different properties, says Andrei Linde, a retired Stanford University physicist who is an author of the theory of inflation. Unseen parts of space could have different particle masses and force strengths, such as heavier electrons or gravity that behaves differently.

Although inflation has stopped in our observable universe, it may continue elsewhere — eternally blowing up more bubbles of space with unique properties. These bubbles would be so distant and distinct that they'd effectively be different universes.

To Linde and some other scientists, this scenario explains a big conundrum in cosmology: why the particle masses and force strengths in our universe seem perfectly tailored for life. If a multiverse exists, that's not such a suspicious coincidence. Among many bubble universes, the conditions for life were bound to pop up somewhere.

Testing this idea may be possible. If our universe is one bubble in a fathomless froth, maybe another universe has bumped into ours, leaving a scar on the afterglow of the Big Bang. But "no one has seen yet the rings that would represent the scars of bubble collisions," says

SPOOKY POOKA

physicist Paul Halpern of Saint Joseph's University in Philadelphia.

Another multiverse idea comes from quantum physics, which says particles can exist in a superposition of possible states until measured. "According to the traditional idea in quantum mechanics," Halpern says, "once somebody takes a measurement, that blurred scenario collapses into a single possibility." For example, an electron that existed in a smear of possible places is detected in just one spot. It's "a little bit odd, because it requires a human measurer," Halpern says. If it's true, how did the universe work before humans existed?

In 1957, physicist Hugh Everett III offered an explanation. Instead of observation causing a spread of quantum possibilities to collapse into a single outcome, perhaps all possibilities unfold in alternate realities. For example, an observer splits into multiple copies of herself who each saw an electron at different locations. "The versions separate seamlessly," Halpern says, "and they live in parallel universes."

But this theory would be hard to test. "We can't have somebody split in an experiment between two possibilities and ask each one what it was like," he says. "If the theory is right, you wouldn't notice it."

Prospects for visiting other universes, if they exist, are similarly dim. Hypothetical tunnels in the fabric of spacetime, known as wormholes, might bridge realities. But creating them "would require so much energy and mass that they would be well beyond current technology," Halpern says.

That's bad news for anyone who dreams of joining forces with their alter egos to save the day. On the bright side, you'll probably never have to fight your evil twin, either. ✖

THE HOMESICK ROVER

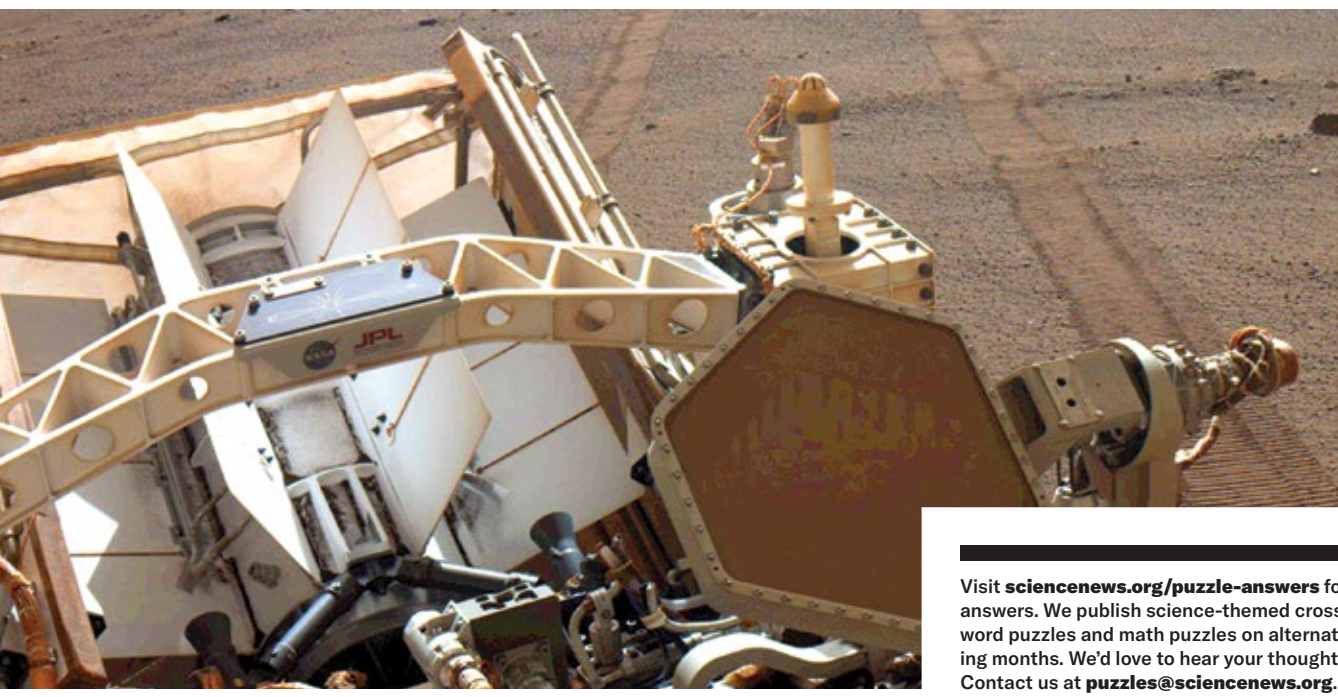
BY BEN ORLIN

Far away, on a large, rocky exoplanet, a rover from Earth has just arrived on a mission of exploration. But the poor thing doesn't want to explore. The moment it begins moving, it grows homesick and wants nothing more than to return to the very spot where it began. Unfortunately, it has received very explicit instructions. The first day, it must travel one kilometer forward in a straight line, then turn 90 degrees. The second day, it must travel two kilometers forward, then turn 90 degrees. The third day, it must travel three kilometers forward, then turn 90 degrees. The fourth day, it must travel four kilometers forward, then turn 90 degrees. And so on, for the duration of an eight-day mission.

The rover wants to return to the site where it landed. But it can choose only which direction to turn, left or right, at the end of each day. How can the rover end the eight-day mission back at its landing site?

Bonus: A hundred rovers with the same set of instructions have been sent to other large, rocky planets, each with a different mission length, ranging from one day to 100 days.

How many of these rovers can end their missions back at their landing sites? ✖



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