A Vaccine for Honeybees | Re-Creating Ötzi's Tattoos

Science News

MAGAZINE OF THE SOCIETY FOR SCIENCE ■ MAY 4, 2024 & MAY 18, 2024

Yellowstone's Invisible Threat

Heat and water lurking below ground could spark a catastrophic explosion

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Science News

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COVER Tourists visiting Yellowstone National Park walk by the Grand Prismatic Spring. *efenzi/iStock/Getty Images Plus*

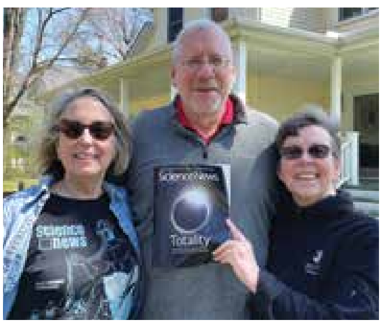
The typical *Science News* reader is ever so atypical

On April 8, millions of people in the United States experienced a thrill of a lifetime — seeing a total solar eclipse.

I was among those lucky people. After failing to get organized early enough to book lodging in the path of totality, I noted my failure in an editor's note. *Science News* readers Kathy and Paul Mathews then emailed me to offer their guest room in Ohio. I didn't want to impose, but Kathy and Paul assured me that it would be no problem. You'd think they welcome itinerant eclipse chasers every day.

Not surprisingly, Kathy and Paul turned out to be kind, funny, smart and curious about the world — typical *Science News* readers. We watched the eclipse on the shore of Lake Erie with their friends, including Dan Pfeiffer, who had stayed up until 1 a.m. the night before prepping telescopes and building a projector to assure the best possible viewing experience. It was sublime.

Kathy and Paul also are typical of many longtime print readers; they worked in STEM, and Paul teaches statistics. But that definition of "typical" reader is evolving. Last year, more than 17 million people read *Science News* articles on our website. Online readers are less likely to work in STEM or education, often encountering us when they see one of our articles pop up in search engine results or on social media. And 8 million or so people follow us on Facebook, Instagram, TikTok and other social platforms.



Editor in chief Nancy Shute with readers Paul and Kathy Mathews.

Adding even more variety, students at almost 6,000 high schools get free copies of the magazine through our Science News Learning program. Most of the schools serve low-income communities that often lack up-to-date textbooks. The magazine and accompanying educator resources help teachers and young people connect with the latest science. The program is made possible by contributions from individuals and institutions; you can learn more about the program at www.sciencenews.org/learning.

And we're increasingly reaching out to students and teachers in middle schools. Last fall, we tested sending *Science News Explores*, our magazine for young people ages 9 and up, to schools along with "big" *Science News*. Students and teachers were enthusiastic, and we're hoping to be able to make both magazines available to more schools starting this fall.

One more thing: This issue is being distributed at the Regeneron International Science and Engineering Fair, a program of our parent nonprofit Society for Science. About 1,700 high school students from around the world will convene in Los Angeles this month to present their original research and compete for awards and scholarships. It's thrilling to see young people already putting science to work to make the world a better place. Welcome to the next generation of *Science News* readers. — *Nancy Shute, Editor in Chief*

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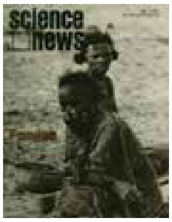


Excerpt from the May 11, 1974 issue of *Science News*

50 YEARS AGO

Physiology of the phantom limb

Nearly everybody who has had a leg or arm amputated sometimes experiences the sensation or feeling that they still have their missing limbs. Some of them experience pain in their "phantom limbs."... One assumes that [cut nerves] frequently fire off impulses to the central nervous system and... create the sensation of a limb still being present.... [Scientists] have now confirmed that these events occur, at least in experimental animals.

UPDATE: The cause of phantom limb pain is more complicated than just misfiring nerves. Post-amputation changes in the spinal cord and brain may also contribute, mounting evidence suggests. Therapies such as pain relievers and using visual feedback from mirrors to trick the brain can offer some relief. But researchers are still searching for more effective treatments. In 2019, scientists reported that electrically stimulating nerves near amputation sites not only helped two men detect pressure and motion through a prosthetic leg, but also reduced their phantom pain (*SN: 10/12/19 & 10/26/19, p. 8*).

Tattooed lines on Ötzi's wrist were probably made by poking holes in the skin with a pointed, pigment-coated tool.

RETHINK

How Ötzi the Iceman really got his tattoos

An offbeat experiment has poked holes in a popular assumption about Ötzi the Iceman's tattoos.

The roughly 5,200-year-old naturally mummified body, found in the Italian Alps in 1991, has 61 tattoos — black lines and crosses on the left wrist, lower legs, back and abdomen. A common but untested idea holds that charcoal ash was rubbed into skin incisions made with a sharp stone tool, resulting in the world's oldest known tattoos (*SN: 1/23/16, p. 5*).

FIRST

Mating crab spiders mimic a tropical flower

Female crab spiders are masters of disguise, blending in with flowers to nab insects while fooling predators such as birds. Now, scientists have discovered a male spider joining the camouflage. The finding may be the first known example of cooperative mimicry in spiders, ecologists Shi-Mao Wu and Jiang-Yun Gao of Yunnan University in Kunming, China, report in the March *Frontiers in Ecology and the Environment*.

When this male crab spider sits on top of a larger female, the pair blends in with *Hoya pandurata* flowers. The female looks like a lot like the petals, while the male matches the flower's pistil and stamen.

In a Yunnan rainforest, Wu spotted a male *Thomisus guangxicus* spider that looked like a pistil and stamens on a flowering *Hoya pandurata* plant. Wu became even more excited when he realized that the male wasn't alone. "It was lying on the top of a bigger female," he says. When Wu returned four days later, the pair was still together.

One plausible explanation is selection pressure, says Thomas Sherratt, an evolutionary ecologist at Carleton University in Ottawa, Canada. Male crab spiders that are darkly colored may have a better chance at avoiding predators while mating with yellowish females on flowers. When these males and females get together, it creates a joint illusion, he says. — *Saugat Bolakhe*

FROM TOP: SOUTH TYROL MUSEUM OF ARCHAEOLOGY, M. SAMADELLI/EURAC, G. STASCHITZ; S.-M. WU/YUNNAN UNIV.

Now, a tattooing experiment and a review of tattooing practices in traditional societies suggest that a handheld, single-pointed tool with pigment on its tip was used to punch closely spaced holes in Ötzi's skin, researchers report March 13 in the *European Journal of Archaeology*. This hand-poke tattooing technique has been reported since the 19th century among nonindustrialized cultures throughout the world, including in Ötzi's home region of Central Europe.

"Our study shows that the past 30 years of conventional wisdom as to how the Iceman was tattooed is incorrect," says Aaron Deter-Wolf, an archaeologist at the Tennessee Division of Archaeology in Nashville.

In a 2022 study, he teamed up with two professional tattooists who specialize in traditional, nonelectric techniques. Danny Riday, a New Zealand–based tattooist, inked his own leg with eight identical line designs using eight traditional tools and four traditional methods.

An analysis of modern tattoos (left) made with traditional techniques and tools hints that a sharp bone awl (right) found in Ötzi's toolkit could have made the ancient man's tattoos.

Tools were made from animal bone, obsidian, copper, a boar tusk and a steel needle. Techniques consisted of hand poking; using wood to tap pigment-coated bone points into skin; slicing skin with an obsidian blade then rubbing in pigment; and pulling a pigmented thread through the skin with a needle.

In the new study, Deter-Wolf and colleagues compared magnified images of Riday's healed tattoos with ultraviolet and high-resolution digital images of Ötzi's tattoos.

Tattoos created with different tools and techniques displayed distinctive physical signatures, Deter-Wolf says. Ötzi's markings are up to 3 millimeters wide and include stippling, rounded ends and irregular pigment seepage along their edges — hallmarks of hand poking using a pointed bone tool or copper awl.

The study can't definitively determine how Ötzi got his tattoos, but it provides "extensive and plausible explanations" to support hand poking, says human remains conservationist Marco Samadelli of the Institute for Mummy Studies at Eurac Research in Bolzano, Italy.

A bone awl among Ötzi's belongings might be sharp enough for use in tattooing, Deter-Wolf says, but it has yet to be analyzed for tattoo-related damage or pigment residue. — *Bruce Bower*

SCIENCE STATS

Tree cover disparities in U.S. cities impact rates of heat-related death

In the United States, urban neighborhoods whose residents primarily are people of color tend to have fewer trees than neighborhoods with mostly white residents. A new analysis now links this inequity to more heat-related illness and death.

Majority nonwhite neighborhoods have 11 percent less tree cover on average than majority white ones, which leads to summertime air temperatures being 0.2 degrees Celsius higher, urban ecologist Rob McDonald of the Nature Conservancy and colleagues report April 8 in *npj Urban Sustainability*.

11
percent
Average difference in tree cover between nonwhite and white U.S. cities

~200
heat-related deaths
Additional excess deaths per year in nonwhite U.S. cities

The difference in shade also means that nonwhite communities experience about 200 more heat-related deaths and 30,000 more doctor visits annually, a comparison of 2020 census data with data on tree cover and heat-related mortality and morbidity found. Trees' cooling effect prevents 442 deaths and 115,000 doctor visits per year in nonwhite areas, and 662 deaths and 85,000 doctor visits per year in white areas. — *Jude Coleman*

MYSTERY SOLVED

Tree rings log a famous solar storm

The strongest solar flare in recorded history burst into Earth's atmosphere in 1859, bathing the sky in auroras. People across the globe witnessed the celestial chaos, but physical evidence of the storm has been elusive — until now. Tree rings in Finland's far north preserve traces of the storm, known as the Carrington Event, in the form of carbon-14, a team led by ecologist Joonas Uusitalo of the University of Helsinki reports March 16 in *Geophysical Research Letters*.

Solar particles entering Earth's atmosphere react with other molecules to produce carbon-14. Trees absorb the extra carbon-14, preserving a record of the storm. To search for evidence of the Carrington Event, Uusitalo's team examined six trees: three in Finland above the Arctic Circle and three in the midlatitudes. In the polar trees, rings dating to around the time of the event had higher levels of carbon-14 than those in the midlatitude trees. Polar trees may be more sensitive to solar storms due to how Earth's magnetic field deflects solar particles poleward and to speedy air exchange in the Arctic. — *Carolyn Gramling*

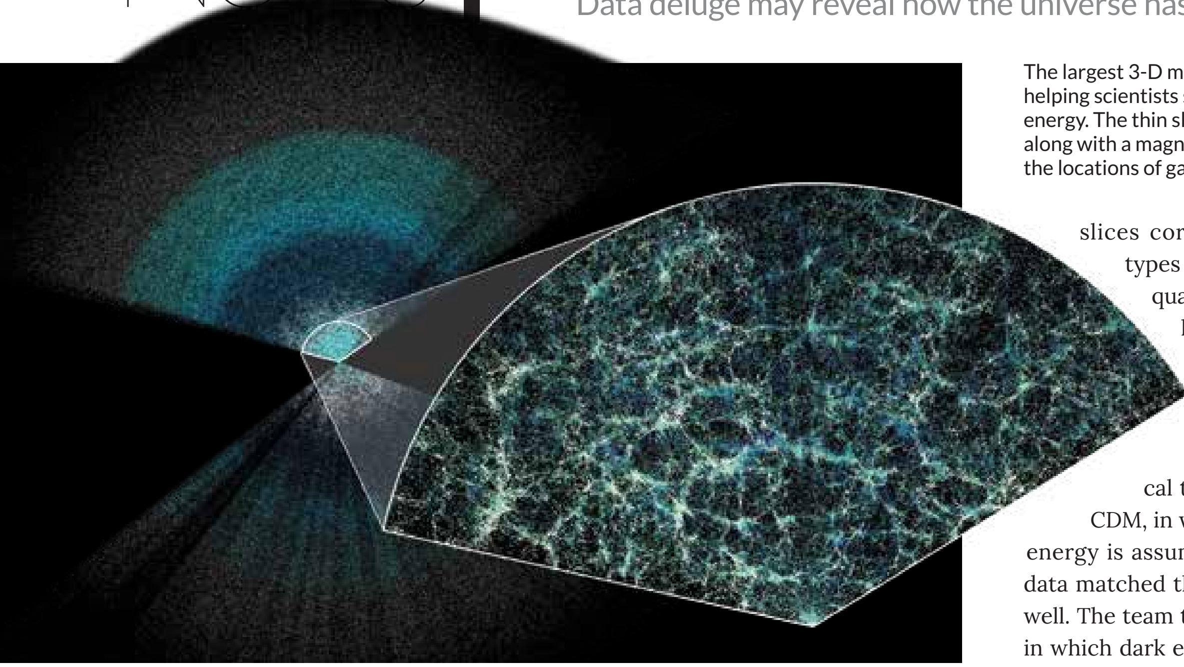
Markku Oinonen takes a core from a Finnish tree to look for signs of an 1859 solar storm.

CLOCKWISE FROM TOP LEFT: A. DETER-WOLF *ET AL*/*EXARC JOURNAL* 2022; HARALD WISTHALER/SOUTH TYROL MUSEUM OF ARCHAEOLOGY; J. UUSITALO/UNIV. OF HELSINKI

COSMOLOGY

3-D map hints at dark energy's secrets

Data deluge may reveal how the universe has grown over time



The largest 3-D map of the universe yet is helping scientists study the properties of dark energy. The thin slice of the map shown here, along with a magnified section (inset), contains the locations of galaxies and quasars.

CLAIRE LAMMAN/DESI COLLABORATION, CUSTOM COLORMAP PACKAGE BY CMASTRO

BY EMILY CONOVER

A giant survey of the cosmos is revealing new details of a mysterious facet of the universe: dark energy. When combined with other observations, the data hint that dark energy, commonly thought to maintain a constant density over time, might evolve along with the cosmos.

The result is "an adrenaline shot to the cosmology community," says physicist Daniel Scolnic of Duke University.

> The result is "an adrenaline shot to the cosmology community."
> DANIEL SCOLNIC

Dark energy, an invisible enigma that causes the universe's expansion to speed up over time, is poorly understood, despite making up the bulk of the universe's contents. To explore that puzzle, the Dark Energy Spectroscopic Instrument, DESI, has produced the largest 3-D map of the universe yet, scientists report April 4 in 10 papers posted on the DESI website. Analyzing patterns in the distributions of galaxies and other objects on the map can help scientists determine the history of how the universe has expanded.

Although consistent with cosmologists' standard picture of the universe, the data also allow for the possibility that dark energy's equation of state, which describes how the pressure of dark energy relates to its density, might vary over time. That would mean an upheaval in the way scientists understand the universe's history.

The studies analyze DESI's first year of data, mapping the locations of 6.4 million galaxies and quasars, the ultrabright cores of violently active galaxies. This map lets scientists estimate the universe's expansion rate, thanks to a handy size reference.

Sound waves in the early universe set up patterns in the density of matter. These baryon acoustic oscillations persist as galaxies form. The result is that galaxies are more likely to be separated from one another by a preferred distance. That distance acts like a ruler, which is stretched by the expansion of the universe. Measuring the size of that ruler over various cosmic eras can show how the universe expanded.

DESI scientists divided the universe into seven epochs that stretch as far back in time as 11 billion years and measured the universe's expansion over time. Different slices corresponded to different types of data, from galaxies to quasars to measurements of how hydrogen gas absorbs quasars' light.

The scientists compared their data with the standard cosmological theory, known as lambda CDM, in which the density of dark energy is assumed to be constant. The data matched that lambda CDM picture well. The team then considered a theory in which dark energy's equation of state varies over time.

DESI data alone couldn't precisely determine how dark energy evolved. To improve the estimate, the team combined the data with those from supernovas and the oldest light in the universe. The combined data fit well to an evolving dark energy. What's more, the significance of the effect was more than 3 sigma, depending on which supernova data were used. In physics, 5 sigma is considered the gold standard for discovery; 3 sigma is an intriguing hint.

DESI will collect data for five years and log 37 million galaxies and 3 million quasars. The data may substantiate this hint of new physics, says Nathalie Palanque-Delabrouille, a DESI physicist at Lawrence Berkeley National Laboratory in California.

Cosmology is already beset with controversy over clashing measurements of the Hubble constant, the current rate of the universe's expansion. DESI's measurements don't resolve the tension, but the situation could change if scientists move away from the standard lambda CDM model. That's because the tension is based on the assumption that lambda CDM is correct, says DESI physicist Dillon Brout of Boston University. "This ... would potentially blow the [Hubble] tension wide open." ■

PHYSICS

Nuclear clocks leap closer to reality

Tabletop laser nudges thorium nuclei into a higher energy state

BY EMILY CONOVER

The time is nigh for nuclear clocks.

In a first, scientists have used a tabletop laser to bump an atomic nucleus into a higher energy state. It's a feat that sets scientists on a path toward creating the first nuclear clock, which would keep time based on the inner workings of atomic nuclei.

The advance is a "remarkable breakthrough," says Olga Kocharovskaya, a physicist at Texas A&M University in College Station.

Nuclear clocks could be simpler and more portable than atomic clocks, which are currently scientists' most precise timekeepers. And nuclear clocks could be used to test fundamental physics theories in new ways.

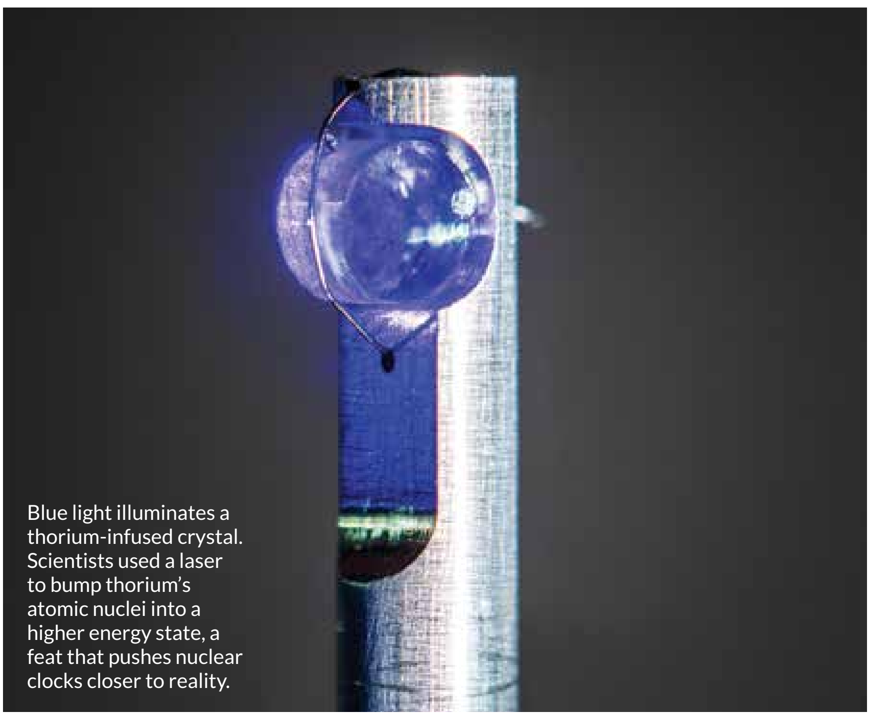
With the new result, a nuclear clock seems more attainable than ever. "We know now that it's conceptually feasible," says Peter Thirolf, a physicist at the Ludwig Maximilian University of Munich.

Typical atomic clocks are based on the physics of the electrons that surround atomic nuclei. These electrons inhabit individual energy levels within atoms. To coax an electron to jump to a specific higher energy level, the subatomic particle needs to be provided with just the right amount of energy from a laser. That energy corresponds to a specific frequency of the laser's light.

To home in on that frequency, scientists aim a laser at a collection of atoms and scan the laser's frequency until the electrons make the jump. That frequency is then used, like an atomic metronome, to keep time.

Nuclear clocks would use the transitions of atomic nuclei, rather than the electrons around atomic nuclei, to mark time. While most atomic nuclei have energy levels that are too far apart for a laser to kick off the jump, one special nucleus is an outlier. A variety of the element thorium, thorium-229, has an unusually small energy jump, accessible to lasers.

Until recently, scientists didn't know the size of that jump very well. In 2023, however, researchers measured it to a higher precision than ever before (*SN: 7/1/23, p. 8*).



Blue light illuminates a thorium-infused crystal. Scientists used a laser to bump thorium's atomic nuclei into a higher energy state, a feat that pushes nuclear clocks closer to reality.

PTB, TU WIEN

That allowed physicists to take the next step. Researchers used a laser to bump thorium-229 nuclei to a higher energy level and observed the light emitted in the jump back down. The experiment pinned down the energy of the transition to 8.35574 electron volts, the team reports in a paper to appear in *Physical Review Letters*. That number is consistent with the 2023 measurement, but is about 800 times as precise. To make a nuclear clock, scientists will need to increase the precision of this measurement even more.

"We were very excited, of course," says coauthor Ekkehard Peik, a physicist at the National Metrology Institute of Germany in Braunschweig. "It was a long search." Peik and colleagues first proposed the idea of making nuclear clocks with thorium-229 in 2003.

In the experiment, the thorium-229 was embedded in a crystal of calcium fluoride. This differs from atomic clocks, in which atoms are contained in a vacuum chamber. The possibility of making future nuclear clocks out of solid materials is part of the appeal.

"Potentially you could imagine building a much simpler, portable system, taking this clock out of the lab," says Jun Ye, a physicist at JILA in Boulder, Colo., who was not involved with the research.

And because nuclear clocks are based on different physics than atomic clocks, comparing the two types of timepieces could allow for new studies of fundamental physics (*SN: 7/3/21 & 7/17/21, p. 12*). For example, scientists could search for variations in the fundamental constants of nature, a set of numbers governing the cosmos that are normally assumed to be immutable (*SN: 11/12/16, p. 24*). Nuclear clocks could also allow new searches for dark matter, unidentified massive particles that pervade the universe.

There's still much more work to be done to build a nuclear clock. And even once scientists have built one, Ye says, "it will take years, if not decades, of work to catch up with atomic clocks." But, he says, "just being able to see the transition opens the door." ■

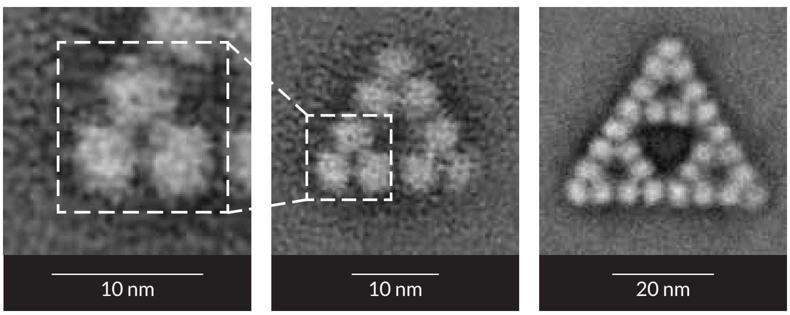
MATH

Naturally occurring molecule forms a fractal

Fractals are everywhere in nature, from river deltas to tree branches. These structures look similar from afar and when you zoom in close. Certain fractals known as regular fractals, including the whorls of Romanesco cauliflower, are identical on different scales. But regular fractals hadn't been spotted in nature on the molecular level — until now.

A protein found in the bacterium *Synechococcus elongatus* assembles itself into a fractal called a Sierpiński triangle, evolutionary biochemist Georg Hochberg of the Max Planck Institute for Terrestrial Microbiology in Marburg, Germany, and colleagues report April 10 in *Nature*. When placed in water, the protein citrate synthase links up into triangles, which come together to make even larger triangles (shown in a series of electron microscope images, below).

Researchers have previously designed synthetic molecules that can form regular fractals. But the bacterial protein is the first with such fractal flair to be discovered in nature. Hochberg's team couldn't identify any practical purpose for the pattern and concluded that it's an evolutionary accident. "Different kinds of complex-looking structures come and go on evolutionary timescales, sometimes with a use, sometimes without one," Hochberg says. "Their symmetry can be beguiling to us, and that's why we think they have meaning." — *Emily Conover*



TECHNOLOGY

Robot predicts human smiles

Emo was trained to mirror facial expressions in real time

BY HELEN BRADSHAW

With its hairless silicone skin and blue complexion, Emo the robot looks more like a mechanical member of the Blue Man Group than a typical human. Until it smiles.

Roboticist Yuhang Hu of Columbia University and colleagues trained Emo to smile in sync with humans. The robot can predict a human smile 839 milliseconds before it happens and smile back, the team reports in the March *Science Robotics*.

In most humanoid robots, there's a noticeable delay before they can smile back at a person. That's often because the robots are imitating a facial expression after the person has made it.

"I think a lot of people actually interacting with a social robot for the first time are disappointed by how limited it is," says Chaona Chen, a human-robot interaction researcher at the University of Sheffield in England. "Improving robots' expressions in real time is important."

Through synced facial expressions, Hu says, future iterations of robots could be sources of connection for lonely people (*SN: 11/4/23, p. 24*).

Cameras in Emo's eyes let the robot detect subtleties in human expressions that it then emulates using actuators underneath the silicone skin. Emo learned that turning on specific actuators creates specific expressions by looking at itself in a camera while the team ran random motor commands through the actuators.

"The robot knows, OK, if I want to make a smiley face, I should actuate these 'muscles,'" Hu says. Beyond smiling, Emo can also raise its eyebrows and frown.

Next, the robot analyzed more than 750 videos of humans making facial expressions, learning which muscle movements indicate which expressions are about to occur. In thousands of tests with hundreds of additional videos, Emo correctly predicted which facial expression a human would make and re-created it in sync with the human more than 70 percent of the time.

Emo's more timely facial expressions combined with its blue skin could help relieve the uncanny valley effect, the awkward and eerie feelings that humanoid robots often evoke (*SN: 8/3/19, p. 12*). If people think a robot is supposed to look like a human, "then they will always find some difference or become skeptical," Hu says. Instead, Emo's rubbery blue face can help people "think about [the robot] as a new species. It doesn't have to be a real person," he says.

Emo can't yet communicate verbally, but equipping the robot with generative AI chatbot functions, similar to those of ChatGPT, could expand Emo's capabilities (*SN: 12/16/23 & 12/30/23, p. 20*). The robot would be able to anticipate facial reactions from verbal cues in addition to human muscle movement, Hu says. Eventually, perhaps Emo could respond verbally, too.

First, though, Emo's lips need work. Robot mouth movement often relies on the jaw to do all the talking, not the lips. "People immediately lose interest ... and it's really weird," Hu says.

Once Emo has chatbot capabilities and lips that work like humans' do, the robot could be an engaging companion. Having the robot as company on late nights in the lab would be a welcome addition, Hu says. "Maybe when I'm working at midnight, we can complain to each other about why there's so much work, or tell a few jokes." ■

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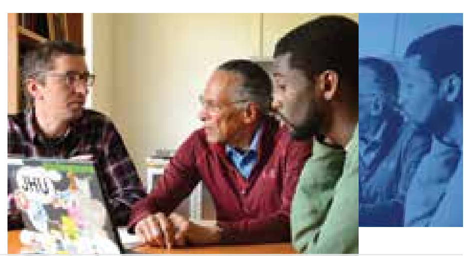


NEUROSCIENCE

How chickadees recall hidden snacks

Brain bar codes could reveal the way episodic memory operates

BY JAKE BUEHLER

Much like squirrels, black-capped chickadees hide food, keeping track of many little treasures wedged into cracks or holes in tree bark. When a bird returns to one of their many food caches, a particular set of nerve cells in the memory center of the brain gives a brief flash of activity, a new study finds. When the chickadee goes to another stash, a different combination of neurons lights up.

These neural combinations act like bar codes, researchers report in the April 11 *Cell*. The discovery may offer key insights into how brains encode and recall episodic memories — accounts of specific past events, such as what you did on your birthday last year or where you left your wallet.

Episodic memory is challenging to study in nonhuman animals, says neuroscientist Selmaan Chettih of Columbia University. "You can't just ask a mouse what memories it formed today."

But the precise behavior of black-capped chickadees (*Poecile atricapillus*) provides a golden opportunity for scientists. Every time a bird makes a cache, it represents a single, well-defined moment logged in the hippocampus — a brain structure that is vital for memory.

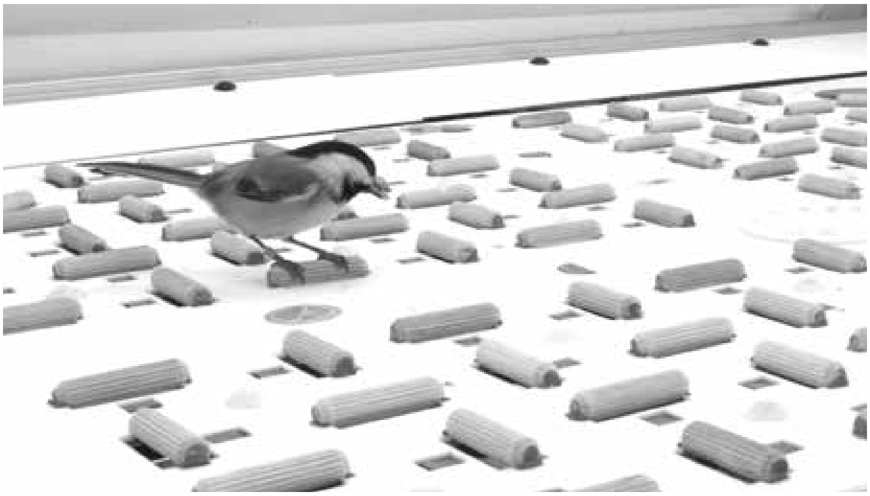
So Chettih and colleagues built an arena containing 128 small storage sites. The team inserted probes into the brains of five chickadees to track the electrical activity of individual neurons, comparing that activity with detailed recordings of the birds' body positions and behaviors.

A specific subset of neurons representing at most 7 percent of the entire hippocampus briefly lit up when the chickadees cached and retrieved seeds, Chettih says. Each cache appeared to have its own unique combination of active neurons, or neural bar code, and those bar codes differed even for individual caches at the same location.

It's possible bar codes are a type of engram, the proposed physical manifestation of a memory (SN: 2/3/18, *p.* 22). Bar codes are probably present in many species, considering how similar hippocampus physiology is between animals that are separated by hundreds of millions of years of evolution, Chettih says. However, more research is needed to confirm this idea.

In chickadees, bar codes seem to work in parallel with another group of neurons in the hippocampus called place cells, which encode information on an animal's location (SN: 5/18/13, *p.* 18). Place cells have been widely theorized as the foundation of episodic memory.

A black-capped chickadee grabs a sunflower seed. Chickadees stash seeds for later, and the birds' brains log the memory of stashes using a neural bar code.



In an experiment, this black-capped chickadee stored sunflower seeds in various places in an arena. Neural probes revealed how the bird's brain stored and recalled the memory of each hidey-hole.

FROM TOP: BLIGHTYLAD-INFOCUS/ISTOCK/GETTY IMAGES PLUS; S. CHETTIH *ET AL*/*CELL* 2024

Our perceptions of memory are enmeshed with location, says Kazumasa Tanaka, a neuroscientist at the Okinawa Institute of Science and Technology in Japan who was not involved in the research. "When you recall some specific event that happened in the past, that episodic memory cannot be dissociated from where that event happened, or when that event happened."

Surprisingly, the activity of place cells didn't change during caching, the researchers found. That suggests there's an added nuance to this understanding of memory, Chettih says. He suspects that the hippocampus creates a separate index that binds together all the different inputs that turn an experience into a distinct memory.

There are multiple candidates for indexing systems in the hippocampus, Tanaka says. It's possible that episodic memory arises from multiple, concurrent coding schemes, he says.

Chettih and colleagues also discovered a seed code, in which neurons log the presence or absence of a seed in a cache.

Neuroscientist Thomas McHugh of the RIKEN Center for Brain Science in Wakō, Japan, is intrigued by the potential interconnections between the chickadees' bar codes, seed codes and the locations logged by place cells. "Understanding how they interact is probably going to tell us a lot more about how memory works," McHugh says. ■

Watch a video of chickadees taking memory tests at **bit.ly/SN_BirdMemory**

ANIMALS

A vaccine for bees has a startling perk

Immunization against deadly bacteria also fought off a virus

BY TINA HESMAN SAEY

WASHINGTON — The first vaccine designed for insects may make honeybees healthier overall.

Honeybee hives vaccinated against a bacterial disease had much lower levels of an unrelated viral disease than did unvaccinated hives, veterinarian Nigel Swift of Dalan Animal Health in Athens, Ga., reported April 3 at the World Vaccine Congress.

Dalan researchers designed the vaccine to protect against American foulbrood — a fatal disease caused by a spore-forming bacterium called *Paenibacillus larvae*. Adult bees don't get sick but can spread spores in the hive, where the disease infects and kills larvae. Spores can remain viable for more than 50 years, so beekeepers with infected colonies must destroy hives by irradiating or burning them to keep the disease in check. A vaccine may save bee lives and beekeepers' livelihoods.

Foulbrood disease is just one of many problems plaguing bees, Swift said. "Pesticides, parasites, climate change, nutritional stress — these all make bees more susceptible to infectious diseases." From April 2022 to April 2023, beekeepers in the United States lost an estimated 48 percent of their colonies, according to Bee Informed Partnership, a nonprofit research organization.

Dalan's vaccine against foulbrood disease doesn't rely on tiny syringes. Instead, bees are inoculated through a sugar paste that the researchers spike with heat-killed *P. larvae*. Worker bees eat the candy and incorporate it into their royal jelly, which they feed to the queen. Inside the queen's gut, bits of the bacteria attach to a protein, which in turn transports the vaccine fragments to the ovaries where they can be deposited in eggs. Larvae that hatch from the eggs should be protected from the disease.

Testing the vaccine wasn't easy. One larvae-producing site in Florida was hit by a hurricane, "another was taken out by bears," Swift said. But the team persisted. In lab tests, Dalan scientists infected larvae from both vaccinated and placebo-treated hives with *P. larvae*. About twice as many placebo larvae died as vaccinated larvae, the researchers reported in 2022. Based on that evidence, the U.S. Department of Agriculture gave conditional approval for the bee vaccine, Dalan announced in 2023.

Beekeepers who had been using the vaccine told Dalan that immunized hives seemed to have all-around improvements in health that couldn't be explained by just reducing the incidence of foulbrood disease. The company decided to look at a variety of diseases, honey production and other measures of bee health along with the efficacy of the vaccine in a real-world setting. An apiary called Vidalia Apicultural Services & Bee Co. in Lyons, Ga., let Dalan use 400 hives for the study, which lasted for one season. Half of the hives got a new vaccinated queen and half got a new unvaccinated one.

In one sense, the test was a bust. No cases of foulbrood disease were found in any of the hives. "This apiary was just too good" at controlling the disease, Swift said. So the company couldn't determine how effective the vaccine was against its intended target.

Yet the researchers found a surprising result: Vaccinated hives were protected from a viral disease spread by varroa mites. Both vaccinated and unvaccinated hives started the study with the same number of mites and a baseline level of virus, as measured by a PCR test. Virus levels continued to rise in the unvaccinated hives but declined in the vaccinated ones. At the end of the study, vaccinated hives had accumulated 83 percent less virus than unvaccinated hives did, Swift said. The number of mites per hive remained the same.

"It's an important finding for sure, if it's repeatable," says biochemist Andrea Gwyn of the biopharmaceutical company GSK, headquartered in Middlesex, England. Gwyn, who works on vaccines for people, is a hobbyist beekeeper. She is interested in whether queen bees can pass on defenses against foulbrood and perhaps other infections for more than one egg-laying season and whether a queen's drone sons and daughter queens could pass on protections to their own offspring.

Swift and colleagues aren't sure why immunizing bees against bacteria seems to protect against a virus. Bees' immune systems aren't as specific as those of humans and other mammals, so perhaps anything that revs up bees' immune responses helps the insects take on multiple threats.

"It's humbling.... You get these results sometimes that weren't what you were expecting," Swift said. "This could be somebody's Ph.D. now to go and tackle this particular topic." ■

A new vaccine aimed at protecting honeybees from a serious bacterial infection may do double duty by warding off a virus.

Hendra virus can jump from spectacled flying foxes (one shown) to horses to humans when the fruit bats seek out food sources in agricultural or urban areas during winter.

SPECTACLED FLYING FOX (*PTEROPUS CONSPICILLATUS*)/MOMENT/GETTY IMAGES PLUS

ENVIRONMENT

Protect habitats to avert pandemics

A road map lays out ways to reduce the risk of viral spillover

BY BRIANNA RANDALL

Want to limit the transfer of viruses between animals and humans? A new report gives examples of how to do that by keeping ecosystems intact.

The pandemic prevention road map, published in *Nature Communications* on March 26, recommends protecting or restoring places where animals forage and rest, and minimizing human-wildlife encounters in more developed areas.

Most outbreaks of previously unknown infectious diseases, like COVID-19 or HIV, are caused when a virus jumps from an animal to a human. That jumping is called zoonotic spillover. Wild animals stressed by food shortages or habitat loss become more susceptible to viral infections and may even shed more viruses.

Protecting forests, rivers and other natural spaces has been touted as a cost-effective way to prevent pandemics. The new road map, based on case studies of zoonotic spillover from bats, gives specific recommendations for how to do this.

After studying Hendra virus, which has killed four of the seven humans infected since 1994, researchers in 2022 reported that spillovers occurred when winter food shortages caused fruit bats to seek out flowering plants in urban gardens or agricultural areas. In eastern Australia, the virus jumped to horses grazing in areas where infected bats excreted urine or feces. Sick horses then infected humans.

"Once you really understand how spillover happens, the solutions can become evident," says Raina Plowright, a disease ecologist at Cornell University who coauthored the 2022 study and the new report. For instance, to prevent Hendra outbreaks, one strategy now being tested in Queensland is to replant five species of flowering trees. "Sometimes really small changes in an ecosystem can have really profound effects," Plowright says.

Another way to avert spillover is to protect wild places and break contact with wild animal populations, says road map coauthor Iroro Tanshi, an ecologist at the University of Washington in Seattle. In Nigeria, where Tanshi studies bats, she engages local communities in preventing human-caused forest fires and in providing people with alternative sources of protein to reduce the need to hunt bats.

Bat species host four of nine diseases that have the greatest potential risk to public health, according to the World Health Organization. However, the road map's tactics can "apply to other animals that can be viral reservoirs" like rodents, primates or birds, says coauthor Winifred Frick, chief scientist at Bat Conservation International, a nonprofit headquartered in Austin, Texas.

Ecological countermeasures such as those laid out in the road map may also protect animals from contracting viruses from humans (SN: 11/21/20, *p.* 4; SN: 9/10/22, *p.* 6). Viruses are twice as likely to jump from humans to animals than vice versa. A recent analysis revealed that almost two-thirds of 59,000 viruses studied jumped from humans while only about one-third jumped to humans, microbial genomicist Cedric Tan and colleagues report online March 25 in *Nature Ecology & Evolution*.

"Viruses jumping between different animal species is an endless process," says Tan, of the University College London Genetics Institute. The road map's tactics are "definitely worth exploring," he says. But whether ecological protections would reduce the risk of zoonotic jumps in all cases is unclear, Tan cautions.

Plowright hopes that, alongside investments in biomedical and epidemiological technology to prevent future pandemics, decision makers will simultaneously invest in conserving ecosystems to stop spillover from happening in the first place.

Her main recommendation: Reduce the number of roads into wild places. Roads pave the way for infrastructure development that destroys wildlife habitat, Plowright says. They also facilitate contact between people and wild animals. Other researchers have demonstrated that higher road density increases the risk of Ebola infection, and that Ebola virus spreads along main roads.

Policy makers and public health officials should prioritize studying zoonotic spillovers before a virus becomes an epidemic or pandemic, rather than as an afterthought, Plowright says. "We should take every spillover as an opportunity to learn how it happened, figure out the drivers, and come up with solutions." ■

PLANTS

Plant invasions can take centuries

'Time bombs' highlight how sneaky invasive species can be

BY SUSAN MILIUS

A stealthy, destructive weed, the sycamore maple began its "don't worry, just love me" phase of invading Great Britain so long ago that it didn't have what we'd call a scientific name. That was in 1613, and Carl Linnaeus, who set up modern Latin naming, wouldn't be born for almost another century.

Altogether, 320 years passed before the stately tree species (*Acer pseudoplatanus*) from Central Europe and Western Asia revealed itself as a lurking wrecker of ecosystems outside its native range, scientists report in the March *Nature Ecology & Evolution*. Dense masses of new sprouts can change open spaces into thickets of young maples that crowd out native plants and even ambush forests from below.

The sycamore maple's lag between charmer and menace is extreme, but about a third of the roughly 3,500 invasive plant species examined in the new study seemed harmless when they first showed up in a new region, warns weed ecologist Mohsen Mesgaran of the University of California, Davis. These plants took at least five years to reveal their destructive nature. Some of them just need time, Mesgaran says. "Then we have this storm — explosion! — of this species rapidly growing."

He and colleagues analyzed more than a million data points from herbarium records showing when and where plants were collected across nine regions around the world. In six regions, some destructive plants lagged for more than 100 years. After that century-plus of what looked like plants just meekly getting by, their populations skyrocketed. They started choking out native species and disrupting the creatures that relied on those plants.

The first place that hitchhikers land in a new ecosystem may be survivable, but not ideal. A new climate niche often doesn't kill off the newcomer, but also doesn't let it flourish, the team proposes. Humans may dismiss the new greenery as harmless when it's merely a ride away from better digs that could let it turn troublesome.

What's more, temperature changes play a role in when and where the plant time bombs finally explode. That's an unsettling thought as the planet warms and temperature patterns shift.

Even taking the rosy view that laggards aren't the majority of weeds in the study, the finding that 35 percent lagged deceptively is "still bad," says invasion ecologist Shaun Coutts of the University of Lincoln in England. That portion is "thousands of potentially damaging introductions all over the world," he says.

The findings are a flashing-red warning against moving plants out of their native range. "Any judgment that we make on a species based on its past and present is not going to be a good predictor of what it's going to do in the future," Mesgaran says. "Don't think, 'Oh yeah, this species has been around — nothing has happened.'" ■

Check out a list of invasive plant time bombs at **bit.ly/SN_SneakyPlants**

An artificial intelligence program that analyzes social media posts to identify when depression is ticking up didn't detect depression in a Black population.

PSYCHOLOGY

AI misses depression in Black people

Findings raise questions about how mental health is measured

BY SUJATA GUPTA

People with depression tend to write and speak about how bad they feel, years of research has shown. But linguistic features linked to depression seem to be absent in the social media posts of Black people, researchers report in the April 2 *Proceedings of the National Academy of Sciences*.

"We now have over a decade of research [that] has shown how language can be a very powerful indicator of mental health and signs of depression. But one thing we hadn't understood until this study was how demographic factors ... impact that measurement," says Munmun De Choudhury, a computer scientist at Georgia Tech in Atlanta who is an expert in using social media data to study mental health.

Researchers and public health officials have been testing machine learning programs that are designed to predict links between certain language markers and health outcomes. These programs could act as an early warning system by scouring social media posts to identify spikes in depression across a given population.

However, the new findings suggest that such AI programs could miss depression in a big slice of the population. If that's the case, then "there are profound public health implications," De Choudhury, says.

> The program's ability to predict depression in Black participants was close to zero.

Sunny Rai, a computer scientist at the University of Pennsylvania, and colleagues recruited over 850 people in the United States for the new study. Half of the participants were Black and half were white, and the two groups were matched by age and gender. Participants completed an online depression survey, the Patient Health Questionnaire 9, and gave the team access to their Facebook posts. The scientists then fed those social media posts into a text analysis program.

Consistent with earlier work, the use of first-person singular pronouns — I, me and my — increased alongside depression severity scores for the entire cohort. Conversely, use of first-person plural pronouns — we, our and us — was linked to lower depression scores. And as depression scores went up, so too did words reflecting negative emotions, such as those referring to feelings of emptiness and longing, disgust, despair, lack of belonging and self-criticism.

That picture changed when the scientists broke down responses by race. The text analysis program did relatively well at predicting depression in the white group, but did poorly at predicting depression in the Black group. In fact, the program's ability to predict depression in Black participants was close to zero. Even when the team trained it on just Black participants' social media posts, the program failed to identify any linguistic patterns.

"We re-ran the experiment so many times because we thought we were doing something wrong," Rai says.

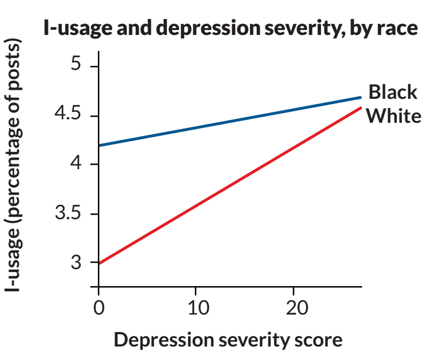
Why the program struggled to predict depression in Black people is unclear, Rai says. Maybe signs of depression in Black people aren't linked to communication. Or maybe depression cues link to nonwritten forms of communication, such as changes to body language, rate of speaking or tone. Or maybe the public nature of social media discourages Black people from sharing too much about how they're feeling.

It's even possible that depression lacks universal features, says Ryan Boyd, a psychologist and computational social scientist at Stony Brook University in New York. That would suggest there are flaws in these types of machine learning programs and the information used to train them. For instance, the assumption with this sort of research is that the standardized questionnaire used to measure depression works well, Boyd says. But mounting evidence suggests that may not be the case, especially with certain populations, such as Black men.

"The model is only as good as the measurement we are basing it on," Boyd says.

Sorting out just what is going on requires first determining if social media is a uniquely poor format for studying depression or if Black people's depression does not manifest in speech even in other settings, such as in private conversations with medical staff, Rai says. "We found this on Facebook, but of course this needs to be replicated ... [outside] a public space." ■

Read between the lines An analysis of social media posts found the use of first-person singular pronouns like "I" significantly increased alongside depression scores for white but not Black populations. SOURCE: S. RAI *ET AL*/*PNAS* 2024



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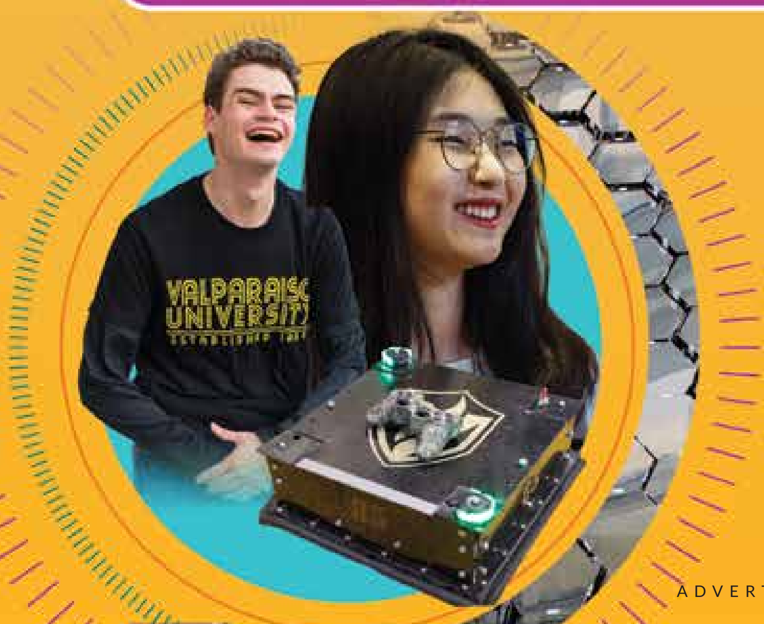


HEALTH & MEDICINE

Why COVID-19 might turn severe

Lung immune cells' reaction may lead to pneumonia

BY AIMEE CUNNINGHAM

Health care workers at a hospital in Ecuador examine a chest X-ray from a patient with COVID-19 in 2022. A type of immune cell that resides in lung tissue may play a role in the progression of a coronavirus infection to pneumonia.

RODRIGO BUENDIA/AFP VIA GETTY IMAGES

The intense reaction of one of the lungs' guardians against infection may help explain why COVID-19 can become severe.

The guardians, immune cells called interstitial macrophages, patrol lung tissue. These cells can be infected by SARS-CoV-2, the coronavirus that causes COVID-19, scientists report April 10 in the *Journal of Experimental Medicine*. Overwhelmed by the onslaught, these immune cells trigger an extreme inflammatory response that may contribute to the development of pneumonia, a disease that damages the lungs and makes breathing difficult.

"There is this gap in our knowledge of how human lung tissue really responds in the earliest phases" of a SARS-CoV-2 infection, says José Ordovás-Montañés, an immunologist at Boston Children's Hospital and Harvard Medical School. The new work puts a spotlight on interstitial macrophages' role, he says. "I think this is an interesting piece of the puzzle."

A bout of COVID-19 can begin after someone breathes in the coronavirus. Launched by a sneeze or a cough, the virus spreads through the air (*SN: 12/18/21 & 1/1/22, p. 19*). Evidence suggests the virus first infects cells that line the nasal cavity or the throat, and then the immune system response kicks in. From that point, many people clear the infection, says viral immunologist Catherine Blish of Stanford University School of Medicine. But some people don't, and the virus can spread into the airways of the lungs and infect cells lining the air sacs, the structures where oxygen and carbon dioxide are exchanged.

Blish and colleagues wanted to investigate the next steps of a COVID-19 infection in the lungs and what might drive the progression to pneumonia. The team worked with thin slices of human lung tissue, procured from organ donations or surgeries in which some of the tissue needed to be removed. The researchers exposed the tissue to SARS-CoV-2 to see which cells became infected.

"It was really no contest," Blish says. The vast majority were macrophages, immune cells that take up viruses and other pathogens, break them down and present the parts to other immune cells. This helps rev up the body's immune response.

Specifically, there were two types of infected macrophages: those that reside in the lung tissue, called interstitial, and those associated with the air sacs. Putting purified macrophages of each type in lab dishes with SARS-CoV-2 revealed that the cells were being infected, not just gobbling up the coronavirus.

The team also probed the immune response of the two macrophage populations. The macrophages in the air sacs weren't as dominated by the virus and produced a proportionate inflammatory response. But the coronavirus took over the interstitial macrophages' cellular machinery. These macrophages responded by ramping up the production of proteins that target viruses and call in other immune cells, the scientists found. The cells are "sending massive alarm signals … 'There's an invader, danger, danger'," Blish says.

In the body, this kind of immune response can lead to a huge influx of cells and inflammatory proteins into the lungs' air space, Blish says. That can compromise the air sacs' ability to function and help set the stage for pneumonia.

Blish and colleagues also found that SARS-CoV-2 enters the interstitial macrophages through a different access point than the very well-known receptor for other types of cells, ACE2. This may help explain why treatments that target ACE2 haven't worked well for severe pneumonia, Blish says.

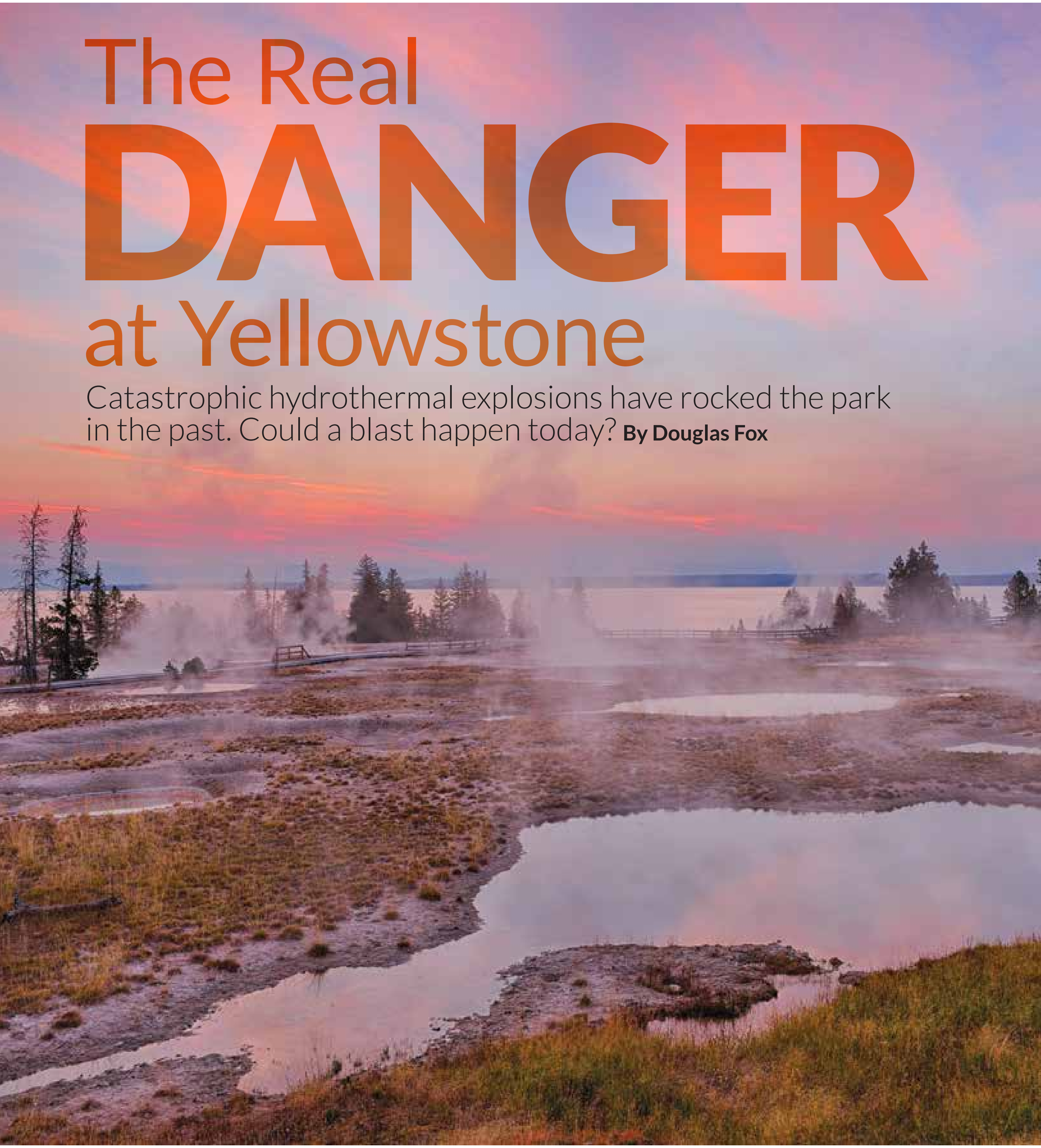
Experiments with lung slices can't exactly replicate what's going on in the body. The study doesn't answer how the virus would get into the lung tissue and gain access to the interstitial macrophages, Blish says.

"It's a sensible model to put forward," Ordovás-Montañés says. But with the lung slices, "you give equal chance to any cell that was either on the outside part or on the inside part of the lung" to become infected, he says.

It may be helpful to complement this research with studies in animal models in which the lungs' physiology is intact, Ordovás-Montañés says, though those types of studies also don't exactly translate to what's happening in people. "Each model is going to give you a slightly skewed view of reality." ■

The Real DANGER at Yellowstone

Catastrophic hydrothermal explosions have rocked the park in the past. Could a blast happen today? **By Douglas Fox**



The area around West Thumb Geyser Basin and Yellowstone Lake (in the background) has seen many hydrothermal explosions, which occur when hot water beneath the surface suddenly flashes into steam.

Mount Ontake in Japan rises 3,067 meters above sea level — a windswept giant standing head and shoulders above densely forested hills. This ancient volcano is a popular trekking site. A trail traverses its ash- and boulder-strewn ridges. There are several huts and a shrine. On September 27, 2014, hikers took advantage of a blue sky and gentle wind. At 11:52 a.m., over a hundred of them stood on the summit, eating snacks and taking photos. Disaster struck with little warning.

The windows and doors of a nearby hut rattled, vibrated by a low-frequency shock wave inaudible to humans.

People glanced around curiously and quickly saw it — half a kilometer down the southwest slope, a gray cloud billowed from the mountain.

The ash cloud swept over the summit with a blast of hot air, leaving people shaken and blinded, but otherwise unhurt. Disoriented in that gray fog, they couldn't see what arrived soon after.

Thud-thud. Thud. Rocks blasted out of the mountain rained down from the sky. The barren mountaintop offered no shelter to those who desperately sought it in the swirling, gagging dust.

The tempo of hail quickened, as millions of rocks came down — most smaller than baseballs but some as large as beach balls. More and more people fell.

Roughly a million tons of ash and rock spewed from the mountain that day, ejected through several craters that hadn't existed a moment before. Fifty-eight people died, most killed by falling rocks. Five others were never found.

When scientists investigated the aftermath, they found no new lava flows and no freshly formed ash. What exploded from the mountain wasn't lava or fire; it was water.

The explosion was powered by a seemingly innocuous pool of water, derived from rain and snowmelt, hidden beneath the surface. The water was suddenly heated from below, perhaps by a burp of hot gas from a deep magma chamber. The water flashed into steam.

Subterranean cracks were pried apart as this vaporized water expanded to hundreds of times its original volume. This high-pressure wedge drove the cracks to the surface — blowing out holes that widened into craters as the escaping vapor flung rocks and old ash into the air.

The tragedy at Ontake is not unique. A similar explosion killed 22 people and injured two dozen others on White Island off the coast of New Zealand in 2019. Hydrothermal explosions can happen in many other places around the globe, including Greece, Iceland and Northern California.

They can even happen in areas without active volcanoes. Yellowstone National Park, where no magma eruption has happened in 70,000 years, has seen hundreds of hydrothermal explosions of various sizes. "In recorded history, it's been only small ones," says Paul Bedrosian, a geophysicist at the U.S. Geological Survey in Lakewood, Colo. "But we know [Yellowstone] is capable of creating whoppers."

News stories often speculate on whether Yellowstone's massive magma system will awaken and erupt, but these hydrothermal explosions represent a far greater risk today.

Massive craters show that Yellowstone has seen explosions many times larger than the one at Mount Ontake. For a long time, scientists thought that Yellowstone's huge explosions might have only happened under specific conditions that existed thousands of years ago at the close of the last ice age. But research in Yellowstone and other places where large hydrothermal explosions happen suggests that belief is misplaced.

"These [big] hydrothermal explosions are very, very dangerous," says Lisa Morgan, a USGS scientist emerita and volcanologist in Denver who has spent 25 years studying the biggest explosions in Yellowstone's history. "It could very well happen today."

Hydrothermal explosions often occur with far less warning than regular magma eruptions. And reconstructing what triggers them, especially the largest ones, has proved challenging, says Shane Cronin, a volcanologist at the University of Auckland in New Zealand. "Globally, no one has really seen many of these happen," he says. "They're quite mysterious."

The phreatic steam explosion at Mount Ontake in Japan in 2014 shot tons of rock and old volcanic ash into the air.

But Morgan is getting a clearer picture of the triggers, and whether predicting the timing of these explosions might be possible. Exploring the bottom of Yellowstone's largest lake, she and her colleagues have discovered a restless landscape dotted with hundreds of previously unknown hot vents, some of the world's largest hydrothermal explosion craters and the brittle geologic pressure cookers that could one day unleash new explosions. While Yellowstone Lake has the most violent history, it's becoming clear that other parts of the park could also produce large blasts.

An explosive history

Yellowstone sits at the northeast end of the Snake River Plain — a conspicuous, flat corridor that plows through an otherwise mountainous region. This scar was created by a hot spot in Earth's mantle — the geologic equivalent of a gas burner on a stove — which the North American tectonic plate is slowly sliding over, fueling a northeast-trending chain of massive volcanic eruptions over the last 17 million years. The most recent super-eruption occurred 640,000 years ago, vomiting forth enough lava to build several Mount Rainiers. This blast emptied a huge underground chamber, which then collapsed — causing the landscape to slump into an oval-shaped caldera, roughly as big as Rhode Island and ringed with faults.

A magma chamber still sits beneath Yellowstone, left over from that huge eruption. It holds an estimated 10,000 cubic kilometers of magma. But the chamber is only about 15 to 20 percent liquid, making it far too viscous to erupt anytime soon.

Although magma underlies much of the park, it comes closest to the surface, within five kilometers, beneath the north edge of Yellowstone Lake. With magma temperatures above 800° Celsius, the heat flowing up through the ground is "just screaming high," Bedrosian says. In some places, it's 100 times the average on Earth's surface.

In the park, rainwater and snowmelt percolating down toward the chamber are heated to over 250° Celsius but remain liquid because the immense pressure underground prevents the water from expanding into steam. That hot fluid, mixed with carbon dioxide and stinky hydrogen sulfide gas, spurts back up through cracks in the surrounding rocks — dissolving sodium, silica, chloride, arsenic and other minerals — and eventually reaches the surface where it feeds thousands of hot springs, geysers and bubbling mud pots that make Yellowstone a geologic wonder.

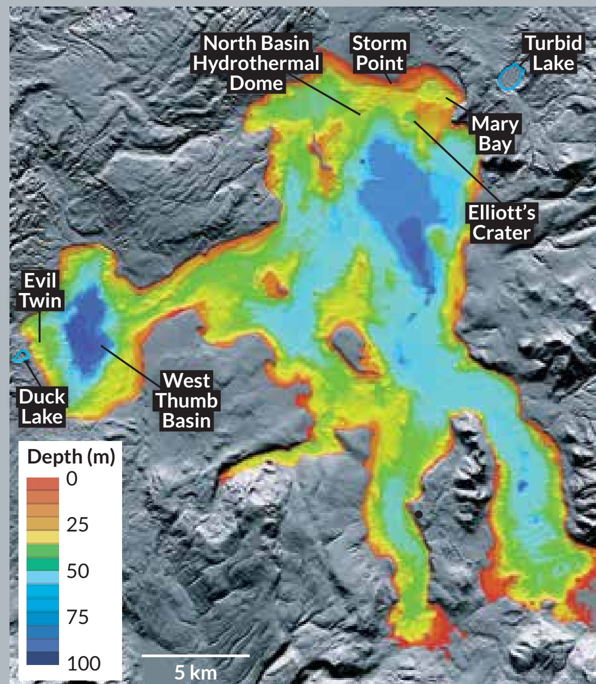
Although scientists have studied Yellowstone's hydrothermal system since the 1870s, not until 1966 did people start to realize that it could produce horrific explosions.

That summer, Patrick Muffler, then a young scientist with the USGS, stepped for the first time into Pocket Basin, near Yellowstone's western edge. He was there to map the hydrothermal system for NASA, which wanted to understand the volcanic landscapes that future missions to Mars might find.

This broad, sagging meadow is pocked with bubbling hot springs that lace the air with the faint sour smell of hydrochloric

PREVIOUS PAGE: MARTIN RUEGNER/GETTY IMAGES; THIS PAGE: THE ASAHI SHIMBUN VIA GETTY IMAGES

Yellowstone's bottom On the floor of Yellowstone Lake (colors indicate water depth) are hydrothermal explosion craters, like Elliott's Crater and Mary Bay, plus domes like the North Basin Hydrothermal Dome, which mark where explosions could occur.



L.A. MORGAN *ET AL*/USGS, ADAPTED BY B. PRICE

acid. The basin is surrounded on three sides by a low ridge sprinkled with a few scraggly trees. As Muffler and his supervisor, Donald White, explored the landscape, White quickly recognized something familiar.

White was one of a handful of people around the world at the time who studied hydrothermal systems. In 1951, he had visited the small town of Lake City, Calif., five nights after a strange cataclysm had happened there. An inconspicuous cluster of hot springs feeding a lush, marshy meadow of bulrushes and grass had exploded, flinging 300,000 tons of mud and rock onto the surrounding fields. Most of those rocks were jumbles of gravel and sand, cemented together with white zeolite and opal minerals. White knew that these materials form when mineral-saturated hydrothermal waters reach the cooler surface and their dissolved substances crystallize. He concluded that the blast had been a hydrothermal explosion that was somehow triggered as underground water flashed into steam.

As White and Muffler walked up the ridge surrounding Pocket Basin, their boots crunched over similar rocks. White theorized that this basin was a hydrothermal explosion crater much larger than the one at Lake City—roughly the size of Yankee Stadium. The ridge was a heap of debris flung out of the hole.

The steam explosions at Mount Ontake and New Zealand's White Island were probably triggered by a sudden increase in heat flow from magma or gases deeper down. For this reason, they are technically known as phreatic explosions, though their destructive power still comes from the sudden expansion of water into steam. As White and Muffler looked at Pocket Basin, they believed the Yellowstone steam explosion had been triggered by something else—an environmental change on the surface.

The explosion debris sat directly atop rocks and gravel left behind when a glacier—the Pinedale ice cap—retreated at the close of the last ice age, around 13,500 years ago. While the glacier was present, the hot springs would have melted the ice overhead, creating an ice-dammed lake, says Muffler, who retired in 2001 but still works with USGS. The weight of that lake would have pressurized the hot springs beneath, preventing the water from boiling even if it was well over 100° C. Muffler and White speculated that as the glacier retreated, the ice dam burst and the lake's water level plummeted.

"If you can get rid of that water instantly, that depressurizes the system—and bang, it goes off," Muffler says. No longer constrained by pressure, the water expanded instantly into steam and blew apart the rocks enclosing the hot springs.

In 1971, Muffler and White proposed that at least 10 other large hydrothermal explosion craters might be scattered across Yellowstone. A few years later, geologists added one more crater to the list: Mary Bay, a lobe extending off the north edge of Yellowstone Lake. At 2.6 kilometers across, it remains the largest hydrothermal explosion crater ever found on Earth, forming around the same time as Pocket Basin.

These findings initiated a long-standing debate about whether these monster explosions in Yellowstone could only be caused by retreating ice, or whether other types of triggers could set off these blasts today.

Morgan, who started studying these explosions in the late 1990s, has slowly homed in on an answer.

What lies beneath

In September 1999, an 8-meter-long aluminum boat traced slow, straight lines back and forth across the northern part of Yellowstone Lake. Two instruments were mounted on the stern of the boat. One scanned the lake bottom with narrow sonar beams, recording the echoes to capture the ups and downs of the lake bottom. The other fired periodic seismic shock waves into the lake. Those waves penetrated the lake floor before reflecting back, revealing a picture of the sediment and stone layers beneath the lake bottom.

Morgan organized this project with Pat Shanks, a USGS geochemist who had started studying hydrothermal vents in the lake. He was in bad need of a map of the lake floor to replace his time-consuming method of finding vents: venturing out onto the flat water in a boat early in the morning to see where gas bubbles rose from vents below.

Morgan, Shanks and several other scientists gathered each evening in a nearby building to review the new lake floor maps that the technicians were printing out. "It was like having cataracts taken off of your eyes," Morgan says, "like night and day."

Before long, these maps revealed an unknown structure southwest of Mary Bay. Now called Elliott's Crater, this 830-meter-wide depression is the third-largest hydrothermal crater in world.

Later that month, people crowded inside the boat's cabin to watch live video as a remote-controlled submersible descended some 50 meters underwater for a closer look. The inner walls of the crater loomed nearly vertical in the murky water. Foot-long suckerfish "lined up like airplanes" on the edge of the crater, Morgan recalls. "They love the hot water."

The submersible explored several smaller craters, some twice as wide as a football field, nested within Elliott's Crater. Inside them were hydrothermal vents. These vents were often flanked by microbial mats; small crustaceans cavorted about just outside the plumes of searing water, grazing on drifting microbes, while trout darted in and out, hunting the crustaceans.

The ROV's mechanical arm grabbed rocks from the bottom. Examining them later, Shanks found the rocks mottled in greens and blues — signs of iron- and magnesium-rich chlorite minerals, which formed as hydrothermal waters altered rocks lying beneath the lake or welded together sediments on the lake bottom. These samples, presumably, were shards of rock blasted into the air by the explosion, some of which fell back into the crater.

The team spent the next three Septembers mapping the rest of the lake floor. "We found it to be a far more hydrothermally and tectonically active lake than anyone had ever expected," Morgan says.

Several active faults run through the lake. Over 250 hydrothermal vents nestle within V-shaped depressions that hot water had either dissolved or blasted out of the lake floor. In addition to Elliott's Crater, the team discovered two other craters at least half a kilometer across plus numerous ones smaller than 200 meters.

Here and there, rounded domes protruded from the lake floor. Seismic profiles revealed them to be soft sediments draped on top of a hard crust. Each dome probably marks where hydrothermal waters had emerged from one or more vents and fused sediments together with silicate and chlorite minerals. Over time, an impermeable barrier formed, allowing less and less water to exit the vents. As pressure built up beneath, the cap gradually arched up, Bedrosian says.

When such a dome seals, "you're going to have a pressure cooker as opposed to a pot boiling on the surface," Bedrosian says. It may set the stage for catastrophe.

In fact, during ROV dives, Morgan and Shanks saw what appear to be the blasted edges of a dome on the fringes of Elliott's Crater. They also found hundreds of intact domes. Most were less than 2 meters across — but some much bigger.

The North Basin Hydrothermal Dome, for instance, spans 750 meters and rises seven stories above the lake floor. Hot water exits the dome through dozens of small vents, at least for now. "But over time, that's going to change, and those open spaces will seal with silica," Morgan says. Once that happens, "it's a perfect candidate for a potential hydrothermal explosion."

In search of triggers

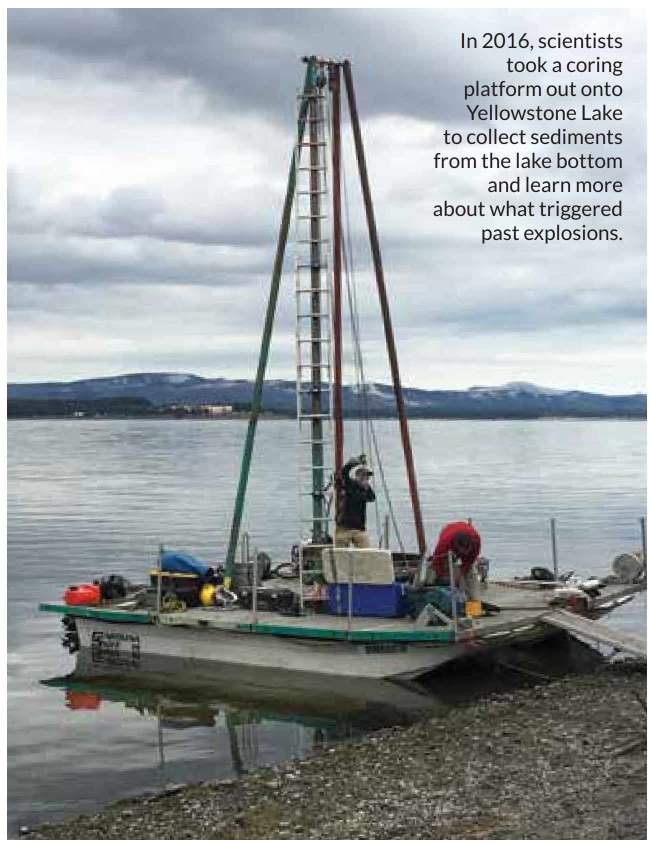
As the mapping of Yellowstone Lake was still under way in 2000, Morgan sought approval to pluck cores from the lake bottom to pinpoint when the largest explosions had occurred and what triggered them. Getting that permit from the National Park Service took 16 years. "One of their biggest concerns was that you put a corer [into the lake floor] and we have an explosion," she says.

In 2016, she and collaborators finally retrieved eight sediment cores, without incident. These cores plus some others from additional field campaigns revealed debris deposits from at least 16 different hydrothermal explosions stacked atop one another, with intervening layers of mud representing peaceful times in between. These include the Elliott's Crater and Mary Bay explosions and previously unknown smaller ones. Based on estimates of how quickly mud accumulates on the lake floor, three of the smaller explosions happened in the last 350 years or so — the most recent, around 1860.

Analyses of the larger explosions, which Morgan, Shanks and their colleagues published in GSA *Bulletin* in 2022, suggest that they were not set off by the retreat of the Pinedale ice cap, as previously suspected.

The debris layer from Elliott's Crater sits just below a well-known volcanic ash layer derived from the eruption of Mount Mazama, which formed Crater Lake in Oregon 7,600 years ago. Morgan's team estimates that Elliott's Crater exploded 8,000 years ago, triggered by a major earthquake that happened around the same time. The quake caused a fault that runs through the lake to slip 2.8 meters and could have easily cracked the hydrothermal dome, bursting it like a party balloon.

This dovetails with other research suggesting that two major explosion craters near the lake also formed well after the



In 2016, scientists took a coring platform out onto Yellowstone Lake to collect sediments from the lake bottom and learn more about what triggered past explosions.

LISA MORGAN/USGS

Pinedale ice cap retreated, one about 9,400 years ago and the other 2,900 years ago. “We don’t think the recession of glacial ice is a big factor,” Morgan says.

Even the Mary Bay explosion, which lake cores confirm occurred around when the ice cap retreated, was probably triggered by something else. Geologic evidence points to a roughly magnitude 6.5 quake that unleashed a tsunami.

Morgan and colleagues think the wave swept into the north end of the lake, past its present-day shoreline, and washed out a pile of rocks and earth that had dammed the north end. The hills surrounding the lake preserve evidence of what happened next.

Eroded into these slopes are two stranded shorelines, one above the other, formed by the lake when its water level was higher in the past. The lower shoreline is younger, with an estimated age of roughly 13,000 years, suggesting that the lake level suddenly dropped from the higher shore to the lower shore, right around the time of the earthquake.

“The lake dropped suddenly 14 meters,” Morgan says. “That’s huge.”

It would have lowered the water pressure over Mary Bay by around 20 or 30 percent. If the mineral dome overlying that hot water was already strained to its limit, then that sudden drop in pressure could have caused a catastrophic rupture.

Lauren Harrison, a geologist at Colorado State University in Fort Collins, recently discovered another kind of event that can instigate these explosions. She has carefully studied the Twin Buttes explosion crater, a broad divot the size of an 18-hole golf course, located roughly 40 kilometers west of Yellowstone Lake. Its debris field spills a kilometer down a mountainside, with washing machine–sized boulders jumbled at the bottom. When Harrison used airborne lidar to create a 3-D map of the debris, she realized that it came from two separate events. First, a landslide swept down the mountain, carrying the boulders. Then explosion debris rained down on top of the landslide.

The landslide, she argues, marks the collapse of a massive, rickety pile of rocks that formed over a cluster of thermal vents while the Pinedale ice cap still existed. Rocks being carried by that glacier were gradually cemented together by silicate minerals burbling out of the vents. After the ice cap retreated, the pile could no longer support its own weight and collapsed.

> When a dome seals, “you’re going to have a pressure cooker.”
>
> **PAUL BEDROSIAN**

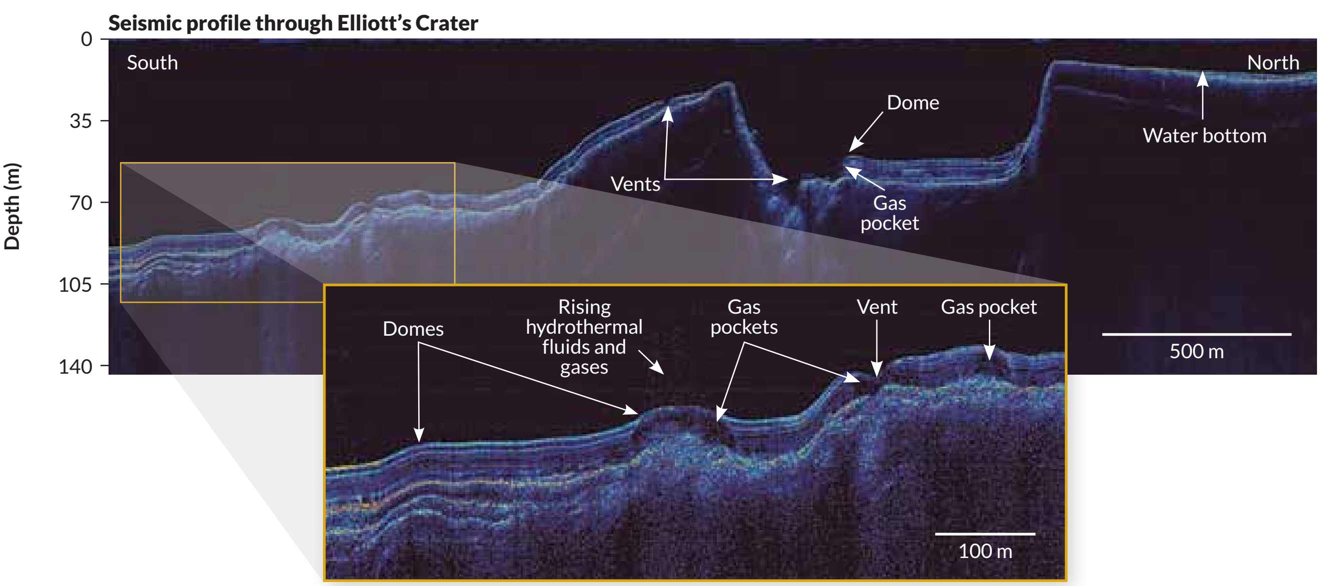
“That [landslide] is a perfect, immediate depressurization event,” Harrison says. The superheated water, no longer buried under rocks, flashed explosively into steam. So this explosion may have been caused indirectly by ice retreat, but the precipitating event was a landslide.

What unifies all of these events — earthquakes, tsunamis and landslides — is that they can happen today, without warning, Morgan says. But there’s more to learn. Cronin wonders, for example, whether one hydrothermal explosion can trigger another.

He is studying an ominous example in New Zealand, where a cluster of at least 25 explosion craters runs along a 10-kilometer section of the Ngapouri-Rotomahana Fault, through a quilted landscape of farms and forest. “You’re looking at craters up to 300 to 500 meters wide, and [fallen debris] extending out at least a kilometer in many cases,” Cronin says.

The blasts all happened about 700 years ago. His team is trying to pin down the exact timing. He believes they may have unfolded over a period of months or years, with each explosion triggering the next one, possibly by creating new cracks in the

Danger zone Measuring the reflections of seismic shock waves sent into the bottom of Yellowstone Lake has allowed scientists to get a detailed view of this hotbed of hydrothermal activity. A cross section of Elliott’s Crater reveals vents where hydrothermal fluids and gases rise up. Domes show where sediments are fusing over vents and blocking the release of fluid. If a dome ever breaks, it could set off an explosion.



L.A. MORGAN ET AL/J. VOLCANOL. GEOTHERM., L.A. MORGAN ET AL/GSA SPECIAL PAPERS 2009, ADAPTED BY B. PRICE

Some rocks at Yellowstone, including the one shown, contain minerals indicative of having been altered by hot water, a clue to a past explosion.

bedrock that destabilized other hydrothermal areas. The notion of such a domino effect is alarming. But the idea that a single earthquake might have triggered them simultaneously is even more so. "It's important for us to figure out if they are all happening at the same time," Cronin says. "This kind of scenario is far more hazardous" than a single explosion.

Sizing up the danger

The 2014 Ontake disaster might seem like the worst-case outcome of either a phreatic or hydrothermal explosion. But far worse things can happen.

Morgan estimates that the Mary Bay explosion ejected roughly a quarter of a cubic kilometer of mud, sand and water-saturated rock from its crater. That is 100 to 400 times the volume ejected by the Ontake explosion. It is also roughly 50 times the volume of sand and rock ejected in the Storax Sedan nuclear test, when the U.S. military detonated a 104-kiloton bomb underground in the Nevada desert in 1962.

The Mary Bay explosion also tossed refrigerator-sized boulders out of the water and sent smaller debris up to 2 kilometers into the air—landing as far as 20 kilometers away. The blast sent a wave of boiling mud surging onto the lake shore, forming a pile up to eight stories tall.

The explosion unfolded as a chain reaction, Morgan says. As the top layer of rock exploded off the lake floor, the removal of its weight depressurized the water-saturated rock below, allowing it to explode, which in turn depressurized yet another layer of rock and fluids farther down—and so on. Layers in the lake cores suggest that three main explosions occurred, probably within minutes, Morgan says, with smaller explosions perhaps continuing "on and off for hours or days."

She and others are now studying hydrothermal domes in and around Yellowstone Lake that could explode. In 2016, Bedrosian and Carol Finn, a USGS geophysicist, peered inside the North Basin Hydrothermal Dome and other structures in Yellowstone using a remote sensing technique called electrical resistivity, which hints at the chemical composition of minerals and the presence of water in the subsurface.

This effort revealed some sort of hot material with high resistivity hidden beneath the dome's hard cap. Bedrosian, who is still analyzing the data, thinks it's primarily steam, since salty water would have lower resistance.

That's good news. It suggests that the hydrothermal fluid rising beneath this dome is already boiling much farther down—and what reaches the dome is mostly vapor, rather than superheated liquid. If the dome were to become destabilized, there's not enough liquid water present to expand into vapor and power a major explosion, though a small blast would be possible. But if fluid circulation changes, it could fill the dome with superheated liquid water, creating a more dangerous situation.

Some of the ingredients for a big explosion may already exist in other parts of the park. In the Lower Geyser Basin, where the massive Pocket Basin and Twin Buttes craters reside, water burbling from the ground is high in sodium chloride. This chemical profile indicates that the fluids have not boiled before reaching the surface, and therefore they retain their full explosive potential. The same is true of Norris Geyser Basin, which hosts three other big explosion craters, and Upper Geyser Basin, where Old Faithful sits.

Even if monitoring for signs of impending hydrothermal explosions is not yet possible, Morgan isn't arguing that Yellowstone is inherently unsafe. Park tourists face much higher risks from dehydration during a hike or self-inflicted burns if they stray off the trails and step into scalding mud. But the damage caused by a rare, huge explosion would be extreme.

So even as Morgan studies other explosion craters, she keeps an eye on places that might someday explode, including Storm Point, on the north shore of Yellowstone Lake, near Mary Bay. This dome, 800 meters across, often has snow-free areas during winter due to the heat seeping from it. The ground can reach 50° C in some low, sandy spots, similar to a hot summer sidewalk. Plants are scarce and the gravelly ground is hard and unforgiving, cemented with hydrothermal minerals. Hot water still bubbles out of vents along the edges of the dome, so for now it still has a safety valve that can vent pressure.

But if it seals off, "it's like a ticking time bomb," Morgan says. Then, it will only need a sudden trigger, like an earthquake—"and everything's going to explode." ■

Explore more

- Lisa A. Morgan *et al*. "The dynamic floor of Yellowstone Lake, Wyoming, USA: The last 14k.y. of hydrothermal explosions, venting, doming and faulting." *GSA Bulletin*. June 7, 2022.

Douglas Fox is a freelance science journalist based in Northern California.

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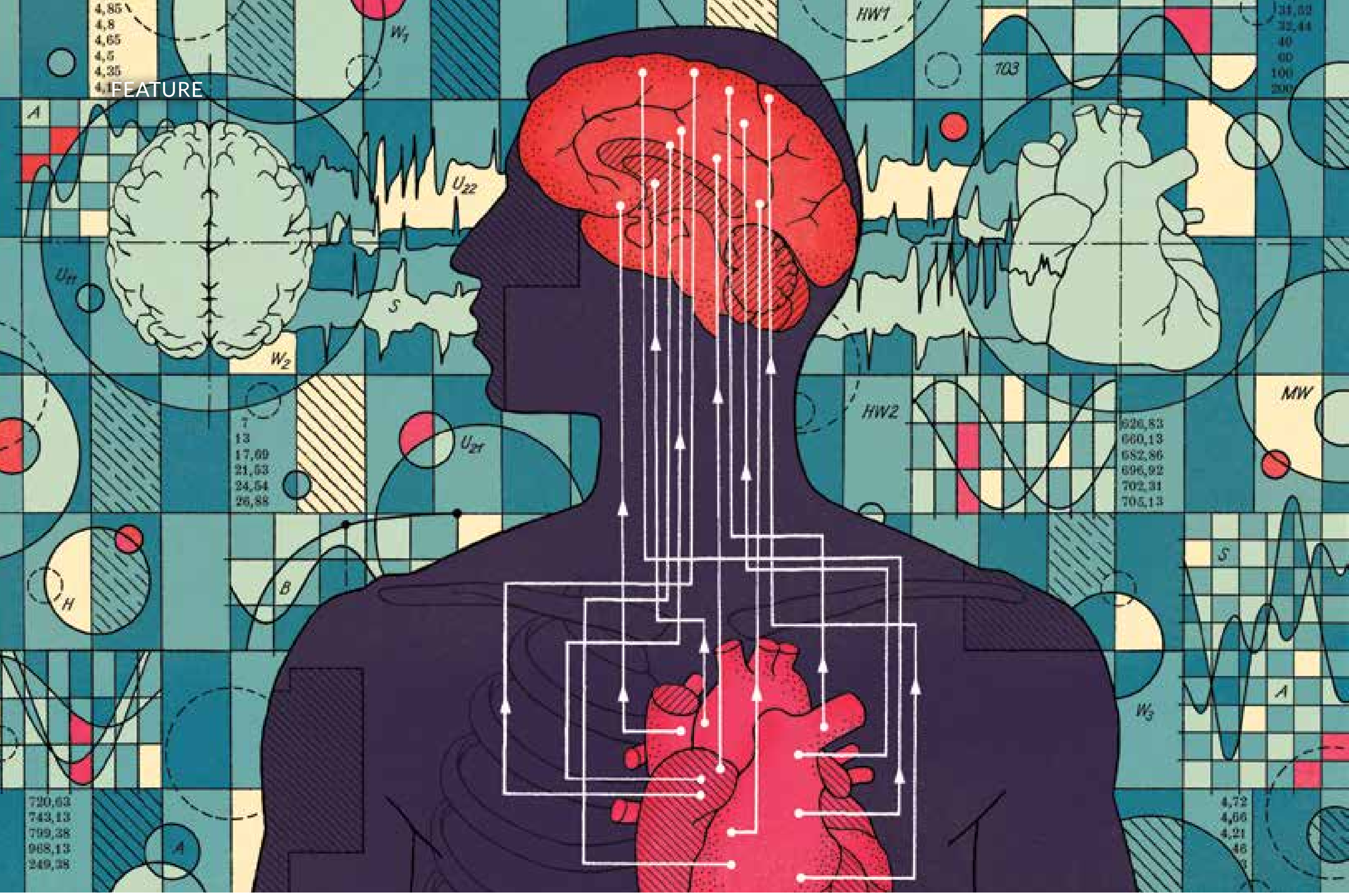


From the heart

Deciphering the organ's messages to the brain could improve mental health and unlock secrets of consciousness **By Laura Sanders**

Everyone knows that the brain influences the heart.

Stressful thoughts can set the heart pounding, sometimes with such deep force that we worry people can hear it. Anxiety can trigger the irregular skittering of atrial fibrillation. In more extreme and rarer cases, emotional turmoil from a shock — the death of a loved one, a cancer diagnosis, an intense argument — can trigger a syndrome that mimics a heart attack.

But not everyone knows that the heart talks back.

Powerful signals travel from the heart to the brain, affecting our perceptions, decisions and mental health. And the heart is not alone in talking back. Other organs also send mysterious signals to the brain in ways that scientists are just beginning to tease apart.

A bodywide perspective that seeks to understand our biology and behavior is relatively new, leaving lots of big, basic questions. The complexities of brain-body interactions are "only matched by our ignorance of their organization," says Peter Strick, a neuroscientist at the University of Pittsburgh.

Exploring the relationships between the heart, other organs and the brain isn't just fascinating anatomy. A deeper understanding of how we sense and use signals from inside our bodies — a growing field called interoception — may point to new treatments for disorders such as anxiety.

"We have forgotten that interactions with the internal world are probably as important as interactions with the external world," says cognitive neuroscientist Catherine Tallon-Baudry of École Normale Supérieure in Paris.

These internal signals, most of which we are wholly unaware of, may even hold clues to one of the grandest scientific puzzles of all — what drives human consciousness.

CHRISTIAN GRALINGEN

The heart pulls the brain's strings

Coalitions of cells in the brain exert exquisite control over the heart. In some parts of the brain, more than 1 in 3 nerve cells influence the heart's rhythm, Tallon-Baudry and her colleagues reported in 2019 in the *Journal of Neuroscience*. One of these brain regions, the entorhinal cortex, is famous for its role in memory and navigation. It makes sense that these two jobs — physically moving through the world and influencing heart rate — would fall to the same neurons; the tasks of seeing a jogging path and priming the heart for running are linked.

The brain bosses the heart around. But that's not the whole story — not even close. Scientists are finding that information from the heart can boss around our brains and our behavior, too.

Each heartbeat serves as a little signal to the brain. It's an event, much like seeing an apple or hearing the first note of a song. But unlike those external events, the heartbeat signals come from inside the body. The brain senses these internal signals. Each heartbeat prompts a reliable and measurable neural reaction that scientists call a heartbeat-evoked response, or HER.

And though this heart-initiated, neural thrumming is only on the inside, it can influence what we see in the outside world, Tallon-Baudry and colleagues have found. In one study of 17 people, messages from the heart sharpened eyesight. When certain areas of the brain responded strongly to heartbeat, creating a large HER, people were more likely to see faint gray lines around a red dot. When the HER was weaker, people were less likely to see the lines, the researchers reported in 2014 in *Nature Neuroscience*.

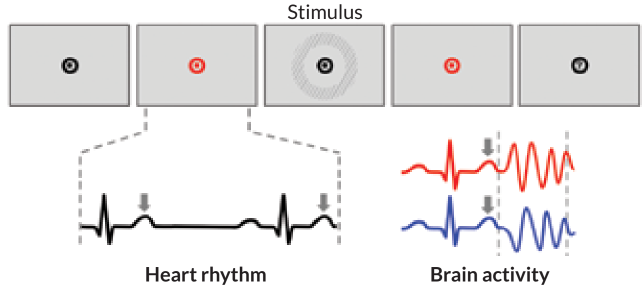
Signals from the heart also appear to play a role in memory. In lab experiments, people were shown brief blips of words on a screen. When a word showed up as the heart was contracting, a squeezing phase called systole, people were more likely to forget the word on later memory tests, neuroscientist Sarah Garfinkel and colleagues reported in 2013 in *Psychophysiology*.

There are hints that the heart can influence intuitions, decision making and emotions. People who were better able to feel their hearts' rhythms reacted more intensely to emotional images than people who were worse at sensing their heartbeat, for instance.

These results and others suggest the tantalizing possibility that our brains are taking in and using information from the heart — and perhaps other interoceptive awareness — to help us make sense of the world. But findings from people are often correlational. It's been hard to know whether beating hearts caused the effects or whether they just happened at the same time.

A recent study in mice got around this problem in an unexpected way (SN: 4/8/23, *p.* 9). The experiment relied on a powerful technique that can control neuron behavior with light, developed in part by neuroscientist Karl Deisseroth at Stanford University. Called optogenetics, the method uses specific wavelengths of light to force cells to fire an electrical impulse. Along with Deisseroth, bioengineer Ritchie Chen used the technique to control mice's heartbeats with exquisitely precise timing. "We can target a specific cell without ever touching it," says Chen, of the University of California, San Francisco.

With each flash of a light, delivered through a fabric vest worn by the mice, muscles in the heart ventricles contracted, slamming blood out of the heart and into the body. "It was incredibly exciting to see these really precise heart contractions being evoked with light just delivered through the skin," Chen says.



Seeing with heartbeats Study participants were asked to look out for a hard-to-see gray circle (stimulus), while scientists measured their heartbeats (left, bottom) and brain activity (right, bottom) in the same moment (gray arrows). When the brain responded strongly to the heart rhythm, people were more likely to report seeing the gray circle.

H.D. PARK. *ET AL*/*NATURE NEUROSCIENCE* 2014

The researchers then studied the brains and behaviors of mice whose hearts were set racing. An artificially fast heartbeat didn't always affect mouse behavior, the team was surprised to learn. In some situations, the mice didn't seem to notice. But when they encountered danger — an exposed area, where in the wild the mice would be vulnerable to predators, or a sip of water that could come with a shock — the mice behaved more anxiously when their hearts were forced to race than when their hearts beat normally.

A pounding heart "wasn't this primal circuit to induce panic," Chen says. The mice were integrating signals from their heart and signals from their environment to arrive at a course of action. "And that was exciting to us because it meant that the brain was involved."

Further experiments turned up a key player in the brain: the insula. The human insula, one on each side of the brain, has been shown to have a role in emotions, internal sensations and pain. Shutting down neuron activity in the mice's insula silenced the racing heart's influence on behavior, the team found.

"Being able to manipulate the heart in this way," Tallon-Baudry says, "opens all sorts of ways to look at things that are much more subtle and might not be related to anxiety at all." The precise control of optogenetics could help researchers investigate the heart's influence on perceptions, decisions and memory — some of the key attributes that shape how a thinking, remembering, feeling person experiences the world.

Wiring diagrams are missing

In Chen's study, how signals moved from the heart to the insula and beyond isn't clear. "We are very much at the beginning of circuit dissection between the brain and the body," he says.

Still, scientists know some of the routes signals can take as they move from the heart to the brain. The textbook version goes something like this: Muscles in the heart ventricles contract, squeezing blood out. Cells in nearby blood vessels, including the aorta and carotid artery, sense the change and relay it to nerves.

One of those nerves is the vagus nerve, a rambling superhighway to the brain that sends missives about heart rates, digestion and breathing (SN: *11/28/15, p. 18*). Once the information arrives at the brain, it bounces from spot to spot in unknown ways. Our knowledge of these biological daisy chains is woefully incomplete, Tallon-Baudry says. “The full story is not so easy to get.”

Strick, the neuroscientist at the University of Pittsburgh, shares the same lament: “There are nerves that speak to the organs, and the organs speak to the brain, but we don’t know anything about the wiring diagram,” how and where these bits of crucial information actually get exchanged. And that’s an important thing to be missing. “You can say, “Who is driving whom?’ But we’re even more primitive than that. We don’t have a wiring diagram,” he says.

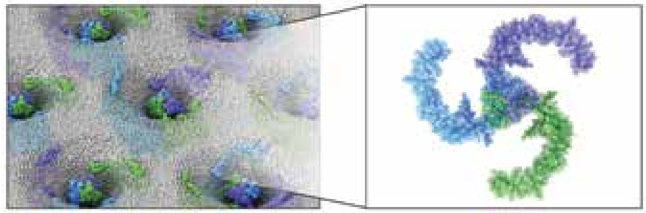
One way of scoping out the wiring involves, of all things, rabies virus. Years ago, Strick realized that he could use the virus to trace cell connections in the brain and body thanks to the virus’ very unusual trick: Rabies virus can hop backward from neuron to neuron, from message receiver to message sender. When designed to carry a fluorescent molecule, the virus can illuminate entire neural circuits in an animal.

That’s what Strick and colleagues have done with various organs — stomach and kidney, for instance — and the brain. Some of the most tantalizing connections he has found are between the adrenal glands, which pump out fight-or-flight hormones in an emergency, and specific brain regions, especially neural locales that control muscles.

And that’s what Strick would like to do with the heart as well. So far, he has a single glimpse of that data from a monkey. “We have one successful heart injection, and the data’s amazing,” Strick says. “The regions of the cerebral cortex that control the heart are mind-blowing. But it’s an n of 1.” This preliminary result needs to be confirmed in more animals, Strick emphasizes.

Tracing these paths would illuminate anatomical connections that undoubtedly exist. Strick and his colleagues are keen to explore more of the body, including the immune system’s spleen and the pancreas.

But another project has raised the possibility of a shortcut that jumps from heart to brain, and it was discovered by accident. Neuroscientist Veronica Egger of the University of Regensburg



Propeller-shaped proteins called PIEZO channels sit in cell membranes and serve as mechanical sensors. Forces, such as the pressure changes created by pulsing blood vessels, can alter the channels’ shape, alerting the cell to the change.

in Germany and colleagues were curious about the connections between nerve cells that process odors. To get a good look at the behavior of these cells, the team co-opted an ultrasimple system: a rat’s olfactory bulb, which is a part of the brain that handles smells, and the single blood vessel that supplies it with nutrients. In the experiment, an artificial pump sent fluid through the vessel.

But the experiment yielded a worrisome signal: rhythmic, collective activity in the nerve cells that seemed to be created by the pump. “Every neuroscientist knows pump artifacts and hates them,” Egger says.

But this signal, it turned out, was no artifact. It was the real deal. On a hike, Egger had a flash of insight that led to the discovery. Perhaps, she thought, the neurons were sensing the pressure caused by the pump directly.

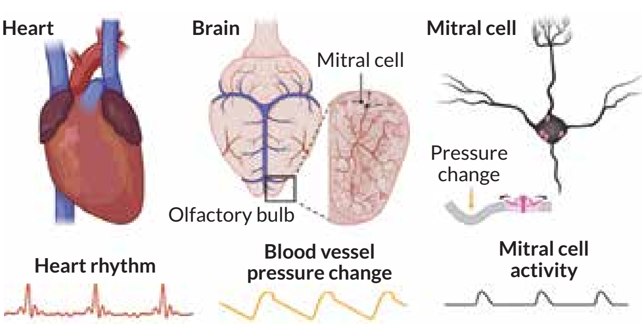
This direct sensing is a cellular possibility. In 2021, neuroscientist Ardem Patapoutian, a Howard Hughes Medical Institute Investigator at Scripps Research in La Jolla, Calif., had received a Nobel Prize for the discovery of mechanical sensors called PIEZO1 and PIEZO2, present in many animals including humans. These sensors, which sit in cell membranes and look like three-bladed propellers, can detect pressure changes, including the inflating of lungs that comes after a deep breath, the stretch of a full bladder and the pressure of blood moving through a vessel.

Poised on neurons in the olfactory bulb, these sensors might be detecting when the pump had pushed fluid. When Egger and her colleagues analyzed the system, they found that the neurons were in fact responding to the pressure changes from the pump. Blood pushing through vessels in mice’s brains also influenced the firing activity of nerve cells elsewhere, further experiments revealed. That included the hippocampus, which is involved in memory, and the prefrontal cortex.

These effects, described in the Feb. 2 *Science*, aren’t large; they’re quite subtle, Egger says. “We haven’t seen this before because it’s a very weak effect.” Still, the effect seems to indicate that neurons throughout these rodents’ brains have their fingers on the body’s literal pulse — an immediate signal that doesn’t need to travel through nerves from the heart.

“It is extremely likely that human brains do this,” Egger says, though that remains to be shown. Also unclear is what the brain might do with this pulse information or how it might be used to take measure of the body’s internal state. “What the brain needs this fast pathway for is completely unknown,” she says. “We just know that it happens.”

Message delivered Brain cells can take the heart’s pulse directly. When heart muscles squeeze (left), blood is pumped out into vessels, including those in the brain (rat brain shown, middle). In the olfactory bulb, specialized nerve cells called mitral cells (right) sense and respond to the pressure change, connecting the three rhythms (bottom lines).



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https://sos-vo.org/NSA24Puzzle

Why should we listen to the heart?

With all these lines of research, the field of interoception is energized in a way it hasn't been before, says Garfinkel, of University College London. "It's blown my mind how much the field has changed, and how much people are embracing the idea."

One of the reasons for the momentum is that body-brain communications might point to ways to treat disorders such as anxiety. "I do think it opens a window in understanding more about the fundamental etiology of these conditions," Garfinkel says. "Looking at the brain, you're looking at part of the story."

Though Garfinkel was focused on study participants' brain activity initially, she saw that their bodies were also responding, with racing hearts and other signs of panic. "Interoceptive numbing," in which a person is less able to accurately sense their bodily signals, has been linked to suicide attempts. And a lessened awareness of heart activity has been tied to a poorly understood kind of seizure.

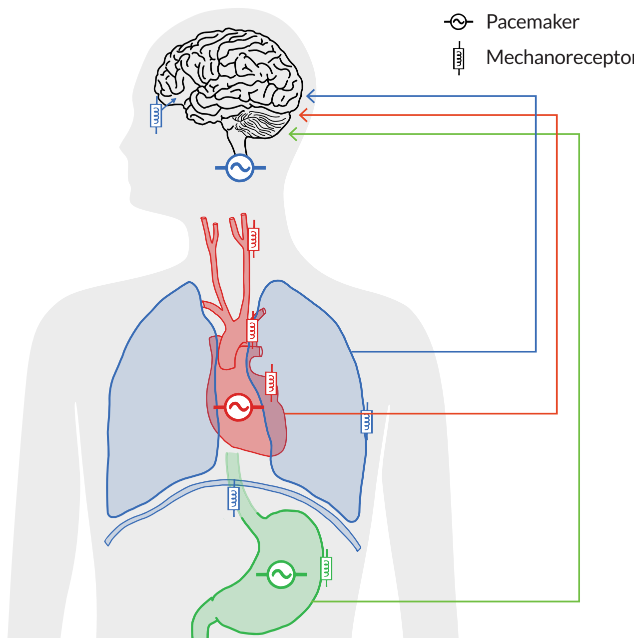
These days, Garfinkel is listening in on people's heart-brain conversations and testing whether training people to better detect their own heartbeat could alleviate anxiety. Anyone can experience anxiety, but autistic people have higher than average rates of anxiety. In 2021 in *eClinical Medicine*, Garfinkel and colleagues reported that after undergoing rounds of training to better sense the rhythm of their hearts, people with autism reported being less anxious. The training procedure asked people to say whether a steady beat they listened to was the same or different from their own internal heartbeat. Over six training sessions, each lasting about half an hour, people's accuracy improved. And their anxiety scores went down.

Garfinkel and her colleagues have since found similar results in people without autism, though those results have not yet been published.

It's not at all clear why this training procedure might alleviate anxiety, Garfinkel says. But still, the link may point to ways to treat anxiety. In many ways, the body is easier to change than the brain, Garfinkel says. "Rather than hit people with heavy medications that change their brain, it's intriguing and exciting to think there's an easier route — to change the body."

Understanding interoception may yield insights that go beyond alleviating anxiety. Some scientists, including Tallon-Baudry, suspect that signals from inside our bodies collectively help give rise to consciousness. The concept that consciousness requires a body that can be sensed and an organism striving to stay alive isn't new, but recent interoception results have added evidence to support the idea that the body's drive to monitor itself may be more important than previously thought.

Tallon-Baudry and her colleagues studied 68 people who had been fully unconscious. Their goal was to split these people into two groups: Those who still have no signs of consciousness, and those who had signs of consciousness in their brains. The team used HER signals, when a heartbeat prompts a neural thrum, to predict which people may have fleeting moments of consciousness but are unable to show it. "This is the moment when we do find the brain is responding to the heartbeat," she says. These results, published in 2021 in the *Journal of Neuroscience*, highlight just how rich and powerful signals from the heart to the brain can be, she says.



All together now Pacemaker cells in the heart, stomach and brain stem (controlling the lungs) and cells that can sense mechanical changes (mechanoreceptors) generate signals that can be used by the brain. These various body rhythms may contribute to a range of tasks, from perceptions to consciousness itself.

And remember that study she did that linked the HER thrum to whether a person saw a faint grid? She says that the people's perception of the grid had a lot to do with the eyes, the visual system, but it also depended on having a perspective — a point of view. But the perception also requires a person to experience the vision, interpret it and have that point of view — the "I" in the simple sentence, "I see it."

Interoceptive signals, and not just those from the heart, but also from the lungs, stomach, muscles, skin and more, may help create a person's sense of self — their "I," their identity as a conscious, aware entity with a point of view. Tallon-Baudry and colleagues described last year in *Nature Neuroscience* how rhythmic signals from the heart, the lungs and the stomach all converge in the brain. That review also advanced the idea that a sense of self relies on internal body signals.

Without a body and a beating heart, a stomach that can rumble and lungs that fill, the brain would be adrift. We navigate the world by seeing, hearing and touching too. We make choices to stay alive. Perhaps the real magic of consciousness comes from the combinations — of heart and brain, of the outside world and inside world, as mysterious as it may yet be. ■

Explore more

- Tahnée Engelen, Marco Solcà and Catherine Tallon-Baudry. "Interoceptive rhythms in the brain." *Nature Neuroscience*. October 2023.

T. ENGELEN ET AL/NATURE NEUROSCIENCE 2023

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Oluwatoyin Asojo, shown at Dartmouth Cancer Center with colleagues, deciphers the structures of pathogens' proteins.

ROB STRONG

Protein Whisperer

Oluwatoyin Asojo fights neglected diseases and mentors scientists from underrepresented groups

By Carmen Drahl

When Oluwatoyin Asojo was about 9 years old, she started volunteering regularly at an orphanage near where she lived in Nigeria. She remembers seeing children infected with parasitic worms or with faces disfigured from leprosy.

"It was eye-opening," Asojo says. She was raised on campus at one of Africa's finest universities and Nigeria's oldest — the University of Ibadan. Her mother was a schoolteacher, and her father ran teaching labs and his own anatomy and histology lab, where Asojo helped out as a kid. A published poet in high school, she hobnobbed with famous bards at the Ibadan poetry club. "You just realize just how blessed you are, living in this little cocoon," she says.

Helping those without her privilege became the driving force behind Asojo's career. Today, she has dual roles. As an expert in puzzling out protein structures, she's taken on proteins involved in diseases that disproportionately affect people in some of the world's poorest regions. Think malaria, HIV and scourges the research establishment typically overlooks, like leishmaniasis, a parasitic disease transmitted by sand flies. Notably, she's contributed to vaccines being tested in people to prevent hookworm — one of the illnesses she saw at the orphanage. In her second role as a university leader, she's guided scores of students from communities that are traditionally underrepresented in science. Last year, she left a chair position at Hampton University in Virginia to become the associate director of strategic initiatives at Dartmouth Cancer Center.

UNSUNG CHARACTERS

This article is part of a *Science News* series highlighting people of science — past and present — who we believe should be better known. Watch for more of these stories, and send your ideas to editors@sciencenews.org

A passion for proteins

Young Asojo wanted to do something about diseases, but despite her parents' wishes, she didn't think medical school would be a good fit. She left Nigeria on a scholarship at 16, moving to Canada and then Texas for higher education. At the University of Houston, where she got a Ph.D. in chemistry, watching proteins form solid crystals enraptured her. "It was like, 'Whoa, this is so beautiful.'"

In a technique called X-ray crystallography, scientists can use the crystallized form of a protein or other molecule to determine the 3-D layout of its atoms. Through two postdoctoral fellowships and a job at a pharmaceutical company in the late 1990s and early 2000s, Asojo mastered the technique.

Drugmakers use crystallography to understand the proteins involved in disease, including those essential for parasite survival and for viral entry into cells. Those structures can guide the development of medications or vaccines. But Asojo encountered few researchers applying crystallography to the illnesses she saw in the orphanage. Here was her chance.

In 2002, while a postdoc, Asojo began collaborating with the Human Hookworm Vaccine Initiative, an international effort funded in part by the Gates Foundation. She continued that work as she launched her own research investigations at the University of Nebraska Medical Center in Omaha.

Hookworm as parasitic adversary

Hookworm affects up to an estimated 740 million people. Most live in sub-Saharan Africa, Asia and Latin America, though pockets of infections exist elsewhere, including the United States. Humans and other animals get infected by coming into contact with soil containing hookworm larvae. The parasites penetrate the skin and migrate to the gut, where they feed on blood. Infected people may lose weight or have diarrhea or anemia. They pass eggs in their feces, starting the cycle anew. Medications don't always work, and repeat infections are common.

Asojo deciphered her first hookworm protein structure in 2005, for *Na*-ASP-2, which hookwarm larvae emit. The protein would become the active component of a vaccine tested in clinical trials, with the aim of preventing larvae from reaching the gut. She also contributed to a report describing how to mass-produce and purify the protein, precursor steps to crystallography and essential to ensuring a reliable supply of vaccine for testing.

Asojo solved four more hookworm protein structures. They offered details on how the proteins might interact with the immune system. In at least one case, her structure provided clues to a protein's role in parasite survival.

Crystallography is arduous work, says Graham Chakafana, a protein biochemist at Hampton University. A scientist must coax a protein to form crystals by trying a slew of chemical additives. Sometimes only one or two of those steps works, he says. "Imagine how devastating it is, because you might get to the middle and then fail." If anyone can power through that, Chakafana says, it's Asojo. "She's not someone who gives up."

Asojo attributes her persistence to her upbringing. "People gave me the freedom to mess up," she says. It taught her something: "Failure does not reflect on my intelligence. Failure just means I learned."

Asojo's philosophy was tested in 2012, when the experimental *Na*-ASP-2 hookworm vaccine caused hives in volunteers. The setback prompted a pivot to other vaccine candidates still in development. They contain other proteins Asojo also worked on. "It's not about if the project fails," she says. "It's, did we learn enough?"

"Failure does not reflect on my intelligence. Failure just means I learned."
OLUWATOYIN ASOJO

A leader and role model

By 2018, Asojo was eager to grow in a new role. In mentoring students for well over a decade, she'd noticed that many of her mentees from historically Black colleges and universities, or HBCUs, weren't given the same preparation for research as counterparts at other schools. "I wanted to work full time with students and junior faculty to catalyze their success," she says.

She moved to Hampton University, an HBCU, where she became chemistry and biochemistry department chair in 2019. Her focus shifted from doing her own research to training new researchers. She secured funding to test ways to help Black students stay in courses with high dropout rates, like first-year chemistry. Another grant funded development of a curriculum that prepares Hampton's most ambitious scholars to enroll in ultracompetitive Ph.D. and M.D./Ph.D. programs.

Her move to Dartmouth Cancer Center last August is a natural progression of that work. She's eager to recruit and retain students and early-career faculty from groups that tend to be underrepresented in the sciences.

In this photo taken in the 1970s in Nigeria, young Asojo (far left) is shown with her siblings and (back row) her mother Theresa T. Asojo, University of Ibadan physiologist V.S.V. Fernand and her father Akinola Asojo.

COLLECTION OF AKINOLA ASOJO

The trajectory of one student, named Jeremy Young, speaks to that work. At Hampton, Young lost a merit scholarship because a more-challenging-than-usual course load caused him to just miss a GPA requirement. Asojo helped him find other funding to support his education. Today, he attends graduate school at Johns Hopkins University School of Medicine.

"I'm a first-generation college student, and I didn't really have anybody who looked like me who was a chemist or a scientist," Young says. "I still owe my budding scientific career and the future career that I have in science to Dr. Asojo, because of how impactful she was for me in that moment." ■

Explore more

- Learn more about hookworm at bit.ly/HookwormCDC

Carmen Drahl is a freelance science writer based in Washington, D.C.

At Michigan Tech, researchers turn plastic into protein powder.

Of all the world's problems, faculty researcher Stephen Techtmann has two on his mind: plastic pollution and world hunger. Can one problem help solve the other? In his award-winning microbiology lab at Michigan Tech, Techtmann and his team of student researchers feed the plastics to oil-eating bacteria that chew them up and use them as fuel to grow. The end result doesn't look like plastic at all—it resembles a yeast byproduct that comes from brewing beer. This majority-protein byproduct is then dried out and turned into an edible powder. While the initial goal is to use the protein powder for disaster relief efforts, Techtmann hopes that plastic-turned-protein-powder could become the sustainable meat substitute of tomorrow.

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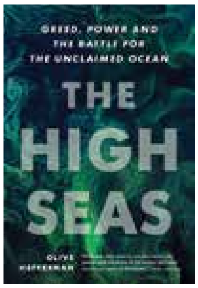
BOOKSHELF

The race to claim the high seas is on

The ocean is a rich, fertile and seemingly lawless frontier. It's a watery wild west, irresistible to humans hoping to plunder its many riches.

That is the narrative throughout *The High Seas: Greed, Power and the Battle for the Unclaimed Ocean*, a fast-paced, thoroughly reported and deeply disquieting book by science journalist Olive Heffernan, also the founding chief editor of the journal *Nature Climate Change*.



The High Seas
Olive Heffernan
GREYSTONE BOOKS, $32.95

The book begins by churning rapidly through the waves of history that brought us to today, including how we even define the high seas: all ocean waters more than 200 nautical miles from any country's coastline. In many ways, the modern ocean grab was set in motion some 400 years ago. A bitter feud between Dutch and Portuguese traders culminated in a legal document called the *Mare Liberum*, or the "free seas," which argues that the ocean is a vast global commons owned by no one.

Heffernan devotes a chapter each to different ways people are increasingly staking claims to international waters, an expansion called the Blue Acceleration. Some are hunting for new fishing grounds or prospecting for seafloor ores. Others are searching for new medicines in the DNA of deep-sea microbes, sponges or sea lilies. Still others are exploring how to boost the ocean's carbon uptake to help slow climate change. Even the space industry wants a piece of the ocean — to create watery graveyards for defunct spacecraft.

The careening from one ocean ambition to another underscores one of the book's biggest takeaways: We've established a precarious new type of ocean ecosystem, and it is going to be incredibly difficult — maybe impossible — to juggle all the priorities while also protecting ocean health and biodiversity.

Consider Trondheim, Norway, where Heffernan visits the SINTEF SeaLab. One of the world's wealthiest oil states, Norway wants to move its economy away from oil and more toward aquaculture, partly by dramatically increasing the production of its coastal salmon farms. The ocean's twilight zone, the murky waters that extend from about 100 meters to 1,000 meters below the surface, where sunlight no longer penetrates, could provide an immense untapped resource of feeder fish for those farmed salmon. By at least one estimate, Heffernan writes, the twilight zone contains as much as 95 percent of the ocean's fish by weight.

But these twilight denizens are also key to the ocean's ability to sequester atmospheric carbon. Crustaceans, fish and other creatures rise toward the surface to feed on carbon-bearing plankton at night, and then sink into the depths during the day — carrying that carbon into the deep.

Such conflicting desires to plunder and protect show up over and over again. Nations urging conservation in one arena may push for increasing exploration or exploitation in another, Heffernan writes. The European Union in 2021, for example, offered subsidies to its fishing fleet to range farther offshore, even as it committed to sustainable fishing. Nations keen to commit to protecting marine life and combating climate change may be the same countries that support deep-sea mining, which may be detrimental to life on the ocean floor.

The problem, Heffernan says, isn't that the high seas are without any rules. Rather, there's "a mishmash of organizations and bodies, each using their own rulebook." Plus, she adds, "I now realize that many of those tasked with governing this space willfully ignore science and disregard expert advice."

There are global efforts afoot to establish uniform, consistent regulations on ocean activities. In particular, Heffernan notes that in 2023, United Nations member states passed the High Seas Treaty, which would establish marine protected areas in international waters. If ratified, the treaty could be a big step toward conserving ocean biodiversity.

But be warned: This is not an uplifting book. By the final chapter — titled, somewhat unconvincingly, "Hope for the high seas" — it's hard to know what anyone could actually do to help save the ocean. What *The High Seas* does, and powerfully, is convey the sheer scope and complexity of the Blue Acceleration. We're at a crucial juncture, Heffernan writes: "We can continue going ever deeper and further offshore in our quest for new sources of wealth, or we can strike a more sustainable balance." — *Carolyn Gramling*

One pressure on international waters is the search for new sources of fish to support aquaculture (a salmon farm in Norway is shown).

MARIUSLTU/GETTY IMAGES PLUS

CONVERSATIONS WITH MAYA

ERIKA EBBEL ANGLE
CEO and cofounder, Ixcela
Founder, Science from Scientists

Maya Ajmera, President & CEO of Society for Science and Executive Publisher of Science News, chatted with Erika Ebbel Angle, CEO and cofounder of Ixcela, a biotech company improving health outcomes through the treatment of gut microbiomes. Angle also founded the nonprofit Science from Scientists, which brings scientists into classrooms to deliver lab-based lessons. Angle competed in the 1999 Science Talent Search (STS) and the 1997 International Science and Engineering Fair (ISEF), both programs of Society for Science.

Do you have any favorite memories from STS and ISEF?

My favorite was ISEF, which took place in Kentucky. The energy of the event, with students from all around the world, all extremely excited about science and their projects, was incredibly unique and awesome. When you think of science fair, you might think you'll meet super science dorks, but I met well-rounded, talented people with multiple interests. I went to a small private school, and ISEF opened my mind to the world.

I also had some incredible experiences with STS, bonding with my group of finalists and being interviewed by high-profile media. It was wonderful to be celebrated for my achievements and hard work. During the identity development of a child, knowing that they're celebrated helps to create a sense of confidence and feeling that someone cares.

What led you to pursue a career in science?

When I was in elementary school, I had to do a science fair project, and of course, it's a mad scramble to decide what to do. I decided I wanted to see whether cells commit suicide when they were infected by viruses. I was 11 and started by calling local labs looking for an internship. As you can imagine, it didn't go very well. But one lab actually called back, and the director invited me to come on in. And so I did. I went back to his lab over and over again to talk to him. Eventually, he let me set up an experiment. I came back the next year, and the work I did evolved into my ISEF and STS projects. He became a mentor for the next 10 years and beyond. That experience led me down this path.

You were Miss Massachusetts 2004, which some might consider unusual in the world of science. How did you get involved in pageants?

When I was a student at MIT, my friends and I found ourselves watching the Miss America pageant one night, and they turned to me and said, "You should do this. You are always complaining that there is no place to dress up, and you have a talent—the piano." I said absolutely not. So they signed me up for it.

The way it works is you compete in your local pageant, which qualifies for the state pageant. If you win the state pageant, you compete in the Miss America pageant. When I arrived at the local pageant, I didn't know what I was doing, but the judges were very kind and helped me through it. I didn't win.

Initially, I thought I was done. But then I thought, "Doing this is going to help me become a more well-rounded individual." So I signed up for another local pageant, and then another. Eventually, I won a local pageant that qualified me for the state. I went through the process two more times, learning along the way, and in year three, I was named Miss Massachusetts and went to the Miss America pageant.

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Erika Ebbel Angle (second from right) participated in a 2017 Society for Science panel discussion featuring (from left to right) Maya Ajmera, Sara Sakowitz and Michelle Hackman.

What led to your work at Ixcela?

After I competed my bachelor's degree at MIT and was touring the state as Miss Massachusetts, I visited a Veterans Affairs hospital. The head of research introduced me to Wayne Matson, who eventually cofounded Ixcela with me. We were both interested in solving real-world problems that will help people live better lives, which is one of the things that led to my interest in working in his lab. Matson and I worked together in his lab while he was connected to Boston University's medical school, which is where I received my Ph.D.

Together, we decided to design a consumer product that would look at certain biomarkers in blood that are related to the gut microbiome that could be intervened upon to help people solve many of their serious health issues, from chronic gastrointestinal issues to anxiety.

Recently, we have been exploring oncology. We're running a series of pilots with cancer hospitals to explore whether patients on chemotherapy and immunotherapy may benefit from Ixcela's gut microbiome programs. When patients are on these therapies, typically the first thing that gets "mashed up" is their gut microbiome. Through pilot programs, we're able to reduce some of the horrible side effects that patients are dealing with and give hospitals an option for improving patient experience while lowering costs.

Tell us about Science from Scientists.

Science from Scientists is in 105 schools across California, Massachusetts and Minnesota. There are about 13,000 kids in the program, which focuses on grades 3 through 8. We send real scientists into the classroom every other week for the entire year, where they can answer a broad set of questions from the amazing students, serve as role models and demystify what it means to be a scientist. We seek to get students excited about and interested in STEM, because if they are excited and interested, they will be more likely to pursue a STEM career. And it works! Can you imagine how amazing it is—and it happens frequently—when students approach our scientists after class and ask for their autographs simply because they are scientists?

Science communication plays a vital role across many of your ventures. How do you approach communicating complex scientific concepts or the importance of an organization's mission to the general public?

I have noticed that many scientists aren't very good at communicating because there is often an assumption that everybody knows everything. If you are using terms that only you know, for example, your audience is not going to identify with the problem or understand why it's important. I don't make any assumptions and try to explain every term that is going to be discussed. Just because I live it every day doesn't mean my audience does. Working with elementary and middle school kids really forces me to think carefully about what I'm saying and how I am saying it.

What books are you reading now, and what books inspired you when you were young?

My favorite books as a kid were Richard Preston's *The Hot Zone* and Michael Crichton's *Jurassic Park*. I just started reading Patrick Stewart's memoir, *Making It So*. I'm a big *Star Trek* fan, and Patrick Stewart is remarkable. Prior to that, I was reading some adventure books, including *Voyage of Commitment* by Raymond F. Triplett and *Seven Years in Tibet* by Heinrich Harrer.

There are many challenges facing the world today. What's keeping you up at night?

I think what's challenging today is the population's lack of responsibility and accountability to each other and the world around us. I believe we owe it to the world, society, our families and our friends to pay it forward and try to make the world a better place. There is sort of this sense that people are only motivated by money or profit. It's disheartening. I think there is room to take a stand and make the world a better place.


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MARCH 23, 2024

Patient privacy

People with chronic conditions are taking medical research into their own hands, ***Betsy Ladyzhets*** *reported in "Patient as scientist" (*SN: 3/23/24, p. 22*).*

Connor, a patient highlighted in the story, asked to be identified by only his first name. But the story prints the full name of his spouse. "How exactly does that maintain [Connor's] medical privacy?" reader **Tom Begich** asked.

Connor's spouse, Nicole Bruno, agreed to print her last name because it differs from Connor's, **Ladyzhets** says. As part of *Science News*' fact-checking process, **Ladyzhets** also confirmed other details with the couple before publication.

Actually apex?

Shark bites are quite rare, ***Brianna Randall*** *reported in "Sharks bit fewer than 100 people in 2023" (*SN: 3/23/24, p. 4*).*

Randall wrote that sharks are the ocean's apex predators, animals at the top of a food web, whose population isn't regulated by other predators. Reader **Bruce Bailey** wondered if that's true, given that orcas sometimes prey on great whites.

Many sharks rank in the middle of a food web, but most sharks that bite humans, including great whites, are apex predators, says population geneticist **Gavin Naylor** of the Florida Museum of Natural History in Gainesville. And while orcas can kill or temporarily displace a great white, the whales don't control the sharks' population, says shark biologist **Neil Hammerschlag** of Atlantic Shark Expeditions in Boutiliers Point, Canada.

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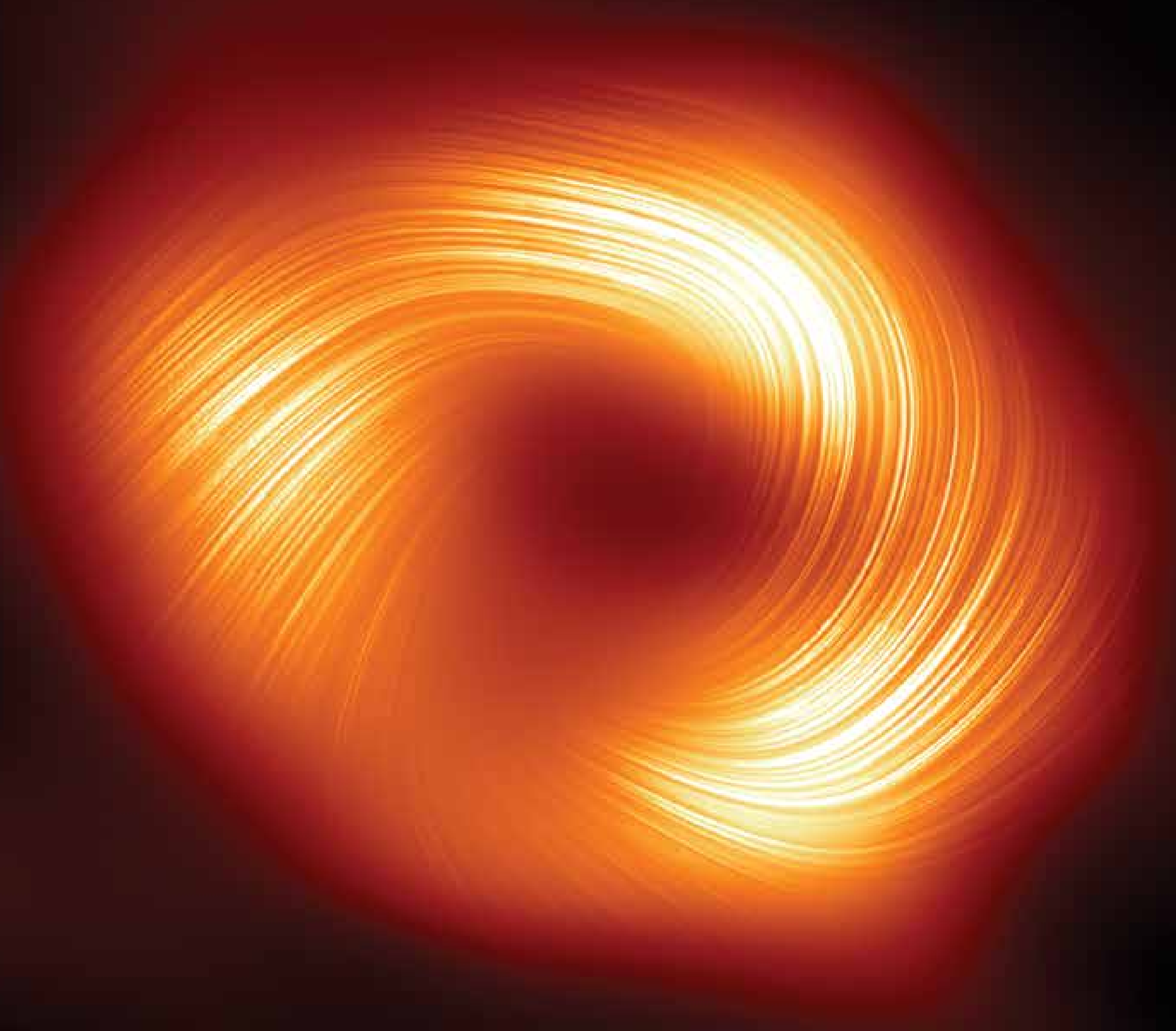

Magnetic fields swirl around our galaxy's central black hole

Astronomers have gotten their best intel yet on the magnetic fields around the gargantuan black hole at the center of the Milky Way.

A new image (above) of the black hole, dubbed Sagittarius A*, reveals it is encircled by highly ordered magnetic structures (not visible), researchers report in two papers published in the April 1 *Astrophysical Journal Letters*. The features are similar to ones previously detected surrounding galaxy M87's supermassive black hole (SN: 4/24/21, p. 6).

Using the Event Horizon Telescope, a global collection of radio telescopes working in tandem, scientists captured polarized light coming from around Sagittarius A*, which lies about 27,000 light-years from Earth. Polarized light has waves that wiggle in the same direction, such as up and down or left and right. Mapping such light often gives astronomers insights into underlying magnetic phenomena. In the new image, the bands show the direction of the polarized light.

The magnetic fields around Sagittarius A* are produced by charged particles in the hot, dense plasma surrounding the black hole. The new data reveal that the magnetic fields just outside the image's glowing ring are relatively strong, about 30 times that of Earth's, though still only about as powerful as a fridge magnet, says astronomer Sara Issaoun of the Harvard & Smithsonian Center for Astrophysics in Cambridge, Mass.

The Milky Way's central black hole is very different from the one in M87. The latter weighs as much as 6 billion suns, lives in a giant elliptical galaxy and ejects a powerful jet of plasma. Sagittarius A* weighs about the same as 4 million suns, lives in a smaller spiral galaxy and has no direct evidence of a jet.

Given such dissimilarities, "we expected to see different properties of their magnetic fields," Issaoun says. The fact that both are highly structured suggests such fields are ubiquitous around black holes and affect how these cosmic vacuum cleaners grow and evolve. —*Adam Mann*

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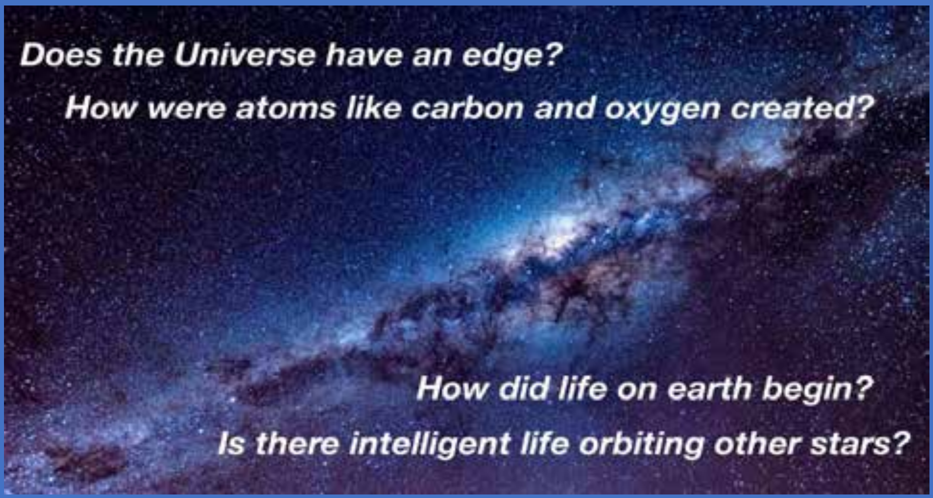

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