The Proton's Charming Quarks | Sea Sponge Snot Rockets

Science News

MAGAZINE OF THE SOCIETY FOR SCIENCE ■ SEPTEMBER 10, 2022

Smokestack Solutions

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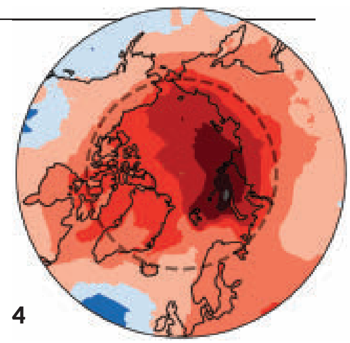

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COVER To keep fossil fuels in the ground and cut planet-heating emissions, plastics are being made from smokestack CO_2. *Mint Images/Mint Images RF/Getty Images Plus*

FROM TOP: HENRIQUES BALIDY; M. RANTANEN/FINNISH METEOROLOGICAL INSTITUTE; CHASING LIGHT – PHOTOGRAPHY BY JAMES STONE JAMES-STONE.COM/MOMENT/GETTY IMAGES

Science is global, so our coverage should be too

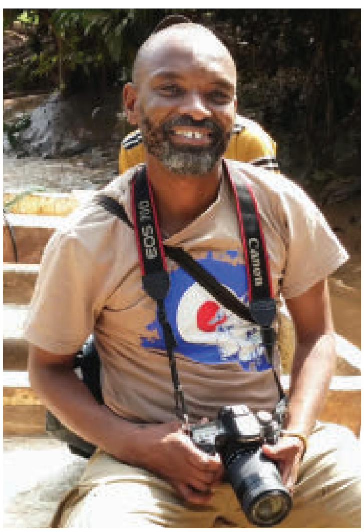
The United States has been a world leader in science for decades, both in investment and in volume of research published. But now many countries beyond North America and Europe, including China, India, Japan and South Korea, have become research powerhouses in their own right.

So covering just U.S.-based research would do the readers of *Science News* a disservice, since it fails to reflect the reality of science as a human endeavor common to all cultures. Thus, we're always on the lookout for journalists in other countries who can report on science beyond our borders.

In this issue, science journalist Geoffrey Kamadi reports from Kenya on community efforts to restore mangrove forests, which can bring in revenue from ecotourism and carbon offsets (Page 16). Local residents conduct surveys of the forest and work with organizations in Kenya and elsewhere to analyze data and sell carbon credits to companies worldwide looking to offset their climate-warming carbon dioxide emissions. The revenue supports jobs and projects including buying new schoolbooks and improving the community's water supply.

To report the article, Kamadi took a seven-hour train trip from his home in Nairobi to the coastal city of Mombasa, and then a 45-minute taxi ride to the village of Gazi. He spent two days talking with residents and researchers and taking photographs. "There's a tangible effect to what they're doing," Kamadi told me by phone. "They can actually see the results of their effort."

Kamadi has always been fascinated by science, he says, so he decided to make it his focus as a journalist. He's written for publications in Africa and beyond. In 2020, his article on how the destruction of a water catchment area for a major river in Kenya is disrupting lives downstream won a AAAS Kavli Gold Science Journalism Award. "Science is about unearthing the truth," he says. "It's about explaining things and providing solutions to things we humans face."



In this issue, Geoffrey Kamadi reports on mangrove restoration in Kenya.

Some of our other recent international coverage of note includes Sibi Arasu's cover story in May on how farmers in India are adopting technologies to reduce their carbon footprint and generate income (SN: 5/7/22 & 5/21/22, p. 36); Yao-Hua Law's nocturnal expedition to report on Malaysia's elusive "flying lemurs" (SN: 11/21/20, p. 22); and Meghie Rodrigues' reporting from Brazil on a city's efforts to get all of its adult residents vaccinated against COVID-19 (*SN Online: 6/2/21*).

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— Nancy Shute, Editor in Chief

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FROM TOP: SOCIETY FOR SCIENCE; COURTESY OF G. KAMADI

For the Man Who Gives Everything and Expects Nothing

If you're anything like my dad, you give your family everything. Your name, your time, your values — the people in your life know they can depend on you for practically anything. In exchange for imparting all of this energy and experience, you expect nothing in return.

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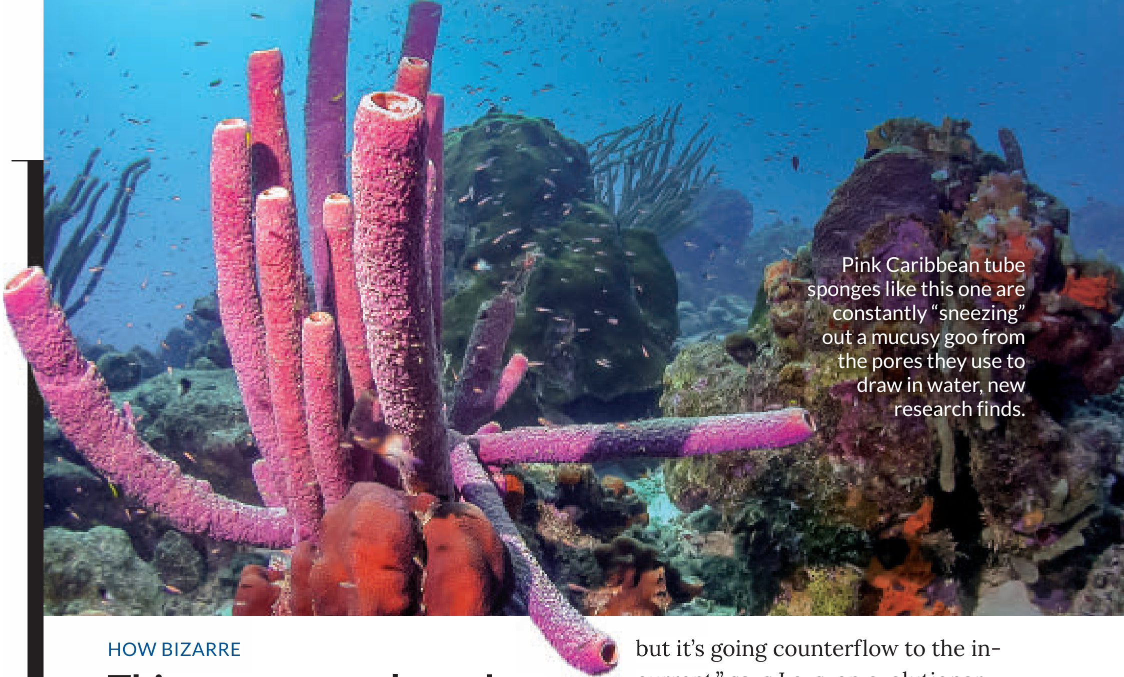
Excerpt from the September 16, 1972 issue of *Science News*

50 YEARS AGO

What holds the proton together

An experiment ... at the CERN Laboratory in Geneva ... gives an important clue to structural arrangements deep within the proton.... The result hints at the existence of a new and very strong fundamental interaction — the process that holds [quarks] together inside the protons.... A number of theorists have speculated about its nature and have even proposed an intermediate particle for it called a gluon.

UPDATE: Physicists finally found evidence for gluons in 1979, in the aftermath of electron-positron collisions at a German particle accelerator (*SN: 4/21/79, p. 262*). Gluons bind quarks inside protons via the strong force — the most powerful force in nature. Recent investigations of gluons' role inside the proton suggest the particles' energy makes up about 36 percent of the proton's mass (*SN: 12/22/18 & 1/5/19, p. 8*). Future particle accelerators could gauge gluons' contribution to the proton's internal pressure, which averages a million trillion trillion times the strength of Earth's atmospheric pressure (*SN: 6/9/18, p. 10*).



Pink Caribbean tube sponges like this one are constantly "sneezing" out a mucusy goo from the pores they use to draw in water, new research finds.

HOW BIZARRE

This sea sponge launches slow-motion snot rockets

The next time you spot a sea sponge, say "gesundheit!" Some sponges sneeze to clear debris from their porous bodies.

As filter feeders, sponges draw in water through inlet pores called ostia and strain it through an internal canal system for nutrients. But there are also inedible bits in the water, such as sediment. To prevent clogs of undesirable junk, a species of Caribbean tube sponge (*Aplysina archeri*) uses mucus to trap and sneeze out unwanted particles from its ostia, researchers report August 10 in *Current Biology*.

Coauthor Sally Leys likens the excretion to a runny nose. "It's constantly streaming, but it's going counterflow to the in-current," says Leys, an evolutionary biologist at the University of Alberta in Edmonton, Canada.

Typically, sponges use contractions dubbed "sneezing" to move water through their bodies in a one-way flow, from ostia to a hole near the sponges' top called the osculum. But time-lapse video of *A. archeri* revealed specks of mucus exiting from the ostia, moving against the flow of incoming water. Sneezelike contractions, some of which took almost an hour, moved the specks across the sponge's surface to points where they collected in gooey clumps.

A. archeri probably is not the only sponge species that uses the technique, Leys says. Biologists need to dig deeper to figure out how widespread it is. *— Jude Coleman*

THE EVERYDAY EXPLAINED

Why spiraling footballs sometimes miss the mark

In American football, some passes are caught and some are dropped — but all wobble as they fly. Spiraling pigskins tend to visibly wobble at either a slow or fast rate, depending on how the ball is thrown, researchers report June 23 in the ASME *Open Journal of Engineering*. That wobble, along with the ball's spin and Earth's rotation, causes passes to stray sideways.

Simulations of a spiraling pass show that a football traveling at around 27 meters per second with around 600 rotations per minute visibly wobbles either one or five times per second, say engineers John Dzielski and Mark Blackburn of the Stevens Institute of Technology in Hoboken, N.J. Wobbling occurs when the ball's spinning momentum interacts with a twisting force, turning the ball's nose away from the direction of flight.

Faster wobbles, which happen when wrist or arm movements apply extra energy during throws, generate lift that can push the ball sideways by up to several meters, the pair found. Earth's rotation also could cause a pass to drift several centimeters. That small impact could double when pockets of low- and high-pressure air sandwich the ball, bending its trajectory. So don't completely blame the quarterback for a failed pass this season. *— Nikk Ogasa*

JOHN ANDERSON PHOTO/ISTOCK/GETTY IMAGES PLUS

Watch a video of a sponge sneezing at **bit.ly/SN_SpongeBoogers**

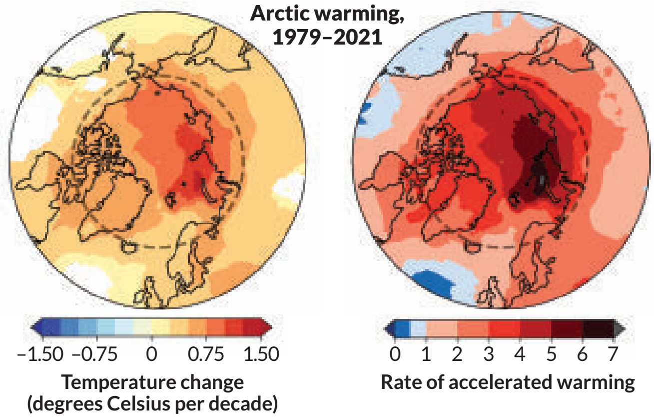
SCIENCE STATS

The Arctic is warming superfast

The Arctic is heating up at a breakneck speed compared with the rest of Earth. Now, analyses show that the region is warming even faster than scientists thought.

Over the last four decades, the Arctic's average temperature increased nearly four times as fast as the global average, researchers report August 11 in *Communications Earth & Environment*. Previous studies have suggested that the Arctic's average temperature is increasing two to three times as fast as elsewhere, as human activities drive climate change.

To calculate the pace of the accelerated warming, scientists at the Finnish Meteorological Institute in Helsinki analyzed observational data from 1979 through 2021. Globally, the average temperature increased by about 0.2 degrees Celsius per decade. The Arctic warmed by 0.73 degrees C per decade (left map, above) — almost four times as fast (right map), the team found. And that's just on average. Some parts of the Arctic, such as the Barents Sea between Russia and Norway, warmed as much as seven times as fast (dark red). — *Carolyn Gramling*



THE SCIENCE LIFE

Chemistry unravels ancient beauty secrets

Art historian Erin Griffey is a beauty maven. "I'm one of those people who reads the backs of beauty products," she says. That's why, while working on a book about beauty culture in Renaissance Europe, Griffey experienced déjà vu.

She noticed that many ingredients in beauty recipes from the 16th to 18th centuries — compiled from books, medical texts, pharmacopoeias and other sources — also appear in modern beauty products. For instance, rosewater is used in modern skin-hydrating mists and sulfur is found in some acne creams.

Such similarities are clues to what Renaissance-era people used the products for and how the products worked. But they are not the whole story. That's because the recipes often also list bizarre or even dangerous ingredients, from bile acids and calves' hooves to lead and poisonous plants. To gain insight, Griffey teamed up with her chemist colleagues at the University of Auckland in New Zealand to re-create the recipes. Thus the Beautiful Chemistry Project was born.

The team started with what Griffey calls "sticky recipes" because they're found in many sources throughout the Renaissance period: rosemary flowers in white wine and myrrh powder with egg white. Since the recipes tend to be vague and varied, chemist Michel Nieuwoudt and her team tinkered with procedures while Griffey searched various sources for clues to ingredient types and ratios.

"We knew we could not re-create it exactly as is," Griffey says of the recipe for rosemary flowers in white wine. "We do not have access to the rosemary plants that grew 500 years ago or the wines and whatever their chemical makeup was." But this legwork "enabled us to get closer to an approximation."

The team boiled rosemary flowers in round-bottom flasks each filled with a different solution, including sweet white wine, dry white wine and ethanol in water. Once the scientists filtered out the flowers and analyzed the resulting mixtures using gas chromatography and mass spectrometry, they found chemical compounds that are common in today's skin care products, including soothing camphor, eucalyptol and the fragrant alcohol linalool (SN: 7/27/02, *p. 56*).

The Renaissance-era recipe stated the potion would "make the face fair." Nieuwoudt's findings suggest how: by toning and moisturizing skin.

The team has also made progress on myrrh powder and egg whites. Experiments suggest that myrrh draws out proteins from egg whites and the egg whites extract resins, sugars and volatiles from the myrrh, resulting in a serumlike product that probably stimulates collagen growth, Nieuwoudt says.

Eventually, the team hopes to bring the re-creations to drugstore shelves, minus any unsafe ingredients. Until then, the beauty for the researchers lies in "digging [the recipes] out and understanding them," Nieuwoudt says.
— *Rina Diane Caballar*

Rosemary flowers boiled in white wine (left) is an ancient beauty potion with compounds found in modern skin care products, chemist Michel Nieuwoudt (middle) and historian Erin Griffey (right) say.

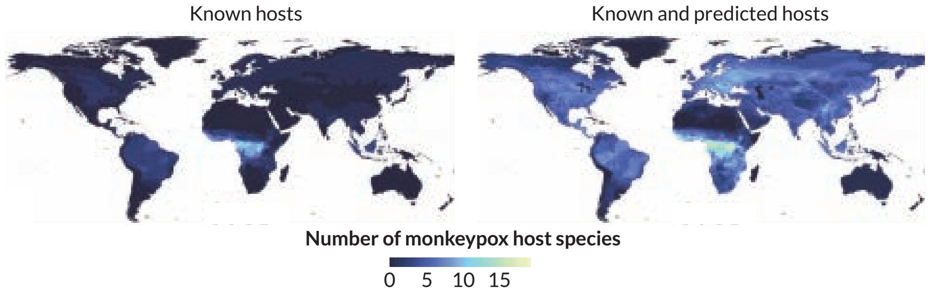
FROM TOP: M. RANTANEN/FINNISH METEOROLOGICAL INSTITUTE; E. GRIFFEY, M. NIEUWOUDT

News

BODY & BRAIN

Pet owner passes monkeypox to dog

Scientists predict the virus can infect many species



Wider spread Monkeypox is known to infect 51 species, including humans. Most known hosts are African animals (light blue, left map). But a new study predicts the virus has the potential to infect a broader range of species around the world (right map).

M.S.C. BLAGROVE ET AL/BIORXIV.ORG 2022, IUCN

BY TINA HESMAN SAEY

The first recorded case of a person passing monkeypox to a dog could be a harbinger of other animals catching the sometimes disfiguring and deadly virus. If that happens, monkeypox might establish animal reservoirs outside of Africa.

Two men in France appear to have spread monkeypox to their Italian greyhound, researchers report August 10 in the *Lancet*. The men reported letting the dog sleep in bed with them.

Monkeypox can spread through skin-to-skin contact, including during sex. Even more casual contact such as dancing in close confines can spread the virus, suggests a study published August 15 in *Emerging Infectious Diseases*. So can contact with objects an infected person has used, including bedding and clothing. Infectious virus lingers more often on such soft, porous materials than on hard surfaces, researchers report August 11 in *Emerging Infectious Diseases*. Some 60 percent of soft goods and 5 percent of hard surfaces tested still carried viable virus for at least 15 days.

In the case of the Italian greyhound, the animal developed pustules 12 days after its owners reported symptoms. Viral DNA from one of the men matched that from the dog, suggesting that he had spread monkeypox to the pet.

Usually monkeypox goes from animals, especially rodents, to people. But human-to-animal spread is fairly common with other viruses; people have given COVID-19 to dogs, cats and zoo animals, for instance. Some pox viruses, including cowpox, can infect a wide range of species.

How widely monkeypox can spread among nonrodent animals isn't known. Scientists have documented that the virus can infect 51 species, including apes, monkeys, anteaters, porcupines and opossums.

Monkeypox is endemic in some parts of Africa. But some scientists worry that the global outbreak, which has infected more than 36,000 people so far, creates more chances for the virus to jump from humans to animals. If that happens, the virus might become established in animal populations around the world, setting up new reservoirs that could cause repeated infections in humans and other animals.

Preliminary research suggests that monkeypox may be able to infect two to four times as many species as previously thought, researchers from the University of Liverpool in England report August 15 in a preprint at bioRxiv.org. To identify potential hosts, the team used machine learning trained to consider factors including the virus's genetic makeup, the number of species in a genus known to be infected by pox viruses, diet composition of potential hosts and where those animals live, says virologist Marcus Blagrove. About 80 percent of the predicted potential new hosts are rodents or primates. But domestic animals like dogs and cats are also predicted to be susceptible to infection.

Red foxes and brown rats are two particularly worrisome potential hosts, the team says. Foxes scavenge from garbage, which could bring them in contact with monkeypox-contaminated items. Brown rats are already known hosts for cowpox. They are common in sewers in Europe and could get infected via feces containing monkeypox. Though the study emphasized the risk in Europe, where over half of the current outbreak's cases have been reported, the findings could be applicable more widely. Brown rats live on every continent except Antarctica. Red foxes roam much of the Northern Hemisphere.

The study also names three European rodents that could become reservoir species. These rodents along with foxes and brown rats should be regularly surveyed for monkeypox to prevent new reservoirs from being established, Blagrove says.

But just because an animal can get infected with monkeypox doesn't mean they can pass it on. "There is a difference between accidental hosts and a reservoir," says Giliane de Souza Trindade, a pox virologist at the Federal University of Minas Gerais in Brazil. Accidental hosts are often dead ends for a virus. A true reservoir species is able to pass the virus from animal to animal. Such species may pass the virus to humans.

If dogs can easily get monkeypox, they may be able to pass it to humans or other animals through feces or saliva, Trindade says. As a precaution, pets that live with people who get monkeypox should be isolated from sick people and from other animals outside the home, she says.

Grant McFadden, a pox virologist at Arizona State University in Tempe, stresses that the dog's case is still an isolated report. "We don't know: Is this a rare thing or have we just not paid attention to it?" For now, he says, efforts should be focused on containing the outbreak among humans. While people with monkeypox should take care not to pass the virus to their pets, this case shouldn't cause undue worry, he says. "We're not at the panic button stage just yet." ■

ATOM & COSMOS

Betelgeuse is no stranger to change

Ancient and modern observations detail the star's evolving look

BY LISA GROSSMAN

The star Betelgeuse has always been a diva. Astronomers from antiquity through the present day have watched the red supergiant pulsing in the constellation Orion, and the star has continually put on a show, two new studies suggest.

Betelgeuse may be struggling to recover from a deep dimming episode a few years ago, one team reports. And the star appears to have put on its reddish stage makeup within the last 2,000 years, before which it wore yellow, another team says.

Together, the findings could tell scientists about how stars spew their guts into space and hint at how long it will be before Betelgeuse explodes in a supernova.

The Great Dimming

In late 2019, Betelgeuse suddenly grew dark for several months, an event astronomers call the Great Dimming. Months of subsequent observations led researchers to an explanation: The star had coughed out plasma that, months later, cooled and condensed into dust that blocked the star's face from the perspective of Earth. The surface of the star also cooled, contributing to the dimming (*SN: 12/5/20, p. 16*).

What happened next was also surprising, astrophysicist Andrea Dupree and colleagues report August 3 at arXiv.org. The star's pulsating glow became erratic.

"For 200 years, it had a nice 400-day oscillation," says Dupree, of the Harvard & Smithsonian Center for Astrophysics in Cambridge, Mass. "But that's gone now." Instead of a regular thrum, she says, the oscillations are "like an unbalanced washing machine, going 'wonka wonka wonka.'"

That suggests the star is still recovering from the loss of material in 2019, Dupree says. She calculates that Betelgeuse ejected several times the mass of the moon from its surface, leaving a large cool spot behind. The star's surface plasma is sloshing around as it returns to equilibrium.

If this picture is correct, it means red supergiants can spray material into interstellar space in discrete bursts, rather than a continuous stream. That's important to know because many of the elements that make up planets and people were formed in stars undergoing what Betelgeuse is going through now. Studying its growing pains and death throes can tell us about our own origins.

But this picture of Betelgeuse is still speculative, says astronomer Edward Guinan, an astronomer at Villanova University in Pennsylvania. Dupree's study is the first to include data collected via a new technique that lets astronomers follow the star year-round, even when Betelgeuse is gone from Earth's night sky for months at a time. Those extra observations might reveal recurring changes that have always been there, rather than picking up something truly new, Guinan says.

The material Betelgeuse lost could become visible to telescopes in 2023, Dupree's team predicts. "That would be proof" that the dimming was due to a single outburst, Guinan says.

Seeing yellow

The Great Dimming isn't the first time humans have recorded a major change in Betelgeuse's personality. Two millennia ago, the star was a different color, astrophysicist Ralph Neuhäuser and colleagues report July 29 in *Monthly Notices of the Royal Astronomical Society*.

The team looked for ancient descriptions of more than 200 stars whose colors should have been visible to the naked eye in the last few thousand years. Most stars observed over human history had the same color recorded in the past as they display today, but not Betelgeuse.

The ancient Roman astronomer Gaius Julius Hyginus, who lived from about 64 B.C. to A.D. 17, described the star as having a similar color to Saturn: yellow. Sima Qian, a Han Dynasty astrologer and archivist, independently described the star as yellow around 100 B.C. Observers from other ancient cultures conspicuously left Betelgeuse out of their lists of red stars.

"I was not expecting…to find a star to change color in historical time," says Neuhäuser, of AIU Jena in Germany.

A star's color signals its evolutionary stage. When stars burn through the hydrogen fuel in their cores, they puff up and expel gases into space. That expansion makes their surface temperatures drop, and they change color from blue to yellow to red in fairly short order—about 10,000 years for a giant star like Betelgeuse, which is around 14 times as massive as the sun.

That relatively recent color change suggests Betelgeuse has just reached the end of its hydrogen-burning life, which means anyone waiting for the star to go supernova will have a very long wait. If the star became a supergiant in the last few millennia, then it has more than a million years to go before the boom. ■

The star Betelgeuse (above) in the constellation Orion turned from yellow to red within the last 2,000 years, scientists say.

CHASING LIGHT – PHOTOGRAPHY BY JAMES STONE JAMES-STONE.COM/MOMENT/GETTY IMAGES

Lionfish are dogged in pursuing smaller, faster prey.

LIFE & EVOLUTION

How lionfish catch fast fish

A persistent pursuit is the slow predator's key to success

BY JAKE BUEHLER

Lionfish aren't the fastest predators on the reef, but they can catch swift prey through pure tenacity, gliding slowly in pursuit until the perfect moment to strike.

That discovery may partially explain the lionfish's impact as an invasive species, researchers report in the Aug. 10 *Proceedings of the Royal Society B*.

Lionfish can blend in against a coral reef long enough to ambush small fish. But they're more visible when feeding in open water. To see how the predators hunt in plain view, researchers placed red lionfish (*Pterois volitans*) in a tank and recorded them as they chased down a small reef fish. In 19 of 23 trials, the lionfish attempted to capture and eat prey. They were successful 74 percent of the time.

The prey swam about twice as fast as the lionfish. But many still fell victim to what the researchers call a "persistent-predation strategy": The lionfish swim toward the fish, aiming for its current position, not the direction to intercept its path. The pursuit is incessant. "If they're interested in something and they want to try to eat it, they just seem to not give up," says Matthew McHenry, a biomechanist at the University of California, Irvine.

In contrast, the prey fish did bursts of fast swimming along with short pauses. "Over time, all those pauses add up and allow this lionfish to get closer and closer and closer," says coauthor Ashley Peterson, a comparative biomechanist also at UC Irvine. The slightest mistake can doom the prey.

"This is a good example of 'slow and steady wins the race,'" says marine ecologist Bridie Allan of the University of Otago in Dunedin, New Zealand. But she wonders how the chase would play out in the wild, without the spatial restrictions of the tank.

If life in the wild resembles the lab, the hunting tactic may contribute to the lionfish's destructive invasions of the Caribbean, western Atlantic and the Mediterranean. But other factors, such as the lionfish's huge appetite or prolific reproduction, might play a bigger role. ■

EARTH & ENVIRONMENT

Beavers help fight climate change

Dams boost water storage and lower temperatures

BY RICHARD KEMENY

In the upper reaches of the Skykomish River in Washington state, a pioneering team of nature's civil engineers is keeping things cool. Relocated beavers boosted water storage and lowered stream temperatures, indicating such schemes could help mitigate the effects of climate change.

Just one year after their arrival, the new recruits brought average water temperatures down by about 2 degrees Celsius while nearby streams without beavers warmed by 0.8 degrees C. Beavers also raised water tables by as much as about 30 centimeters, researchers report in the July *Ecosphere*. While scientists have discussed beaver dams as a way to restore streams and bulk up groundwater, the effects of a large, targeted relocation had been relatively unknown (SN: 3/27/21, p. 22).

"That water storage is … what can keep the ecosystem resilient to droughts and fires," says ecohydrologist Emily Fairfax of California State University Channel Islands, who wasn't involved in the study.

The Skykomish River flows down the west side of Washington's Cascade Range. Climate change is already transforming the region's hydrology: Snowpack is shrinking, and snowfall is turning to rain, which drains quickly. Waters are also warming, which is bad news for salmon populations.

Beavers tinker with hydrology too. They build dams, ponds and wetlands, deepening streams for their burrows and lodges. The dams slow the water, storing it upstream for longer, and cool it as it flows through the ground underneath.

From 2014 to 2016, aquatic ecologist Benjamin Dittbrenner of Northeastern University in Boston and colleagues relocated 69 beavers to 13 upstream sites in the Skykomish River basin, some with relict beaver ponds and others untouched. As beavers are family-oriented, the team moved whole clans to increase the chances that they would stay put.

At the five sites that saw long-term construction, beavers built 14 dams, and the volume of surface water increased to about 20 times that of streams with no new beaver activity. Meanwhile below ground, wells at three sites showed that after dam construction, the amount of groundwater grew to more than twice what was stored on the surface in ponds.

Crucially, the dams lowered temperatures enough to almost completely take the streams out of the harmful range for salmon during a particularly hot summer. "These fish are also experiencing heat waves within the water system, and the beavers are protecting them from it," Fairfax says. "That to me was huge." ■

SIRACHAI ARUNRUGSTICHAI/MOMENT/GETTY IMAGES

EARTH & ENVIRONMENT

Giant undersea crater discovered

Not one, but two asteroids may have slain the dinosaurs

BY NIKK OGASA

Chicxulub, the asteroid that wiped out most dinosaurs, might have had a little sibling.

Off the coast of West Africa, hundreds of meters beneath the seafloor, scientists have identified what appears to be the remains of an 8.5-kilometer-wide impact crater, which they've named Nadir. The team estimates that the crater formed around the same time that another asteroid — Chicxulub, the dinosaur killer — slammed into what's now Mexico (SN: 2/4/17, *p.* 16). If confirmed, it could mean that nonbird dinosaurs met their demise by a one-two punch of asteroids, researchers report in the Aug. 19 *Science Advances*.

"The idea that [Chicxulub] had help — for want of a better phrase — would have really added insult to serious injury," says study coauthor Veronica Bray, a planetary scientist at the University of Arizona in Tucson.

Around 200 impact craters have been discovered on Earth (SN: 12/22/18 & 1/5/19, *p.* 40), the vast majority of which are on land. That's because impact craters at sea gradually become buried under sediment, Bray says, which makes the Nadir structure a valuable scientific find, regardless of its potential role in the dinosaur extinction.

Geologist Uisdean Nicholson of Heriot-Watt University in Edinburgh happened upon the structure while analyzing data collected by seismic waves transmitted underground to detect physical structures offshore of Guinea. Lurking beneath the seafloor, and under nearly one kilometer of water, he discerned a bowl-shaped structure with a broken-up, terraced floor and a pronounced central peak — features expected of a large impact.

Based on the structure's dimensions, Bray, Nicholson and colleagues calculate that, if an asteroid was responsible for the terrain, it was probably over 400 meters wide. What's more, the researchers estimate that the impact would have rocked the ground like a magnitude 7 earthquake and stirred tsunamis hundreds of meters high.

> "The idea that [Chicxulub] had help — for want of a better phrase — would have really added insult to serious injury."
>
> VERONICA BRAY

Despite that fallout, the Nadir impact would have been far less devastating than the one from the roughly 10-kilometer-wide Chicxulub asteroid, says geologist Michael Rampino of New York University, who was not involved in the study. "It certainly wouldn't have had global effects."

Using geologic layers adjacent to Nadir, some with ages obtained by past studies, the team estimated that the structure formed around the end of the Cretaceous Period 66 million years ago. The Nadir asteroid may even have formed a pair with the Chicxulub asteroid, the two having been ripped apart by gravitational forces during a previous Earth flyby, the researchers speculate.

But the study's conclusions have some experts wary. "It looks like an impact crater, but it could also be something else," says geologist Philippe Claeys of Vrije Universiteit Brussel in Belgium. Confirming that the structure is an impact crater will require drilling for solid evidence, such as shocked quartz, he says. Alternative explanations for the structure's identity include the remains of a volcanic caldera or a collapsed dome of salt called a salt diapir.

The Nadir structure's age is another uncertainty. The seismic data show it appears to have formed sometime near the end the Cretaceous Period or maybe a little later, Claeys says. "But that's around the best they can say."

Drilling in the crater for minerals that contain radioactive elements could provide a more precise date of formation, Rampino says.

It's not the first time that scientists have investigated whether the Chicxulub impact had an accomplice. Some studies have suggested that the Boltysh crater in Ukraine may have formed at the same time as Chicxulub, though researchers have since determined that Boltysh formed 650,000 years later.

Bray and colleagues are negotiating for funding to collect samples from the Nadir crater, with aspirations to drill in 2024. That will hopefully settle some of the debate surrounding Nadir's origins, Bray says, though new questions will probably arise too. "If we do prove that this is the sister of the dinosaur killer, then how many other siblings are there?" ■

MARK GARLICK/SCIENCE PHOTO LIBRARY/GETTY IMAGES

Buckled terrain on the seafloor just off the coast of West Africa may have been formed by a 400-meter-wide asteroid crashing into the ocean at about the same time as the impact that wiped out the nonbird dinosaurs (illustrated).

ATOM & COSMOS

Physicists look for the proton's charm

The subatomic particle may contain a heavy type of quark

BY EMILY CONOVER

Protons may be intrinsically charming.

The subatomic particles are a mash-up of three lighter particles called quarks: two of the type known as up quarks and one down quark. But physicists have speculated for decades that protons may also host more massive quarks, called "intrinsic" charm quarks. A new analysis supports that idea, physicists report in the Aug. 18 *Nature*.

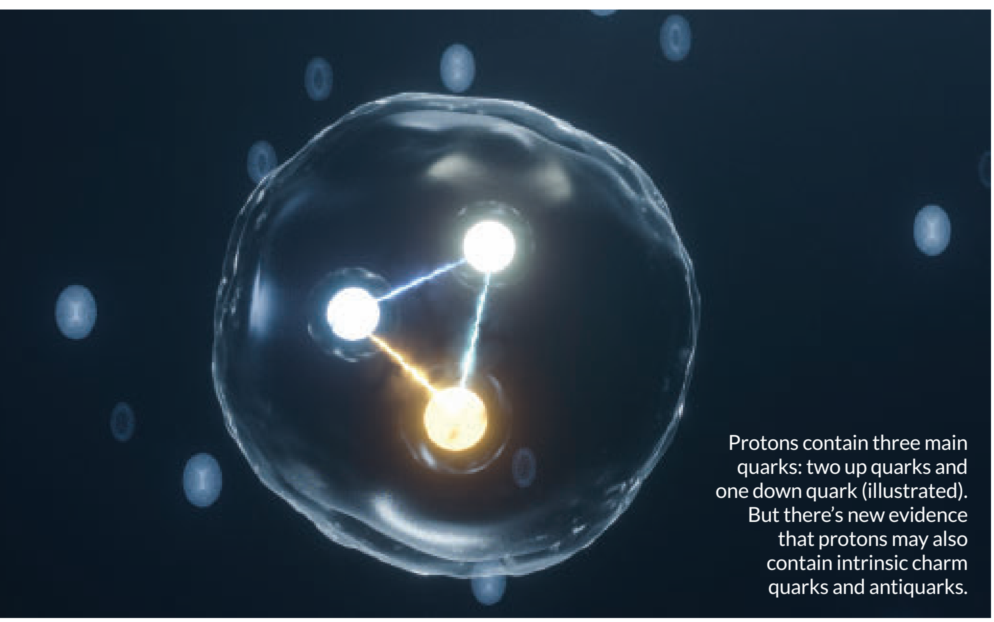
Charm quarks are much heavier than up or down quarks. So heavy that, mind-bendingly, "you can have a component of the proton which is heavier than the proton itself," says theoretical physicist Juan Rojo of Vrije Universiteit Amsterdam.

Rojo and colleagues combined a variety of experimental results and theoretical calculations in hopes of unveiling the proton's hypothetical charm. Measuring this feature is key to fully understanding the proton, one of the most important particles in the universe, Rojo says.

Physicists know that the more deeply you probe a proton, the more complicated it appears. When observed at very high energies, as in collisions at particle accelerators like the Large Hadron Collider, or LHC, near Geneva, protons contain a motley crew of transient quarks and their antimatter counterparts, antiquarks (*SN: 4/29/17, p. 22*). Such "extrinsic" quarks are created when gluons, particles that help "glue" the quarks together inside protons, split into quark-antiquark pairs.

Extrinsic quarks aren't fundamental to the identity of the proton. They're simply a result of how gluons behave at high energies. But charm quarks might exist inside protons even at low energies, in a more persistent, deep-seated form.

In quantum physics, particles don't take on a definite state until they're measured; they are instead described by probabilities. If protons contain intrinsic charm, there would be a small probability to find within a proton not only two up quarks and a down quark, but also a charm quark and antiquark. Since protons aren't well-defined collections of individual particles, a proton's mass isn't a simple sum of its parts (*SN: 12/22/18 & 1/5/19, p. 8*). The small probability means that the full mass of the charm quark and antiquark isn't added to the proton's heft, explaining how the proton may contain particles heavier than itself.



Protons contain three main quarks: two up quarks and one down quark (illustrated). But there's new evidence that protons may also contain intrinsic charm quarks and antiquarks.

Using thousands of measurements from experiments at the LHC and other particle accelerators, combined with theoretical calculations, the team found evidence for intrinsic charm in the proton at a statistical level called three sigma. The content of a particle can be described by how much momentum each of its components carry. The intrinsic charm quarks carry about 0.6 percent of a proton's momentum, the team reports.

But five sigma is typically required for a conclusive result. "The data and analysis are not yet sufficient… to get from 'evidence for' to 'discovery of' intrinsic charm," says Ramona Vogt, a theoretical physicist at Lawrence Livermore National Laboratory in California who wrote a perspective piece on the study for *Nature*.

What's more, defining what is meant by "intrinsic charm" isn't straightforward, muddling the comparison of the new finding with earlier results from different groups. "Previous studies have found different limits on intrinsic charm partly because they have used different definitions and schemes," says theoretical physicist Wally Melnitchouk of Jefferson Lab in Newport News, Va.

Notably, the new analysis incorporates results from the LHCb collaboration, which reported measurements potentially consistent with intrinsic charm in the proton in the Feb. 25 *Physical Review Letters*. Including that data in the study is "what's really new," says theoretical physicist C.-P. Yuan of Michigan State University in East Lansing. But Yuan has reservations about the type of calculation used to interpret the data. "It's not done at what we today call the state-of-art analysis."

Scientists need to pin down the proton's intrinsic charm content to better understand results at the LHC and other facilities that smash protons together and observe what comes out. Researchers have to be able to gauge the ins and outs of the objects they're colliding.

Data from future accelerators such as the planned Electron-Ion Collider could help, says theoretical physicist Tim Hobbs of Fermilab in Batavia, Ill. For now, the proton remains mysterious. "The problem is still with us; it remains very challenging." ■

SEFA KART/ISTOCK/GETTY IMAGES PLUS

EARTH & ENVIRONMENT

How to break down 'forever chemicals'

A new method degrades some PFAS into harmless by-products

BY JUDE COLEMAN

There's a new way to rip apart harmful "forever chemicals," scientists say.

Perfluoroalkyl and polyfluoroalkyl substances, also known as PFAS, are found in nonstick pans, water-repellent fabrics and food packaging, and they are pervasive throughout the environment. Exposure to high levels of some types of PFAS has been linked to an increased risk of cancer and reproductive problems.

PFAS are nicknamed forever chemicals for their ability to stick around and not break down. In part, that's because they have a superstrong bond between their carbon and fluorine atoms (*SN: 7/6/19 & 7/20/19, p. 7*). Now, using a bit of heat and two relatively common compounds, researchers have degraded one major type of forever chemical in the lab. The work, reported in the Aug. 19 *Science*, could help pave the way for a process to break down certain forever chemicals commercially, for instance after they are removed from wastewater.

"The fundamental knowledge of how the materials degrade is the single most important thing coming out of this study," organic chemist William Dichtel said in an August 16 news conference.

Scientists previously have found relatively simple ways of breaking the bonds of select PFAS, but most methods are energy-intensive and require extremely high pressures or temperatures.

Dichtel, of Northwestern University in Evanston, Ill., and colleagues experimented with two substances found in most chemistry labs: sodium hydroxide, or lye, and dimethyl sulfoxide, or DMSO. The team worked with a subset of forever chemicals called PFCAs, which contain carboxylic acid and constitute a large percentage of all PFAS.

When the team combined PFCAs with the lye and DMSO at 120° Celsius and under no extra pressure, the carboxylic acid fell off the chemical and became carbon dioxide. The loss of the acid led to "a cascade of complex reactions," Dichtel said, which caused the molecule to degrade into harmless fluoride ions and smaller carbon-containing products.

"It's a neat method. It's different from other ones that have been tried," says environmental engineer Chris Sales of Drexel University in Philadelphia. "The biggest question is, how could this be adapted and scaled up?" Northwestern has filed a provisional patent on behalf of the researchers.

The new process doesn't work on all forever chemicals, and it wouldn't work on PFAS already in the environment, the team says. But it could one day be used in wastewater treatment plants, where the pollutants can be filtered out of the water, concentrated and then broken down. ■

HUMANS & SOCIETY

Simplified voice box allowed for complex speech

Loss of vocal membranes gave humans better voice control

BY ASA STAHL

A crying baby, a screaming adult, a teenager whose voice cracks — people could have sounded this shrill all the time, a study suggests, if not for a crucial step in human evolution.

It's what we're missing that makes the difference. Humans have vocal cords, muscles in our larynx, or voice box, that vibrate to produce sound. But unlike all other studied primates, humans don't have small bits of tissue above the vocal cords called vocal membranes. That uniquely human trait helps people control their voices well enough to produce the sounds that are the building blocks of spoken language, researchers report in the Aug. 12 *Science*.

Vocal membranes act like a reed in a clarinet, making it easier for some animals to shout loud and shrill. When researchers used MRI and CT scans to look for vocal membranes in 43 different primate species, the scientists were surprised by what they saw: All primates except humans had the tissue.

That loss of vocal membranes would have been a "very major, very revolutionary event in human evolution," says Takeshi Nishimura, a primatologist at Kyoto University in Japan.

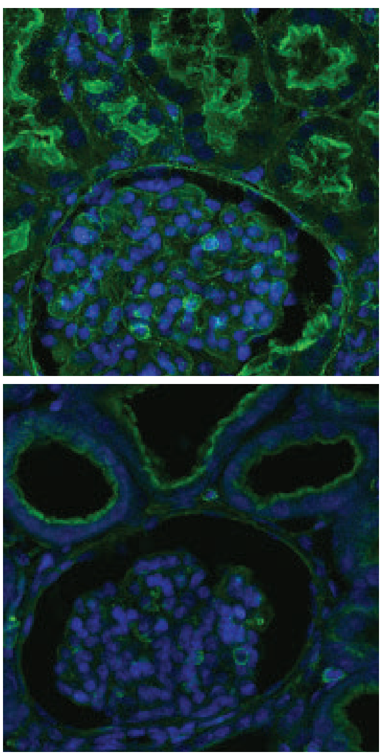
Primates mostly make sound in the same basic way: They push air out from the lungs while vibrating muscles in the larynx to create sound waves. To understand the role of the vocal membranes, Nishimura's team studied videos of voice boxes in action in chimpanzees, rhesus macaques and squirrel monkeys. The team also took larynxes from macaques and chimps that died of natural causes or were euthanized and — in what's common practice for the field — mounted the parts on tubes, pushing air through the larynxes to see how the vocal cords and membranes would react.

In both experiments, the larynxes made sounds that would often fluctuate wildly in pitch. Nishimura's team found that happens only when an animal has both vocal membranes and vocal cords.

In humans, that screeching can happen when we put extreme amounts of pressure on our voice, like when we scream — or when teens struggle with controlling their growing vocal cords and their voices crack. But those are rare cases. Since humans don't have vocal membranes, we usually make more stable sounds than other primates, the team concludes. Our mouths and tongues, the idea goes, can manipulate those stable tones into the complex sounds that language is based on.

"That's a really elegant explanation," says Sue Anne Zollinger, an animal physiologist at Manchester Metropolitan University in England who was not involved in the study. It's almost counterintuitive, she says: "You lose complexity to be able to produce more complex sounds."

Loss of vocal membranes isn't the only thing that makes humans more eloquent than other primates. Human brains are also structured differently from other primates in ways that give us more control over speech (*SN Online*: 12/19/16). ■



DAVID ANDRIJEVIC, ZVONIMIR VRSELJA, TARAS LYSYY, SHUPEI ZHANG/SESTAN LABORATORY/YALE SCHOOL OF MEDICINE

BODY & BRAIN

Restoring cellular life after a pig's death

Call it cellular life support for dead pigs. A complex web of pumps, sensors and artificial fluid can move oxygen, nutrients and drugs into a pig's body, preserving cells in organs that would otherwise deteriorate after the heart stops pumping.

The system, called OrganEx and described in the Aug. 11 *Nature*, builds off a system that can keep aspects of cellular life chugging along in oxygen-deprived pig brains (*SN: 5/11/19 & 5/25/19, p. 6*). "We wanted to see if we could replicate our findings in other damaged organs," says Nenad Sestan, a neuroscientist at Yale University School of Medicine. A similar system might someday be useful for protecting donated human organs destined for transplantation.

OrganEx does the job of hearts and lungs by pumping an artificial fluid throughout a pig's body. Mixed in a 1–1 ratio with the animal's own blood, the lab-made fluid provides fresh oxygen and nutrients, prevents clots and protects against inflammation and cell death. In a test, anesthetized pigs were put into cardiac arrest and left alone for an hour. Some pigs were then placed on a medical system used in hospitals, called extracorporeal membrane oxygenation, or ECMO. That system adds oxygen to the blood and pumps it into the body. Other pigs received the OrganEx treatment. Compared with ECMO, OrganEx provided more fluid to tissues. Fewer cells died, and some tissues even showed cellular signs of repairing themselves from the damage done after the heart stopped. Under a microscope, kidney cells that received OrganEx treatment, for instance, appeared brighter and healthier (top left) than ECMO-treated cells (bottom left). — *Laura Sanders*

Aloft balloons can detect earthquakes

The technique could be used to learn more about Venus' geology

BY FREDA KREIER

The balloon was floating over the Pacific Ocean when the sound waves hit. For 11 seconds, a tiny device dangling beneath the large transparent balloon recorded sudden jerky fluctuations in air pressure: echoes of an earthquake more than 2,800 kilometers away, in Indonesia.

That scientific instrument was one of four hovering high above the Malay Archipelago on December 14, 2021. That day the quartet became the first network of devices to monitor an earthquake from the air, researchers report in the Aug. 16 *Geophysical Research Letters*.

The advance could help scientists track quakes in remote areas on Earth. It also opens the door to one day sending specially equipped balloons to study the geology of other worlds, including our closest planetary neighbor.

"Venus is the sister planet of Earth, but it's the evil twin sister," says planetary scientist David Mimoun of the University of Toulouse in France. "We don't know why the two planets are so different. That's why we need measurements."

The idea of using balloons to study far-off rumblings on Earth has its roots in the Cold War. In the 1940s, the U.S. military launched a top secret project to spy on Soviet nuclear weapons testing using microphones attached to balloons floating high in the atmosphere. When the ground shakes, it releases low-frequency sound waves that can travel long distances in the atmosphere. The military planned on using the microphones to pick up the sound of the ground shaking from a nuclear explosion. But the project was eventually deemed too expensive and dropped — though not before one of the balloons crashed in New Mexico, launching the Roswell UFO conspiracy.

For decades after, balloon science stayed mostly in the realm of meteorology. Then in the early 2000s, Mimoun and colleagues started experimenting with using balloons for space exploration, specifically for studying extraterrestrial quakes.

Analyzing temblors is one of the main ways that scientists can learn about a planet's interior. On worlds with thin atmospheres, such as Mars or Earth's moon, this generally means sending a lander to the surface and measuring quakes directly on the ground (SN: 6/18/22, *p.* 5).

But landers don't last on Venus. The planet's dense atmosphere means that the surface has about the same pressure as Earth's deep ocean, with temperatures averaging around 450° Celsius — hot enough to melt lead. "Basically, it's hell," Mimoun says.

Landers have made it to the surface of Venus before (SN: 6/19/76, *p.* 388). But the probes lasted less than two hours before succumbing to the extreme heat and pressure. The chances of measuring a quake in that short time frame are slim, says Siddharth Krishnamoorthy, a research technologist at NASA's Jet Propulsion Laboratory in Pasadena, Calif., who wasn't involved in the balloon study. So while radar images of Venus have revealed a world dotted with volcanoes, scientists still don't know for sure if the planet is geologically active, he says.

Scientists have previously suggested using orbiters to detect quakes on Venus (SN: 9/10/05, *p.* 174). But quake-detecting balloons have better resolution and could provide the key to revealing the planet's interior activity, Mimoun says. But first he and colleagues had to show that they could design devices small enough to be carried by balloons but sensitive enough to pick up earthquakes far below.

In 2021, the team attached microbarometers to 16 balloons launched from Seychelles, an island country off the coast of East Africa. In December, four of the balloons — having drifted thousands of kilometers apart — recorded similar low-frequency sound waves. These changes in air pressure resembled ground readings of a magnitude 7.3 earthquake near the Indonesian island of Flores, indicating that the earthquake produced the sound waves. The researchers used the changes in air pressure to pinpoint the epicenter of the quake and calculate its magnitude.

Scientific balloons like this one, shown inflating in Seychelles in 2021, could one day be used to study earthquakes, volcanoes and other aspects of Venus' geology.

"This is a huge step forward in demonstrating the utility of this technology," says Paul Byrne, a planetary scientist at Washington University in St. Louis who was not involved with the study.

Even if balloons that are designed to survive the Venusian atmosphere are unable to pick up quakes, they might be able to detect changes in air pressure that reveal clues about Venus' volcanoes and mysterious highlands, Byrne says.

A probe last touched the planet's surface in 1985. And though several orbiters have spied on Venus over the years, only one is currently dedicated to the planet. Fortunately, Venus is entering a renaissance of interest from space agencies. At least two NASA missions to visit the planet are planned for the end of this decade.

Mimoun hopes that quake-detecting balloons will be part of the next major mission. The data could help researchers understand why Earth and Venus — similar in size and distance from the sun, relative to the other planets — went down different paths. "We have no clue," he says. "We need to go back." ■

ATOM & COSMOS

Gravity could aid dark matter search

Proposed detector would sense the stuff as it breezes past Earth

BY JAMES R. RIORDON

The secret to directly detecting dark matter might be blowin' in the wind.

The mysterious substance continues to elude scientists even though it appears to outweigh visible matter in the universe by a ratio of about 5-to-1. All laboratory attempts to directly detect dark matter — seen only indirectly by the effect it has on the motions of stars and galaxies — have gone unfulfilled.

Those attempts have relied on the hope that dark matter has at least some other interaction with ordinary matter in addition to gravity (SN: 11/12/16, p. 14). But a proposed experiment called Windchime, though decades from being realized, will try something new: It will search for dark matter using the only force it is guaranteed to feel — gravity.

"The core idea is extremely simple," says theoretical physicist Daniel Carney, who described the scheme in Orlando, Fla., in May at a meeting of the American Physical Society's Division of Atomic, Molecular and Optical Physics. Like a wind chime rattling in a breeze, the Windchime detector would try to sense dark matter "wind" blowing past Earth as the solar system whips around our galaxy.

If the Milky Way is mostly a cloud of dark matter, as astronomical measurements suggest, then we should be sailing through it at about 220 kilometers per second. This creates a dark matter wind, for the same reason you feel a wind when you stick your hand out the window of a moving car.

The Windchime detector is based on the notion that a collection of pendulums will swing in a breeze. In the case of backyard wind chimes, it might be metal rods or dangling bells that jingle in moving air. Though other efforts have looked for a dark matter wind, Windchime is unique in that it would rely on gravity. Its pendulums would be arrays of minute, ultrasensitive sensors that will be jostled by the gravitational forces they feel from passing bits of dark matter. Instead of air molecules bouncing off metal chimes, the gravitational attraction of the particles that make up the dark matter wind would cause distinctive ripples as the wind blows through a billion or so sensors in a box measuring about a meter per side.

While it may seem logical to search for dark matter directly using gravity, no one has tried it in the nearly 40 years that scientists have been pursuing dark matter in the lab. That's because gravity is, comparatively, a very weak force and difficult to isolate in experiments.

"You're looking for dark matter to [cause] a gravitational signal in the sensor," says Carney, of Lawrence Berkeley National Laboratory in California. "And you just ask … could I possibly see this gravitational signal? When you first make the estimate, the answer is no. It's actually going to be infeasibly difficult."

> "You're looking for dark matter to [cause] a gravitational signal.… Thirty years ago, this would have been totally nuts to propose."
>
> DANIEL CARNEY

That didn't stop Carney and a small group of colleagues from exploring the idea anyway in 2020. "Thirty years ago, this would have been totally nuts to propose," he says. "It's still kind of nuts, but it's like borderline insanity."

The Windchime Project collaboration has since grown to include 20 researchers. They have a prototype Windchime built of commercial accelerometers and are using it to develop the software and analysis that will lead to the final version of the detector, but it's a far cry from the ultimate design. Carney estimates that it could take another few decades to develop sensors good enough to measure gravity from dark matter.

Carney bases the timeline on the development of LIGO, which looks for gravitational ripples coming primarily from collisions among massive objects like black holes and neutron stars (SN: 3/5/16, p. 6). When LIGO was first conceived, he says, it was clear that the technology would need to be improved by 100 million times. Decades of development resulted in an observatory that views the sky in gravitational waves. With Windchime, "we're in the exact same boat," he says.

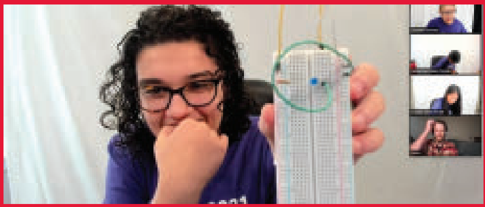
Even in its final form, Windchime will be sensitive only to dark matter bits that are at least roughly the mass of a fine speck of dust. That's enormous on the spectrum of known particles — more than a million trillion times the mass of a proton.

"There is a variety of very interesting dark matter candidates at [that scale] that are definitely worth looking for … including primordial black holes from the early universe," says Katherine Freese, a physicist at the University of Michigan in Ann Arbor who is not part of the Windchime collaboration. Black holes slowly evaporate, she notes, which could leave many relics formed shortly after the Big Bang at the mass Windchime could detect.

But if Windchime never detects anything at all, the experiment would still stand out from other dark matter detection schemes, says Dan Hooper, a physicist at Fermilab in Batavia, Ill., who is not affiliated with the project. That's because it would be the first experiment that could entirely rule out some types of dark matter.

If the experiment turns up nothing, Hooper says, "independent of anything else you know about dark matter particles, they aren't in this mass range." With existing experiments, a failure to detect anything could instead be due to flawed guesses about the forces that affect dark matter (SN: 8/13/22, p. 11).

Windchime is so far the only proposed experiment where seeing nothing would definitively tell researchers what dark matter isn't. With a little luck, though, the detector could uncover a wind from tiny black holes, or even more exotic dark matter bits, blowing past as we careen around the Milky Way. ■



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Kroeker | Manya Kukkar | Sharvil Kulkarni | Soaham Kumar | Priyam Kumaran | Mathangi Sanjay Kurup | Abigail Denise Lacayo | Anderson Lam | Darren Lau | Korynna Lau | Ethan Lavan | Daniel Lawner | John Lee | Noah Leighton | Emma Lee Lewis | Jason Anyi Lian | Sasha Lichtman | Yuha Lim | Brianna Liu | Chloe Liu | Jayden Liu | John Liu | Frank Eugene Lucci | Daisy Jane Luke | Violet Rae MacAvoy | Michael Lipeng Macri | Nandana Maheskumar | Vedant Malik | Rajarshi Mandal | Srijon Mandal | Gautam Manikandan | Jake Maniscalco | Louisa Markert | Alex Joe Mathew | Angel Mary Mathews | Aanvi Mathur | Vishak Meenachi | Akshadha Mehta | Samaira Mehta | Isabel Merriman | Cael Andrew Mess | Gabriel Hosein Mikati | Aadi Mishra | Sanvi Mishra | Parker Clayton Mitchell | Alexander Montgomery | Kasey Moore | Shaivi Moparthi | Kaileigh Morris | Ashvik Sai Nacham | Toshiro Nagafuji | Supriya Nair | Akira Nakamura | Akhila Reddy Nalladimma | Sharanya Natarajan | Jacob Tan Nguyen | Luka Anthony Nguyen | Eric Nie | Anika Nunes | Mira Nuthakki | Gabriella Sofia Olson | Jackson Scott Owens | Sritej Sai Padmanabhan | Laasya Pandravada | Shaily Nirav Pandya | Arlo John Lotilla Pangilinan | Kaya Parikh | Erinne Park | Kinnoree Rabeya Pasha | Neev Patel | Reeva Patel | Shiv Pillai | Siona Aditi Pramoda | Amritha Praveen | Avery Ryan Pyzik | Abigail Hou Qi | Caleb Quinby | Valerie Savanna Rahe | Anya Rai | Mujtaba Raja | Atharv Rajesh | Riya Rakesh | Haripriya Ramakrishnan | Vallabh Ramesh | Sahas Ravoor | Sia Reddy | Zain Rehman | Andrew Reveles | Michael Ribay | Sophia Ali Rizvi | Avery Alexandra Robinette | Luke Rodgers | Brielle Rola | Eleanor Rossi | Amanda Roth | Raya Sai | Nyambura Sallinen | Arjun Samavedam | Pranav Sambhu | Moitri Santra | Sanjan Singh Sarang | Monish Saravana Kumar Divya Sundari | Gavin Bootan Sarmiento | Mona Sophie Schwickert | Keshvee Sekhda | Aryan Shah | Nitya Ankit Shah | Sofia Shah | Zane Shaiyen | Zain Shariff | Kaitlyn Sharrer | Elizabeth Shen | Elizabeth Shen | Ethan Benjamin Shlossberg | Aryaman Dixit Shukla | Rayyan Ahmed Siddiq | Caleb Sigelman | Emma Abigail Simmons | Sarah Charlotte Simmons | Tavishi Sinha | Alexander Luong Sinn | Tanvi Sivakumar | Abhijith Sivaprakash | Quinton John Smith | Ana Spiride | Wyatt Steel | Liam Stemmle | Sebastian Stoker | Brian Stone | Sandhya Sudarsanam | Brian Sun | Mio Sutherland | Nikila Swaminathan | Jonathan Alexander Szeto | Ansh Thakkar | Lakshmi Thanikasalam | Nidhi Thankasala | Ahil Thendral | Nichelle Thinagar | Daniel Thomas | Jacob Thompson | Evie Thomsen | Kriesh Tivare | Gauri Todur | Maya Julia Trutschl | Kai Unwin-Wisnosky | Anjana Vaidyaraman | Ani Van More | Hamsini Vegi | Kethan Vegunta | Aditi Vijaya Venkataraman | Taylor Verdell | Nandini Verma | Neethika Vijay | Álvaro Daniel Villafuerte | Achuth Vinay | Eshan Vipuil | Anwita Suhrid Wadekar | Aman Rajalaxmi Wairkar | Senya Walker | Eliana Wang | Kallie Wang | Matthew Wang | Melody Wang | Adonis M. 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Mwatime Hamadi, a tour guide at Gazi Ecotourism Ventures in Kenya, explains how dropping the propagule from her hand into the soil below will germinate a new mangrove plant.

Saving the Mangroves

A community in Kenya shows the benefits of protecting the carbon-storing trees

By Geoffrey Kamadi

On the fringe of Kenya's Gazi village, 50 kilometers south of Mombasa, Mwatime Hamadi walks barefoot on a path of scorching-hot sand toward a thicket of trees that seem to float where the land meets the Indian Ocean. Behind her moves village life: Mothers carry babies on their backs while they hang laundry between palm trees, women sweep the floors of huts thatched with palm fronds and old men chat idly about bygone days under the shade of mango trees.

Hamadi is on her way to Gazi Forest, a dense patch of mangroves along Gazi Bay that coastal residents see as vital to their future. Mangroves "play a crucial role in safeguarding the marine ecosystem, which in turn is important for fisheries we depend on for our livelihood," she says as she reaches a boardwalk that snakes through the coastal wetland.

Hamadi is a tour guide with Gazi Ecotourism Ventures, a group dedicated to empowering women and their community through mangrove conservation. This group is part of a larger carbon offset project called Mikoko Pamoja that has taken root and is now being copied farther south on Kenya's coastline and in Mozambique and Madagascar.

> "The mangrove vegetation was a thriving, healthy ecosystem in precolonial times.... We're trying to bring back a semblance of that ecosystem."
>
> **ISMAIL BARUA**

Through Mikoko Pamoja, residents of Gazi and nearby Makongeni are cultivating an economic ecosystem that relies on efforts to preserve and restore the mangrove forests. Revenue from carbon credits sold plus the money Hamadi and others earn from ecotourism are split between salaries, project costs and village improvements to health care, sanitation, schools and more.

Mikoko Pamoja, launched in 2013, is the world's first mangrove-driven carbon credit initiative. It earned the United Nations' Equator Prize in 2017, awarded for innovative solutions to poverty that involve conservation and sustainable use of biodiversity.

"The mangrove vegetation was a thriving, healthy ecosystem in precolonial times," says Ismail Barua, Mikoko Pamoja's chairperson. During British rule, which stretched from the 1890s to 1963, the colonial government issued licenses to private companies to export mangrove wood. They did this without community involvement, which led to poaching of trees. Even after Kenya gained independence, mangroves were an important source of timber and fuel for industrial processes, main drivers of extensive destruction of the forests.

Today, mangrove restoration is helping the region enter a new chapter, one where labor and resources are well-managed by local communities instead of being exploited. "The community is now able to run its own affairs," Barua notes. Through innovative solutions and hard work, he says, "we're trying to bring back a semblance of that ecosystem."

A fragile carbon sponge

The dominant mangrove species in Gazi Forest is *Rhizophora murcronata*. With oval, leathery leaves about the size of a child's palm and spindly branches that reach to the sun, the trees can grow up to 27 meters tall. Their interlaced roots, which grow from the base of the trunk into the saltwater, make these evergreen trees unique.

Salt kills most plants, but mangrove roots separate freshwater from salt for the tree to use. At low tide, the looping roots act like stilts and buttresses, keeping trunks and branches above the waterline and dry. Speckling these roots are thousands of specialized pores, or lenticels. The lenticels open to absorb gases from the atmosphere when exposed, but seal tight at high tide, keeping the mangrove from drowning.

The thickets of roots also prevent soil erosion and buffer coastlines against tropical storms. Within these roots and branches, shorebirds and fish — and in some places, manatees and dolphins — thrive.

Mangrove roots support an ecosystem that stores four times as much carbon as inland forests. That's because the saltwater

OPPOSITE PAGE: G. KAMADI; THIS PAGE: DOLIMAC/ISTOCK/GETTY IMAGES PLUS slows decomposition of organic matter, says Kipkorir Lang'at, a principal scientist at the Kenya Marine and Fisheries Research Institute, or KMFRI. So when mangrove plants and animals die, their carbon gets trapped in thick soils. As long as mangroves stay standing, the carbon stays in the soil.

Robust estimates of mangrove forest area in Kenya before 1980 are not available, Lang'at says. However, with the clear-cutting of mangrove forests in Gazi Bay in the 1970s, he says, the area was left with vast expanses of bare, sandy coast.

Other parts of the country experienced similar losses: Kenya lost up to 20 percent of its mangrove forests between 1985 and 2009 because no mechanism existed for their protection. The losses had a steep price: Just as mangroves absorb more carbon than inland forests, when destroyed, they release more carbon than other forests. And since the mangroves provided habitat and shelter for fish, their destruction meant that fishers were catching less.

Recognizing this high cost, as well as the ecosystem's other benefits, Kenya's government ratified the Forest Conservation and Management Act of 2016, a law protecting mangroves and inland forests. Cutting down mangroves is now banned throughout the country, except in very specific areas under very specific circumstances.

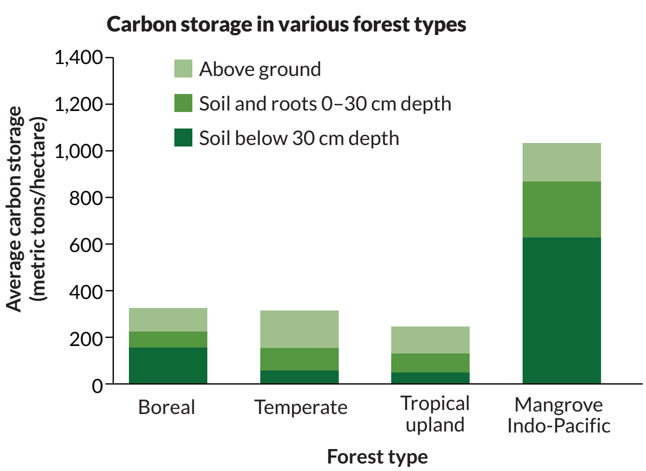
20 percent
Amount of mangrove forest Kenya lost between 1985 and 2009

Available data suggest that Kenya's rate of mangrove loss has declined in the last two decades. The country is now losing about 0.65 percent of its mangrove forest annually, according to unpublished evaluations conducted in 2020 by KMFRI. Since the turn of the millennium, global mangrove deforestation has slowed as well, hovering between a loss of 0.2 and 0.7 percent per year, says a 2020 study in *Scientific Reports*.

Mikoko Pamoja offers hope for turning around those declines. The project, whose Swahili name means "mangroves together," has its roots in a small mangrove restoration effort that started in 1991 in Gazi Bay, spearheaded by KMFRI. The effort evolved into a scientific experiment to see what it would take to restore a degraded ecosystem. It attracted collaborators from Edinburgh Napier University, Europe's Earthwatch Institute and other organizations across Europe.

Now, Gazi Forest boasts 615 hectares of mangrove forest, including 56,000 individual seedlings planted by the community. Plans to plant more mangrove trees — at least 2,000 per year — are in the works.

Carbon keepers Compared with other major forest types, mangrove forests capture and store more carbon dioxide, especially within tree roots and surrounding soil. SOURCE: D. DONATO *ET AL*/*NATURE GEOSCIENCE* 2011



Creating carbon credits

Gazi Forest siphons carbon from the atmosphere at a rate of 3,000 metric tons per year, says Rahma Kivugo, the outgoing project coordinator for Mikoko Pamoja. These aren't merely ballpark numbers: To sell the carbon offsets collected by Mikoko Pamoja, forest managers must calculate the amount of carbon stored by mangroves.

Volunteers venture into the forest twice a year, checking on 10 selected 10-square-meter plots in the wild forest and five plots in planted forest. Workers measure the diameter of mature trees at an adult's chest height. They then estimate the trees' height. Finally, they classify young trees as knee-height, waist-height, chest-height and higher.

From these observations, researchers estimate the volume of mangrove material above ground in each plot and extrapolate for the whole forest area.

Once they have an idea of the volume of plant material above ground, team members can estimate root volume below ground using a standardized factor specific to mangrove forests, says Mbatha Anthony, a research assistant at KMFRI in charge of carbon accounting. Even though mangrove forests store a lot of soil carbon, the project calculates carbon stored only by the tree itself because "calculating soil carbon is a resource-intensive undertaking for a small project like Mikoko Pamoja," Anthony says.

With an estimate of the total volume of biomass in the forest in hand, "we can then translate that into tons of carbon," says environmental biologist Mark Huxham of Edinburgh Napier University, who helps Mikoko Pamoja with its calculations. In general, 50 percent of aboveground biomass is carbon. Below ground, 39 percent of biomass is carbon.

The amount of carbon stored by Gazi Forest is then relayed to the Plan Vivo Foundation, a group based in Scotland that certifies carbon calculations. Once its calculations are certified, Mikoko Pamoja receives Plan Vivo Certificates, or PVCs.

One PVC is equivalent to one metric ton of carbon dioxide emission reductions. These PVCs are submitted to the Association for Coastal Ecosystem Services — an organization that markets carbon credits for Mikoko Pamoja and similar projects. Through ACES, Mikoko Pamoja's PVCs can then be purchased by anyone who wishes to offset their carbon emissions.

Roughly 117 hectares of Gazi Forest have been demarcated for the sale of carbon credits. "Mikoko Pamoja generates

E. OTWELL

approximately $15,000 annually from the sale of carbon credits," Anthony says. From 2014 to 2018, the project generated 9,880 credits — 9,880 tons of avoided carbon dioxide emissions.

A community at work

Mikoko Pamoja sells carbon credits at more than $7 per ton. Revenues get split in a clearly defined manner, according to what residents decide are pressing needs of Makongeni and Gazi villages. Around 21 percent pays wages of residents involved with Mikoko Pamoja. And "more than half of what is earned goes toward community projects," Kivugo says.

In total, about $117,000 has gone to community projects since Mikoko Pamoja was founded. These projects include donating medicine to health clinics and textbooks to schools and digging clean water wells. Plans are under way to revive a windmill in Gazi for pumping water and renovate Makongeni's primary school.

"The need in the community is great. So carbon trading is unlikely to meet all the needs," Huxham says. But the funds make a significant contribution to local livelihoods, which primes the community to support conservation, he says.

The approach seems to be working. On a winding path into the forest, visitors encounter a signboard, with large letters in Swahili declaring, "Take note! This is a Mikoko Pamoja area protected by the community. Littering is prohibited! Trimming trees is prohibited!"

Active community participation is central to Mikoko Pamoja's success. Not only do community members plant mangrove seedlings and survey trees to gauge carbon storage, community scouts monitor the health of this ecosystem.

Scouts clean up litter within the forests and survey the forest's biodiversity. From a wooden watchtower above the forest, scouts also track and report illegal logging.

"Should we spot suspicious activities in the forest, we will call the Kenya Forest Service rangers, who have the authority to detain and arrest any trespasser," says local scout Shaban Jambia.

Back at the boardwalk, Hamadi leads a small knot of visitors through the mangroves, pausing occasionally to touch a tree's waxy leaves. She plucks a propagule — a dark-brown pod longer than her hand — from a tree belonging to the mangrove species *Bruguiera gymnorhiza*.

She drops the propagule over the boardwalk's handrail, into the soft marsh soil about 1.5 meters below. It lands, sticking almost perfectly perpendicular in the ground. "This will soon take root and germinate into a new plant," she explains to the visitors. "That's how this species propagates."

Hamadi, the tour guide, is one of 27 members of the Gazi Women Mangrove Boardwalk group. Members offer interpretive services to visitors for a fee. The women also prepare Swahili cuisine for sale to groups visiting the area.

"A dish of coconut rice served with snapper fish is particularly popular, washed down with flavored black tea or tamarind juice," says Mwanahamisi Bakari, the group's treasurer.

These ecotourism efforts have attracted international support. The World Wide Fund for Nature Kenya, for instance, constructed a conference facility, which the women's group rents to those who want to use the location as a backdrop to discuss sustainability efforts.

G. KAMADI

Ismail Barua, chairperson of Mikoko Pamoja, stands at a water distribution kiosk funded by the organization's conservation work.

A template for others

Mikoko Pamoja's success is spurring conservation efforts throughout Kenya and beyond. For instance, on southern Kenya's coast is the Vanga Blue Forest, a swath of mangroves five times as large as Gazi Forest. Of Vanga Blue's more than 3,000 hectares of mangrove forest, a little more than 15 percent — 460 hectares — has been set aside for the sale of carbon credits following Mikoko Pamoja's example.

In 2020, with help from KFMRI, a network of scientists from countries along the western Indian Ocean published a blueprint for mangrove restoration. These guidelines are now being customized to suit the restoration plans of individual countries, says Lang'at. The group is also using Mikoko Pamoja's carbon credit example to set up projects of its own.

Madagascar's first community-led mangrove carbon project, known as Tahiry Honko (which means "preserving mangroves" in the local Vezo dialect), was introduced in 2013 and then certified for carbon sale by Plan Vivo in 2019. With Mikoko Pamoja as a guide, Tahiry Honko "is helping tackle climate breakdown and build community resilience by preserving and restoring mangrove forests," says Lalao Aigrette, an adviser at Blue Ventures, the conservation group coordinating the preservation effort.

Tahiry Honko is generating carbon credits through the conservation and restoration of over 1,200 hectares of mangroves

Mangrove restoration projects have spread outside of Kenya's Gazi Bay to places such as Limpopo estuary in Mozambique (shown), where residents collect and transport young seedlings.

surrounding the Bay of Assassins on Madagascar's southwest coast.

In Mozambique, studies are under way to gauge how much mangrove preservation can protect communities against cyclones, says Célia Macamo, a marine biologist at Eduardo Mondlane University in Maputo, Mozambique.

In the meantime, the Limpopo estuary and other locations along the Mozambican coast are sites of mangrove restoration efforts. KMFRI is helping local organizers structure their efforts. "We also hope they will assist us when we start working with carbon credits," Macamo adds.

Blue economies

Less than 1 percent of Earth's surface is covered by mangroves, equivalent to 14.8 million hectares. "Because this area is minuscule compared to terrestrial forests, mangroves have been neglected throughout the world," says James Kairo, chief scientist at KMFRI.

At Gazi Bay, a 2011 assessment by the United Nations Environment Programme estimated that the mangrove forests are worth about $1,092 per hectare per year, thanks in part to the potential of fisheries, aquaculture, carbon sequestration and damages averted by the coastal protection that mangroves provide. Assuming that numbers in Gazi Bay hold for the rest of the world, mangroves could provide more than $16 billion in economic benefits planetwide.

Toward the end of 2020, Kenya's government included mangroves and seagrasses for the first time in its Nationally Determined Contributions, or NDCs — the greenhouse gas emission reduction commitments for countries that ratified the Paris Agreement. The agreement seeks to limit global warming to below 2 degrees Celsius above preindustrial levels.

This inclusion commits Kenya to conserving mangroves to balance its emissions. Kenya's government now "recognizes the potential and importance of the mangrove and seagrass resources that Kenya has," Huxham says.

"This is a great commitment on the part of the government. The next challenge is the implementation of these commitments," says Kairo, who sits on the advisory board of the U.N. Decade of Ocean Science for Sustainable Development (2021–2030), which aims to support efforts to reverse the cycle of decline in ocean health.

Now, scientists and community managers for that effort need to determine how mangroves can adapt to rising sea levels. "How can communities next to the sea live in harmony with this system, without impacting on their resiliency and productivity?" Kairo asks.

Mikoko Pamoja is helping provide answers, Kairo adds. Thanks in large part to that small project that began in a secluded corner on the Kenya coast, those answers are now spreading to the rest of the world. ■

Explore more

- U.N. Environment Programme. "Guidelines on mangrove ecosystem restoration for the western Indian Ocean." 2020.

Geoffrey Kamadi is a freelance science journalist based in Nairobi, Kenya.

HENRIQUES BALIDY

FEATURE

Making Carbon Capture Fashionable

Chemists are using CO_2 instead of petroleum to make plastics

By Ann Leslie Davis

Clothing company Zara launched a line of dresses made partially from waste CO_2 in 2021. Other businesses are following suit.

It's morning and you wake on a comfortable foam mattress made partly from greenhouse gas. You pull on a T-shirt and sneakers containing carbon dioxide pulled from factory emissions. After a good run, you stop for a cup of joe and guiltlessly toss the plastic cup in the trash, confident it will fully biodegrade into harmless organic materials. At home, you squeeze shampoo from a bottle that has lived many lifetimes, then slip into a dress fashioned from smokestack emissions. You head to work with a smile, knowing your morning routine has made Earth's atmosphere a teeny bit carbon cleaner.

Sound like a dream? Hardly. These products are already sold around the world. And others are being developed. They're part of a growing effort by academia and industry to reduce the damage caused by centuries of human activity that has sent CO_2 and other heat-trapping gases into the atmosphere (*SN: 3/12/22, p. 16*).

The need for action is urgent. In its 2022 report, the United Nations Intergovernmental Panel on Climate Change, or IPCC, stated that rising temperatures have already caused irreversible damage to the planet and increased human death and disease (*SN: 5/7/22 & 5/21/22, p. 8*). Meanwhile, the amount of CO_2 emitted continues to rise. The U.S. Energy Information Administration predicted last year that if current policy and growth trends continue, annual global CO_2 emissions could rise from about 34 billion metric tons in 2020 to almost 43 billion by 2050.

ZARA

Carbon capture and storage, or CCS, is one strategy for mitigating climate change long noted by the IPCC as having "considerable" potential. A technology that has existed since the 1970s, CCS traps CO_2 from smokestacks or ambient air and pumps it underground for permanent sequestration. Today, 27 CCS facilities operate around the world — 12 in the United States — storing an estimated 36 million tons of carbon per year, according to the Global CCS Institute. The 2021 Infrastructure Investment and Jobs Act includes $3.5 billion in funding for four additional U.S. direct capture facilities.

But rather than just storing it, the captured carbon could be used to make things. This year for the first time, the IPCC added carbon capture and utilization, or CCU, to its list of options for drawing down atmospheric carbon. CCU captures CO_2 and incorporates it into carbon-containing products like cement, jet fuel and the raw materials for making plastics. Still in early stages of development and commercialization, CCU could reduce annual greenhouse gas emissions by 20 billion tons in 2050 — more than half of the world's global emissions today, the IPCC estimates.

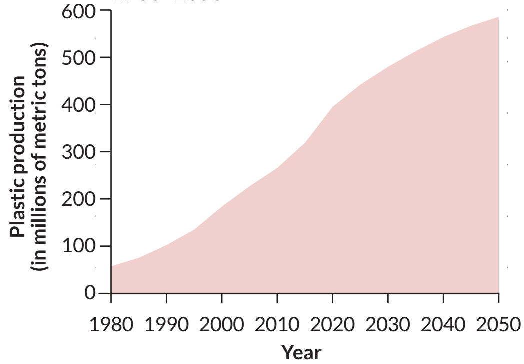
Such recognition was a big victory for a movement that has struggled to emerge from the shadow of its more established cousin, CCS, says chemist and global CCU expert Peter Styring of the University of Sheffield in England. Many CCU-related companies are springing up and collaborating with each other and with governments around the world, he adds.

The potential of CCU is "enormous," both in terms of its volume and monetary potential, said mechanical engineer Volker Sick at a CCU conference in Brussels in April. Sick, of the University of Michigan in Ann Arbor, directs the Global CO_2 Initiative, which promotes CCU as a mainstream climate solution. "We're not talking about something that's nice to do but doesn't move the needle," he added. "It moves the needle in many, many aspects."

The plastics paradox

The use of carbon dioxide in products is not new. CO_2 is used to make soda fizzy, keep foods frozen (as dry ice) and convert ammonia to urea for fertilizer. What's new is the focus on making products with CO_2 as a strategy to slow climate change. Today's CCU market, estimated at $2 billion, could mushroom to $550 billion by 2040, according to Lux Research, a Boston-based market research firm. Much of this market is driven by adding CO_2 to cement — which can improve its properties as well as reduce atmospheric carbon — and to jet fuel, which can lower the industry's large carbon footprint. CO_2-to-plastics is a niche market today, but

Global growth in plastic production, 1980–2050



Awash in plastic
Plastics are made from fossil fuels, and their production is on the rise. Researchers hope to do things differently, using carbon that is already above ground to make plastics. SOURCE: IEA

C. CHANG

the field aims to battle two crises at once: climate change and plastic pollution.

Plastics are made from fossil fuels, a mix of hydrocarbons formed by the remains of ancient organisms. Most plastics are produced by refining crude oil, which is then broken down into smaller molecules through a process called cracking. These smaller molecules, known as monomers, are the building blocks of polymers. Monomers such as ethylene, propylene, styrene and others are linked together to form plastics such as polyethylene (detergent bottles, toys, rigid pipes), polypropylene (water bottles, luggage, car parts) and polystyrene (plastic cutlery, CD cases, Styrofoam).

But making plastics from fossil fuels is a carbon catastrophe. Each step in the plastics life cycle — extraction, transport, manufacture and disposal — emits massive amounts of greenhouse gases, mostly CO_2, according to the Center for International Environmental Law, a nonprofit law firm based in Geneva and Washington, D.C. These emissions alone — more than 850 million tons of greenhouse gases in 2019 — are enough to threaten global climate targets.

And the numbers are about to get much worse. A 2018 report by the Paris-based intergovernmental International Energy Agency projected that global demand for plastics will increase from about 400 million tons in 2020 to nearly 600 million by 2050. Future demand is expected to be concentrated in developing countries and will vastly outstrip global recycling efforts.

Plastics are a serious crisis for the environment, from fossil fuel use to their buildup in landfills and oceans (SN: *1/16/21, p. 4*). But we're a society addicted to plastic and all it gives us — cell phones, computers, comfy Crocs. Is there a way to have our (plastic-wrapped) cake and eat it too?

Yes, says Sick. First, he argues, cap the oil wells. Next, make plastics from aboveground carbon.

Doing the carbon math

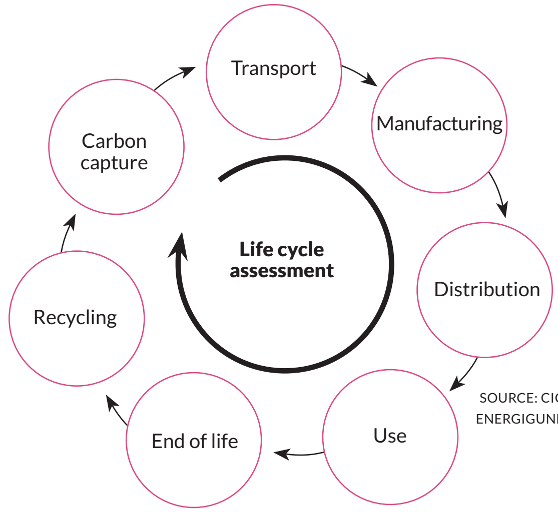
Calculating the carbon-reduction benefits of, say, making a pair of sneakers with CO_2 is complex. There's the fossil fuel that stayed in the ground, a definite carbon savings. But what about the energy cost of cooling the CO_2 into liquid form and transporting it to a production facility? And what about when your kid outgrows the shoes in six months and they can't be recycled into a new product because those systems aren't yet in place?

As companies try to reduce their carbon footprint, many are doing life cycle assessments to quantify the full carbon cost of products, from procurement of materials to energy use in manufacturing to product transport to user behavior and end-of-life disposal. It's a mind-bogglingly difficult metric, but such bean counting is needed to hold the planet to a livable temperature, says low-carbon systems expert Andrea Ramirez Ramirez of Delft University of Technology in the Netherlands.

Carbon accounting is easy to get wrong, she says. Differences in starting points for determining a product's "lifetime" or assumptions about energy sources can all affect the math.

Carbon use can be reduced at many points along the production chain, she says — by using renewable energy in the manufacturing process, for instance, or by adding atmospheric CO_2 to the product. But if other points along the chain are energy-intensive or emit CO_2, the final tally may show a positive rather than a negative number.

A product is carbon negative only when its production actually removes carbon from the environment, temporarily or permanently. The Global CO_2 Initiative, with European and American universities, has created LCA guidelines to standardize measurement so that carbon accounting is consistent and terms such as "carbon neutral" or "carbon negative" have a verifiable meaning. —*Ann Leslie Davis*



SOURCE: CIC ENERGIGUNE

Today, there are products made of 20 to over 40 percent CO_2. Finally, he says, build a circular economy, one that reduces resource use, reuses products, then recycles them into other new products.

"Not only can we eliminate the fossil carbon as a source so that we don't add to the aboveground carbon budget, but in the process we can also rethink *how* we make plastics," Sick says. He suggests they be specifically designed "to live very, very long so that they don't have to be replaced…or that they decompose in a benign manner."

But creating plastics from thin air is not easy. CO_2 needs to be extracted, from the atmosphere or smokestacks, for example, using specialized equipment. It often needs to be compressed into liquid form and transported, generally through pipelines. Finally, to meet the overall goal of reducing the amount of carbon in the air, the chemical reaction that turns CO_2 into the building blocks of plastics must be run with as little extra energy as possible. Keeping energy use low is a special challenge when dealing with the carbon dioxide molecule.

A bond that's hard to break

There's a reason that carbon dioxide is such a potent greenhouse gas. It is incredibly stable and can linger in the atmosphere for 300 to 1,000 years. That stability makes CO_2 hard to break apart and add to other chemicals. Lots of energy is typically needed for the reaction.

"This is the fundamental energy problem of CO_2," says chemist Ian Tonks of the University of Minnesota in Minneapolis. "Energy is necessary to fix CO_2 to plastics. We're trying to find that energy in creative ways."

Catalysts offer a possible answer. These substances can increase the rate of a chemical reaction, and thus reduce the need for energy. Scientists in the CO_2-to-plastics field have spent more than a decade searching for catalysts that can work at close to room temperature and pressure, and coax CO_2 to form a new chemical identity. These efforts fall into two broad categories: chemical and biological conversion.

First attempts

Early experiments focused on adding CO_2 to highly reactive monomers like epoxides to facilitate the reaction. Epoxides are three-membered rings composed of one oxygen atom and two carbon atoms. Like a spring under tension, they can easily pop open. In the early 2000s, industrial chemist Christoph Gürtler and chemist Walter Leitner of Aachen University in Germany

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found a zinc catalyst that allowed them to break open the epoxide ring of polypropylene oxide and combine it with CO_2. Following the reaction, the CO_2 was joined permanently to the polypropylene molecule and was no longer in gas form — something that is true of all CO_2-to-plastic reactions. Their work resulted in one of the first commercial CO_2 products — a polyurethane foam containing 20 percent captured CO_2. Today, the German company Covestro, where Gürtler now works, sells 5,000 tons of the product annually in mattresses, car interiors, building insulation and sports flooring.

More recent research has focused on other monomers to expand the variety of CO_2-based plastics. Butadiene is a hydrocarbon monomer that can be used to make polyester for clothing, carpets, adhesives and other products.

In 2020, chemist James Eagan at the University of Akron in Ohio mixed butadiene and CO_2 with a series of catalysts developed at Stanford University. Eagan hoped to create a polyester that is carbon negative, meaning it has a net effect of removing CO_2 from the atmosphere, rather than adding it. When he analyzed the contents of one vial, he discovered he had created something even better: a polyester made with 29 percent CO_2 that degrades in high pH water into organic materials.

"Chemistry is like cooking," Eagan says. "We took chocolate chips, flour, eggs, butter, mixed them up, and instead of getting cookies we opened the oven and found a chicken potpie."

Eagan's invention has immediate applications in the recycling industry, where machines can often get gummed up from the nondegradable adhesives used in packaging, soda bottle labels and other products. An adhesive that easily breaks down may improve the efficiency of recycling facilities.

Tonks, described by Eagan as a friendly competitor, took Eagan's patented process a step further. By putting Eagan's product through one more reaction, Tonks made the polymer fully degradable back to reusable CO_2 — a circular carbon economy goal. Tonks created a start-up this year called LoopCO_2 to produce a variety of biodegradable plastics.

Microbial help

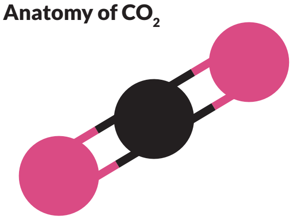
Researchers have also harnessed microbes to help turn carbon dioxide into useful materials including dress fabric. Some of the planet's oldest-living microbes emerged at a time when Earth's atmosphere was rich in carbon dioxide. Known as acetogens and methanogens, the microbes developed simple metabolic pathways that use enzyme catalysts to convert CO_2 and carbon monoxide into organic molecules. In the atmosphere, CO will react with oxygen to form CO_2. In the last decade, researchers have studied the microbes' potential to remove these gases from the atmosphere and turn them into useful products.

LanzaTech, based in Skokie, Ill., uses the acetogenic bacterium *Clostridium autoethanogenum* to metabolize CO_2 and CO emissions into a variety of industrial chemicals, including ethanol. Last year, the clothing company Zara began using LanzaTech's polyester fabric for a line of dresses.

The ethanol used to create these products comes from LanzaTech's two commercial facilities in China, the first to transform waste CO, a main emission from steel plants, into ethanol. The ethanol goes through two more steps to become polyester. LanzaTech partnered with steel mills near Beijing and in north-central China, feeding carbon monoxide into LanzaTech's microbe-filled bioreactor.

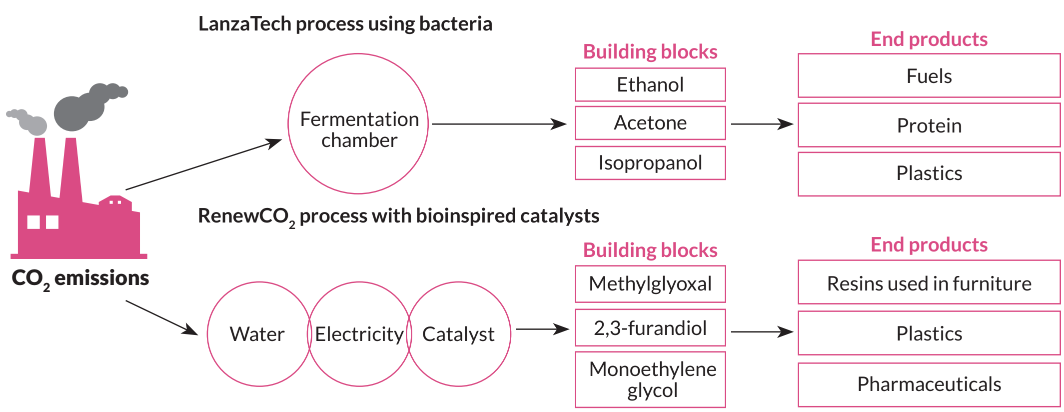
Steel production emits almost two tons of CO_2 for every ton of steel made. By contrast, a life cycle assessment study found that LanzaTech's

Anatomy of CO_2



It takes a lot of energy to break the strong double bonds between the carbon (black) and oxygen atoms (red) in a carbon dioxide molecule. To save energy, researchers are experimenting with chemical and bioinspired catalysts.

Carbon capture with biological conversion



Bacteria business

LanzaTech genetically modifies bacteria to transform carbon dioxide into ethanol and other building blocks for plastics and other products. RenewCO_2 uses nickel-based catalysts inspired by bacteria to do the same — break down CO_2 using little energy to make new things.

ALL: C. CHANG

Chemist James Eagan and colleagues created a degradable polyester made partially with waste CO_2.

THE UNIV. OF AKRON

ethanol production process lowered greenhouse gas emissions by approximately 80 percent compared with ethanol made from fossil fuels.

In February, researchers from LanzaTech, Northwestern University in Evanston, Ill., and others reported in *Nature Biotechnology* that they had genetically modified the *Clostridium* bacterium to produce acetone and isopropanol, two other fossil fuel–based industrial chemicals. Company CEO Jennifer Holmgren says the only waste product is dead bacteria, which can be used as compost or animal feed.

Other researchers are skipping the living microbes and just using their catalysts. More than a decade ago, chemist Charles Dismukes of Rutgers University in Piscataway, N.J., began looking at acetogens and methanogens as a way to use atmospheric carbon. He was intrigued by their ability to release energy when making carbon building blocks from CO_2, a reaction that usually requires energy. He and his team focused on the bacteria's nickel phosphide catalysts, which are responsible for the energy-releasing carbon reaction.

Dismukes and colleagues developed six electrocatalysts that are able to make monomers at room temperature and pressure using only CO_2, water and electricity. The energy-releasing pathway of the nickel phosphide catalysts "lowers the required voltage to run the reaction, which lowers the energy consumption of the process and improves the carbon footprint," says Karin Calvinho, a former student of Dismukes who is now chief technical officer at RenewCO_2, the start-up Dismukes' team formed in 2018.

RenewCO_2 plans to sell its monomers, including monoethylene glycol, to companies that want to reduce their carbon footprint. The group proved its concept works using CO_2 brought into the lab. In the future, the company intends to obtain CO_2 from biomass, industrial emissions or direct air capture.

Barriers to change

Yet researchers and companies face challenges in scaling up carbon capture and reuse. Some barriers lurk in the language of regulations written before CCU existed. An example is the U.S. Environmental Protection Agency's program to provide tax credits to companies that make biofuels. The program is geared toward plant-based fuels like corn and sugarcane. LanzaTech's approach for making jet fuel doesn't qualify for credits because bacteria are not plants.

Other barriers are more fundamental. Styring points to the long-standing practice of fossil fuel subsidies, which in 2021 topped $440 billion worldwide. Global government subsidies to the oil and gas industry keep fossil fuel prices artificially low, making it hard for renewables to compete, according to the International Energy Agency. Styring advocates shifting those subsidies toward renewables.

"We try to work on the principle that we recycle carbon and create a circular economy," he says. "But current legislation is set up to perpetuate a linear economy."

The happy morning routine that makes the world carbon cleaner is theoretically possible. It's just not the way the world works yet. Getting to that circular economy, where the amount of carbon above ground is finite and controlled in a never-ending loop of use and reuse will require change on multiple fronts. Government policy and investment, corporate practices, technological development and human behavior would need to align perfectly and quickly in the interests of the planet.

In the meantime, researchers continue their work on the carbon dioxide molecule.

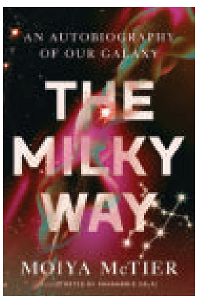
"I try to plan for the worst-case scenario," says Eagan, the chemist in Akron. "If legislation is never in place to curb emissions, how do we operate within our capitalist system to generate value in a renewable and responsible way? At the end of the day, we will need new chemistry." ■

Explore more

- *Gaseous Carbon Waste Streams Utilization: Status and Research Needs*. National Academies Press. 2019. bit.ly/NAS-CCU

Ann Leslie Davis is a freelance science writer based in the San Francisco Bay Area.

A new book reminds readers that the view of the Milky Way in the night sky has dazzled humans for millennia.



The Milky Way
Moiya McTier
GRAND CENTRAL PUBLISHING, $27

BOOKSHELF

Our home galaxy tells all in its new 'autobiography'

Meet the Milky Way in its own words.

The Milky Way: An Autobiography of Our Galaxy takes a tour of our home in the cosmos from an unexpected perspective. Astrophysicist and folklorist Moiya McTier presents herself not as the author, but as the lucky human vessel through which the Milky Way has chosen to tell its story. Then she lets the galaxy take it away, with humor, heart and a huge dose of snark.

The book alternates chapters between science and mythology, reflecting McTier's dual specialties (her bio says she was the first student in Harvard University's history to study both). "Many of you don't realize this, but myths were some of your species' first attempt at scientific inquiry," the Milky Way tells us.

The Milky Way is telling its story now because it's sick of being ignored. Once upon a time, humans looked to the glittering smudge of stars in the sky for insight into when to plant crops or avoid floods. We told stories about the Milky Way's importance in the origin and fate of the world.

Our galaxy ate it up: For an entity that spends most of its time ripping up smaller galaxies and watching its own stars die, "your stories made me feel loved and needed and, perhaps for the first time in my long existence, more helpful than I was ruinous." But in the last few centuries, technology and light pollution have pulled humankind away. "At first, I thought it was just a phase," the Milky Way says. "Then I remembered … that several hundred years is actually a long time for humans."

So the Milky Way decided to remind us why it's so important. Its autobiography covers big-picture scientific questions about galaxies, like where they come from ("When a gas cloud loves itself very much," the Milky Way explains, "it hugs itself extra tight, and after a few hundred million years, a baby galaxy is born. Leave the storks out of it, please."). It also gets into what galaxies are made of, how they interact with other galaxies, and how they live and die. The book then zooms out to cover the origins and possible ends of the universe, mysteries like dark matter and dark energy, and even humankind's search for other intelligent life.

The author takes pains to explain scientific jargon and the technical tools that astronomers use to study the sky. A lot of popular astronomy writing glosses over how astronomers think about cosmic distance or exactly what a spectrum is, but not the this book. If you've ever been curious about these insider details, *The Milky Way* has you covered.

McTier's version of our home galaxy is heavily anthropomorphized. The Milky Way is brash, vain and arrogant in a way that may hide a secret insecurity. Its central black hole is characterized as the physical embodiment of the galaxy's shame and regrets, a source of deep existential angst. And its relationship with the Andromeda galaxy is like a long-term, long-distance romance, with each galaxy sending stars back and forth as love notes until the two can eventually merge (SN: 3/27/21, *p.* 9).

This could have felt gimmicky. But McTier's efforts to make the metaphors work while keeping the science accurate and up-to-date made the premise endearing and entertaining.

I laughed twice on Page 1. I learned a new word on Page 2. I dog-eared the endnotes early on because it became instantly clear I would want to read every one. I read this book while traveling in rural upstate New York, where the sky is much clearer than at my home outside of Boston. *The Milky Way* reminded me to look up and appreciate my home in the universe, just like its narrator wanted. *— Lisa Grossman*

SERGE BRUNIER, NASA

JULY 16, 2022 & JULY 30, 2022

Biggest bacteria?

A newfound species of bacteria, Thiomargarita magnifica, *averages 1 centimeter long and can be seen by the naked eye, making it the largest bacteria yet discovered,* ***Erin Garcia de Jesús*** *reported in "Newfound bacteria make a big splash"* (SN: 7/16/22 & 7/30/22, p. 17)*.*

Reader **J.C. Smith** pointed out that another article in the magazine seems to contradict the findings in this story. In "Live wires," **Nikk Ogasa** reported that cable bacteria, which channel electricity, can grow up to 5 centimeters long (SN: 7/16/22 & 7/30/22, p. 24).

This is no contradiction, **Garcia de Jesús** says. *T. magnifica* is a single-celled species of bacteria, which means all of the cellular functions necessary for the organism's survival happen within its one cell. Cable bacteria, on the other hand, are multicellular, with different cells performing different functions. "*T. magnifica* is the largest single-celled bacterium ever found," **Garcia de Jesús** says.

Given that bacteria are typically defined as single-celled organisms, reader **Barry Maletzky** wondered how multicellular cable bacteria can be considered part of the group.

Most bacteria are single-celled, **Ogasa** says, but several multicellular species do exist. "For instance, some cyanobacteria, sometimes called blue-green algae, are also multicellular. That allows the organisms to split the jobs of photosynthesis and nitrogen absorption between cells."

Mapping out space

Massive objects that warp spacetime can redirect gravitational waves. Researchers might someday leverage those waves as a kind of gravity "radar" to peer inside stars and find globs of dark matter, ***Asa Stahl*** *reported in "Gravitational wave 'radar' could map the universe"* (SN: 7/16/22 & 7/30/22, p. 12)*.*

Reader **Neil Kaminar** wondered if changes in the frequency of light coming from massive objects could be used to detect the distortion of spacetime.

In theory, yes, says **Glenn Starkman**, a physicist at Case Western Reserve University in Cleveland. When light travels through spacetime toward or away from a massive object, gravity changes the frequency of the light, he says. Scientists have witnessed one form of this process, called gravitational redshift, in action on Earth.

But this effect would probably not be very useful when it comes to gravitational radar, **Starkman** says. After light moves toward a massive object, changing its frequency, it would then move away from the object. That process would shift the light's frequency toward what it was before the encounter, mostly canceling out the effect, **Starkman** says.

Science and society

In "We won't shy away from covering politicized science," editor in chief ***Nancy Shute*** *reflected on* Science News' *history of reporting on the science of politically contentious issues and asserted our commitment to continue that coverage* (SN: 7/16/22 & 7/30/22, p. 2)*.*

Brigitte Dempsey was glad to read **Shute's** editor's note in the wake of the U.S. Supreme Court striking down Roe v. Wade, the landmark decision that had protected a person's right to an abortion. Since then, debates around abortion and pregnancy biology have become more heated, and accurate science is often missing from the discussions (SN: 7/16/22 & 7/30/22, p. 6). "Bravo for meeting the issue square on," **Dempsey** wrote. "Our only hope to bring reason to bear…is to let science speak."

Join the conversation

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COMMITTED TO STEM EDUCATION

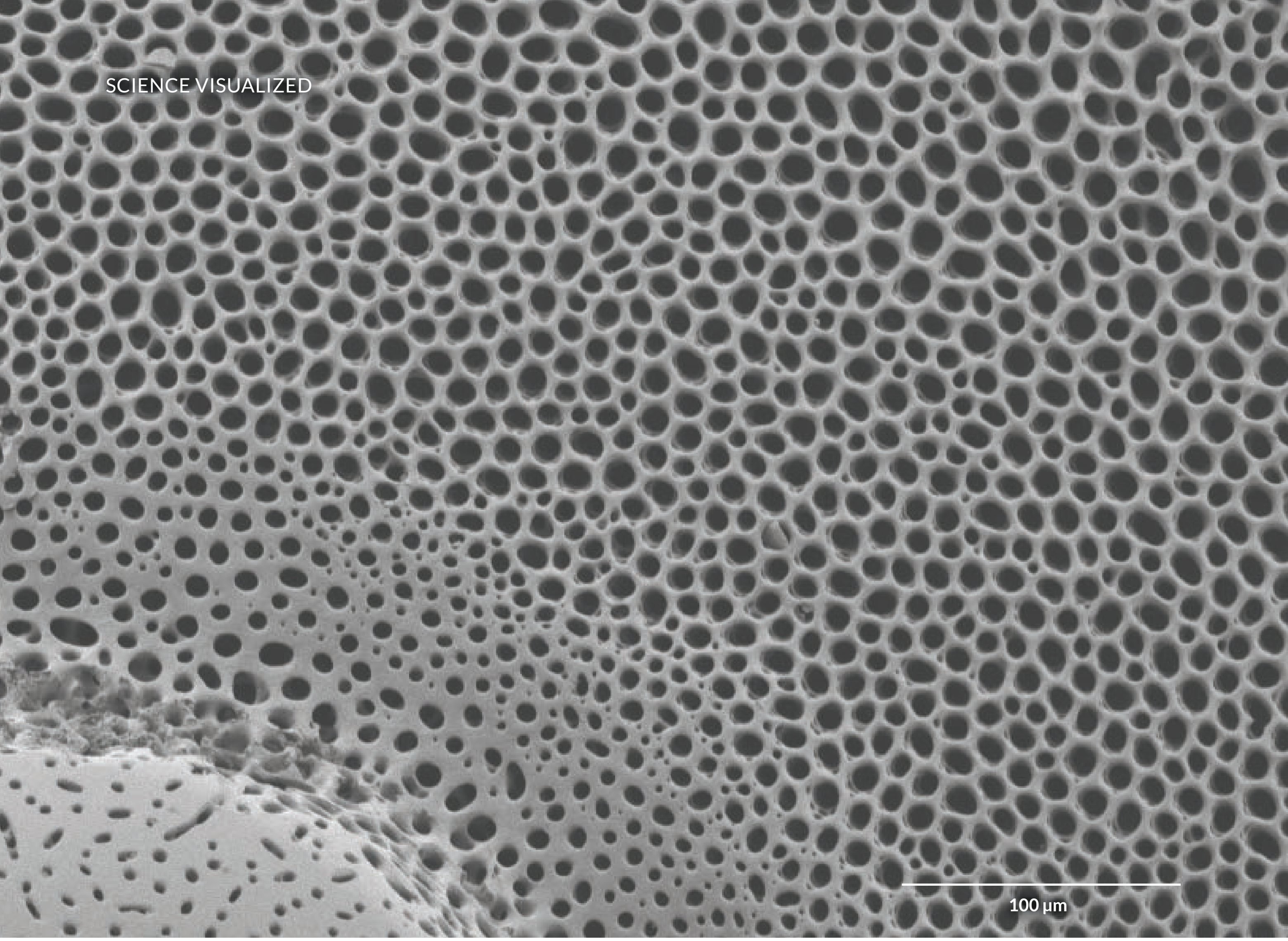
The last few years have been hard on educators and students alike. But these challenges have not deterred Elizabeth Bieri (pictured above with a student), a chemistry teacher at Cristo Rey Jesuit Preparatory School of Houston. Through unprecedented obstacles, Elizabeth has stayed focused on her mission: "Teaching to me is an act of justice because all students deserve the opportunity for an excellent education, no matter their circumstance."

Fortunately, Elizabeth, who previously taught seventh-grade science and who is entering her fifth year as a teacher, is not alone in her goal. During the last school year, she was one of 66 educators from 31 states, the District of Columbia and Puerto Rico who took part in the Society for Science's Advocate Program. The program provides participants with training and support focused on teaching scientific research and helping students enter science competitions, along with a stipend and a paid trip to Washington, D.C., to attend a Society-hosted conference. These educators are doing the vital work of providing opportunities to students from groups that are traditionally underrepresented in STEM fields.

The program also aims to create a community among these committed educators. On her experience as an Advocate, Elizabeth says: "I feel genuinely supported in a way that allows me to bring my best self for my students and provide them with opportunities to develop their scientific research skills, which is something that will benefit them in so many areas of life."

Learn more about the Society's Advocate Program:
societyforscience.org/advocate-program

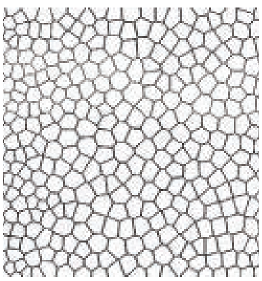
SOCIETY FOR SCIENCE



The geometry of sea urchin skeletons

Sea urchin skeletons may owe some of their strength to a common geometric design. Components of their skeletons follow a similar pattern to that found in honeycombs and dragonfly wings, researchers report in the August *Journal of the Royal Society Interface*. Studying this natural order could inspire the creation of new, strong yet lightweight materials.

Urchin skeletons display "an incredible diversity of structures at the microscale, varying from fully ordered to entirely chaotic," says marine biologist and biomimetic consultant Valentina Perricone. These may help the animals maintain their shape when faced with predator attacks and environmental stresses.



Perricone and colleagues studied sites on common sea urchins (*Paracentrotus lividus*) where the spines attach. These tubercles withstand strong forces. Under a scanning electron microscope, the arrangement of walls and voids (shown above) that make up a tubercle looked like a common natural order known as a Voronoi pattern, the team found.

In mathematical terms, a Voronoi pattern is made by dividing a region into polygons, each built around a point called a seed (*SN: 10/27/18, p. 32*). The polygons follow the nearest neighbor rule: Every spot in a polygon is nearer to its seed than to any other polygon's seed. Also, the boundary that separates two polygons is equidistant from both their seeds.

A computer-generated Voronoi pattern (left) had an 82 percent match with the pattern found in sea urchin skeletons. This arrangement, the team thinks, yields a strong yet lightweight skeletal structure. The pattern "can be interpreted as an evolutionary solution" that "optimizes the skeleton," says Perricone, of the University of Campania "Luigi Vanvitelli" in Aversa, Italy.

Urchins, dragonflies and bees aren't the only potential beneficiaries of Voronoi patterns. "We are developing a library of bioinspired, Voronoi-based structures" that could "serve as lightweight and resistant solutions" for materials design, Perricone says. These, she hopes, could inspire new developments in materials science, aerospace, architecture and construction. —*Rachel Crowell*

BOTH: V. PERRICONE