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ScienceNews

THE SOCIETY FOR SCIENCE ■ JUNE 5, 2021

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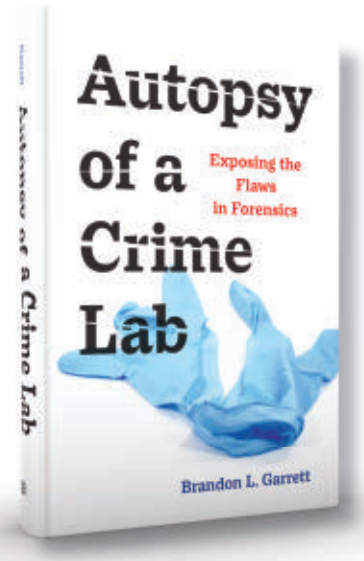
THE SCIENCE AND POLITICS OF LIVING AND DYING



"A convincing argument against the current state of forensic science, as well as promising solutions for the way forward. An excellent resource."
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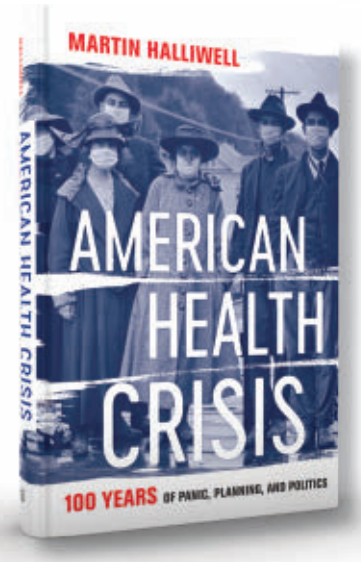
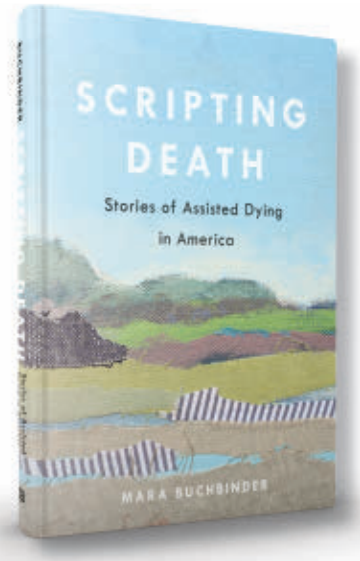


"A tour de force. This will become a sourcebook for anyone interested in the politics of health in the United States."
—Priscilla Wald, author of *Contagious: Cultures, Carriers, and the Outbreak Narrative*



"A rich description of the law, bureaucracy, and the hurdles to physician aid-in-dying. Eye-opening."
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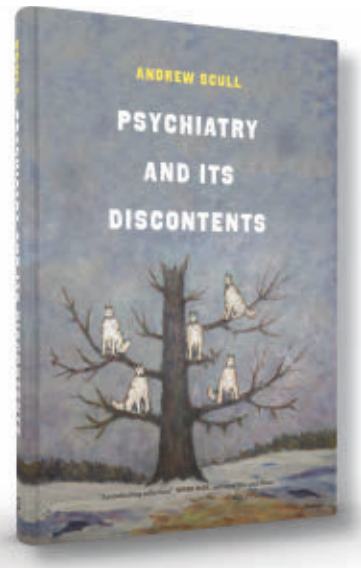

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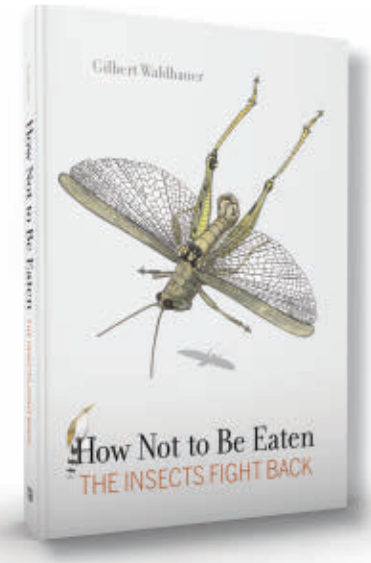
—Medical Health News



NEW IN PAPERBACK
"[These] vivid stories are sure to inspire a closer attention to the small, everyday dramas playing out on spider webs, on flowers and all around us."
—American Scientist

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ScienceNews

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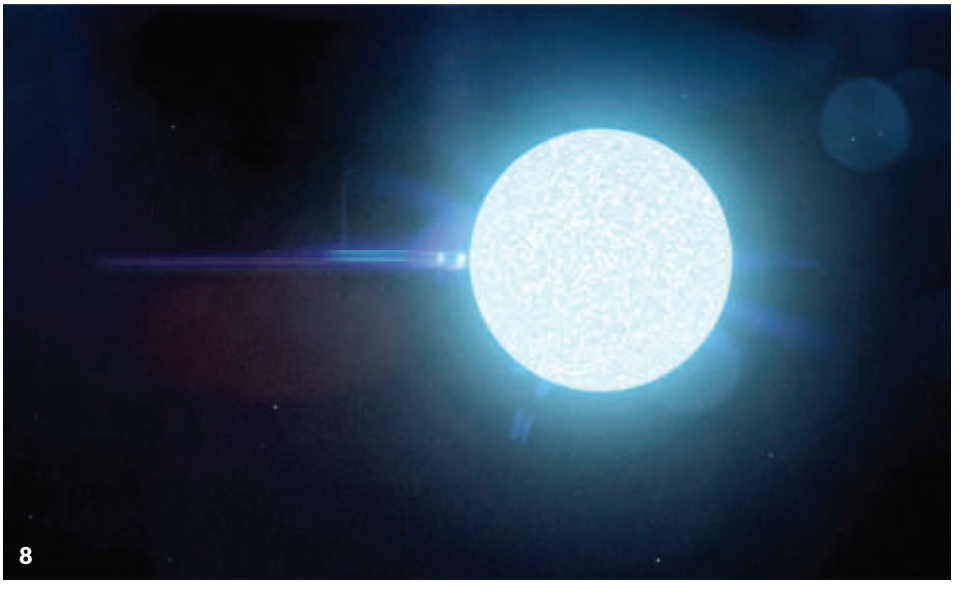
Features

News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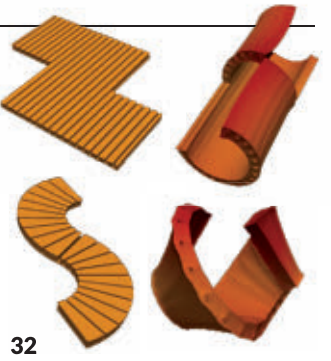
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Departments

COVER One clever idea for keeping children safe in a pandemic: Suit them up for a NASA "clean room" camp. *Space Center Houston*

FROM TOP: SCIENCE GALLERY DUBLIN; MORPHING MATTER LAB/CARNEGIE MELLON UNIV.; NASA'S GODDARD SPACE FLIGHT CENTER

When *Science News* readers talk, we listen

You may think of reading *Science News* as a solitary pleasure, but I have news for you: You're not alone. At this moment, someone else is probably reading this very same editor's note, or the story on Page 10 about the mysterious ways the coronavirus affects people's brains, or maybe the Page 14 piece about how feral donkeys and horses dig water wells that slake the thirst of many living things, even a visiting researcher.

And that's not just hype. Between our flagship print magazine and the millions of people who read us online (24 million website users in 2020), plus students and teachers at more than 5,000 schools in our *Science News* in High Schools program, you've got a lot of company. Good company, too. Our readers are a savvy crew, and they don't hesitate to let us know when we've made a mistake (thank you!), to ask questions, or to add perspective to an article. And though like any news organization we get our share of random rants, opening up our feedback inbox (feedback@sciencenews.org) never fails to delight me.

Take the recent letter from Judith Shea, who wrote in response to our special report on the science of misinformation, including the long history of attacks on vaccines (*SN: 5/8/21 & 5/22/21, p. 32*). "I wonder if anyone my age is 'anti-vaccination,'" writes Shea, who was born in 1941. As children, she writes, "all of us and all of our friends got sick over and over," suffering from measles, chicken pox, rubella, whooping cough and more. "Polio was the most dreaded," she writes. "We would lie awake at night imagining what it would be like to have our legs, arms, or even our whole bodies paralyzed."

When Shea had her own children in the 1960s, "Wow, it was so much better. No polio worries, no damage to unborn children from viruses such as measles."

Some letters are heartbreaking, including one from a teacher in response to our article on the continuing underrepresentation of minorities in STEM (*SN: 5/8/21 & 5/22/21, p. 20*). Nanceen Hoskins described her own experience seeing students of color in lower grades being discouraged from taking honors classes, even when they're more than capable. "Ultimately, the system continues to see those of color as less intelligent, which is then reinforced through statistics because they were tripped at the gate before being able to run."

We also get firsthand stories from scientists who have had a front-row seat to the science, including a recent note from A. Michael Noll about our feature on the evolution of videocalling (*SN: 4/24/21, p. 22*). He worked on developing videoconferencing technology in the 1970s — and even contributed to the videophone sequence in the movie *2001: A Space Odyssey*.

And we're always thrilled when Benny Rietveld's name shows up in the inbox. He's not only a longtime reader (subscribing, as he notes, "since before the internet"), but also the bass player for the legendary band Santana. His latest missive critiqued a headline on "damage" caused by vaccine hesitancy. "I personally would want everyone to read the article, and making the immediate judgment in the title runs the risk of turning away potential readers who may have an anti-vax stance to begin with." Good point, Mr. Rietveld. Please keep writing, and thank you for the music! — *Nancy Shute, Editor in Chief*

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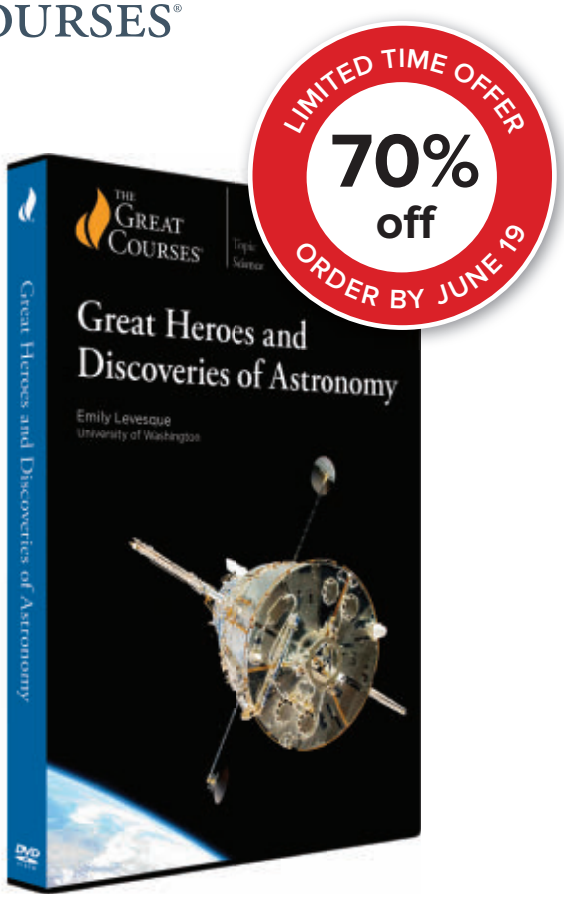

Meet the Shining Stars of Astronomy

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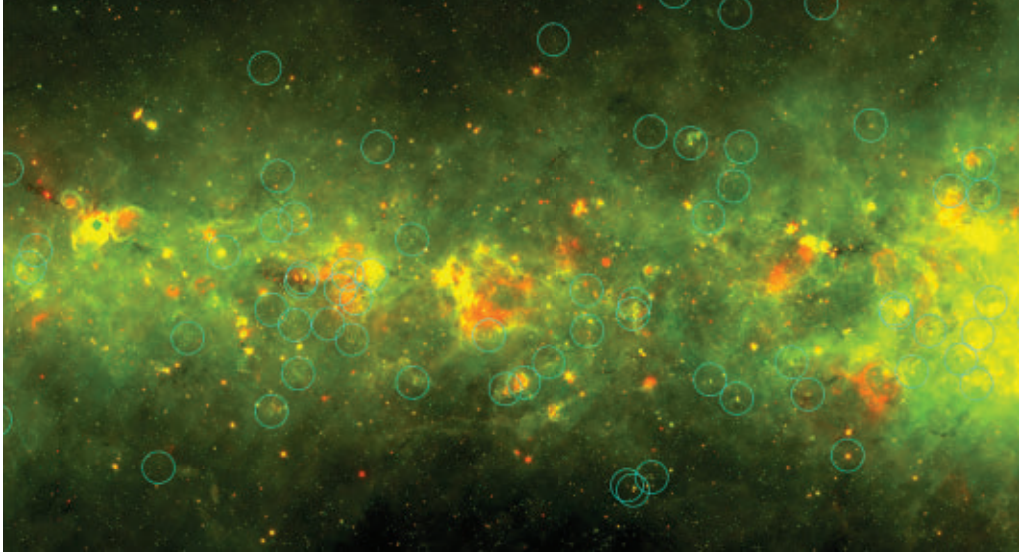
Excerpt from the June 5, 1971 issue of *Science News*

50 YEARS AGO

Information outflow

The United States' population is growing at a rate of one percent a year, and even with lower fertility rates this trend will probably continue. If the fertility rate dropped to 2.1 children per woman, the population of the country would level off in the year 2037 at 267 million. But, this would require an unlikely 50 percent decrease in the birth rate.

UPDATE: Those projections recently veered off course. As of April 2020, 331.5 million people lived in the United States, census data show. But from July 2019 to July 2020, the population grew by just 0.35 percent — the lowest annual growth rate in over a century. For most of the last 50 years, the population grew by about 1 percent per year, partly thanks to immigration. While the fertility rate dropped below 2.1 children per woman after 1971 and the birth rate declined by 29 percent between 1970 to 2014, the foreign-born population quadrupled to over 40 million people. But immigration has slowed. In 2020, the fertility rate dropped to a record low of 1.64 children per woman.



The Milky Way is strewn with yellowballs (circled in this false-color infrared image), regions of ionized gas bubbles where baby stars are born.

MYSTERY SOLVED

Bubble-blowing baby stars form 'yellowballs'

Scientists have solved the case of mysterious cosmic objects dubbed "yellowballs." Each of these celestial specks marks the birthplace of many stars with a wide range of masses, rather than a single supermassive star, researchers report in the April 16 *Astrophysical Journal*.

The stars in these clusters are relatively young, only about 100,000 years old. "I think of these as stars in utero," says Grace Wolf-Chase, an astronomer at the Planetary Science Institute who is based in Naperville, Ill. For comparison, the massive stars forming in the Orion Nebula are

THE EVERYDAY EXPLAINED

How physics helps Brazil nuts come out on top

A new experiment reveals, in a nutshell, why the largest particles in some mixtures tend to gather at the top.

This phenomenon is known as the Brazil nut effect, since jostling mixed nuts tends to bring bulky, oblong Brazil nuts (the largest nuts shown below) to the top of a container. The effect can also be seen in cereal boxes and even among space rocks (*SN: 10/4/14, p. 4*). Understanding how it works could help manufacturers create more uniform mixtures of ingredients for food processing, or more even distributions of active ingredients in medicine tablets, researchers report April 19 in *Scientific Reports*.

The Brazil nut effect has been tough to crack because it's difficult to track how individual objects move around in the middle of a mixture, says Parmesh Gajjar, an imaging scientist at the University of Manchester in England. Using X-ray CT scans, Gajjar and colleagues followed the motion of individual peanuts and Brazil nuts in a box as it was shaken back and forth — creating the first 3-D videos of the Brazil nut effect in action.

In the videos, the Brazil nuts mostly laid horizontally when they were dumped into the container. But as the box shook, collisions between nuts nudged some of the Brazil nuts to point more vertically. That vertical orientation allowed smaller peanuts higher in the mixture to tumble down and accumulate at the bottom, pushing the Brazil nuts upward. While this finding could satisfy the curiosity of mixed nut aficionados, that's peanuts compared with the practical use it could have for the pharmaceutical industry.

—Maria Temming

Watch a video of jostling nuts at **bit.ly/SN_BrazilNut**

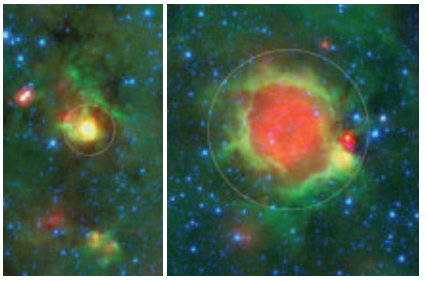
FROM TOP: CHARLES KERTON/IOWA STATE UNIV., SPITZER/NASA; BOBLIN/E+/GETTY IMAGES PLUS

about 3 million years old; the middle-aged sun is 4.6 billion years old.

Volunteers with the Milky Way Project first identified the objects while scouring pictures of the galaxy taken by the Spitzer Space Telescope. The now-defunct observatory saw the cosmos in infrared light, which allowed astronomers to "probe what's going on in these cold environments before the stars are actually born," Wolf-Chase says.

The citizen scientists had been looking for baby stars thought to be at least 10 times the mass of the sun that were blowing ionized gas bubbles. Some users began labeling certain objects with the tag #yellowballs because that's what they looked like in the false-color images. Between 2010 and 2015, the volunteers found 928 yellowballs.

Since yellowballs were a serendipitous discovery, researchers knew they probably hadn't caught enough to definitively ID the objects. So in 2016,



A yellowball (circled, left), first thought to be a precursor to a gas bubble (right) blown around a massive young star, is actually a bubble blown by a cluster of less massive stars.

volunteers set out to find more. By the following year, the group had spotted more than 6,000 yellowballs.

Wolf-Chase's team compared about 500 of those balls with catalogs of star clusters and other structures to figure out what the balls were. "We have a good answer: They're infant star clusters," Wolf-Chase says. A cluster blows an ionized bubble similar to the kind blown by a big young star. — *Lisa Grossman*

In experiments, an enzyme-laced plastic film (left) broke down after one week in compost (right). After two weeks, the plastic disintegrated entirely.

TEASER

A new technology turns plastic into compost

A pinch of polymer-munching enzymes could make biodegradable plastic truly compostable. At temperatures just above those typical of a hot summer day, enzyme-laced films of plastic disintegrated in standard compost or plain tap water within days to weeks, researchers report in the April 22 *Nature*.

"Biodegradability does not equal compostability," says polymer scientist Ting Xu of the University of California, Berkeley and Lawrence Berkeley National Laboratory. Most biodegradable plastics go to landfills, where conditions aren't right for the plastics to efficiently break down. Embedding polymer-chomping enzymes in biodegradable plastic should accelerate decomposition. But in practice, such enzymes clump together and only partially snip plastics' molecular chains, leaving behind microplastics (*SN: 1/16/21, p. 5*). Xu's team added enzymes along with an anticlumping additive to two biodegradable plastics, including one used in food packaging. The enzymes severed nearly every chain link, completely breaking down the plastic. The technology doesn't yet work on all plastics, but Xu has filed a patent application and a coauthor founded a start-up to commercialize the technique. "We want this to be in every grocery store," she says. — *Carmen Drahl*

SCIENCE STATS

Scientists get the skinny on lead's neutron skin

Some atomic nuclei are thin-skinned, with a slim border of neutrons.

Physicists now know how thick that neutron skin is for one type of nucleus. The skin of lead-208 — a variety of lead with 126 neutrons and 82 protons — is about 0.28 trillionths of a millimeter thick, researchers report in the April 30 *Physical Review Letters*.

Lead-208's nucleus is roughly spherical, a ball of protons overlapping with a slightly bigger ball of neutrons. Measuring the size difference between the balls reveals the thickness of lead's neutron skin. Gauging the proton ball's size is straightforward: Physicists can shoot electrically charged particles at the nucleus and study how the particles scatter from the positively charged protons. But because neutrons don't have an electric charge, the volume they enclose is harder to measure.

Researchers with the Lead Radius Experiment, or PREX-II, at Jefferson Lab in Newport News, Va., measured how electrons scatter from the nucleus according to their spin, or angular momentum. Because electrons interact with neutrons at different rates depending on the direction of their spin, the experiment revealed the width of the neutron ball and thus the neutron skin thickness. The skin was slightly thicker than physicists had predicted. That's a result that "makes everyone sit up and pay attention," says Krishna Kumar, a PREX-II co-spokesperson at the University of Massachusetts Amherst.

Similar measurements could help scientists better understand theories of the atomic nucleus and other realms where neutrons are crammed together, such as in neutron stars. — *Emily Conover*

0.28

trillionths of a millimeter

Thickness of the neutron skin of a lead atom's nucleus

FROM TOP: JPL-CALTECH/NASA; ADAM LAU/BERKELEY ENGINEERING

GENES & CELLS

Unique viral DNA thwarts bacteria

Some phages swap A for Z in their genetic alphabet

BY TINA HESMAN SAEY

Some bacteria-killing viruses spell out their genetic instructions in a different DNA alphabet.

Over 40 years ago, Russian scientists reported that a type of bacteriophage replaces the DNA building block adenine, often called A, with 2-aminoadenine, designated Z. But no one knew how the phage, named cyanophage S-2L, went from A to Z, or why.

Now, independent research groups have discovered how the viruses make and build Z into their genetic instructions, and one reason they do it, the teams report April 23 in *Nature Communications* and in the April 30 *Science*.

The findings have implications for both the origins of life on Earth and the search for life on other planets, says Farren Isaacs, a molecular and synthetic biologist at Yale University who coauthored a commentary in the same issue of *Science*. "It's a really fundamental discovery."

In the 1990s, xenobiologist Philippe Marlière, who studies life that is strange, alien or unfamiliar to science, came across a 1977 Russian study describing cyanophage S-2L. While at the Pasteur Institute in Paris, he and colleagues deciphered the phage's complete set of genetic instructions. In the genome were instructions for building an enzyme, called PurZ, that could carry out the first step in making Z.

It turns out that cyanophage S-2L not only builds Z, but also has enzymes that break down A. That leaves the phage no choice but to incorporate Z into its DNA, biochemist Pierre Alexandre Kaminski of the Pasteur Institute and colleagues report in *Nature Communications*.

Marlière, president of the European Syndicate of Synthetic Scientists and Industrialists in Berlin, had left his original results unpublished until now, after discovering more phages that contain PurZ. Siphoviridae phages, which infect a wide variety of bacteria, do things differently than cyanophage S-2L. Those phages all have versions of an enzyme called DpoZ that preferentially inserts Z instead of A into the DNA, Marlière and colleagues report in *Science*.

Huimin Zhao, a synthetic biologist at the University of Illinois at Urbana-Champaign, had independently heard about phages that use Z-containing DNA. His own search of databases found 60 phages that have PurZ, including phages from the Siphoviridae and Podoviridae families. His team, reporting in *Science*, also worked out the biochemical pathway the phages use to make and incorporate Z, and found enzymes that degrade A.

Zhao suggests that replacing A with Z is a countermeasure against bacterial defense enzymes, known as restriction enzymes, that chop up DNA from invading phages. Such enzymes have a hard time recognizing and cutting DNA containing Z bases, he and colleagues found. "The phage is trying to avoid being destroyed by the host," he says.

It's possible that other phages that use Z or other alternative DNA bases may still be out there, says Steven Benner, a chemist and astrobiologist at the Foundation for Applied Molecular Evolution in Alachua, Fla. "What these guys have done is discover an entire biosphere that was missing from our inventory."

Although there is debate over whether viruses are truly alive, the findings could influence the search for life on other planets (*SN: 4/30/16, p. 28*). Instead of looking for the standard DNA bases — guanine, thymine, adenine and cytosine — maybe researchers should be searching for 2-aminoadenine, the Z base, Benner says.

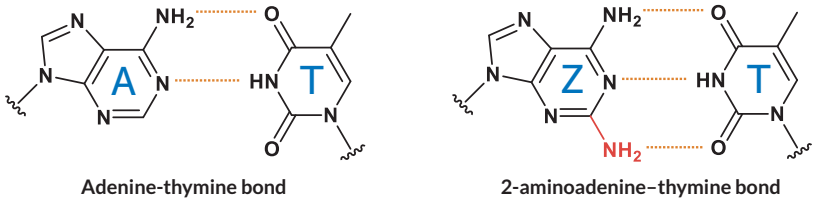
After all, Z forms three hydrogen bonds with thymine, instead of the two hydrogen bonds that hold A-T base pairs together. That makes Z-T–paired DNA more stable and potentially able to withstand hotter or harsher conditions better than conventional DNA, Benner says.

With the extra stability, one might wonder why all organisms on Earth don't use Z. Stability isn't everything, says Floyd Romesberg, a synthetic biologist in La Jolla, Calif., at the pharmaceutical and biotech company Sanofi. DNA has to be unwound and split apart to be copied. That may be harder to do with Z-T base pairs. Z also changes how DNA curves and bends, perhaps making it harder to pack into tight spaces the way A-containing genetic material can. That might make A better for other organisms.

Or perhaps it was just an accident that A came first. Once cells started using that base, too many things would have to change to completely switch to another base, says Romesberg, who has been working for years to get bacteria to incorporate exotic DNA bases (*SN: 6/14/14, p. 14*).

Viruses' stripped-down genomes are more flexible, Romesberg says: They carry around less machinery because they make the host do most of the work. Even the Z phages do just the first step in making Z and rely on several host enzymes to finish the recipe.

It's unknown whether cellular organisms can write Z into their DNA too. ■



Adenine-thymine bond | 2-aminoadenine–thymine bond

Pairing up The standard DNA base adenine, known as A, links up with its partner thymine, T, via two hydrogen bonds (orange, left diagram). The base 2-aminoadenine, called Z (right), has one more amino group (red) than adenine. That addition allows Z to form an extra hydrogen bond (orange) with thymine, which makes the Z-T pairing more stable than A-T pairs.

D. CZERNECKI *ET AL*/*NATURE COMMUNICATIONS* 2021

Africa's oldest known grave unearthed

Humans purposely buried the dead during the Middle Stone Age

BY BRUCE BOWER

A child whose lifeless body was carefully placed in an East African cave around 78,300 years ago has made a grand return.

Researchers who unearthed the ancient youngster's remains say that they've found the oldest known intentional human burial in Africa. The investigators, who report the discovery in the May 6 *Nature*, have named the ancient youngster Mtoto, a Swahili word that means "child."

"Mtoto was buried in a sheltered part of a cave that was repeatedly occupied by people over a span of nearly 80,000 years up to about 500 years ago," archaeologist Michael Petraglia of the Max Planck Institute for the Science of Human History in Jena, Germany, said at a May 3 news conference. Local people still visit this spot to worship and conduct rituals.

The discovery of Mtoto suggests that "a tradition of symbolically significant burials, at least for the very young, might have been culturally embedded in parts of Africa" toward the end of the Middle Stone Age, which ran from around 320,000 to 30,000 years ago, bioarchaeologist Louise Humphrey of the Natural History Museum in London writes in a commentary in the same issue of *Nature*.

Excavations at Panga ya Saidi, or PYS, a cave site located in forested hills about 15 kilometers from Kenya's coast, revealed Mtoto's grave. Petraglia and Max Planck archaeologist Nicole Boivin led work there starting in 2010.

Preliminary signs of Mtoto's burial appeared in 2013. Digging revealed part of a shallow pit, but fragmentary bones visible in the pit were too fragile to remove or study closely. Stone tools typical of Africa's Middle Stone Age had turned up in the same sediment, giving researchers a sense of how old the bones were. Lab analyses indicated that the sediment had last been exposed to sunlight about 78,300 years ago.

Investigators excavated the entire pit in 2017 and covered it in plaster for transport to the National Museums of Kenya in Nairobi. There, researchers noticed that two teeth in the pit looked human.

The plastered pit was then sent to paleoanthropologist María Martinón-Torres at the National Research Center on Human Evolution in Burgos, Spain. After removing plaster around the earthen block, her team used CT imaging to create digital versions of the PYS bones, revealing the partial skeleton of a young *Homo sapiens* child. Fossil positions indicated that the child had been placed on his or her right side, with knees bent up toward the chest. Many bones were intact enough to be removed from the pit.

The size and development of three isolated molars in the pit indicated that the child had died at age 2.5 to 3 years. Microscopic study of the fossils and chemical analyses of pit sediment indicated that the child's body was interred soon after death, before decomposition began. That explains why parts of the child's skeleton remain well-preserved, including a skull base connected to three neck bones.

JORGE GONZÁLEZ; ELENA SANTOS

This virtual reconstruction shows the original position of a child's bones in a Kenyan grave dug around 78,300 years ago, making it the oldest known human interment in Africa.

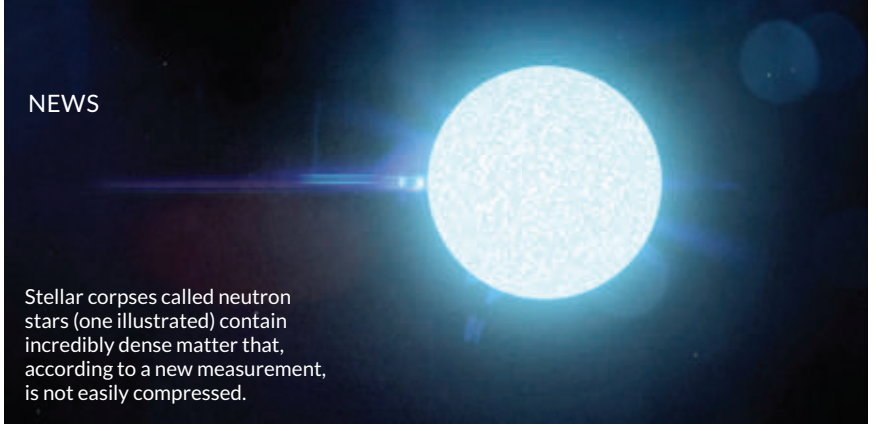
Special care was taken in burying Mtoto, Martinón-Torres said. For instance, the skull base and attached neck bones had collapsed away from other back bones in a way suggesting that the child's head originally lay on a support or pillow that had decayed. Rotation of a collarbone and two ribs suggested that Mtoto's upper body had originally been wrapped in a shroud.

An infant found in a pit inside southern Africa's Border Cave in 1941 has previously been cited as Africa's earliest burial. But evidence for that argument remains uncertain, Petraglia said. The Border Cave infant dates to between 74,000 and 58,000 years ago.

Even if Mtoto is the oldest burial in Africa, more and even older Middle Stone Age burials have been found in Eurasia and the Middle East than in Africa. Humans were buried in an Israeli cave more than 90,000 years ago (*SN: 11/1/03, p. 277*). And Neandertals may have buried their dead in an Iraqi Kurdistan cave 60,000 to 70,000 years ago (*SN: 3/28/20, p. 17*).

Mtoto and the possible Border Cave burial fit a Middle Stone Age pattern in Eurasia of interring infants and children in public spots, says archaeologist João Zilhão of the University of Barcelona, who was not involved in the study. After around 30,000 years ago, Eurasian infants and children were buried in remote locations (*SN: 5/8/99, p. 295*), unlike teens and adults, he says. It's not clear why age-related differences in the treatment of the dead occurred at that time.

Many Middle Stone Age Africans may have buried the dead of all ages in isolated spots, not in caves where people continued to live, says archaeologist Lyn Wadley of the University of the Witwatersrand in Johannesburg, who also was not involved in the study. If that's the case, finding more African burials from Mtoto's time will most likely be a challenge. "Open-air burials are not easy to find and preservation is likely to be poor," she says. ■



Stellar corpses called neutron stars (one illustrated) contain incredibly dense matter that, according to a new measurement, is not easily compressed.

ATOM & COSMOS

Neutron stars may not be so squishy

A dead star's large width hints at its matter's squeezability

BY EMILY CONOVER

Like a dried-up lemon from the back of the fridge, neutron stars are less squeezable than expected.

New measurements of the most massive known neutron star find that it has a surprisingly large diameter, suggesting that the matter within isn't as squishy as some theories predicted, physicists with the Neutron star Interior Composition Explorer, or NICER, collaboration reported April 17 at a virtual meeting of the American Physical Society.

When a dying star explodes, it can leave behind a memento: a remnant crammed with neutrons. These neutron stars are extraordinarily dense — like compressing Mount Everest into a teaspoon, said NICER astrophysicist Zaven Arzoumanian of NASA's Goddard Space Flight Center in Greenbelt, Md. "We don't know what happens to matter when it's crushed to this extreme point."

The more massive the neutron star, the more extreme the conditions in its core. Jammed together at tremendous densities, particles may form unusual states of matter. For example, particles known as quarks — usually contained within protons and neutrons — may roam freely in a neutron star's center.

The core's composition determines its squeezability. If quarks are free agents within the most massive neutron stars, the immense pressure will compress the neutron star's core more than if quarks remain within neutrons. Because of that compressibility, for neutron stars, more mass doesn't necessarily translate to a larger diameter. If neutron star matter is squishy, the objects could shrink as they become more massive (*SN: 8/29/20, p. 11*).

To understand how neutron star innards respond to being put through the cosmic wringer, scientists used the NICER X-ray telescope aboard the International Space Station to estimate the diameters of rapidly spinning neutron stars called pulsars. In 2019, NICER sized up a 26-kilometer-wide pulsar with about 1.4 times the mass of the sun (*SN: 2/1/20, p. 5*).

Researchers have now gauged the girth of the heftiest confirmed neutron star, with about 2.1 times the mass of the sun. But the beefy neutron star's diameter is about the same as that of its more lightweight compatriot, two independent NICER teams reported at the meeting. One team found a diameter of around 25 kilometers while the other estimated 27 kilometers.

Many theories predict that the more massive neutron star should have a smaller diameter. "That it is not tells us that, in some sense, the matter inside neutron stars is not as squeezable as many people had predicted," said astrophysicist Cole Miller of the University of Maryland in College Park, who presented the second result.

The finding suggests that inside a neutron star, quarks are not confined within neutrons, said astrophysicist Sanjay Reddy of the University of Washington in Seattle, who was not involved in the research. But the quarks still interact with one another strongly rather than roam about unencumbered, Reddy said. ■

ATOM & COSMOS

Antistars could lurk in Milky Way

Some missing antimatter might survive as stars

BY MARIA TEMMING

Fourteen pinpricks of light on a gamma-ray map of the sky could fit the bill for antistars, or stars made of antimatter, a new study suggests.

These antistar candidates seem to give off the kind of gamma rays that are produced when antimatter — matter's oppositely charged counterpart — meets normal matter and both annihilate. This could happen on the surfaces of antistars as their gravity draws in normal matter from interstellar space, scientists report in the April 15 *Physical Review D*.

"If, by any chance, one can prove the existence of the antistars ... that would be a major blow for the standard cosmological model," says theoretical astrophysicist Pierre Salati of the Annecy-le-Vieux Laboratory of Theoretical Physics in France who was not involved in the work. It "would really imply a significant change in our understanding of what happened in the early universe."

Although the universe is generally thought to have been born with equal amounts of matter and antimatter, the modern universe contains almost no antimatter. Physicists typically think that some process led to matter particles vastly outnumbering their antimatter alter egos (*SN: 12/21/19 & 1/4/20, p. 12*). But an instrument on the International Space Station recently cast doubt on this assumption by detecting hints of a few antihelium nuclei — more than physicists would expect to find. If those observations are confirmed, antistars could have shed such stray antimatter.

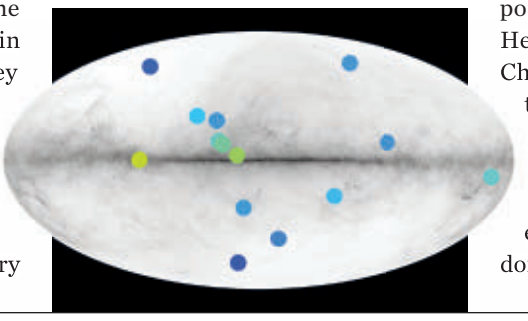
Intrigued by the possibility that some of the universe's antimatter may have survived in the form of stars, astrophysicist Simon Dupourqué of the Institute of Research in Astrophysics and Planetology in Toulouse, France, and colleagues examined 10 years of observations from

NASA'S GODDARD SPACE FLIGHT CENTER

the Fermi Gamma-ray Space Telescope. Among nearly 5,800 gamma-ray sources in the catalog, 14 points of light gave off gamma rays with energies expected of matter-antimatter annihilation and did not look like any other known type of gamma-ray source, such as a pulsar or black hole.

Based on the number of observed candidates and the sensitivity of the Fermi telescope, the team calculated how many antistars could exist in the Milky Way. If antistars existed within the plane of the Milky Way, where they could accrete lots of gas and dust made of ordinary matter, the antistars could emit lots of gamma rays and be easy to spot. As a result, the handful of detected candidates would imply that one antistar exists for every 400,000 normal stars. If, on the other hand, antistars tended to exist outside the plane of the galaxy, they would have much less opportunity to accrete normal matter and be much harder to find. In that scenario, there could be up to one antistar lurking among every 10 normal stars.

Fourteen celestial sources of gamma rays (colored dots in this map of the Milky Way; yellow indicates bright sources and blue shows dim sources) may be stars made of antimatter.



Proving that any celestial object is an antistar would be extremely difficult. Besides the gamma rays produced by matter-antimatter annihilation, the light given off by antistars is expected to look just like the light from normal stars. "It would be much easier to disprove," Dupourqué says.

The existence of antistars would imply that substantial amounts of antimatter somehow managed to survive in isolated pockets of space, says physicist Julian Heeck of the University of Virginia in Charlottesville who was not involved in the work. But Heeck doubts that antistars would be abundant enough to account for all the universe's missing antimatter. "You would still need an explanation for why matter overall dominates over antimatter." ■

ATOM & COSMOS

Saturn's heart is fuzzy and diffuse

Ring ripples reveal a sprawling core deep within the gas giant

BY KEN CROSWELL

One of Saturn's rings has revealed properties of its core, hidden deep beneath the planet's golden atmosphere.

That core isn't the lump of rock and ice that many scientists had envisioned. Instead, the core is diffuse, pervaded by huge amounts of hydrogen and helium and so spread out that it spans 70,000 kilometers, about 60 percent of the planet's diameter, researchers report online April 28 at arXiv.org.

The new intel should help planetary scientists better understand not only how giant planets formed in our solar system, but also the nature of such worlds orbiting other stars.

To ascertain the structure of Saturn's core, astronomer Christopher Mankovich and astrophysicist Jim Fuller, both of Caltech, examined waves in the giant planet's rings. Just as earthquakes help seismologists probe Earth's interior, oscillations inside Saturn can reveal its internal composition. These oscillations alter Saturn's gravitational forces, inducing waves in the rings — especially the C ring, which is the nearest of the three main rings to the planet (*SN: 3/2/19, p. 5*).

An analysis of a wave in that ring, along with data on Saturn's gravity field from the now-defunct Cassini spacecraft, revealed that the core has about 17 Earth masses of rock and ice. But there's so much hydrogen and helium mixed in that the core has 55 Earth masses altogether — more than half of Saturn's total, Mankovich and Fuller report in a study to appear in *Nature Astronomy*.

"It's a new way to look at gas giant planets in the solar system," says Ravit Helled, a planetary scientist at the University of Zurich. "This knowledge is important because it reflects on our understanding of giant exoplanets," and indicates that giant planets in other solar systems probably have more complex structures than many researchers had thought.

The discovery also illuminates how Saturn formed, says Nadine Nettelmann, a planetary scientist at the German Aerospace Center in Berlin.

Older theories posited that a gas giant such as Saturn arises when rock and ice orbiting the sun start to conglomerate. Tenuous gaseous envelopes let additional solid materials sink to the center, forming a compact core. Only later, according to this theory, does the core attract lots of hydrogen and helium — the ingredients that make up most of the planet. Although these elements are gases on Earth, Saturn's great gravity squeezes most of them into a fluid.

But newer theories say instead that plenty of gas got incorporated into the core of rock and ice when it was taking shape 4.6 billion years ago. As the planet accreted additional mass, the proportion of gas rose. The structure Mankovich and Fuller deduce for Saturn's core supports this formation history, Nettelmann says. Saturn's very center, representing the oldest part of the planet, has the greatest proportion of rock and ice. The fraction of rock and ice decrease gradually rather than abruptly from the core's center to its edge, reflecting the core's development over time.

"I find the conclusions very important and very exciting and the line of reasoning very convincing," Nettelmann says. Still, she cautions that additional waves in the rings should be analyzed for confirmation. ■

S. DUPOURQUÉ/IRAP

BODY & BRAIN

Scientists probe COVID-19 brains

New clues tease apart virus's role in stroke, mental disorders

BY LAURA SANDERS

For more than a year now, scientists have been racing to understand how the mysterious virus that causes COVID-19 damages not only our bodies, but also our brains.

Early in the pandemic, some infected people noticed a curious symptom: the loss of smell. Reports of other brain-related symptoms followed: headaches, confusion, hallucinations and delirium. Some infections were accompanied by depression, anxiety and sleep problems.

Researchers are still trying to figure out how many people experience these psychiatric or neurological problems, who is most at risk and how long such symptoms might last. And details remain unclear about how the virus, which has infected more than 150 million people worldwide, exerts its effects.

"We still haven't established what this virus does in the brain," says Elyse Singer, a neurologist at UCLA. There are probably many answers, she says. "It's going to take us years to tease this apart."

For now, some scientists are focusing on the basics, including how many people experience these sorts of brain-related problems after COVID-19.

A recent study of electronic health records reported an alarming answer: In the six months after a COVID-19 diagnosis, 1 in 3 people had experienced a psychiatric or neurological diagnosis. That result, published in the May 1 *Lancet Psychiatry*, came from the health records of more than 236,000 COVID-19 survivors. Researchers counted diagnoses of 14 ailments, ranging from mental illnesses such as anxiety or depression to neurological events such as strokes or brain bleeds.

"We didn't expect it to be such a high number," says psychiatrist Maxime Taquet of the University of Oxford. One in 3 "might sound scary," Taquet says. But it's not clear whether the virus, called SARS-CoV-2, causes these disorders directly.

The vast majority of those diagnoses were depression and anxiety, "disorders that are extremely common in the general population," says Jonathan Rogers, a psychiatrist at University College London. What's more, depression and anxiety are on the rise among everyone during the pandemic, not just people infected with the virus.

Mental health disorders are "extremely important things to address," says Allison Navis, a neurologist at the post–COVID-19 clinic at the Icahn School of Medicine at Mount Sinai in New York City. "But they're very different than a stroke or dementia," she says.

About 1 in 50 people with COVID-19 had a stroke, Taquet and colleagues found. Among people with severe infections that came with delirium or other altered mental states, the incidence was much higher — 1 in 11 had strokes.

Taquet and colleagues' study looked back at diagnosis codes. Often entered by hurried clinicians, those codes aren't always reliable. And while the study finds a relationship, it can't conclude that COVID-19 caused any of the diagnoses. Still, the results hint at how COVID-19 affects the brain.

Early on in the pandemic, the loss of smell suggested that the virus might be able to attack nerve cells directly. Perhaps the virus could breach the skull by climbing along the olfactory nerve, which carries smells from the nose directly to the brain, some researchers thought.

Most studies so far have failed to turn up much virus in the brain, if any, says Avindra Nath, a neurologist who studies central nervous system infections at the National Institutes of Health in Bethesda, Md. Nath and colleagues expected to see signs of the virus in brains of people with COVID-19. It wasn't there.

That absence suggests that the virus is affecting the brain in other ways, possibly involving blood vessels. So Nath's team scanned blood vessels in postmortem brains of people who had been infected with the virus. The MRI machine used was so powerful that it's not approved for clinical use in living people. "We were able to look at the blood vessels in a way that nobody could," Nath says.

In a postmortem brain from a person who had COVID-19, a clotting protein called fibrinogen (dark red) indicates that the blood vessels are damaged and leaky.

A. NATH

Damage abounded, the team reported in the Feb. 4 *New England Journal of Medicine*. Small clots sat in blood vessels. The walls of some vessels were unusually thick and inflamed. And blood leaked out of the vessels into the surrounding brain tissue. "You can see all three things happening at the same time," Nath says.

Those results suggest that clots, inflamed linings and leaks in the barriers that normally keep blood and other harmful substances out of the brain may all contribute to COVID-19–related brain damage. But several unknowns prevent any definite conclusions about how these damaged blood vessels relate to people's symptoms or outcomes. There's not much clinical information available about the people in Nath's study. Some likely died from causes other than COVID-19, and no one knows how the virus would have affected them had they lived.

Inflammation elsewhere in the body can cause trouble in the brain too, says psychiatrist Maura Boldrini of Columbia University in New York City. Inflammatory signals released after injury can change the way the brain makes and uses chemical signaling molecules called neurotransmitters, which help nerve cells communicate. Messages carried

by key neurotransmitters such as serotonin, norepinephrine and dopamine can get scrambled when there's lots of inflammation.

Neural messages can get interrupted in people who suffer traumatic brain injuries. For example, researchers have found a relationship between inflammation and mental illness in football players and others who experienced hits to the head.

Similar evidence comes from people with depression, says Emily Troyer, a psychiatrist at the University of California, San Diego. Some people with depression have high levels of inflammation, studies have found. "We don't actually know that that's going on in COVID," she cautions. "We just know that COVID causes inflammation, and inflammation has the potential to disrupt neurotransmission, particularly in the case of depression."

Among the cells that release inflammatory proteins in the brain are microglia, disease-fighting cousins of immune cells elsewhere in the body. Microglia may also be involved in the brain's response to COVID-19. Microglia primed for action were found in about 43 percent of 184 COVID-19 patients, Singer and others reported in a review published January 18 in *Free Neuropathology*. And in a series of autopsies of COVID-19 patients' brains, 34 of 41 brains contained activated microglia, researchers from Columbia University Irving Medical Center and New York Presbyterian Hospital reported April 15 in *Brain*.

With these findings, it's not clear that SARS-CoV-2 affects people's brains differently from other viruses, Navis says. In her post–COVID-19 clinic at Mount Sinai, she sees patients with fatigue, headaches, numbness and dizziness — symptoms that are known to follow other viral infections too. "I'm hesitant to say this is unique to COVID," she says.

Teasing apart all the ways the brain can suffer amid this pandemic, and how that affects any given person, is impossible. Increases in depression and anxiety might be especially sharp in people who endured stressful diagnoses, illnesses and isolation.

Just being in an intensive care unit can lead to confusion. A 2013 study found that delirium affected 606 of 821 people — 74 percent — while they were in ICUs for respiratory failure and other serious emergencies. With COVID-19, post-traumatic stress disorder afflicted about a third of people who had been seriously sick (*SN: 3/27/21, p. 4*).

Lingering questions — what the virus does to the brain, who will suffer the most and for how long — probably won't be answered for a long time. The varied and damaging effects of lockdowns, doctors' and patients' imprecision describing symptoms and the virus's indirect effects on the brain create a devilishly complex puzzle. For now, doctors are busy focusing on ways in which they can help and designing larger, longer studies to better understand the virus's effects on the brain. That information will be key to helping people move forward. ■

LIFE & EVOLUTION

Climate-friendly archaea don't pass gas

Newfound microbes recycle carbon without giving off methane

BY CAROLYN GRAMLING

Earth's hot springs and hydrothermal vents are home to a previously unidentified group of archaea. And, unlike similar tiny, single-celled organisms that live deep in sediments and munch on decaying plant matter, these archaea don't produce the climate-warming gas methane, researchers report April 23 in *Nature Communications*.

DNA detective work Sediments collected from hot springs in China and hydrothermal vents off Mexico (orange dots) contained DNA belonging to a newly discovered group of archaea dubbed Brockarchaeota. Microorganisms collected at other sites (blue) are likely to be members of this group too.

"Microorganisms are the most diverse and abundant form of life on Earth, and we just know 1 percent of them," says Valerie De Anda, an environmental microbiologist at the University of Texas at Austin. "Our information is biased toward the organisms that affect humans. But there are a lot of organisms that drive the main chemical cycles on Earth that we just don't know."

Archaea are a particularly mysterious group (*SN: 3/14/20, p. 4*). It wasn't until the late 1970s that the organisms were recognized as a third domain of life, distinct from bacteria and eukaryotes — the domain that includes everything else, from fungi to animals to plants.

For many years, archaea were thought to exist only in the most extreme environments on Earth, such as hot springs. But archaea are actually everywhere, and these microbes can play a big role in how carbon and nitrogen cycle between Earth's land, oceans and atmosphere. One group, Thaumarchaeota, includes the most abundant microbes in the ocean, De Anda says. And methane-producing archaea in cows' stomachs cause the animals to burp large amounts of the gas into the atmosphere (*SN: 11/28/15, p. 22*).

Now, De Anda and colleagues have identified an entirely new phylum — a large branch of related organisms on the tree of life — of archaea. The first evidence of these new organisms was within sediments from seven hot springs in China as well as from deep-sea hydrothermal vents in the Guaymas Basin in the Gulf of California off Mexico. Within these sediments, the researchers found bits of DNA that they meticulously assembled into the genetic blueprints, or genomes, of 15 different archaea.

The team compared the genomes with thousands of previously identified microbial genomes described in publicly available databases. But "these sequences were completely different from anything that we know," De Anda says. She and her colleagues named the new group Brockarchaeota in honor of Thomas Brock, a microbiologist who was the first to grow archaea in the lab and who died in April.

Brockarchaeota microbes, it turns out, actually live all over the world. Once De Anda and her team had pieced together the new genomes and then hunted for them in public databases, they discovered that genetic material from these previously unknown organisms had been found in hot springs, hydrothermal vent sediments and lake sediments from South Africa to Indonesia to Rwanda.

Within the Brockarchaeota genomes, the team hunted for genes related to metabolism — what nutrients the microbes consume and what kind of waste they produce. Initially, the team expected that, like other archaea from such environments, these archaea would be methane producers. Brockarchaeota and methane-producing archaea do munch on the same materials: one-carbon compounds such as methanol or methylsulfide. "But we couldn't identify the genes that produce methane," De Anda says. "They are not present in Brockarchaeota."

That means that these archaea must have a previously unknown metabolism through which they can recycle carbon — for example, in sediments on the seafloor — without producing methane. Given how widespread Brockarchaeota organisms are, they could be playing a hidden but significant role in Earth's carbon cycle, De Anda says.

"It's twofold interesting — it's a new phylum and a new metabolism," says Luke McKay, a microbial ecologist of extreme environments at Montana State University in Bozeman. The fact that this entire group remained under the radar for so long "is an indication of where we are in the state of microbiology," McKay says.

But, he adds, the discovery is also a testament to the power of metagenomics, in which researchers painstakingly tease apart individual genomes out of a large hodgepodge of microbes in a given sample of water or sediments. Thanks to this technique, researchers are identifying more and more parts of the previously mysterious microbial world.

"There's so much out there," De Anda says. "Every time you sequence more DNA, you start to realize that there's more out there that you weren't able to see the first time." ■

UNIVERSITY OF TEXAS AT AUSTIN

MATTER & ENERGY

Strict timekeeping creates entropy

As a clock gets more accurate, it generates more disorder

BY EMILY CONOVER

Today's most advanced clocks keep time with an incredibly precise rhythm. But a new experiment suggests that clocks' precision comes at a price: entropy.

Entropy, or disorder, is created each time a clock ticks. Now, scientists have measured the entropy generated by a clock that can be run at varying levels of accuracy. The more accurate the clock's ticks, the more entropy it emitted, physicists report online May 6 in *Physical Review X*.

"If you want a better clock, you have to pay for it," says physicist Natalia Ares of the University of Oxford.

Time and entropy are closely intertwined concepts. Entropy is known as the "arrow of time," because entropy tends to grow as time passes — the universe seems to consistently move from lower entropy to higher entropy (*SN: 7/25/15, p. 15*). This march toward increasing entropy explains why some processes can proceed forward in time but not in reverse: It's easy to mix cream into coffee but impossible to unmix the drink. Machines also increase disorder as they operate, for example by giving off heat that boosts the entropy of their surroundings. That means even a standard, battery-powered clock produces entropy as it ticks.

Physicists had previously calculated that, for tiny quantum clocks, there's a direct relationship between the maximum possible accuracy of their ticks and the amount of entropy emitted. But larger clocks are too complex for such calculations. So it wasn't clear if such a rule held for other types of clocks too.

To test how much entropy was released in the ticking of a simplified clock, Ares and colleagues made a clock from a membrane tens of nanometers thick and 1.5 millimeters long suspended across two posts. An electrical signal sent into the clock jostled the membrane, causing it to flex up and down. This bending motion repeated at regular intervals, like the steady ticks of a clock, and an antenna registered that motion. The more powerful the electrical signal was, the more accurately the clock ticked. And as the clock's accuracy increased, the entropy — a result of heat produced in the antenna's circuit — increased in lockstep. That result suggests that the theoretical relationship for quantum clocks also applies to other types of clocks.

"What I'm not so sure of is how universal is this type of relationship that they find," says physicist Juan Parrondo of the Complutense University of Madrid. The researchers studied only one variety of clock. It's not yet clear whether the relationship between accuracy and entropy applies to clocks more generally, Parrondo says.

But some scientists suspect the relationship may be universal, revealing a fundamental aspect of how clocks function. The new study is "a data point in favor that it's probably the case for all clocks," says quantum physicist Ralph Silva of ETH Zurich.

For a clock to operate reliably, it must undergo a process that has a preferred direction in time. If the clock didn't create entropy, it would be just as likely to run forward as backward. And the more entropy the clock creates, the less likely it is that the clockwork will suffer from fluctuations that would degrade its accuracy. If the accuracy of all clocks does come at a cost of increased entropy, that trade-off may reflect a close link between the passage of time and its measurement. ■

EARTH & ENVIRONMENT

Lightning boosts air-cleaning chemicals

Lightning could play an important role in cleaning the atmosphere by forging lots of chemicals called oxidants, researchers report in the May 14 *Science*. Oxidants clear the air by reacting with pollutants to form molecules that fall as rain or stick to Earth's surface. In 2012, a NASA jet flying through storm clouds over Colorado, Oklahoma and Texas (lightning from a 2017 storm at right) detected two oxidants — hydroxyl radicals and hydroperoxyl radicals — at combined concentrations of up to thousands of parts per trillion. The highest concentration of hydroxyl radicals previously observed in the atmosphere was a few ppt, while the most hydroperoxyl radicals observed was about 150 ppt. Electricity can generate such large quantities of the chemicals, lab experiments confirmed. Lightning could account for up to 16 percent of atmospheric hydroxyl radicals, the team says. Understanding lightning's effects on the atmosphere may become more important as climate change sparks more lightning. — *Maria Temming*

DREW ANGERER/GETTY IMAGES

LIFE & EVOLUTION

Equids supply water to thirsty wildlife

Wells dug by feral donkeys and horses may help ecosystems

BY JONATHAN LAMBERT

Water drives the rhythms of desert life, but animals aren't always helpless against the whims of weather.

In the American Southwest, wild donkeys and horses often dig into the dusty sediment to reach cool, clear groundwater to quench their thirst. New research shows that this equid ingenuity has far-reaching benefits for the ecosystem.

Equid wells can act as desert oases, providing a major source of water during dry times that benefits a whole host of desert animals and trees, researchers report in the April 30 *Science*.

Donkeys and other equids, like this kulan in Central Asia, dig wells in search of water. Such wells in the American Southwest may benefit ecosystems by boosting water access.

Introduced to North America in the last 500 years or so, wild donkeys and horses are often cast as villains in the West. These species can trample native vegetation, erode creek beds and outcompete native animals. But when Erick Lundgren, a field ecologist at Aarhus University in Denmark, first observed wild donkeys digging wells in 2014, he wondered whether these holes might benefit ecosystems, similar to the way elephant-built water holes can sustain a community in the African savanna.

"Because of the way we value [feral] horses and donkeys, the orthodoxy tends to focus on how they harm ecosystems," he says. "We wanted to see whether these holes provided a resource when water is scarce."

Over the course of three summers from 2015 to 2018, Lundgren and colleagues mapped out the surface area of water in wells and groundwater-fed streams at four sites in Arizona's Sonoran Desert.

Water availability was highly variable among sites, but equid wells generally increased accessible water, especially as temperatures rose. At one site, wells were the only source of drinking water once the local stream completely dried up. Elsewhere, wells provided up to 74 percent of available surface water. Wells also decreased the distance between water sources by an average of 843 meters, easing tensions that can escalate among drinkers at isolated water holes, Lundgren says.

Once wells were dug, other animals came in droves. Cameras staking out wells, riverbanks and dry spots at five sites in the Sonoran and Mojave deserts documented 57 vertebrate species, from migratory songbirds to mountain lions, slurping at the wells. That's about equal to the number of species seen at streams and 64 percent higher than at dry spots.

"We even caught a black bear drinking from a well," says Lundgren, who also takes swigs from the wells from time to time. "The water is quite cool,

LIFE & EVOLUTION

Antibiotic slows a fatal coral disease

Amoxicillin is 95 percent effective at halting tissue loss

BY CASSIE MARTIN

Slathering corals in a common antibiotic seems to soothe a mysterious tissue-eating disease, new research suggests.

Just off Florida, a type of coral infected with stony coral tissue loss disease, or SCTLD, showed widespread improvement several months after being treated with amoxicillin, researchers report April 21 in *Scientific Reports*. While the deadly disease eventually reappeared on some treated corals, the results provide a spot of good news while scientists continue the search for what causes it.

Divers discovered SCTLD on reefs near Miami in 2014. Characterized by white lesions that rapidly eat away at coral tissue, the disease plagues nearly all of the 580-kilometer-long Great Florida Reef and has spread to reefs in the Caribbean (*SN: 8/3/19, p. 14*).

Since the cause is unknown, scientists are left to treat the lesions through trial and error. Two treatments that show promise involve divers applying a chlorinated epoxy or an amoxicillin paste to infected patches. "We wanted to experimentally assess these techniques to see if they're as effective as people have been reporting anecdotally," says Erin Shilling, a coral researcher at Florida Atlantic University's Harbor Branch Oceanographic Institute in Fort Pierce.

In April 2019, Shilling and colleagues identified 95 lesions on 32 colonies of great star coral (*Montastraea cavernosa*) off Florida's east coast. The scientists dug trenches into some of the corals around the lesions to separate diseased tissue from healthy tissue, then filled the moats and covered the diseased patches with the antibiotic paste or chlorinated epoxy.

Within about 11 months of the treatment, some 95 percent of infected coral tissues treated with amoxicillin had healed. Meanwhile, only about 20 percent of infected tissue treated with chlorinated epoxy had healed in that time — no better than untreated lesions.

But a one-and-done treatment doesn't stop new lesions from popping up over time, the team found. And some key questions remain unanswered, including how well the treatment works for more coral colonies and species, and what longer-term side effects the antibiotic could have on corals and their environment.

© PETRA KACZENSKY

and cleaner than other sources."

Wells can also be nurseries for cottonwood seedlings that require moist, open areas to grow. The seedlings struggle to break through vegetation-stuffed riverbanks and rely on floods for their first sips of water. But at one site, researchers found seedlings thriving in equid holes. Many seedlings survived the summer, growing as tall as 2 meters. In areas where dams reduce flooding, equid wells could fulfill an important ecosystem service for these iconic trees, the team says.

It's too early to conclude that feral donkeys and horses are good for ecosystems, says Jeffrey Beck, a restoration ecologist at the University of Wyoming in Laramie. "The benefits [the equids] demonstrate in this study might be limited to this area."

Still, the team hopes the study can chip away at the notion that introduced species are wholly bad. In some areas, feral equids "are being killed by the hundreds of thousands in the name of purifying nature," says study coauthor and ecologist Arian Wallach of the University of Technology Sydney. These animals are part of nature too, she says, and eradication efforts might ripple through an ecosystem in unforeseen ways. ■

"Erin's work is fabulous," says Karen Neely, a marine biologist at Nova Southeastern University in Fort Lauderdale, Fla. Neely and colleagues saw similar results in their two-year experiment at the Florida Keys National Marine Sanctuary. Her team used the same antibiotic and epoxy treatments on more than 2,300 lesions on upward of 1,600 coral colonies representing eight species.

Those antibiotic treatments were more than 95 percent effective across all species, Neely says. And treating new lesions that popped up after the initial treatment appeared to stop corals from becoming reinfected over time. The research is undergoing peer-review in *Frontiers in Marine Science*.

"Putting these corals in this treatment program saves them," Neely says. "We don't get happy endings very often, so that's a nice one." ■

LIFE & EVOLUTION

Baby mantis shrimp put up their dukes

Larvae start practicing powerful punches at just 9 days old

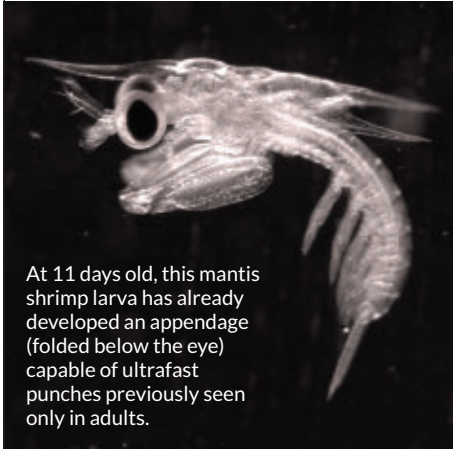
BY CHARLES Q. CHOI

The fastest punches in the animal kingdom probably belong to mantis shrimp — and the carnivorous crustaceans begin unleashing these attacks a little more than a week after hatching, when they have just started to hunt prey, a new study suggests.

For the first time, researchers have peered through the transparent exoskeletons of young mantis shrimp to see the inner mechanisms of their powerful weapons in motion, researchers report in the April *Journal of Experimental Biology*. The findings are letting scientists in on hidden details of how these speedy armaments work, something previously only imagined from surgical dissections and CT scans.

Mantis shrimp are equipped with special pairs of arms that can explode with bulletlike accelerations to strike at speeds of up to roughly 110 kilometers per hour. These weapons act like crossbows. As a latch holds each arm in place, muscles within the arm contract, storing energy within the arm's hinge. When the crustaceans release these latches, all this energy discharges at once (*SN: 8/31/19, p. 10*).

But researchers didn't know at what age mantis shrimp begin launching spring-loaded attacks. Computer simulations predicted that the armaments might be capable of greater accelerations the smaller they got, suggesting young mantis shrimp could have faster weapons than adults, says marine biologist Jacob Harrison of Duke University.



At 11 days old, this mantis shrimp larva has already developed an appendage (folded below the eye) capable of ultrafast punches previously seen only in adults.

J. HARRISON

To solve this mystery, Harrison and colleagues collected the larvae of Philippine mantis shrimp (*Gonodactylaceus falcatus*) off boat docks in Oahu, Hawaii. The team glued the larvae, each about the size of a grain of rice, onto toothpicks and used a high-speed camera to record their punches. The researchers also captured a clutch of *G. falcatus* eggs and raised the hatchlings for 28 days to see how the weaponry developed over time.

Larvae began striking rapidly as soon as nine days after hatching, about when they started feeding on live prey. Punches flew at speeds of about 1.4 kilometers per hour. Given the larvae's tiny arms — only about one-hundredth the length of an adult's — that's roughly proportional to the speed of an adult shrimp's punch, Harrison says. More importantly, it's up to 10 times the swimming speeds of crustaceans and fish roughly as big as the larvae, and more than 150 times those of brine shrimp that the team fed the larvae.

"Mantis shrimp larvae are capable of moving incredibly quickly for something so small," Harrison says. But the larvae did not punch faster than the adults, the team found. That finding suggests there may be some constraints on these weapons at microscopic sizes.

Alternatively, larvae may simply not require weapons faster than those of adults, says Kate Feller, an invertebrate neuroecologist at Union College in Schenectady, N.Y. Larvae might "just need a crossbow that works and don't need it to be this crazy superpowerful thing," Feller says. "The fact these larvae are transparent is a great opportunity to answer questions like how the latch works," she adds. "That's very exciting." ■

Watch a mantis shrimp larva punch in slow motion at **bit.ly/SN_MantisPunch**

SCIENCE GALLERY DUBLIN

Science Museums *in a Pandemic*

To survive the shutdown, many institutions reimagined themselves

By Emily Anthes

On January 30, 2020, Science Gallery Dublin assembled a small group of experts to discuss a strange new disease that had recently emerged in China. Four panelists talked about the origins of the new coronavirus, whether it might be airborne and the prospects for a vaccine. While they agreed that it was important to take the virus seriously, the speakers urged the audience not to panic. There had been no known cases in Ireland. The prospect of a local outbreak seemed remote.

"And that was the last live event we held in the gallery," says Aisling Murray, the gallery's head of programming. That very day, the World Health Organization declared the COVID-19 outbreak a "public health emergency of international concern." Six weeks later, with cases on the rise all over the globe, Science Gallery Dublin shut its doors. It was a moment of reckoning. "What does Science Gallery mean when we don't have a space?" Murray recalls wondering. "How do we

After the pandemic forced Science Gallery Dublin to shut its doors, the museum installed several exhibits, including this 3-D printed dress that helps enforce social distancing, just behind its glass facade to catch the eye of people on the street.

continue to engage our audience?"

As the COVID-19 pandemic began to spiral out of control in March 2020, science museums around the world were forced to abruptly close. In a matter of days, ticket revenue vanished. "It was an existential crisis," says Christofer Nelson, president and CEO of the Association of Science and Technology Centers, or ASTC, in Washington, D.C. "The fundamental business, operational, staffing, community service model of these organizations just went away overnight. And the question was 'What do we do next?' "

The weeks and months that followed were excruciatingly difficult for science museums, which lost more than $600 million in revenue in just the first six months of the pandemic, the ASTC estimates. Many museums and science centers were forced to adopt deep cost-cutting measures; some laid off more than half of their employees.

Few science museums had substantial endowments to pull from, so they scrambled for support. They launched new campaigns for donations, applied for government loans and sought grants and support from community organizations or corporations.

As they tried to make ends meet, they also realized they had to reinvent their programs if they wanted to survive. Over the last year, they have launched a diverse array of exhibits and offerings that are not tied to their physical buildings, and they have helped educate the public about COVID-19. Some museums have even found creative ways to meet serious community needs, providing everything from child care to fresh food.

Along the way, these institutions have redefined what modern science museums can be and how they engage with the world beyond their walls. Though many museums are in various phases of reopening, their experience over the last year may leave a lasting legacy.

Hasty pivot

When museums initially closed last year, most administrators thought the disruption would last only a few months. In those early days and weeks, the institutions shifted into crisis response mode, scrambling to create some kind of public programming. "Within a couple of weeks, we were spinning up what now we would call 'minimum viable products,' " says Tim Ritchie, president of the Museum of Science in Boston. Staff members who typically spent their days giving face-to-face presentations inside the museum on topics from reptiles to space started delivering those talks over Zoom. "It was not that great at first," Ritchie admits. "But people were hungry [for it], and they tuned in."

Many institutions did the same, making some of their traditional exhibits and programs virtual. By the end of March 2020, the California Academy of Sciences in San Francisco had turned its program called NightLife — a regular Thursday night event that charged from $10 to $20 for admission to the museum for science, music and cocktails — into a free weekly online program called NightSchool.

The Great Lakes Science Center in Cleveland converted its in-person demos into Curiosity Corner LIVE! This daily YouTube broadcast included science demonstrations and activities — such as building catapults and lava lamps — for kids and families to do at home.

Seattle's Pacific Science Center filmed the live

"The fundamental business, operational, staffing, community service model of these organizations just went away overnight. And the question was 'What do we do next?' "

CHRISTOFER NELSON

Pacific Science Center, Seattle
Live science show: Combustion

Oregon Museum of Science and Industry, Portland
Scales, Claws and Expanding Jaws

Early in the pandemic, many science museums scrambled to convert their in-person demonstrations into online videos. Pacific Science Center's Marissa Wyll (above left) shares the wonders of combustion. Educator Brad Alston (right) of the Oregon Museum of Science and Industry offers viewers a closer look at Bebe the crested gecko.

science shows that it typically staged in person and shot a series of behind-the-scenes videos, featuring Senora the tarantula, Rigatoni the western hognose snake and other animals in its collection. "We recorded everything that we could, as quickly as we could," says Zeta Strickland, the center's director of preK–12 engagement. The center's most popular live science show, Combustion, has had more than 6,500 views on YouTube.

Museums also used their science communication expertise to address the pandemic itself. There was an "immediate and urgent recognition that this crisis was fundamentally a crisis of science engagement," says the ASTC's Nelson.

Shannon Bennett, a virologist who happens to be the California Academy of Science's chief of science, fielded online questions about COVID-19, while the Pacific Science Center designed an online landing page for pandemic-related information. The page includes a pandemic glossary, a vaccine explainer and a guide to identifying misinformation. The website also offers a curated collection of news articles and links to trusted sources, such as the U.S. Centers for Disease Control and Prevention. "There was so much misinformation and disinformation out there, so we really wanted to be a resource where people can find accurate information," says Danielle Cobb, marketing communications manager for the Pacific Science Center.

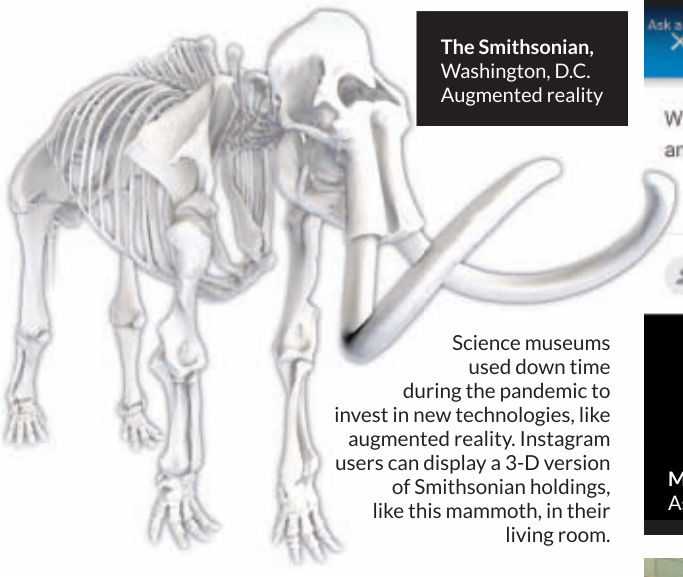
Some museums stepped up to meet more basic community needs. The Mid-Hudson Children's Museum in Poughkeepsie, N.Y., had started running a weekly summer farmers market in its pavilion in 2017. When the pandemic hit, local schools, which offer free breakfast and lunch to all students, shut down. "There was a huge focus on how do you get food to kids that they would otherwise get through the school," says Lara Litchfield-Kimber, the museum's executive director. "What we realized is that in our city, we had an essential business."

The museum rallied its vendors and opened the market, which accepts food stamps, in May, a month before its typical start. The market became a hub of activity, and museum staff worked with city officials to distribute flyers, in English and in Spanish, about COVID-19. (The museum is exploring the possibility of hosting a year-round market.) "The museums that are ... maintaining their strength are those that recognize how to leverage their assets to address the urgent needs of their community," Litchfield-Kimber says.

On the other side of the country, the Oregon Museum of Science and Industry in Portland started offering child care for 20 to 30 children of essential workers. "We have the training. We have the certifications. We have the people. We have the stuff to have kids in the museum — that's just what we do," says John Farmer, the museum's former marketing and communications manager.

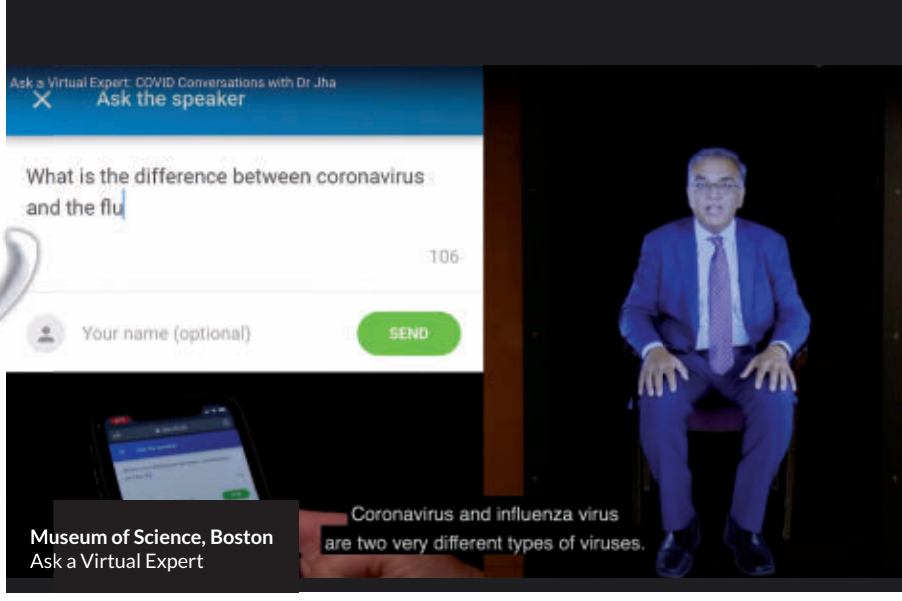
In the fall, the museum converted the child care program into Homeroom, offering a place where children who were enrolled in remote school could spend their days. The museum prioritized families in need, Farmer says, and offered financial aid for the program, which has enrolled more than 100 students over the last year. San Diego's Fleet Science Center organized similar distance learning hubs so children could go to the center and connect to their remote classrooms.

FROM LEFT: PACIFIC SCIENCE CENTER; OREGON MUSEUM OF SCIENCE AND INDUSTRY



The Smithsonian, Washington, D.C.
Augmented reality

Science museums used down time during the pandemic to invest in new technologies, like augmented reality. Instagram users can display a 3-D version of Smithsonian holdings, like this mammoth, in their living room.



Museum of Science, Boston
Ask a Virtual Expert

Science Gallery Dublin
Speed of Science

Many museums also put together resources for schools that had shifted to remote teaching. The California Academy of Sciences reformatted its planetarium films for YouTube so teachers could show films like *Expedition Reef* and *Fragile Planet* to their students. The center also offers free distance learning livestreams, in English and in Spanish, for students from kindergarten through eighth grade.

The New York Hall of Science in Queens began offering virtual science workshops to schools: A museum educator leads an entire class of kids through an hour of activities and demonstrations on topics ranging from optical illusions to the science of sports. The workshops, which cost $150 for a group, sell out months in advance. "What teachers want is a bit of relief," says Margaret Honey, president and CEO of the New York Hall of Science. "They really gravitate toward the experiences."

Pushing the envelope

As the pandemic dragged on, museums started to think longer term. They got more ambitious and creative. "We decided to get better at being digital," Ritchie says.

Last summer, Boston's Museum of Science created Ask a Virtual Expert, an experience powered by artificial intelligence featuring Ashish Jha, dean of the School of Public Health at Brown University in Providence, R.I. Museum staff filmed Jha as he answered more than 500 questions on COVID-19 and then turned the footage into an interactive exhibit. Members of the public can pose questions about the pandemic directly to a digital version of Jha, and he responds.

The Smithsonian, which began 3-D scanning some of its artifacts years ago, used the time that its doors were closed to improve its digital 3-D offerings. On its website, for instance, visitors can peruse or download free, 3-D scans of everything from the Apollo 11 command module to a complete woolly mammoth skeleton. In December, the institution announced a partnership with Instagram that allows users of the photo sharing app to display virtual versions of famous Smithsonian artifacts in their own personal spaces. "You can drop the space shuttle *Discovery* in your backyard and have your family standing next to it and have a screenshot and share it on Twitter," says Vincent Rossi, supervisor of the 3-D program for the Smithsonian's Digitization Program Office.

Other museums found clever ways to create in-person experiences that were COVID-19 safe. Science Gallery Dublin, located on the campus of Trinity College Dublin, took advantage of the glass facade on one side of its building, installing five pandemic-related exhibits just inside the glass. Passersby could peer into the windows and see a cluster of Lego figures arranged to demonstrate the concept of herd immunity or a sensor-laden, 3-D printed dress with a skirt that spreads out to enforce social distancing.

Called "Speed of Science," the exhibition was

Many science museums addressed the COVID-19 pandemic head on. The Museum of Science in Boston used artificial intelligence to create a virtual exhibit that allows people to pose questions about the coronavirus to public health expert Ashish Jha of Brown University (top). A Lego exhibit in one of the streetside display windows at Science Gallery Dublin explained herd immunity (bottom).

CLOCKWISE FROM LEFT: SMITHSONIAN; MUSEUM OF SCIENCE; SCIENCE GALLERY DUBLIN

Kids who attended Space Center Houston's clean room camps wore personal protective equipment to simulate the experience of working in a NASA clean room.

Space Center Houston
Clean room camps

The Center of Science and Industry has been distributing kits of hands-on science activities through local food banks and homeless shelters.

Center of Science and Industry, Columbus, Ohio
COSI Connects kits

Children tested a project last summer that the Mid-Hudson Children's Museum will offer through a new pop-up mobile program.

Mid-Hudson Children's Museum, Poughkeepsie, N.Y.
Prototype project testing

produced in partnership with the pharmaceutical company Pfizer, which had collaborated with the gallery on a pop-up exhibit in 2019. The exhibit's online hub, which includes a podcast on vaccination and vaccine development, has had nearly 5,000 visits.

Last summer, Space Center Houston offered "clean room" camps, which simulated the experience of working in one of the NASA facilities dedicated to ensuring that the objects the agency launches into space are free of potential contaminants. Upon arrival at camp, kids donned gowns, gloves, masks, caps and shoe coverings. "Basically, we shrink-wrap the kids," says William Harris, the center's president and CEO. "It's just like they're in a clean room at NASA." The camps were so popular that the center offered them again over the Thanksgiving, winter and spring breaks.

Meanwhile, the Mid-Hudson Children's Museum used its closure in 2020 to begin a long-planned transition to becoming a more hands-on science center. To jump-start its science programming while the building was closed, the museum bought a van and partnered with NASA to turn it into a mobile, pop-up museum for outdoor, space-related demonstrations and activities.

Expanded reach

As difficult as the pandemic has been, it's also given science museums an opportunity to make long-needed changes and pursue long-standing goals. Even before COVID-19 emerged, the Center of Science and Industry, or COSI, in Columbus, Ohio, had been wanting to find new ways to get out into the community. "Yes, we want to sell tickets to our building," says Frederic Bertley, COSI's president and CEO. "But we have to be more than that."

When COSI closed in March 2020, its staff rolled out an assortment of digital offerings — and launched a TV show — but the team also wanted to re-create the hands-on, tactile experiences that have long been the cornerstone of science museums. The solution was an assortment of COSI Connects kits.

Each kit has five hands-on activities for kids that revolve around a theme: nature, water, space, dinosaurs or the human body. The kits can be purchased online, and COSI distributes them for free through food banks, Boys & Girls Clubs, homeless shelters and other organizations. The museum is in discussions to distribute them through school districts in Ohio and several other states.

"We weren't trying to make money off of this," Bertley says. "We were trying to make sure that

FROM TOP: SPACE CENTER HOUSTON; KEVIN MICHAEL SEYMOUR PHOTOGRAPHY; MID-HUDSON CHILDREN'S MUSEUM

COSI was still relevant, that a state-of-the-art science museum still had a fundamental role in society, even though we were closed." COSI plans to continue offering the kits when the building reopens in early June. "This is how we can have a beyond-Ohio impact," Bertley says.

Indeed, museums are discovering that untethering their programs from their physical buildings has expanded their reach. At the California Academy of Sciences, a pre-pandemic, in-person NightLife event typically attracted roughly 1,700 people. NightSchool, the virtual version, averages more than 10,000 views per installment. These events are free; they don't bring in money. But, says senior digital engagement and community manager Laurel Allen, "we've been able to build bigger communities."

Although the academy initially thought of its online events as a stopgap measure, it has decided to continue them in some form now that the museum has reopened. The majority of viewers are outside the Bay Area and are unlikely to make regular in-person visits.

An immersive virtual tour created by the National Museum of Computing in Milton Keynes, England, last summer has attracted more than 140,000 visitors from the United Kingdom, United States, India and Brazil. "I don't think we ever took for granted the audience reach that we had," says Jacqui Garrad, the museum's director. "But I do think that we maybe didn't try hard enough to engage some of the outside communities."

Some museums have invested in accessibility, overhauling websites to be more friendly to visitors who are blind or have low vision and offering digital programs specifically for visitors who are deaf and hard of hearing. Others have increased their free offerings and resources for low-income families and other underserved communities. The Museum of Science in Boston launched MOS en Español, an online hub for programming in Spanish.

Of course, the pandemic — and the threat to museums' basic business model — is not over yet. "I don't think we're by any means out of the woods," ASTC's Nelson says. Museums were "great at cutting costs," he adds. "But they're now at the bare minimum."

In a June 2020 survey of 750 museum directors, one-third reported that their institutions were at "significant risk" of closing permanently. So far, the ASTC is aware of just one permanent closure among science museums: the Orpheum Children's Science Museum in Champaign, Ill. And while some museums have reopened, visitors have been slow to return; attendance is about half pre-pandemic levels, according to ASTC's ongoing attendance survey.

Mid-Hudson Children's Museum
Farmers market

When the Poughkeepsie, N.Y., area shut down in spring 2020, the Mid-Hudson Children's Museum saw food insecurity grow. The museum already ran a summer farmers market, but extended the season to May through October.

Soon after the pandemic hit, ASTC lobbied the federal government to include museums in relief efforts and pulled together online resources to help its members navigate new financial and operational realities. In the first round of the federal Paycheck Protection Program, nearly 300 of ASTC's members received loans totaling more than $180 million.

When museums close, it's a huge loss for their communities, Nelson says. "Museums really serve as a critical part of their communities' economic, cultural and learning ecosystems."

But the museums that survive may emerge more nimble and resilient — and able to serve the public in new and urgent ways. "We need to double down on this idea of wanting to respond at all times to what the community needs," says Steven Snyder, president and CEO of San Diego's Fleet Science Center. "It's also a proof of concept that we're not locked to our building. Science centers never have been." ■

> "Yes, we want to sell tickets to our building. But we have to do more than that."
>
> FREDERIC BERTLEY

Explore more

- Association of Science and Technology Centers. "Virtual Science Engagement." www.astc.org/coronavirus/educationalresources/

Emily Anthes is a freelance science journalist based in Brooklyn, N.Y.

MID-HUDSON CHILDREN'S MUSEUM

In type 1 diabetes, the pancreas can't make enough insulin to control blood sugar. Patients must monitor their blood glucose levels and inject insulin as needed to avoid immediate and long-term health risks.

E. JASON WAMBSGANS/*CHICAGO TRIBUNE*/TRIBUNE NEWS SERVICE VIA GETTY IMAGES

Repurposed remedy

A 100-year-old weapon against TB shows early promise against multiple diseases

By Amanda B. Keener

Around the world, volunteers are getting a vaccine developed to prevent tuberculosis in studies that have nothing to do with TB. Called Bacillus Calmette-Guérin, or BCG, the shot is being tested as a treatment for type 1 diabetes, Alzheimer's disease, multiple sclerosis and even COVID-19.

BCG is a live but weakened version of *Mycobacterium bovis*, a relative of *M. tuberculosis*, the bacterium that causes the infectious lung disease known as TB. The vaccine has been around for 100 years and is routinely given to children in nearly all non-Western nations.

Almost as soon as BCG was introduced in the 1920s, researchers noticed a drop in infant deaths in some places where the vaccine was used. Later studies revealed that the vaccine protects against a range of infections. Much more recently, a single dose of the vaccine reduced the risk of respiratory infections in elderly study participants compared with those who got a placebo, according to an October 15 report in *Cell*.

The vaccine appears to boost immunity in some situations, but paradoxically, BCG may also calm an overactive immune system. It's this soothing effect that made researchers take a look at BCG for autoimmune and inflammatory diseases, including eczema, asthma, allergies and multiple sclerosis. In MS, a disease in which the immune system attacks nerve cells in the brain and spinal cord, BCG appears to slow damage to the brain.

"Everybody kept getting signals, often from human data, saying this microorganism is doing beneficial things ... whether it was allergy or autoimmunity or multiple sclerosis or diabetes," says immunologist Denise Faustman of Harvard Medical School. "Over the last 10 years, that dataset has just grown and grown." Faustman is testing BCG as a therapy for people with type 1 diabetes. In this autoimmune disease, the immune system attacks insulin-producing cells in the pancreas, leaving the body unable to make the insulin needed to control blood sugar levels.

Faustman is in the midst of a 150-person safety and efficacy trial of BCG in adults with type 1 diabetes. Her team previously showed, in a small study published in 2018, that the vaccine can safely improve blood glucose control in patients with long-term disease who continued taking insulin. The vaccine appears to reprogram immune cells to take up extra glucose, her team reported in *iScience* in May 2020.

Now, she and other researchers are digging into the basic science behind their observations, while

also launching clinical trials of BCG in patients with type 1 diabetes, MS and Alzheimer's. The scientists hope the answers will help drum up support for this line of research, which has drawn skepticism in the scientific community.

An unlikely treatment

Evidence of BCG's unanticipated effects has been quietly accumulating for decades. In some settings the vaccine reduced the overall rate of infant death by about 30 percent, based on a 2016 systematic review in *BMJ* of both clinical trials and observational studies. In the 1980s, the vaccine became a standard immune-boosting treatment for people with bladder cancer. In a study reported in 2019 in *JAMA Network Open*, people who got BCG in childhood had a 2.5-fold lower risk for lung cancer as adults.

But none of this was on Faustman's radar when her type 1 diabetes research led her to BCG. Her goal was to stop the autoimmune attack on beta cells, the cells in the pancreas that make insulin. Normally, beta cells respond to changes in blood glucose and release just enough insulin to trigger other cells to take up glucose from the blood and burn it up for energy.

In type 1 diabetes, immune system T cells destroy beta cells, so people with the disease must frequently monitor their blood glucose and inject insulin to keep glucose levels within a healthy range. Very high or very low glucose levels can cause coma or death. Over a lifetime, less extreme glucose fluctuations lead to blood vessel damage along with kidney, heart and vision problems.

In the late 1990s and early 2000s, Faustman's team and others found that a molecule called TNF alpha, which is made by some immune cells, could selectively kill the T cells that attack beta cells. Among its many jobs, TNF alpha fights bacterial infections and helps the body make T regulatory cells, or T-regs, which act as referees to prevent collateral damage during immune responses. For reasons that are not well understood, in people with type 1 diabetes, T-regs are either too few or defective. Faustman and others found that TNF alpha boosted T-reg numbers and activity in mice and in human cells.

But giving TNF alpha directly wasn't an option; it was expensive and hard to administer safely. So Faustman's team searched for something that could trigger immune cells to make TNF alpha on their own. "The answer that kept popping up was BCG," Faustman says.

Another research group led by immunologist Bhagirath Singh, then at the University of Alberta in Edmonton, Canada, had found in the 1990s that BCG and a related immune stimulant called complete Freund's adjuvant, or CFA, could prevent type 1 diabetes in mice prone to the disease. CFA, which is made with dead *M. tuberculosis*, also protected pancreatic cell transplants in diabetic mice from destruction by the immune system.

Faustman's team found similar results, as well as that diabetic mice given CFA began producing their own insulin; their pancreases seemed to be healing. The finding was intriguing, but in type 1 diabetes research, Faustman cautions, "everything works in the mouse."

In 1994, an Israeli team used BCG and got blood sugar under control, with very little insulin use, in children recently diagnosed with the disease. The results, however, could not be replicated.

That didn't deter Faustman. There are at least a dozen strains of the BCG organism used for vaccines, and scientists have learned that different strains have different effects on the immune system. Faustman's team screened several strains to find one that could trigger TNF alpha and shift the balance between autoimmune T cells and T-regs in samples of white blood cells from people with type 1 diabetes.

With a strain in hand that worked, Faustman's team recruited three adults who had been living for many years with type 1 diabetes, and had never been vaccinated with BCG. Each person got two injections of BCG, four weeks apart. The volunteers continued using insulin while their blood was checked for changes to T cells and levels of hemoglobin A1c, or HbA1c, which tells how well-controlled glucose is in the blood.

During the 20-week study, the researchers saw small changes to T cells, but no big improvement in HbA1c, the measurement that really matters to type 1 diabetes patients.

Wait for it

By this time, Faustman had met researchers from Rome who had found that BCG could reduce the likelihood that people with brain inflammation would develop multiple sclerosis — but the effect was most apparent after months to years. With this longer time frame in mind, Faustman checked in with the patients from her study annually to measure HbA1c levels. After year three, "the HbA1c's were down 10 to 18 percent," Faustman says. "It was not subtle."

To put that into context, for every 10 percent drop in HbA1c, the risks of diseases caused by

The long view

Over time, poor glucose control in people with diabetes can lead to:

- Vision problems
- Kidney disease
- Nerve damage with pain, burning or loss of feeling
- Heart attack and stroke due to blood vessel damage
- Foot infections, amputation
- Depression

blood vessel damage — a major problem in people with diabetes — drop 25 to 44 percent. Faustman's team added six more patients to the study, and all nine volunteers went at least three years with near-normal blood sugar levels. Three of those patients maintained these levels for five years, the team reported in *npj Vaccines* in 2018. And none of the patients reported episodes of blood sugar dropping too low.

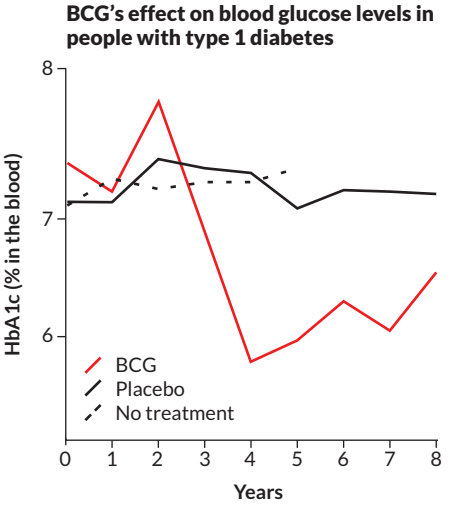
The HbA1c shift was exciting, but Faustman was perplexed when she looked for its cause. The patients' T-regs were more active, as expected, but levels of natural insulin did not go up, suggesting something else was helping to control blood sugar.

A clue came from the breakdown products, or metabolites, in the patients' blood made when cells use glucose. Those metabolites were more abundant in the blood after patients received BCG. Faustman's group also found that before BCG treatment, patients had lower levels of the metabolites than healthy people, which the researchers confirmed by studying blood from another 100 patients with type 1 diabetes.

Looking more closely, the team found that white blood cells — specifically monocytes — from people with type 1 diabetes took up less glucose than did the same cells in healthy people. But exposing patients' monocytes to BCG in the lab corrected this defect in glucose metabolism, the researchers reported last year in *iScience*.

In the same study, the researchers gave a new group of patients three BCG injections in a year and observed that genes related to breaking down glucose were more active in the patients' T cells and monocytes than before the shots.

"BCG was taking these underlying defects in diabetics, both in the immune system and metabolism, and correcting them towards normal," Faustman says. BCG seems to give the patients a new way to dispose of glucose, she says.



Sugar drop In a small study, nine patients with type 1 diabetes (red line) got two shots of BCG. Three years later, that group experienced drops in blood glucose, as measured by hemoglobin A1c. HbA1c levels remained low for several years compared with patients who were untreated (dashed line) or given a placebo (black line). Throughout the experiment, all of the patients continued taking insulin.

SOURCE: W.M. KÜHTREIBER *ET AL/NPJ VACCINES* 2018

C. CHANG

Hope or hype?

Faustman's work has generated a wide range of reactions from people within the type 1 diabetes community. Patients are excited by the possibility of an inexpensive treatment that, while not a cure, could make life easier. With type 1 diabetes on the rise, currently affecting 1.6 million people in the United States, and with the high cost of insulin, anything that could help patients regulate blood sugar without increasing insulin doses could have a big impact.

"Even if it's in addition to current insulin therapy, it's a great hope," says Siham D. Accacha, a pediatric endocrinologist at NYU Long Island School of Medicine in Mineola, N.Y. Managing glucose levels takes a physical, mental and emotional toll on patients and their families, she says. Wearable glucose monitors and automatic insulin pumps help, but "we don't have a treatment that could help improve blood sugar from inside," she says. If BCG has a chance of doing that, she says, "I think it's worth a try."

Accacha adds that BCG has a long safety record; its risks are minuscule compared with other treatments for type 1 diabetes, such as drugs that suppress the immune system, which increases infection risk, or pancreas transplants, which also require immune suppression.

Faustman says patients are also encouraged by the findings because the research included people who have been living with diabetes for a long time, an average of 19 years. Most, if not all, other studies recruit only newly diagnosed people, says David Leslie, an endocrinologist at the University of London. "Anything that could work in established type 1 diabetes is a big deal," he says.

On the flip side, some diabetes researchers and organizations have expressed concerns that Faustman's work might generate false hope. Most recently, during the 2018 meeting of the American Diabetes Association, that organization, along with JDRF (formerly the Juvenile Diabetes Research Foundation), released a statement noting the small size of Faustman's 2018 study, and that all of the volunteers continued taking insulin.

In an e-mail to *Science News*, a JDRF representative reiterated the original statement, adding: "We want every researcher in our field to be successful and we will be monitoring the progress made by Dr. Faustman." Several type 1 diabetes

researchers turned down requests to comment on Faustman's latest work, including one who cited the small number of patients involved as a reason.

Leslie agrees that more data are needed to back up Faustman's claims. He says he has heard negative reactions to Faustman's work in private, but he doesn't think they're warranted. "It's an interesting idea," he says, one that "we shouldn't throw away."

Faustman has not received any BCG funding from two of the biggest type 1 diabetes research funders: the U.S. National Institutes of Health and JDRF. She says she thinks that's because the work "flies in the face" of the field's main efforts over the last 20 years, which include managing glucose levels with pumps and monitors, and detecting and treating type 1 diabetes as early as possible.

Faustman's BCG work has been supported by private donors, including the Iacocca Family Foundation in Boston, or through fundraising by patients and their families. Because BCG is a generic vaccine costing an average of 50 cents a dose, there is little incentive for drug developers to pour money into studies for new uses. "It's not sexy or money-making at all," says Singh, whose own funding for studying BCG-related work dried up in 2001.

"The data will have to speak for themselves," says Ofer Levy, director of the precision vaccines program at Boston Children's Hospital. Levy studies BCG and is familiar with Faustman's work. He says no one is encouraging people with diabetes to get in line for a shot of BCG. "We need rigorous clinical data," he says. "But I do think that it's a plausible hypothesis and very exciting area of research."

Eyes on the off-targets

Faustman is part of a growing community of researchers who study BCG and its unintended effects. She calls them "off-target people."

One of those researchers is Mihai Netea, an immunologist at the Radboud University in the Netherlands. He and his colleagues have shown that BCG triggers trained immunity, a nonspecific sort of memory that readies immune cells to react more strongly to any pathogen later on. It's thought that this is how, in human studies, it protects against bacterial and viral infections, and is what's led several research groups to test it as a prevention against COVID-19.

Netea's team also reported in 2016 in *Cell Reports* that one shot of BCG triggers healthy volunteers' monocytes to break down glucose at a higher rate, and increases the activity of genes required for glucose metabolism within the cells. Netea says he isn't sure that these changes in immune cells are enough to affect glucose levels throughout the whole body, as Faustman posits.

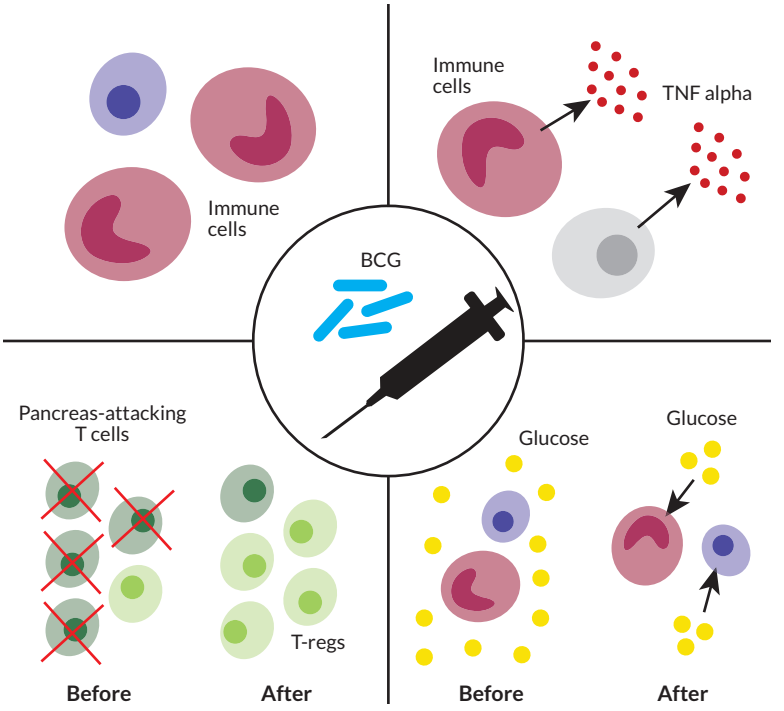
In its ongoing trial, Faustman's team is using radioactive glucose PET scanning to map out where the glucose goes after BCG vaccination. So far, they've seen increased glucose uptake in some of the places where monocytes and other immune cells are found, such as the spleen, bone marrow and descending aorta. After two years, she says, the liver starts to take up more glucose as well, suggesting it may play a role in BCG's effect on blood glucose levels.

Faustman has teamed up with Harvard neurologist Steven Arnold to test BCG in Alzheimer's patients. The breakdown of glucose is lower than

Multiaction BCG appears to affect the immune system in paradoxical ways. It improves trained immunity, so that immune cells react strongly to any pathogens that come along. Yet the vaccine also appears to dampen autoimmunity, allergic conditions and inflammation. It may even beef up the ability of certain immune cells to pull glucose out of the bloodstream, a potential help for people with type 1 diabetes.
SOURCE: A.J. MOULSONA AND Y. AV-GAY/*IMMUNOBIOLOGY* 2021

BCG stimulates trained immunity in monocytes (pink) and other first responder, or innate, immune cells (blue). Those cells then mount faster and stronger reactions if a person is later exposed to other pathogens.

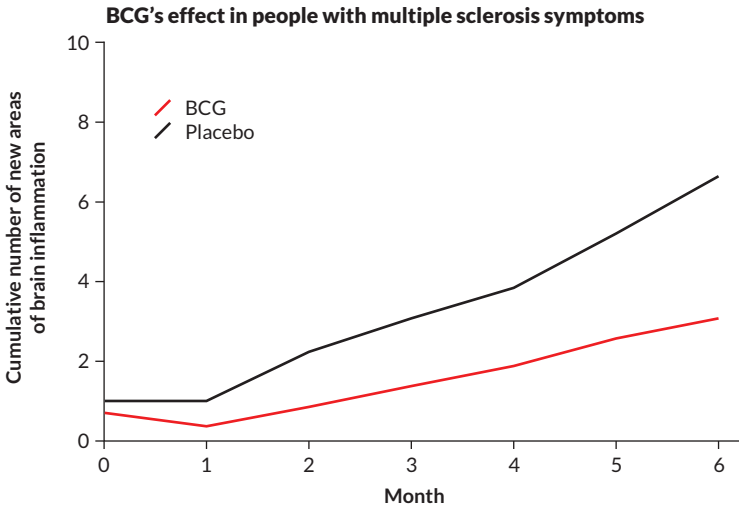
With BCG, monocytes (pink) and other immune cells (gray) make an immune system protein called TNF alpha and lower levels of other molecules that encourage inflammation.



With a boost in TNF alpha, T cells that attack the pancreas (dark green) die in diabetic mice. In human studies, T-regs (light green), which halt autoimmune damage, seem to be more active.

BCG revs up glucose use by monocytes (pink) and T cells (blue) from people with type 1 diabetes. This effect may be responsible for lower levels of glucose in the blood.

C. CHANG



Slow the progress
Patients who had experienced one episode of multiple sclerosis symptoms but had not been diagnosed with MS were given a shot of BCG (red line) or a placebo (black). Over six months, 33 BCG-treated patients had fewer new areas of brain inflammation (as shown on MRI) than the 40 people who received a placebo.
SOURCE: G. RISTORI *ET AL/ NEUROLOGY* 2014

normal in the brains of people with the disease, research has shown. Faustman thinks BCG may offer a reboot of glucose metabolism.

In 2019, a research team from Israel reported in *PLOS ONE* that among people treated for bladder cancer about a decade earlier, 2.4 percent who got BCG developed Alzheimer's while 8.9 percent of those who didn't developed the disease. Arnold's study will enroll 30 people with early Alzheimer's to receive two shots of BCG or a placebo four weeks apart. His team will measure patients' cognitive abilities and biomarkers of disease in blood and cerebrospinal fluid over three months.

Faustman's colleagues in Italy, neurologists Marco Salvetti and Giovanni Ristori of Sapienza University of Rome, have been pursuing BCG as a treatment for multiple sclerosis since the late 1990s. In a pilot study of 12 people with MS, Salvetti, Ristori and colleagues found that BCG reduced the patients' chances of developing new areas of nerve cell damage in the brain.

For a second trial, the team recruited people who had not yet developed MS, but experienced one episode of MS symptoms, such as vision loss or muscle weakness. Thirty-three of those volunteers got one shot of BCG while 40 got a placebo. Over five years, those who got the vaccine were less likely to develop new or worsened areas of brain damage or experience disease flare-ups compared with people who received a placebo. By the end of the study, 70 percent of the placebo group had clinically diagnosed MS, compared with 42 percent of the vaccinated group, the team reported in 2014 in *Neurology*.

The Sapienza team has started another placebo-controlled trial recruiting people with signs of neurological damage that had been discovered by chance in MRIs done for unrelated reasons. People with this kind of damage have a high risk of developing MS after several years. Salvetti says he hopes to find out if BCG can serve as an option to lower these people's risk for MS.

Salvetti is working with immunologist Giuseppe Matarese of the University of Naples Federico II to study the trial participants' T-regs. Matarese's group has found that T-regs from MS patients have trouble multiplying. In studies of mice with MS-like symptoms, BCG increases T-reg numbers. Matarese's team plans to see if it does the same in people. The group is also examining T-regs from healthy volunteers given a single BCG shot in a separate study led by Netea.

Faustman continues to study T-regs. Although her earlier work suggests that BCG boosts breakdown of glucose in people with long-standing type 1 diabetes, she hopes to learn if T-regs can help those more recently diagnosed, whose beta cells may still have a chance to recover. Her team is testing this in a trial of 25 people with newly diagnosed disease. So far, patients in this trial who are under age 21 have experienced drops in HbA1c levels one and two years after receiving BCG, which the team reported last October at the virtual 2020 Federation of Clinical Immunology Societies meeting.

Faustman's group is halfway through its 150-person Phase II clinical trial, and expects to finish in 2023. She presented unpublished data at the meeting suggesting that the shot increases the activity of a gene required for T-reg production. The HbA1c data are still being analyzed.

In early 2021, she asked the U.S. Food and Drug Administration for approval to start a trial in children with type 1 diabetes, but the agency asked her for more animal data. She hopes to go back to ask again later this year.

Accacha, whose practice would participate in the trial, says her patients' parents are very interested in Faustman's work, and eager to enroll their children. "They ask me every year, 'What's going on?'" ■

Explore more

■ Asimenia Angelidou *et al.* "BCG as a case study for precision vaccine development: Lessons from vaccine heterogeneity, trained immunity, and immune ontogeny." *Frontiers in Microbiology*. March 11, 2020.

Amanda B. Keener is a freelance science journalist based in Littleton, Colo.

C. CHANG

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BOOKSHELF

NASA mathematician's life offers window into U.S. race relations

Katherine Johnson became a household name circa 2016, when the bestselling book and Hollywood film *Hidden Figures* highlighted her role as a NASA mathematician during the space race (*SN: 1/21/17, p. 28*). Those works showcased Johnson's ability to perform high-stakes calculations to send astronauts to space, all while she endured racism and sexism from her colleagues. But crunching numbers for NASA is only part of Johnson's story. Her posthumous memoir, *My Remarkable Journey*, tells the rest.

Cowritten with two of her three daughters, Johnson's memoir spends surprisingly little time explaining her work at NASA. Instead, the book focuses on Johnson's personal life, including many experiences that reveal insight into the United States' tumultuous race relations in the 20th century.

Her account begins with her childhood in small-town West Virginia. Even then, Johnson's thirst for knowledge was palpable: She snuck out to follow her older siblings to school, peppered her parents and teachers with questions, and counted everything in sight. While in college at West Virginia State University, Johnson decided she wanted to become a mathematician.

Readers quickly see the profound obstacles that faced educated Black people like Johnson. When she graduated in 1937 at age 18 with the highest GPA in her university's history, Johnson had few employment opportunities. Her only job offer was a teaching gig at an all-Black elementary school.

Johnson uses her own educational and work experiences as windows into broader issues. She frequently pivots from her story to describe her teachers' race-based struggles and the history of the Black schools she attended or served. These asides slow the narrative but reveal something deeper: Johnson's immense pride in Black educational institutions and her gratitude to the Black educators who were her role models.

Later chapters continue zooming out from Johnson's own experiences to historic events. She describes her concerns about allowing her daughters to participate in school integration. "Once I'd seen what those Negro teenagers experienced in Little Rock, I couldn't unsee it," she writes of the white mob violence faced by Black students integrating into a white school in Arkansas. She also advised her daughters not to participate in civil rights protests because she was afraid of them getting hurt or arrested. (They protested anyway.)

At times, however, Johnson's historical asides seem purely expositional. Readers may wish that the memoir directly offered Johnson's unique perspective on some issues. For instance, she describes a protest led by Rev. Ralph Abernathy — Martin Luther King Jr.'s successor as president of the Southern Christian Leadership Conference — in objection to the taxpayer dollars spent on the space race rather than poverty relief. But Johnson doesn't share her own reactions to this event.

Mathematician Katherine Johnson is shown working at NASA's Langley Research Center in Hampton, Va., in 1962.

BOB NYE/NASA

It's also clear that Johnson isn't comfortable bragging about herself. She touts the careers of other accomplished Black scientists and astronauts, but of her own work, she writes, "I was just doing [my] job." That might seem like false modesty, but it rings true coming from a woman who didn't invite her own daughters to her retirement luncheon at NASA because, as she writes in the book, she "didn't want to make a big fuss."

Perhaps more striking than Johnson's unwavering humility is how she faced segregation and discrimination with her head held high. When she moved to the South for her first job, her mother warned her about the racism she would face: "Remember, you're going to Virginia." But Johnson just said, "Well, tell them I'm coming!" And when a white friend told Johnson that his pastor forbade Black guests at his wedding, "I just shrugged it off," she writes. "I was not going to allow his pastor's backward views to change my opinion of the lovely couple."

These examples of relentless determination in the face of adversity linger with the reader, showing what truly makes Johnson's journey remarkable. Yes, her mathematical genius was inspiring. Equally inspiring was her grit.
— Maria Temming

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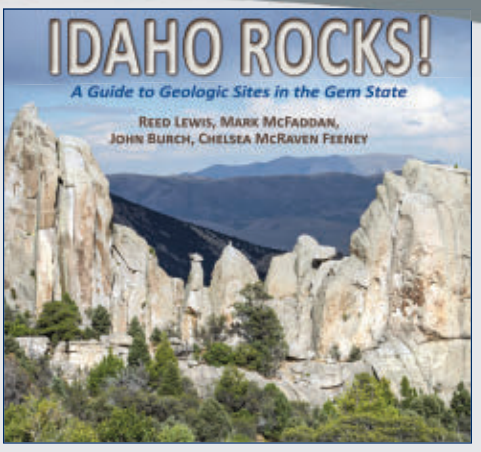

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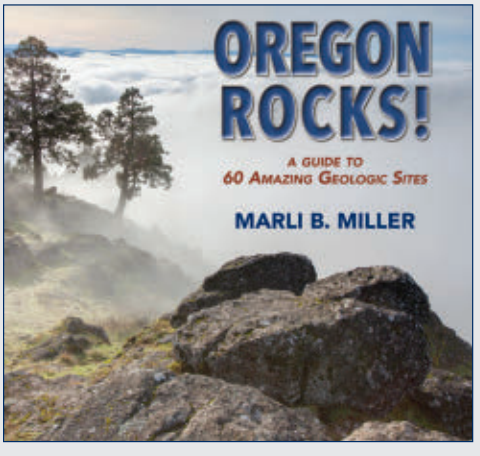

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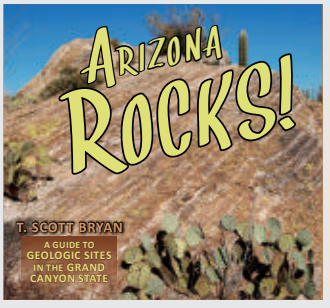

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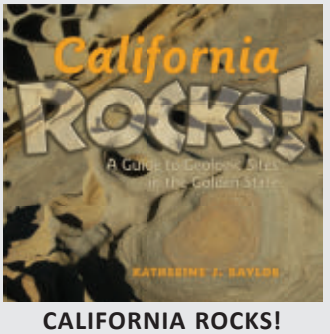

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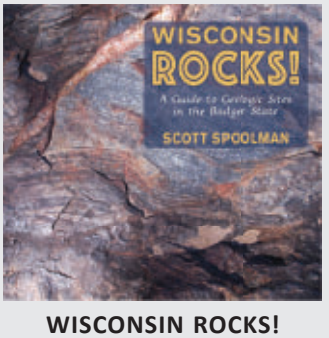

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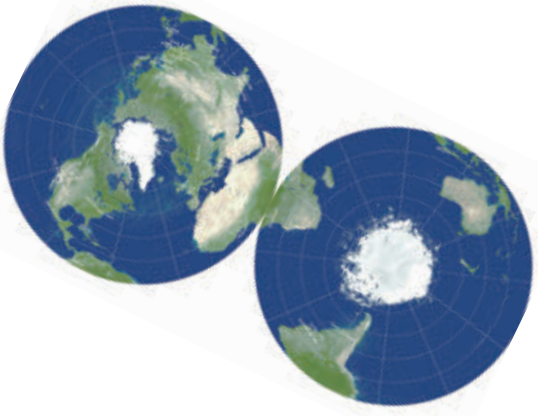

Earth as you've never seen it before

When mapmakers set out to portray the Earth, they have to turn a 3-D sphere into a 2-D map. Smooshing the globe onto a flat plane usually distorts surface features. Some expand. Others shrink — often by a lot. Now two astrophysicists and a mathematician have come up with a clever way to limit those distortions: Project the globe onto two sides of a disk. On the Mercator-type maps used in most classrooms, Greenland looks bigger than Africa, yet is just 7 percent its size. The new projection (seen here) largely eliminates such distortions, its creators say, and offers many potential advantages in science. — *Avery Elizabeth Hurt*

Read more: **www.sciencenewsforstudents.org/earth-map-projection**

Too much sitting could hurt your mental health

The COVID-19 pandemic knocked many people on their butts — literally. As schools and offices closed or imposed social distancing, people began to work from home, travel less and avoid crowded gyms. Many of us already know a couch potato lifestyle can lead to weight gain and chronic diseases, such as diabetes. Less well-known: The brain suffers, too. A large and growing body of data shows too much sitting can foster depression and other mental health problems, beginning in adolescence. But a few studies also suggest this can be less of a problem when our sedentary activities aren't mentally passive, but instead engage the brain. — *Kathiann Kowalski*

Read more: **www.sciencenewsforstudents.org/too-much-sitting**

Bandages made from crab shells speed healing

A new medical bandage helps wounds heal faster. It's made from chitin, the structural material in the exoskeletons and scales of shellfish and insects. Chemist Jinping Zhou of Wuhan University in China was part of a team that turned chitin into a gauze. The researchers found that skin cells and blood vessels grew faster in wounds dressed with this gauze instead of the gauzes used in medicine today. And unlike standard gauze, the body can break down the chitin-based fibers, meaning surgeons could leave the new gauze in the body to treat internal wounds. — *Silke Schmidt*

Read more: **www.sciencenewsforstudents.org/innovation-bandages**

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APRIL 10, 2021

Fast hunk of junk

Maria Temming's story on 'Oumuamua's origins (see "Shapeshifter," far right) drew many reader comments on the object's resemblance (below) to the Millennium Falcon from the *Star Wars* franchise. Reader **Bill Crumly** joked: "The illustration really drives home the point that the origin for 'Oumuamua was long ago in a galaxy far, far away." (Or perhaps more apt: in a part of the Milky Way far, far away.)

WILLIAM HARTMANN

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Up in smoke

A band of researchers is studying how microbes carried by wildfire smoke might affect human and ecological health, ***Megan Sever*** *reported in "Smoke and microbes"* (SN: 4/10/21, p. 22).

Sever's story is "an excellent overview" of pyroaerobiology research, especially that of fire ecologist **Leda Kobziar**, reader **Forrest M. Mims III** wrote. **Mims'** daughter Sarah discovered that smoke can loft microbes into the air nearly 20 years ago when she was a junior in high school, **Mims** noted. Using a "50-cent air sampler she flew from a kite and an inexpensive microscope," she found that smoke from biomass fires in Yucatán, Mexico, had arrived in Texas, carrying bacteria and fungi, he wrote. The father-daughter duo published the results in 2004 in *Atmospheric Environment*.

"That was a critical pioneering study indeed and is cited in each of my papers," says **Kobziar**, of the University of Idaho in Moscow. While Sarah Mims' study didn't spark **Kobziar's** initial curiosity about pyroaerobiology, Mims' story should "inspire young scientists to follow their curiosity," **Kobziar** says. "It certainly has inspired me!"

Sparks of life

Phosphorus from a lightning-forged version of a mineral called schreibersite could have gone into building the first DNA and RNA molecules on Earth, ***Maria Temming*** *reported in "Lightning may have sparked life"* (SN: 4/10/21, p. 7).

Reader **Craig Smith** wondered why DNA and RNA would need phosphorus from schreibersite rather than other naturally occurring forms of the element.

"The version of phosphorus that existed in the soil before the lightning struck was not a version that could be used to make biomolecules," **Temming** says. Phosphorus in the mineral schreibersite is highly reduced, which means it's not tightly bound to oxygen in the mineral. That makes this phosphorus easier to extract from the mineral, and thus easier to incorporate into DNA and RNA molecules, than other naturally occurring forms of the element, she says.

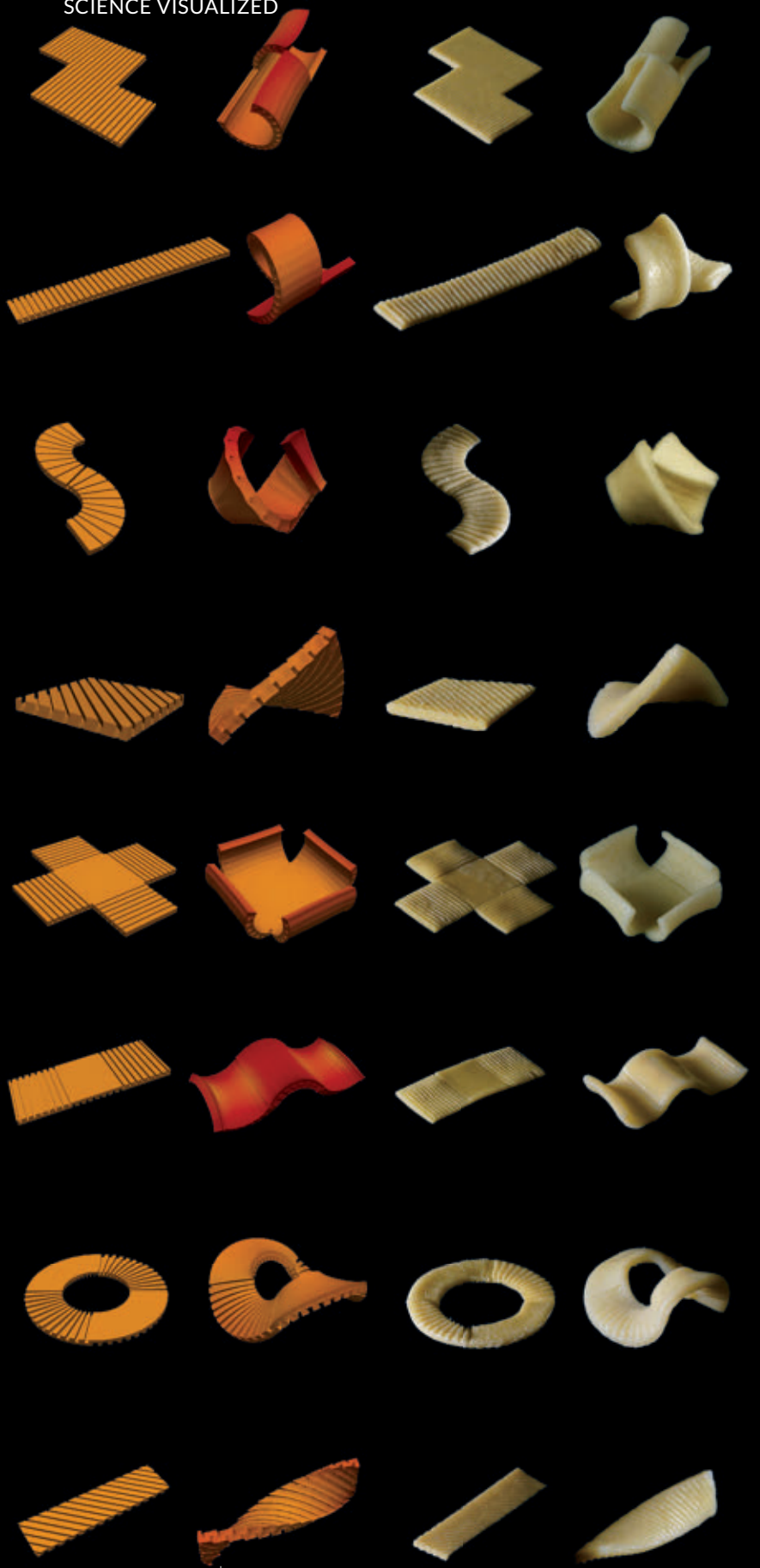
Shapeshifter

The weird-looking interstellar object known as 'Oumuamua may be a piece of nitrogen ice that broke off a Pluto-like exoplanet, ***Maria Temming*** *reported in "'Oumuamua gets a new origin story"* (SN: 4/10/21, p. 6).

Past illustrations of 'Oumuamua suggested that the object had an elongated shape similar to that of a cigar (*SN: 5/9/20 & 5/23/20, p. 12*). If the object is made of nitrogen ice, how could it have retained such a shape given the "crushing gravitational forces of its approach to our sun?" reader **Bob Reckers** asked.

'Oumuamua is actually now thought to be more pancake-shaped than cigar-shaped (see illustration at left). Researchers hypothesize that the object was much thicker when it entered our solar system, **Temming** says. Proximity to the sun winnowed down 'Oumuamua, similar to how rubbing a chunky bar of soap gradually wears the bar down to a flat, sharp shard.

If the object is indeed made of nitrogen ice, then it also must be much shinier than scientists originally expected, **Temming** says. That means 'Oumuamua must also be slightly smaller than scientists thought to account for the amount of light seen reflecting off it as it whizzed by, she says.



Engineering more space-efficient pasta

This pasta is no limp noodle.

Imprinted with carefully designed arrangements of grooves, flat pasta morphs as it cooks, forming tubes, spirals and other shapes similar to those traditionally used for the starchy sustenance. The technique could allow for pasta that takes up less space during shipping, Lining Yao and colleagues report May 5 in *Science Advances*.

Pasta aficionados "are very picky about the shapes of pasta and how they pair with different sauces," says Yao, who studies the design of smart materials at Carnegie Mellon University in Pittsburgh. But those shapes come at a cost: excess packaging and inefficient shipping. For some varieties of curly pasta, more than 60 percent of the packaging space holds air, the researchers calculated.

Starting with flat noodles, Yao and colleagues stamped a series of grooves onto one side. As the pasta absorbed water during cooking, the liquid couldn't penetrate as fully on the grooved side, causing the noodles to swell less on that side than on the smooth side. That asymmetric swelling bent the flat noodles into a curve. By changing the arrangement of the grooves, the researchers controlled the final shape (two columns at near left). Computer simulations of swelling pasta (two columns at far left) confirmed the bending mechanism and may help guide the design of new shapes.

The technique isn't limited to pasta. Another series of experiments, performed with silicone rubber in a solvent, produced similar results. While the cooked pasta held its curved shape thanks to neighboring grooves fusing together, the silicone rubber eventually absorbed enough solvent to flatten out again. Removing the silicone from the solvent caused the silicone to bend in the opposite direction. This reversible bending could be harnessed for other purposes, such as a grabber for robot hands, Yao says.

The pasta makes particularly good camping food, she says. A member of her team brought it along on a recent hiking trip. The pasta slips easily into a cramped pack but cooks into a satisfying shape. *— Emily Conover*

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What does your community mean to you? Has that idea changed in the past year because of the pandemic and its massive effects? How might you solve a challenge impacting your community?

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Winners will be announced September 15th.

Learn more at **sustainabilityfestival.asu.edu** as well as discover how past award winners and leading researchers have approached sustainability challenges.

Call for entries begins

May 1st

@WSSIatASU @asu_sustival @sustainabilitysolutions

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