Rethinking the Thymus | The Search for Dark Stars

Science News

MAGAZINE OF THE SOCIETY FOR SCIENCE ■ AUGUST 26, 2023

Dream Masters

What can scientists learn from lucid dreamers?


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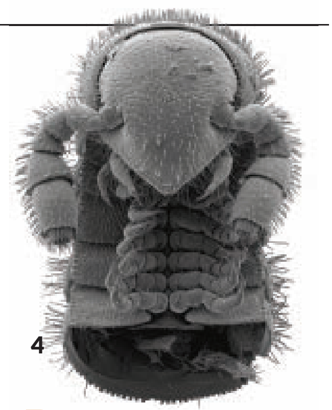

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Departments

COVER Lucid dreamers could help solve the mystery of why we dream and how brains build these fantasies. *Rune Fisker*

FROM TOP: JUAN MIGUEL CERVERA MERLO/ALAMY STOCK PHOTO; P.E. MAREK; NATALIE GLOVELI

A key technology could transform the power grid

Grid-forming inverters don't sound exotic, and indeed they're not. But these prosaic chunks of equipment are key to connecting wind and solar farms with existing power grids in ways that keep the grids stable, especially as renewable energy produces more and more of our electricity.

I learned this and a whole lot more about the infrastructure needed to make electricity-delivery systems climate friendly by reading contributing correspondent Alexandra Witze's article "An electrical grid update" (Page 22). It's part of our ongoing "The Climate Fix" series investigating how people around the world are devising climate change solutions. Other recent coverage has included the most effective strategies to reduce carbon emissions (*SN: 1/28/23, p. 22*) and efforts by Kenya and other East African countries to make use of their abundant geothermal resources (*SN: 7/1/23, p. 22*).

Finding ways to get renewable energy safely into the grid isn't the only upgrade needed. Agriculture also generates a lot of greenhouse gases. Consider cows. They produce a significant percentage of the world's methane emissions, and animal scientists are experimenting with curbing the ruminants' contributions. That includes adding red algae to the animal's food. The algae disrupt gut microbes' ability to produce methane, making cow burps less of a climate threat. But concerns that toxic by-products from the algae might get into milk and beef have led some scientists to switch tactics — instead adding red algae to cow poop, earth and climate writer Carolyn Gramling reports (Page 11). There, the algae reduce methane emissions from decomposing manure. It's not enough to solve the cow-methane problem, but it's a start.

The article on upgrading electrical grids led me to ruminate on the dominance of alternating current, or AC, in electrical systems. It wasn't always a sure thing. Thomas Edison flipped the switch on the world's first central power plant in New York City in 1882, a system with cables running under the streets to homes and businesses. But that direct current, DC, system lost voltage when wires extended more than a mile. Nikola Tesla, a young engineer from what is now Croatia who worked for Edison, thought that AC power, which can be transmitted with less energy loss, would solve that problem.

Edison was not amused: Tesla's AC system threatened Edison's royalties from DC patents. Edison launched a publicity campaign arguing that AC electricity was dangerous, an effort that included using AC electricity to stage public electrocutions of animals. Despite those gruesome tactics, Tesla's system prevailed. He licensed patents to George Westinghouse, a key Edison rival, and joined the new Westinghouse Electric Company. The company proved the viability of AC systems for municipal lighting by winning the contract to design and build the electrical system for the 1893 World's Columbian Exposition in Chicago.

Today, engineers, inventors and entrepreneurs are hard at work on innovations that will replace our 19th century systems with ones that will keep the lights on and protect the planet. I hope that 100 years from now, these innovators will be lauded as the Edisons, Teslas and Westinghouses of the climate solutions era.
— Nancy Shute, Editor in Chief

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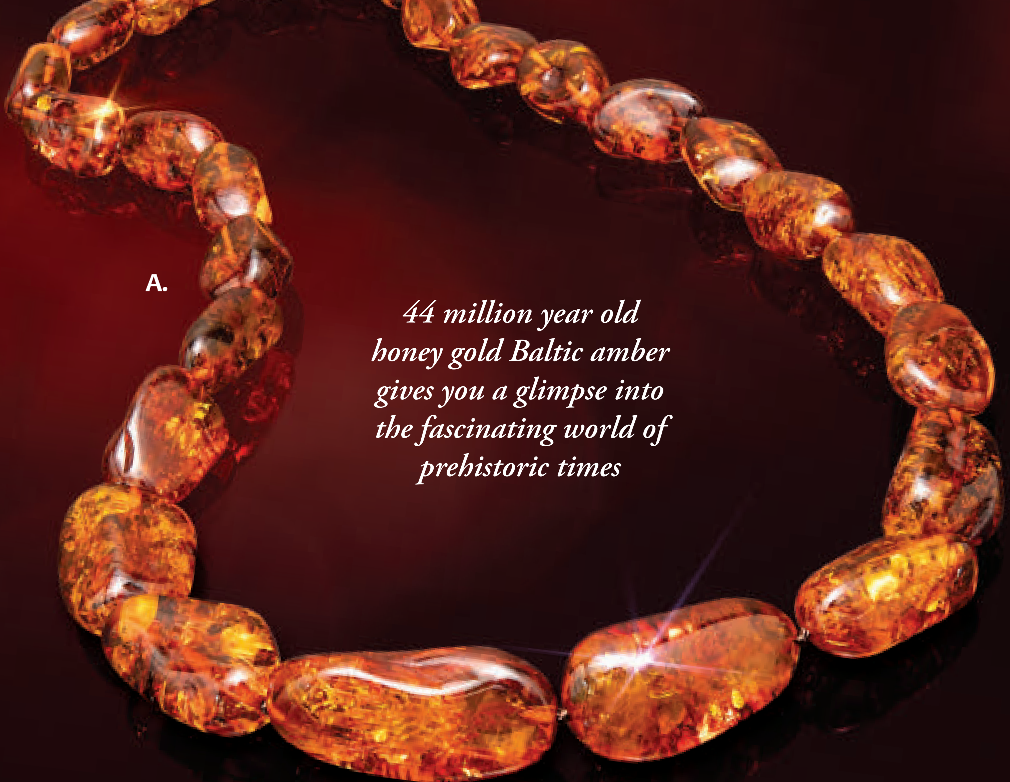

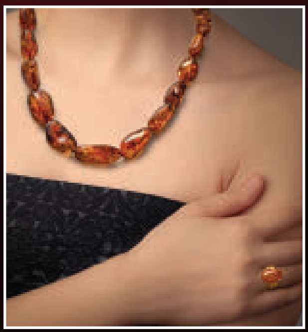

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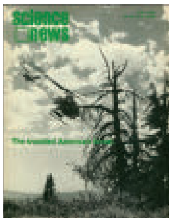


Excerpt from the September 1, 1973 issue of *Science News*

50 YEARS AGO

X-rays of the brain

A new [device], already hailed by some physicians as the most important advance in X-ray diagnosis since its original development, promises to give a detailed new look at the inner brain.... The EMI device produces detailed information about a particular region of the brain with relatively little radiation exposure.

UPDATE: That device was the first X-ray computed tomography, or CT, scanner. Today, the technology lets doctors and researchers peer inside not only the human brain, but also other organs, bones and even blood vessels. CT scanning has also become a useful tool in other areas of science, from archaeology to zoology (*SN: 12/18/21 & 1/1/22, p. 44*). For instance, the technology helped reveal why pumpkin toadlets are clumsy hoppers: Their inner ears may be too small to maintain good balance (*SN: 7/16/22 & 7/30/22, p. 5*). Sharper images made by a "photon-counting" CT scanner — approved last year by the U.S. Food and Drug Administration — could help resolve other mysteries too.

Driver ants (shown) in Equatorial Guinea force other insects into the open, where birds such as the fire-crested alethe (one shown being held by Patricia Rodrigues, inset) can feast on them.

THE SCIENCE LIFE

Where nomadic ants lead, tropical birds will follow

To better understand Equatorial Guinea's tropical birds, ornithologists Luke L. Powell and Patricia Rodrigues scan the ground rather than the trees. They are searching for nests of driver ants (*Dorylus* spp.). These voracious predators march from their underground nests, fanning out into meters-wide swarms to flush out insects and worms. Birds swoop from the trees to catch the fleeing critters. And where the ant swarms go, the birds follow.

Swarms make humming and "tick tick tick" sounds, says Powell, of the University of Porto in Portugal. It is the sound of the ants — and of animals scurrying in panic. "Then you hear the sounds of birds chirping at the edge [of the swarm]."

Ant-following birds are well studied in the neotropical Americas. In Africa, however, "people have seen birds follow ants, but nobody has really looked" to see whether the animals have a specialized relationship, says Rodrigues, of Louisiana State University in Baton Rouge.

The first step to figuring that out was finding driver ant nests. Since 2020, Rodrigues has spent weeks at a time scrutinizing the ground for ants in a forest near Ciudad de la Paz. When she finds them, she knows to keep her distance. "They're superduper aggressive, and they have giant mandibles that can pierce your skin," Rodrigues says. Despite her caution, ant bites inevitably happen.

Rodrigues follows ants carrying food back to their nests. Since driver ants are nomadic and relocate their colonies, she checks every nest daily in case a colony starts to move.

For their latest study, Rodrigues, Powell and colleagues placed cameras at the entrances of seven ant nests. The team analyzed about 80 hours of footage to identify species of birds that stopped by.

When the researchers played calls of ant-following birds like the white-tailed ant thrush (*Neocossyphus poensis*) and fire-crested alethe (*Alethe castanea*), birds representing about 30 other species came around. Many of these birds eat insects and might be homing in on the calls to find food, the team says. In contrast, just seven species responded to played calls of the African green pigeon (*Treron calvus*), which doesn't follow ants.

What's more, data from birds fitted with GPS monitors suggest that ant followers have larger home ranges than the average understory bird. This may be because ant-following birds have to fly farther to survey moving colonies, Powell said July 6 in Coimbatore, India, at a meeting of the Association for Tropical Biology and Conservation.

African tropical birds are more specialized on driver ants than scientists had expected. The team now wants to know how the birds may be affected by changes in driver ant populations due to forest degradation (*SN: 1/30/21, p. 5*). Keeping tabs on this bird-ant relationship could be akin to "keeping your finger on the pulse [of forest health]," Powell says. *— Yao-Hua Law*

Editor's note: Yao-Hua Law attended the Association for Tropical Biology and Conservation meeting on a travel grant from Internews' Earth Journalism Network.

IBON MALAXETXEBARRIA; INSET: P. RODRIGUES

THE –EST

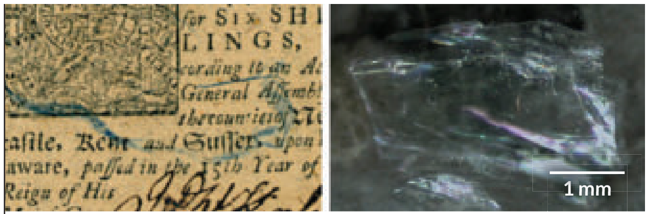
The most intense sunlight on Earth

Forget a vacation in Florida — sun worshippers ought to head to the Atacama Desert in South America. It's there that the sun's rays are the most intense on Earth, scientists report July 3 in the *Bulletin of the American Meteorological Society*.

Satellite data have suggested that the Altiplano — a desert plateau about 5 kilometers above sea level that straddles parts of Chile, Bolivia, Peru and Argentina — experiences the most intense levels of sunlight on Earth. But it's important to verify that claim with on-the-ground observations, says Raúl Cordero, a physicist at the University of Santiago in Chile.

Cordero and colleagues set up a small atmospheric observatory in the Chilean Altiplano. Since 2016, the team has measured solar radiation levels at the site using a palm-sized instrument that's sensitive to ultraviolet, visible and near-infrared light. Based on the first five years of data, the average amount of solar power hitting each square meter of the landscape — 308 watts — was even higher than satellite-based estimates, the researchers report. The daily maximum radiation exceeded that measured near the summit of Mount Everest.

Scientists also recorded extreme bursts of solar radiation. One event in 2017 blasted the site with 2,177 watts per square meter — an intensity that rivals solar radiation on scorching-hot Venus. Thin clouds scattering light toward the ground may cause such events, the team says. *— Katherine Kornei*



PICTURE THIS

How Benjamin Franklin fought money counterfeiters

Though perhaps better known for its newspapers and almanacs, Benjamin Franklin's printing business also churned out paper money. Now, scientists are confirming some of the ways that Franklin and his associates thwarted forgers to help American paper currency succeed. Physical chemist Khachatur Manukyan of the University of Notre Dame in Indiana and colleagues examined about 600 paper bills from colonial North America using X-ray and spectroscopic techniques. The money (examples shown above) contains blue threads (left) and shimmering muscovite minerals (right), features most knock-offs wouldn't have been able to reproduce, the team reports in the July 25 *Proceedings of the National Academy of Sciences*. Muscovite also may have boosted the currency's durability. Some of these techniques served as the basis of more sophisticated methods used later to combat forgers, Manukyan says. *— Joshua Rapp Learn*

INTRODUCING

The Los Angeles thread millipede is ready for its close-up

Despite living near the entertainment capital of the world, the Los Angeles thread millipede has avoided the limelight. But when researchers spotted it, they knew they'd found a creature worthy of center stage.

The newfound species, officially dubbed *Illacme socal*, is small, pale and lives several centimeters under the soil, researchers report June 21 in *ZooKeys*. It's just the third known species in this genus, a group of millipedes that stands out for their subterranean lifestyles and isolation from relatives.

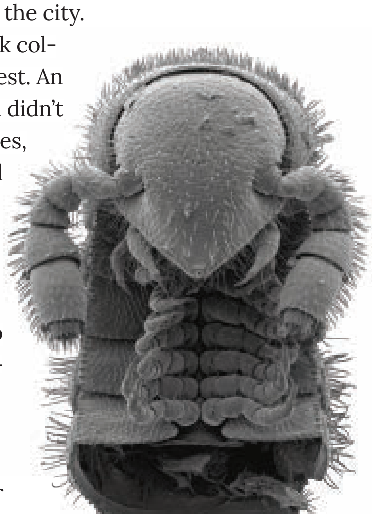
I. socal "looks like somebody plucked a thread out of their shirt," says Paul Marek, a millipede biologist at Virginia Tech in Blacksburg.

Naturalist Cedric Lee of the University of California, Berkeley and his colleague James Bailey discovered the millipede on a slug-finding expedition in 2018 in Lake Forest, Calif. While hunting for gelatinous gastropods, Lee and Bailey stumbled upon a millipede unlike any they'd seen before. The duo uploaded a record of the discovery to iNaturalist, an app that lets users share photos of organisms they find, and pegged the millipede as a member of the Siphonophoridae family.

Marek, an iNaturalist aficionado, has alerts set up for these kinds of critters. The discovery piqued his interest because the only other places he knows this family from in California are hundreds of kilometers northwest of Los Angeles. Lake Forest is roughly 80 kilometers southeast of the city.

During a visit to California, Marek collected 10 specimens from Lake Forest. An examination of male gonads, which didn't match those of any known millipedes, and genome sequencing confirmed that the Los Angeles thread millipede is a newfound species.

While many millipedes live close to the surface, *Illacme* species like to dig deep. So it's not too surprising that *I. socal* went undiscovered for so long. The species is proof of the vast hidden diversity in the soil beneath us, Marek says. "There's a lot more stuff under our feet." *— Darren Incorvaia*



The head of an *Illacme socal* millipede takes center stage in the scanning electron microscope image above. The full body of a specimen is shown at right with a nickel for scale.

FROM TOP: K. MANUKYAN *ET AL*/*PNAS* 2023; P.E. MAREK; P.E. MAREK *ET AL*/*ZOOKEYS* 2023

HEALTH & MEDICINE

Climate disasters put children at risk

Exposure to heat, smoke and more can cause lingering harm

BY AIMEE CUNNINGHAM

Climate-related environmental disasters have not let up. Heat waves are roasting many parts of the world, and July earned the title of hottest month ever recorded. The extreme heat has fueled wildfires in Canada and Greece (SN: 8/12/23, p. 6).

This is harmful to everyone, but especially children. UNICEF estimates that nearly half of all children globally — about 1 billion total — are extremely vulnerable to multiple effects of climate change.

Climate change threatens the health of these children now and throughout their lives, says Frederica Perera, founder of the Columbia Center for Children's Environmental Health at Columbia University. Perera talked to *Science News* about how climate change damages health and which children are at highest risk. The conversation has been edited for length and clarity.

How do the impacts of climate change affect children's health?

Severe heat is contributing to preterm births, and it's causing heat-related deaths and illnesses in infants and children. Children are also suffering from severe weather events: They're suffering physical injury and also psychological trauma. Longer pollen seasons due to climate change are causing more allergy and asthma. Asthma attacks are increased from breathing forest fire smoke. There's the issue of food insecurity and stunted growth due to drought in certain areas of the world. Vector-borne infectious diseases are increasing as ticks and mosquitoes have extended their range.

Why are children at higher risk than adults?

The very rapid and complex developmental programming during the fetal period, infancy and childhood is vulnerable to disruption by toxic pollutants, climate-related shocks and stressors. A second point is that children don't have fully functioning biological defense mechanisms.

Children have less ability to control core body temperature during severe heat waves. The young are dependent on us adults for hydration and for care for heat-related illnesses. With respect to air pollution, children are especially vulnerable because of increased exposure. They breathe more air per kilogram of body weight than adults. [Children's noses are less efficient at filtering inhaled] particles, so a higher proportion of these particles penetrates deeply into the lungs. Their narrow airways are more prone to effects of inflammation.

A wildfire near Athens was one of hundreds that broke out in Greece in July. Such climate-related disasters especially harm the physical and mental health of children.

ARIS MESSINIS/AFP/GETTY IMAGES PLUS

Which children are at greatest risk?

All children are vulnerable, but certain children are hurt first and worst, as we say. In the United States, communities of color and communities of low income have disproportionately higher exposure to air pollution as well as to severe heat and extreme weather events. Polluting sources like major highways, bus and truck depots, industrial plants and power plants are disproportionately located in and near these communities. Discriminatory policies like redlining have created urban heat islands.

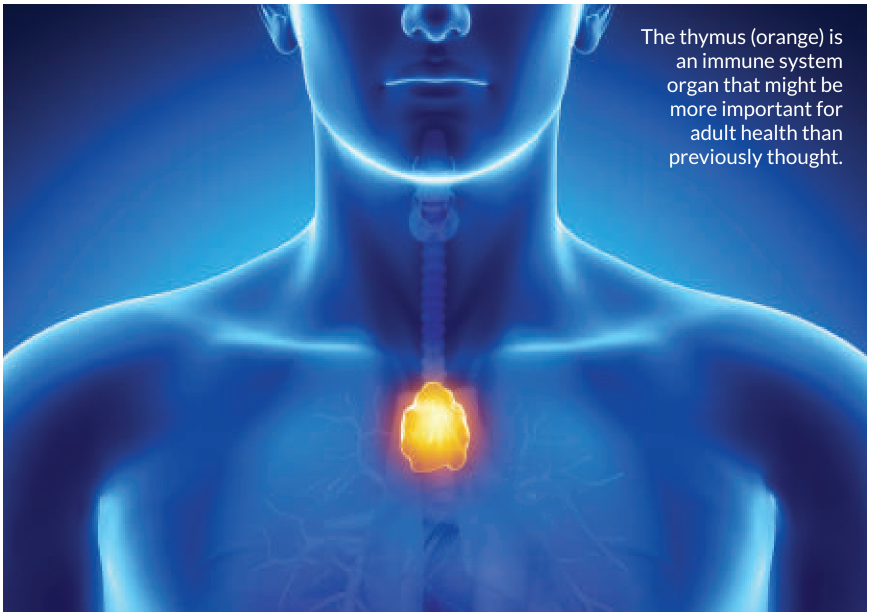
Disproportionate exposure combined with poverty and racism contribute to the disparities in disease rates. In the United States, asthma prevalence and infant mortality in Black children are twice the rates seen in white children. The preterm birth rate is 50 percent higher [among Black women compared with white women].

What do these early health harms mean for children's lives ahead?

We know that there are long-term effects of these early harms. Respiratory conditions frequently persist. Reduced intellectual functioning associated with air pollution, and also malnutrition prenatally or in early life, affects the ability to learn. Stress and trauma from shocks of climate change and other adverse events that are experienced at a young age can affect mental health throughout life.

We should be thinking about the long-term implications of these early health harms. When we look then at policies and other interventions to reduce and eliminate fossil fuel emissions, we see enormous health and economic benefits. Children will be the greatest beneficiaries. ■

Read the entire interview at **bit.ly/SN_ClimateKids**



The thymus (orange) is an immune system organ that might be more important for adult health than previously thought.

HEALTH & MEDICINE

The thymus isn't so expendable after all

Removing the organ is linked to an elevated risk of early death

BY MCKENZIE PRILLAMAN

A mysterious organ that's most active in childhood might play a previously underappreciated role in adults.

In a study of almost 2,300 adults who underwent chest surgery, removing the thymus gland was associated with higher rates of death and of cancer within the next few years, researchers report in the Aug. 3 *New England Journal of Medicine*. The discovery pushes back on a long-held belief that this immune system organ is somewhat expendable in adulthood.

"This is a really important finding," says Dong-Ming Su, an immunologist at the University of North Texas Health Science Center at Fort Worth who was not involved in the work. Before this study, he says, "there was no direct evidence to demonstrate [the thymus's] importance in adults."

The thymus resides in the chest between the lungs, right in front of and above the heart. In infants, the gland almost completely covers the heart. It pumps out T cells, immune cells that detect foreign invaders that could cause illness.

But the gland's activity dwindles after puberty, producing fewer new T cells as people age. Adults mostly rely instead on memory T cells, long-lived cells that rapidly produce specialized T cells in response to intruders that the body has fought before. The thymus gradually wastes away and gets replaced by fat.

"It progressively becomes something that looks like more of a fatty blob," says hematologist-oncologist David Scadden of Massachusetts General Hospital in Boston. Doctors might excise an adult's thymus if it contains an abnormal growth, to help alleviate an autoimmune disease or simply because it's in the way during chest surgery, he says. "It's often removed because it's not thought to be very consequential."

To look at the effects of getting rid of the gland, Scadden and colleagues examined health outcomes in 1,146 patients who had their thymus removed from 1993 to early 2020 at Mass General. The team compared those patients' outcomes with those of an equal number of patients, matched for age, sex and race, who had undergone chest surgery within that time period but kept their thymus.

Within five years after surgery, about 8 percent of thymectomy patients died compared with nearly 3 percent of patients whose thymus remained. That means that removing the thymus gland was associated with nearly three times the risk of death from any cause in that time frame.

Similarly, thymus removal was associated with two times the risk of any type of cancer within five years. More than 7 percent of thymectomy patients developed cancer while nearly 4 percent of patients who kept their thymus did. The increased cancer risk, Scadden says, might come from the immune system's compromised surveillance capabilities.

In a handful of thymus-free patients who developed cancer after surgery and whose blood was analyzed, their T cells seemed unable to identify as many varieties of trespassers compared with T cells from patients who retained their thymus and also developed cancer. Whether the T cells' reduced repertoire in thymectomy patients led to cancer or was a result of cancer remains unclear, Scadden says.

In patients who didn't have cancer, infection or an autoimmune disease before surgery, more than 12 percent who had their thymus removed developed an autoimmune disease within five years after surgery while only about 8 percent of patients who kept their thymus did — a 1.5 times greater risk. Blood samples from about 20 people in each group hinted that thymectomy might be linked to immune system dysregulation.

"This is pretty striking data," says immunologist Donna Farber of Columbia University, who was not involved in the study. "You don't often find these huge survival differences with these kinds of studies."

But the study can't explain why or how thymectomy is connected to increased rates of death or other negative outcomes. "We don't know for sure whether the deleterious effects on health are due to the lack of producing new T cells or some other less well-defined function of the thymus," Scadden says. And Farber suggests that something unrelated to the immune system could even be the cause.

Still, she says, the new work hints that "maybe even that little bit of active thymic tissue you have [is] playing some role." ■

TECHNOLOGY

A durable cloak keeps cars temperate

The fabric saved interiors from getting uncomfortably hot or cold

BY SKYLER WARE

If you've ever burned your hands on a car steering wheel, you know how hot the inside of a car can get on a summer day. But a new fabric could one day help cars and other objects stay cool in the summer and warm in the winter.

A prototype of the fabric, described in the July 21 *Device*, acts as a thermal cloak that keeps the space underneath it from getting too hot or too cold. And since the cloak doesn't require an external power source, it could help reduce energy consumption and greenhouse gas emissions.

Globally, heating and cooling make up 12 percent of total energy consumption. Materials like this thermal cloak could help keep people comfortable during heat waves, says Aaswath Raman, an applied physicist at UCLA who was not involved in the research.

The new material has two layers. Kehang Cui, an engineer at Shanghai Jiao Tong University, and colleagues created the outer layer using white silica fibers coated with hexagonal boron nitride, which reflect visible and ultraviolet light and help dissipate heat. The outer layer reflects about 97 percent of the sunlight that hits the fabric, the researchers found. It also absorbs heat from the surrounding area and emits that energy as infrared light, keeping the temperature under the cloak close to the outside daytime temperature.

As night falls and the external temperature drops, the cloak's inner layer of aluminum foil traps heat to keep the space warm.

Cui and colleagues tested the material's durability under several extreme conditions. Baking the fabric at 800° Celsius, dunking it in liquid nitrogen, subjecting it to the same amount of vibration as a rocket launch, dousing it in acid and blasting it with fire had virtually no effect on the fabric's structure or performance.

The team then created a prototype cloak and tested it on an electric car. On a hot day in Shanghai, the cloak kept the car at about 23° C — up to 8 degrees lower than the outside temperature and 28 degrees lower than the inside of an uncloaked car. On a winter night, the cloak kept the car about 5 degrees higher than the outside air.

The next step is to test the fabric on larger scales, such as on rooftops, Cui says, "to see the impact on our daily lives." ■

On a toasty day in Shanghai, a prototype of a thermal cloak kept the temperature inside an electric vehicle (left) up to 28 degrees Celsius lower than an uncovered car (right).

HUAXU QIAO

ASTRONOMY

Have 'dark stars' come into view?

If they exist, the stars could offer insight into dark matter

BY SKYLER WARE

The James Webb Space Telescope has spotted objects in the early universe that might be never-before-seen kinds of stars — ones powered by dark matter.

These "dark stars" are still hypothetical. Their identification in JWST images is far from certain. But if any of the three candidates — reported in the July 25 *Proceedings of the National Academy of Sciences* — turns out to be a dark star, the finding could offer a glimpse of star formation in the early universe and hint at the nature of dark matter.

First proposed in 2007 by cosmologist Katherine Freese and colleagues, dark stars might have been some of the first stars to form in the universe (*SN: 1/5/08, p. 4*). "They would be very weird looking," says Freese, of the University of Texas at Austin.

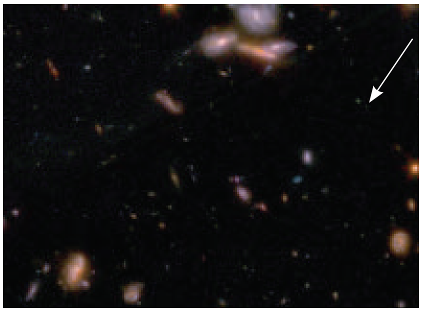
Dark stars are thought to be powered by heat from dark matter interactions rather than by nuclear fusion reactions like in the sun. The stars would have formed from clouds of hydrogen and helium that drew in dark matter, which was abundant in the early universe, as the clouds coalesced. Though the true nature of dark matter isn't known — its presence is inferred largely via its effect on how stars move within galaxies — it's possible that dark matter particles can interact with themselves, annihilating each other when they collide and producing vast amounts of light and heat (*SN: 8/13/22, p. 11*). That heat would keep the clouds of hydrogen and helium from condensing into a dense, hot core like the stars that exist today.

Because the heat from dark matter annihilations would keep the gas clouds from condensing, dark stars could grow to gargantuan size. Theoretically, dark stars could be 10 times as wide as Earth's orbit around the sun. They could also be millions of times as massive as the sun and shine billions of times as bright — potentially bright enough to be spotted by JWST.

Freese and colleagues pored over images from a JWST survey of galaxies that may have originated in the first few hundred million years of the universe — the epoch when dark stars would have emerged. Light from these remote objects is stretched, or redshifted, as the universe expands. So the team zeroed in on four objects already confirmed to be highly redshifted, making them some of the oldest objects seen to date (SN: 8/12/23, *p.* 18).

Those objects are currently thought to be small galaxies from the universe's relative infancy. But because they're so far away, JWST can't resolve them well enough to determine whether they're actually galaxies or large, ultrabright stars, the researchers say.

The team ran computer simulations of how much light a hypothetical dark star might produce at various wavelengths.



Researchers have identified three objects that might be stars in the early universe powered by dark matter. An arrow points to one of the dark star candidates in this image taken by the James Webb Space Telescope.

NASA, ESA, CSA, JADES COLLABORATION

Freese and colleagues compared those spectra with light from images collected by JWST at different wavelengths for each of the four objects. Data from three of those objects are consistent with the simulated dark star patterns, the team reports.

Some scientists are skeptical. Known types of stars could also create the observed light from the three candidates, says astrophysicist Sandro Tacchella of the University of Cambridge. And identifying any of the objects as a dark star would require that the simulated patterns be compared with high-resolution spectra of the objects, says theoretical astrophysicist Brant Robertson of the University of California, Santa Cruz.

Still, detecting dark stars "would be revolutionary," says study coauthor Cosmin Ilie, an astrophysicist at Colgate University in Hamilton, N.Y. It would confirm the existence of dark matter, hint at how dark matter works and help scientists look for dark matter elsewhere in the universe.

Future experiments, like looking for brighter or dimmer light at certain wavelengths, could help reveal whether any of the three objects are dark stars. Freese expects to find more candidates in future JWST data, she says. But for now, whether dark stars exist remains a mystery. ■

PLANETARY SCIENCE

Mercury's magnetism whips up auroras

The mechanism fuels most polar light shows in the solar system

BY ELISE CUTTS

Mercury's auroras are perfectly in character. While temperate Earth gets heavenly light shows over its poles, hellish Mercury gets invisible ribbons of X-ray radiation that cling to its sun-blasted surface.

But as alien as they may appear, Mercury's X-ray auroras have a lot in common with Earth's polar lights, and with auroras throughout the solar system.

Scientists have now directly shown that fluctuations in Mercury's magnetic field can fling electrons toward the planet, where they eventually rain down and cause auroras of X-ray light. This process, called electron precipitation, now appears to be nearly universal in the solar system: It causes auroras on every planet with a global magnetic field except Neptune, researchers report July 18 in *Nature Communications*.

Electron precipitation usually happens because of interactions between a planet's magnetic field and the solar wind — a stream of charged particles spewed from the sun's upper atmosphere.

Buffeted by the solar wind, the magnetic field's sun-facing side gets squished while the night side is swept out into a long tail. Eventually, the tail stretches so much that its magnetic field lines snap and reconnect, sending some field lines flying away from the planet and others toward it.

"In that process, a lot of energy is released," says Ryan Dewey, a space physicist at the University of Michigan in Ann Arbor who was not involved in the work. The energy sends electrons flying planetward, spiraling along magnetic field lines. When these electrons hit the planet or its atmosphere, they release energy as light.

The light's wavelength depends on what the electrons encounter as they rain down. Earth's auroras shine in visible wavelengths because incoming electrons excite molecules of uncharged gases in the atmosphere that release visible light when they return to their normal states. Mercury's auroras shine in X-ray wavelengths because the planet doesn't have an atmosphere. The electrons smack the planet's rocky surface, and energy is released as X-rays.

Scientists first spotted Mercury's X-ray auroras in data from NASA's MESSENGER probe, which orbited the planet from 2011 to 2015. The researchers reasoned that electrons must rain down on Mercury to cause its X-ray glow, but MESSENGER didn't have instruments to measure the precipitating particles.

The European Space Agency's spacecraft BepiColombo does. An analysis of data from the probe's first flyby of Mercury in 2021 revealed surges of fast-moving, high-speed electrons followed by waves of progressively slower, lower-energy ones. "This is exactly what we'd describe as a precipitating signature," says study coauthor Sae Aizawa, a space plasma physicist at the University of Pisa in Italy.

The findings hint at what's to come once BepiColombo enters Mercury's orbit in 2025, Dewey says. "It's very exciting to see just how much we can learn from even just a short pass through the magnetosphere," he says. "It's a glimpse." ■

The asteroid Dimorphos appears as a bright object with a long tail in this Hubble telescope image. The space rock now has 37 boulder companions (small blue dots) after a NASA spacecraft collided with it last September.

ASTRONOMY

DART launched boulders into space

The NASA probe lightened a moonlet by 5,000 metric tons

BY SID PERKINS

When a probe smashed into a small asteroid last year, the collision did more than change the asteroid's orbit — it also blasted a few dozen boulders into space.

In September 2022, NASA steered the DART spacecraft into Dimorphos, a moonlet of the larger asteroid Didymos, to test a strategy for knocking any future Earth-bound asteroids off course (SN: 11/5/22, *p.* 14). A few months after the impact, the Hubble Space Telescope spied a halo of 37 previously unseen objects accompanying the space rock duo in their orbit around the sun, researchers report in the July 20 *Astrophysical Journal Letters*.

The boulders probably aren't bits that were pulverized from larger rocks during the impact. Instead, simulations suggest they were intact when they were blasted off Dimorphos and could have been launched off the moonlet's surface by the energy of either the collision, the seismic waves bouncing around inside it in the wake of the impact or both.

Still, "there's a lot of uncertainty in such simulations," says planetary astronomer David Jewitt of UCLA. Based on the brightness of the objects, some of the dimmest ever spied by Hubble in our solar system, Jewitt and colleagues estimate that each boulder may be as wide as 7 meters. Altogether, the boulders weigh about 5,000 metric tons, or roughly the weight of 300 gravel-filled dump trucks.

On average, the boulders are drifting away from Dimorphos and Didymos at about 1 kilometer per hour, a little faster than the escape velocity for the double-asteroid system. That means the boulders, as well as a presumed multitude of rocks too small and dim for Hubble to see, will eventually break away from the asteroid system's orbit and circle the sun on their own, Jewitt says. ■

HEALTH & MEDICINE

Supplements lack key ingredients

Some tested products contain FDA-prohibited compounds

BY MEGHAN ROSEN

Fat incinerator. Metabolism booster. Thermo activator. Some over-the-counter sports supplements sold in the United States advertise ingredients with purported performance-enhancing properties, but it's anyone's guess what's really in that pill or powder.

Just 11 percent of nearly 60 dietary supplements actually contain an accurate amount of key ingredients listed on the label, scientists report in the July *JAMA Network Open*. Forty percent did not have a detectable amount of the ingredients.

"It's incredible that in 40 percent of the products, the manufacturer doesn't even bother" putting in the key ingredient, says physician Pieter Cohen of Cambridge Health Alliance in Somerville, Mass.

Cohen and colleagues chemically analyzed 57 sports supplements with labels that listed *Rauvolfia vomitoria*, methylliberine, halostachine, octopamine or turkesterone — plants or plant compounds that could serve as stimulants or muscle builders. Only 34 contained the ingredient claimed. Six had about the right amount; 28 had inaccurate amounts that varied from 0.02 percent to 334 percent of the quantity indicated on the label.

"That's alarming," says Luis Rustveld, a dietician and epidemiologist at Baylor College of Medicine in Houston. Some people may be sensitive to these ingredients, he says. "They may be getting a whole lot more than they thought."

Cohen's team also found that seven of the products tested contained at least one compound prohibited by the U.S. Food and Drug Administration. Scientists have previously identified hundreds of supplements tainted with potentially harmful drugs (SN: 11/10/18, *p.* 8).

Unlike prescribed drugs, the FDA does not have the authority to approve dietary supplements before they hit store shelves. But the agency requires that supplements at least contain the ingredients listed on the label, Cohen says.

Just because a supplement is on the market does not mean it's safe, effective or contains what it advertises, says nutrition specialist Patricia Deuster of the Uniformed Services University in Bethesda, Md. "It is virtually impossible for the average person … to make informed decisions about purchasing supplements without outside assistance." Third-party organizations that analyze supplements and offer their approval can be helpful, she adds.

Consumers should use skepticism when deciding what and whether to buy, Rustveld says. Claims that sound too good to be true are "probably not true," he says. ■

NASA, ESA, D. JEWITT/UCLA

CLIMATE

Red algae curbs cow pie methane

Adding a dash to manure could cut greenhouse gas emissions

Cows produce roughly a quarter of global methane emissions. Adding algae to their manure may help reduce those emissions.

GEORGE PACHANTOURIS/MOMENT/GETTY IMAGES PLUS

BY CAROLYN GRAMLING

Earth has a cow problem. Cattle are one of the largest emitters of climate-warming methane to the atmosphere.

But adding a type of red algae known for its methane-inhibiting properties to cow manure might help. Doing so reduces the production of methane within manure by about 44 percent, researchers report July 13 in *Frontiers in Sustainable Food Systems*. That offers a promising new avenue to reduce overall methane emissions from cattle, the scientists say.

Cattle are responsible for about a quarter of the world's methane emissions (SN: 5/7/22 & 5/21/22, p. 22). Bacteria in cattle guts make the potent greenhouse gas during digestion that is then released to the world, mostly via burps. A smaller amount of methane is also emitted directly from the cow manure during decomposition. Previous studies have estimated that about 80 percent of the methane emitted by ruminant animals comes from the gut and about 20 percent comes from manure.

Scientists have been actively seeking solutions to the gut-produced methane. Adding just a pinch — 0.5 percent of the dry feed — of the red algae *Asparagopsis taxiformis* to the cows' food can prevent about 65 percent of that methane production, previous studies have shown.

Ubiquitous in tropical oceans, this red algae contains the organic compound bromoform, which inactivates enzymes that normally help the methane reaction along. Researchers have raised concerns that milk and meat from cows fed the algae may contain toxic levels of bromoform. The U.S. Environmental Protection Agency has assessed bromoform as a probable human carcinogen.

Mohammad Ramin, an animal scientist at the Swedish University of Agricultural Sciences in Umeå, and colleagues wondered whether it might be possible to add the algae directly to manure. That wouldn't reduce the gut-produced methane, but it might reduce overall cattle emissions without impacting meat or milk.

Methane emitted from manure is primarily a problem when it comes to dairy cows, says animal scientist Sara Place of Colorado State University in Fort Collins, who was not involved in the research. Dairy cows tend to be raised in environments with oxygen-poor soils that are well-suited for methane-producing bacteria. Cows raised for beef tend to live and defecate in open pasturelands or in dry, enclosed feedlots, where the ground is less conducive to methane production.

In the new study, Ramin and colleagues added algae to the manure of four dairy cows. Two cows had been fed the algae, and two hadn't. Each sample was divided further, with one subsample given additional algae and the other left alone. Then, all the samples were allowed to slowly decompose in the laboratory. The team analyzed the methane content in the subsamples multiple times over nine weeks.

As expected, adding algae to food reduced how much methane the manure initially contained. But once the manure began to decompose, the production of new methane wasn't affected by whether the cows had eaten the algae or not.

The team also examined the microbes living in the manure samples. There wasn't much difference between the algae-fed cows and the control cows, which suggests that algae food supplements aren't that effective at inhibiting methane production outside the stomach. But adding the algae directly to the manure did make a noticeable difference in the amount of methane coming from decomposition.

When no algae was added directly to the manure, there was a small but measurable difference in manure methane production between cows fed the algae (5 liters of methane per kilogram of dry matter) and those that weren't (6 l/kg). But adding algae directly to the manure erased that difference: Regardless of whether the cows were also fed the algae, methane production within the manure was less than 3 l/kg of dry matter.

A major strength of the new work is that it focuses on a solution to an understudied part of the cow-methane problem, says Christopher Glasson, a chemist at the University of Waikato in Tauranga, New Zealand, who studies agrichemicals derived from seaweed. But it may not be cost-effective to cultivate *A. taxiformis* solely for this purpose, Glasson says.

A. taxiformis may still be most effective at suppressing fermentation in a cow's gut rather than in its manure. The good news, Glasson says, is that state-of-the-art feed-additive technologies that use specific extracts from the algae rather than the whole biomass greatly mitigate the risk of bromoform toxicity.

That algae in the cows' feed doesn't affect methane production in their manure might also be good news, Place says. One proposed avenue for mitigating emissions from manure is to harness the methane to make biogas (SN: 11/28/15, p. 22). If you feed cows algae to mitigate methane and don't see any results in the manure, "that could be good for biogas production," Place says — a possible twofer for the industry. ■

LIFE & EVOLUTION

Bees and wasps share a building tip

Adding odd-sided cells to nests unites small and large hexagons

BY DARREN INCORVAIA

Honeybees and yellow jackets don't look much like mathematicians — for one thing, they're smaller. But collectively, each insect species can solve a common architectural conundrum using a geometric solution that they evolved independently of one another.

As their colonies grow, these bees and wasps eventually need to add larger hexagonal cells to their nests. But nest material takes time and energy to make, and it's hard to efficiently combine hexagons of different sizes into a single continuous array.

Both the honeybees and wasps have solved this problem by mixing in pairs of five-sided and seven-sided cells, which bridge the gap between different sizes of the six-sided hexagons. This fix is close to the optimal mathematical solution to this problem, researchers report July 27 in *PLOS Biology*.

"We've known for a long time that the hexagonal comb bees and wasps use is the most efficient, stable shape," says Lewis Bartlett, a honeybee biologist at the University of Georgia in Athens who was not involved with the research. "But mixing different-sized hexagons is tricky."

The colonies of honeybees and social wasp species are run by female workers who raise the offspring of their mother, the queen. The insects do this in hexagonal cells that honeybees build out of wax and wasps construct from paper (*SN: 9/25/21, p. 14*). At a certain point in its life cycle, the colony switches from raising workers to raising reproductive males and new queens. Since reproductive members are often bigger than workers, the hexagonal cells need to get bigger.

"Think of someone tiling your bathroom floor," says biologist Michael Smith of Auburn University in Alabama. "If you have two different sizes of hexagons, and you're going to group the small ones on one side and the big ones on the other side, you're inherently going to have some kind of an issue when you try to fit them together."

To figure out how bees and wasps solve this tiling puzzle, Smith and colleagues analyzed 115 images of colonies of five species of honeybee (*Apis* spp.); four species of *Vespula* wasp, commonly known in North America as yellow jackets; and one species of paper wasp (*Metapolybia mesoamerica*).

Using an automated image analysis tool developed by team member Kirstin Petersen, a roboticist at Cornell University, the scientists extracted data from 22,745 nest cells. Such data included lengths of cell walls and how many neighbors each cell has. Smith verified the data for each cell by hand. "I was the unfortunate sap," he says, "but I was also happy to do that."

The automated tool allowed the team to get data from irregular cells that aren't perfect hexagons. Many scientists had ignored these types of cells due to the difficulty of measuring them manually.

When scientists tickled lab rats (one shown) and played a game with them, nerve cells in a brain region called the PAG became active. The team suspects that this region controls playfulness.

NATALIE GLOVELI

NEUROSCIENCE

Brains may have a playfulness switch

Blocking the activity of certain cells reduces play behavior in rats

BY SIMON MAKIN

Rats are extremely playful creatures. They love playing chase and they literally jump for joy when tickled. Central to this playfulness, a new study finds, are nerve cells in a specific region of the brain.

Neurons in the periaqueductal gray, or PAG, are active in rats during different kinds of play, scientists report July 28 in *Neuron*. Blocking the activity of those neurons makes the rodents much less playful.

The results give insight into a poorly understood behavior, particularly in terms of how play is controlled in the brain. "There are prejudices that it's childish and not important, but play is an underrated behavior," says Michael Brecht, a neuroscientist at Humboldt University of Berlin.

Scientists think play helps animals develop resilience. Some researchers even relate the behavior to optimal functioning. For people, "when you're playing, you're being your most creative, thoughtful, interactive self," says Jeffrey Burgdorf, a neuroscientist at Northwestern University in Evanston, Ill., who was not involved in the study. This is the opposite of some depressive states, and Burgdorf's own research aims to turn understanding of the neuroscience of play into new therapies for mood disorders.

In the study, Brecht and colleagues got lab rats used to being tickled and played with in a game of chase-the-hand. When

These seemingly misshapen cells turned out to be anything but.

When transitioning from small worker cells to big reproductive cells, all the bees and wasps built pairs of adjoining five-sided and seven-sided cells to bridge the gap. A five-seven pairing has the same number of open sides as a pair of hexagons — both types of conjoined pairs have 10 sides available to connect to other cells — so it doesn't disrupt the pattern. And the larger size of the seven-sided cell allows the bees and wasps to seamlessly make larger hexagons on the other side of the cell.

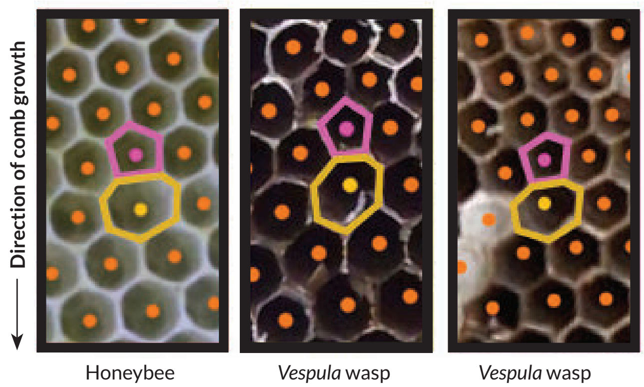
"They're always building the five-sided cell first, and then the seven-sided cell," Smith says. A mathematical model of this strategy, built by team member Nils Napp, a Cornell computer scientist, found that what the bees and wasps are doing is close to the optimal geometric solution.

The most efficient way to build an array of shapes such that each cell is big enough to raise a baby bee or wasp can be represented by a Delaunay triangulation. Imagine a sheet of paper marked with dozens of dots. Then, fill the sheet with triangles by connecting only neighboring dots. Finally, around each triangle, draw a circle that touches each corner.

In the layout of a Delaunay triangulation, no dot is inside any of those circles. Drawing additional lines that connect centers of neighboring circles produces a tiling of polygons, much like the latticework of hexagons found in the bee and wasp nests. Adding bigger hexagons to the nest slowly inches the whole array away from perfection, such that gaps may form or the workers may need to build an unusable cell to keep the nest together, Napp's model shows.

The optimal thing to do is to add a five-seven pair just as the Delaunay condition is about to be violated. Across the bee and wasp species, about 85 percent of all non-hexagonal cells are in five-seven pairs, just like the model predicts.

The honeybees and wasps used in this study are separated by 179 million years of evolution and build their nests out of different materials. "But both evolved to use this five-seven rule for transitioning between hexagon sizes," Bartlett says. "Evolution has a tendency to solve challenges optimally." ■



In honeybee and wasp nests, pairs of five- and seven-sided cells (pink and yellow) connect smaller, older hexagonal cells to larger, newer ones as colonies transition from mostly workers to reproductive males and new queens. The species seem to have evolved this architectural strategy independently.

M.L. SMITH *ET AL*/*PLOS BIOLOGY* 2023

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rats play, they squeal at a frequency of 50 kilohertz, which humans can't hear. The researchers recorded these ultrasonic giggles as a way of measuring when the rats were having "fun."

Brecht and colleagues suspected the PAG — which is involved in many instinctual responses and automatic functions, such as controlling breathing and pain — might be involved in play behavior. That's partly because of the PAG's role in controlling vocalizations, which help coordinate play. If your playmate stops laughing, it is time to stop play-fighting.

The team recorded activity from individual cells in the PAG while rats played chase-the-hand or were tickled. Columns of cells in the PAG were active during play, the researchers found. "These cells really go crazy, especially in response to tickling," Brecht says.

Importantly, the same cells were active during both chasing and tickling. "This was where we thought: These are the cells," Brecht says. "They're not about moving, or touch. They're about fun."

Making the rats anxious by putting them on an elevated, brightly lit platform suppressed playfulness and giggles, and reduced activity in these "fun" cells.

The team then genetically altered the cells so that their activity could be controlled using light. Blocking activity in just these cells caused the rats to play less and become less ticklish, as shown by an absence of giggles.

The findings suggest that the PAG is required for play, probably as part of a neural circuit, the team says. Brecht and colleagues have previously found play-responsive neurons in the somatosensory cortex, a brain region responsible for perceiving touch.

However, other research has shown that animals without a somatosensory cortex still play. Brecht doesn't think the same will be true for animals lacking the play-associated part of the PAG. "We think it's a control structure for playfulness," he says.

Improving the understanding of this circuitry may help researchers improve their knowledge of depression in people (*SN: 2/11/23, p. 18*). "The people that really, really need help are the ones that can't play," Burgdorf says. The new study is a step toward understanding what such depressive states look like in the brain, which could one day help clinicians choose the best treatments for different patients, he says.

The team plans to study the PAG in other animals to see how it might differ across species and to see if it helps explain why some animals are more playful than others, Brecht says. One of the first things he did after realizing the region's importance in rats was to look at the PAG in humans.

"And guess what? It's very large," Brecht says. "That's not a coincidence: No animal plays as many games as we do." ■

ARCHAEOLOGY

Saddle vies for the title of oldest known

Equestrian gear from China may date to over 2,400 years ago

BY BRUCE BOWER

A woman buried more than 2,400 years ago in what's now northwestern China has galloped into a scientific afterlife atop the earliest directly dated horseback riding saddle.

Scientists have radiocarbon-dated the well-preserved soft saddle to sometime between 727 B.C. and 396 B.C. Excavated at what's known as the Yanghai cemetery, this expertly crafted piece of riding equipment is about as old as, or possibly older than, the previous record holders, archaeologist Patrick Wertmann of the University of Zurich and colleagues report in the September *Archaeological Research in Asia*.

Soft saddles found in tombs of mobile herders and warriors from the Scythian Pazyryk culture of northern Asia date to between 430 B.C. and 420 B.C. Those dates are inferred from analyses of tree rings in wood that was used to construct the tombs.

Despite its simple design, "the Yanghai saddle was manufactured by a specialist familiar not only with needle- and leatherwork but with horse riding and the anatomy of horse and rider," Wertmann says. The finished product, which shows signs of extensive use, had been placed with the deceased woman's body and was positioned as if she were riding still.

The Yanghai saddle shares basic features with modern soft saddles, including two wing-shaped hides sewn together to form a seat, divided by a long, narrow strip of hide that was placed over a horse's spine. Rounded pieces of hide attached to the front and back of the wing-shaped pieces would have helped riders to maintain an upright position and raise themselves up, say, when shooting an arrow.

Different stitching techniques using either sinew or leather thread hold the Yanghai saddle together. Saddle stitching, a method still practiced today that creates two rows of interlocking threads using a single row of holes, connected front and back supports to the saddle seat. Simpler stitching methods were used to repair tears in the saddle and to close incisions in each main hide that could be opened to stuff animal hair and straw into the saddle seat for cushioning.

When and where people began to ride horses and use saddles remains uncertain. Yamnaya herders in the area of Romania, Bulgaria and Hungary may have ridden horseback as early as around 5,000 years ago, based on an analysis of the herders' skeletal features (*SN: 4/8/23, p. 12*). Ancient artwork from around 4,800 years ago in Mesopotamia shows horses being ridden without saddles, Wertmann says.

But only saddles provide clear evidence of horseback riding, says anthropological archaeologist Alicia Ventresca-Miller of the University of Michigan in Ann Arbor. Subtle construction differences between the Yanghai saddle and others found at several regional sites, presumed to be of around the same age as the Yanghai find, "suggest that knowledge of saddle-making was being transferred between [communities] that then made variable types of saddles," says Ventresca-Miller, who did not participate in the new study.

At Yanghai, where 531 tombs have been excavated, researchers have recovered whips, bridles and other items associated with horseback riding that date to as early as around 3,300 years ago. Only one other grave aside from the woman's tomb, thought to be of about the same age, has yielded a saddle. But that find is fragmentary and has not been radiocarbon-dated.

Yanghai excavations have also produced the oldest known pair of pants, worn by a presumed horseback rider around 3,000 years ago (*SN: 3/12/22, p. 14*).

Saddle-making emerged as riders became concerned with their own comfort and safety and the health of their horses, Wertmann suspects. Comfortable saddles would have enabled everyone in a community to ride horses and spurred increases in long-distance horseback trips, Ventresca-Miller says.

Wertmann's team cannot say whether Yanghai people, who lived in year-round settlements, or a mounted herding community from elsewhere in Central and East Asia made the ancient woman's saddle. She may have migrated to Yanghai from a herding group and brought the saddle along. Or Yanghai people may have acquired the saddle through trade. Or local experts in leather- and needlework may have crafted the saddle. ■

This ancient horseback riding saddle (top view shown) from northwestern China dates to between 727 B.C. and 396 B.C. and displays sophisticated stitching techniques.

P. WERTMANN *ET AL*/*ARCHAEOLOGICAL RESEARCH IN ASIA* 2023

A Time of Porpoise

A memorable beach moment: You're basking in the warm sun, toes in the sand, letting the gentle turn of the foam-capped waves lull you into a state of complete relaxation. As your eyes scan the endless horizon of blue on blue, you're rewarded with a school of dolphins making their way across the sea.

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Dispatches from the Dreamscape

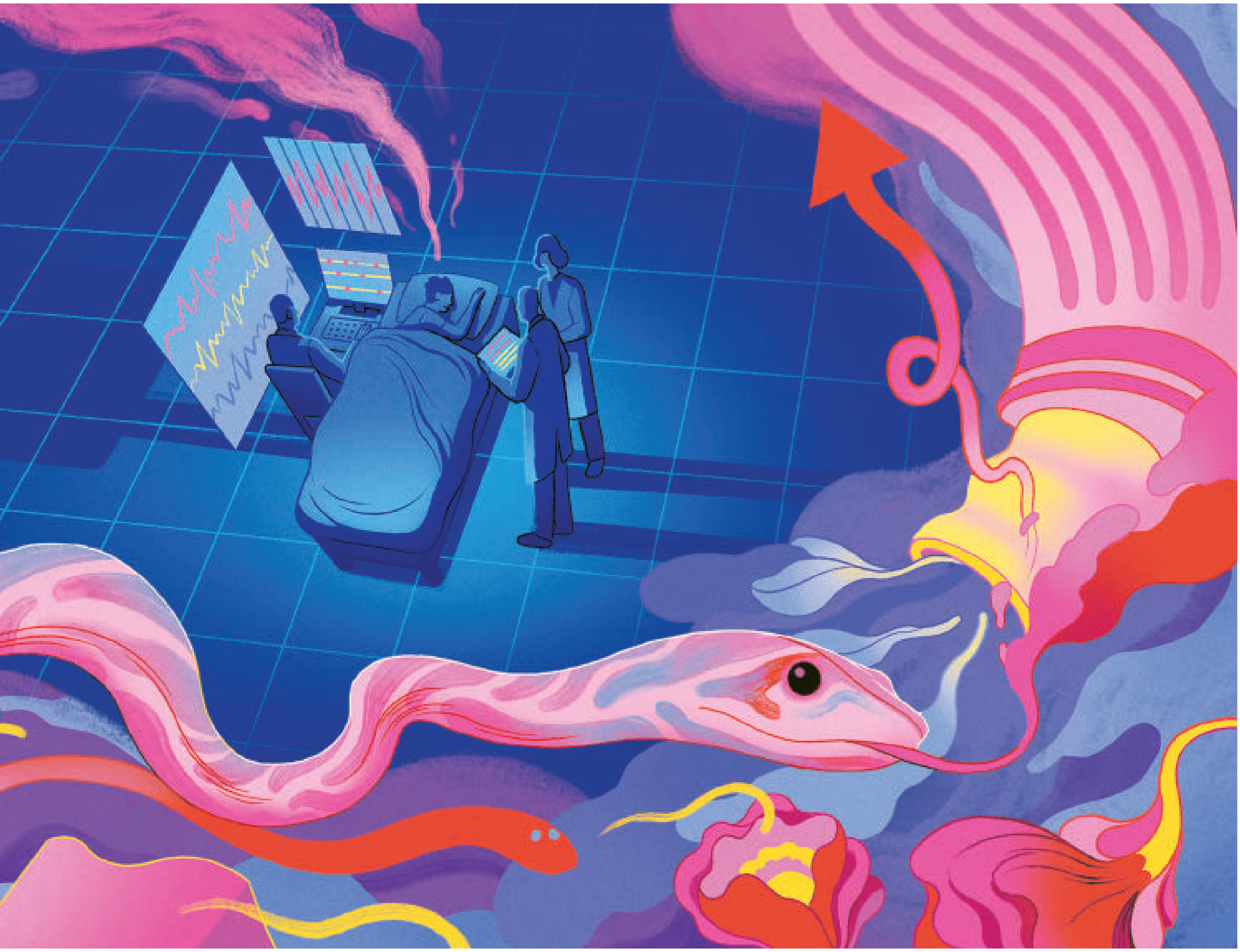
What lucid dreamers could tell us about the strange worlds rendered by sleeping minds

By Maria Temming

When Christopher Mazurek realizes he's dreaming, it's always the small stuff that tips him off.

The first time it happened, Mazurek was a freshman at Northwestern University in Evanston, Ill. In the dream, he found himself in a campus dining hall. It was winter, but Mazurek wasn't wearing his favorite coat.

"I realized that, OK, if I don't have the coat, I must be dreaming," Mazurek says. That epiphany rocked the dream like an earthquake. "Gravity shifted, and I was flung down a hallway that seemed to go on for miles," he says. "My left arm disappeared, and then I woke up."



RUNE FISKER

Most people rarely if ever realize that they're dreaming while it's happening, what's known as lucid dreaming. But some enthusiasts have cultivated techniques to become self-aware in their sleep and even wrest some control over their dream selves and settings. Mazurek, 24, says that he's gotten better at molding his lucid dreams since that first whirlwind experience, sometimes taking them as opportunities to try flying or say hi to deceased family members.

Other lucid dreamers have used their personal virtual realities to plumb their subconscious minds for insights or feast on junk food without real-world consequences. But now, scientists have a new job for lucid dreamers: to explore their dreamscapes and report out in real time.

Dream research has traditionally relied on reports collected after someone wakes up. But people often wake with only spotty, distorted memories of what they dreamed. The dreamers can't say exactly when events occurred, and they certainly can't tailor their dreams to specific scientific studies.

"The special thing about lucid dreaming is that you can get even closer to dream content and in a much more controlled and systematic fashion," says Martin Dresler, a cognitive neuroscientist at the Donders Institute in Nijmegen, Netherlands.

Lucid dreamers who can perform assigned tasks and communicate with researchers during a dream open up tantalizing opportunities to study an otherwise untouchable realm. They are like the astronauts of the dream world, serving as envoys to the mysterious inner spaces created by slumbering minds.

So far, tests in very small groups of lucid dreamers suggest that the strange realities we visit in sleep may be experienced more like the real world than imagined ones. With more emissaries enlisted, researchers hope to probe how sleeping brains construct their elaborate, often bizarre plots and set pieces. Besides satisfying age-old curiosity, this work may point to new ways to treat nightmares. Lucid dream studies could also offer clues about how dreams contribute to creativity, regulating emotions or other cognitive jobs — helping

"Gravity shifted, and I was flung down a hallway that seemed to go on for miles.... My left arm disappeared, and then I woke up."

CHRISTOPHER MAZUREK

solve the grand mystery of why we dream.

But there are still a lot of problems to solve before lucid dreaming research can really take off. Chief among them is that very few dreamers can become lucid on demand in the lab. Those who can often struggle to do scientists' bidding or communicate with the waking world. Pinpointing the best techniques to give more people more lucid dreams may assuage those issues. But even if it does, not all scientists agree on what lucid dreams can tell us about the far more common, nonlucid kind.

Lucid dreaming's proof and potential

Tales of lucid dreams date back to antiquity. Aristotle may have been the first to mention them in Western literature in his treatise *On Dreams*. "Often when one is asleep," he wrote, "there is something in consciousness which declares that what then presents itself is but a dream."

If Aristotle had lucid dreams often, though, he was probably an outlier. Only about half of people say they've ever had a lucid dream, while a mere 1 percent or so say they lucid dream multiple times a week. Modern enthusiasts use various techniques to boost their likelihood of lucid dreaming — such as repeatedly telling themselves before bedtime that they will have a lucid dream, or making a habit of checking whether they're awake several times a day in the hopes that this routine carries over into their dreams, where a self-check may help them realize they're asleep. But those practices don't guarantee lucidity.

The rarity of lucid dreaming may be why modern science took some convincing that it's even real. For millennia, lucid dreamers' own testimonies were the only evidence that someone could be self-aware while catching z's. Some scientists wondered if so-called lucid dreams were just brief waking hallucinations between bouts of sleep.

But within the last few decades, experiments have offered proof that lucid dreams are truly what they seem. It turns out, when someone in a dream purposely sweeps their gaze all the way left, then all the way right, their eyes can match those movements behind closed lids in real life. These motions, measured by electrodes near the eyes, stand out from the smaller optical jitters typical of REM sleep, when most lucid dreams happen. This gives dreamers a crude way to signal they've become lucid or send other messages to the outside world (SN: 9/19/81, *p.* 183). Meanwhile, brain waves and muscle paralysis throughout the rest of the body confirm that the dreamer is indeed asleep.

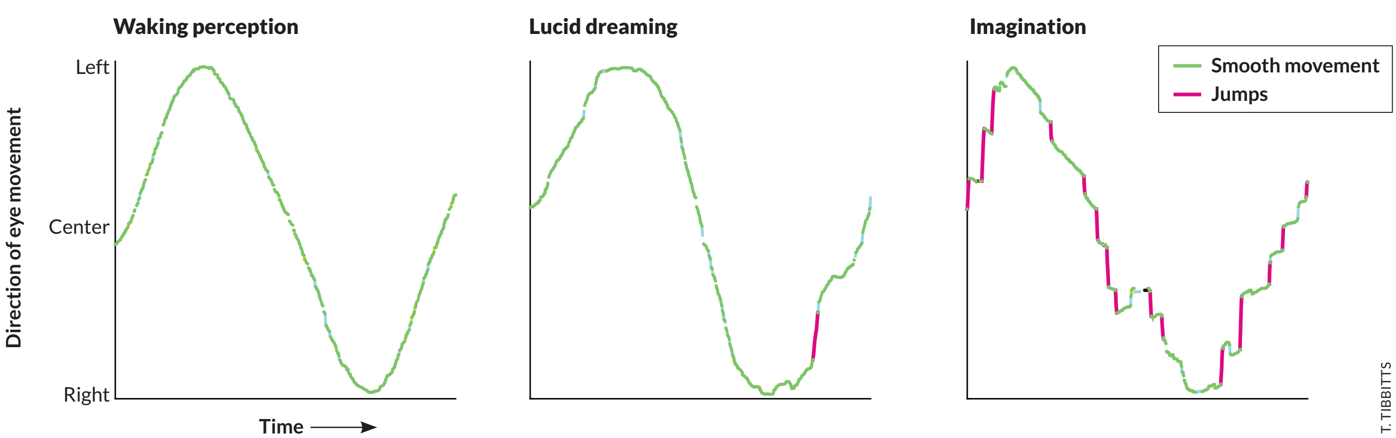
Neuroscientists are just beginning to realize the potential of that line of communication. Lucid dream research "has been enjoying a renaissance over the last decade," says neuroscientist Tore Nielsen. He directs the Dream & Nightmare Laboratory at the Center for Advanced Research in Sleep Medicine in Montreal. "This renaissance has made it one of the cutting-edge areas of dream study."

One research team recently deployed experienced lucid dreamers to find out whether dream imagery is more like real-life visuals or imagined ones. While asleep, six lucid dreamers moved their thumbs in either a circle or a line (or both) and traced that motion with their eyes. Participants repeated the same task while awake with their eyes open and in their imaginations with their eyes closed. People's gazes panned jerkily when they tracked the imagined movements, as though they were viewing something in low resolution. But in dreams, people's eyes tracked the movements smoothly just as in real life, the team reported in 2018 in *Nature Communications*.

"It's been debated really all the way back to the ancient Greeks, are dreams more like imagination, or is it more like perception?" says study coauthor

Eye tracking

A person's eyes can smoothly track left and right movements when they are awake (left) or in a lucid dream (middle). But when someone closes their eyes and tries to imagine tracking that motion, their eyes pan in small jumps (right), suggesting that lucid dreams are experienced more like waking perception.
SOURCE: S. LABERGE *ET AL*/ *NAT. COMMUN.* 2018



Benjamin Baird, a cognitive psychologist and neuroscientist at the University of Texas at Austin. "The smooth tracking data suggests that, at least in that sense, the imagery is more like perception."

This and other early experiments offer a taste of what dreamstronauts could teach us. But any conclusions based on just a handful of dreamers have to be taken with a grain of salt. "They're more like proof-of-concept studies," says Michelle Carr, a cognitive neuroscientist at the Center for Advanced Research in Sleep Medicine. "It needs to be studied in bigger samples."

That means finding — or creating — more expert lucid dreamers.

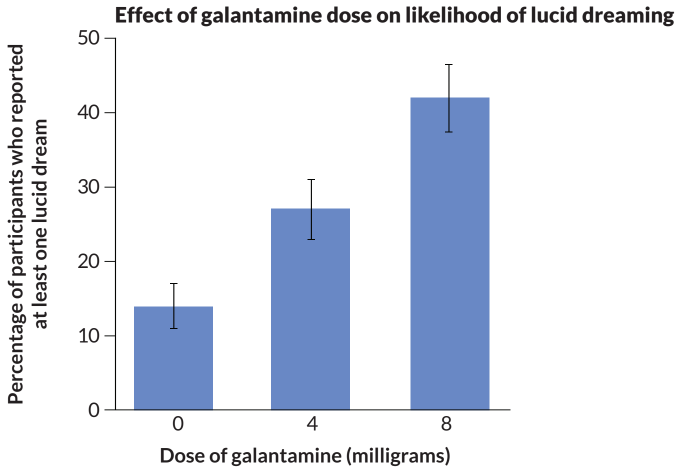
Lucid dreamers wanted

If you want to have a lucid dream, there are a few strategies you can use to up your chances. Besides regularly questioning whether you're awake and setting an intention before bed to become lucid, you can keep a dream diary. Getting familiar with common characters, events or themes in your dreams may help you recognize when you're dreaming. Some aspiring lucid dreamers also use a tactic called "wake-back-to-bed." They wake up extremely early in the morning, stay up for a while, then get more shut-eye. That jolt of alertness right before tumbling back into REM sleep may help them become lucid in a dream.

Such techniques can be hit-or-miss, though. And data on their effectiveness are still pretty murky, Baird says. One study with about 170 Australians, for instance, suggested that checking if you're awake, setting an intention to become lucid and doing wake-back-to-bed all together can increase your odds of lucid dreaming. But it wasn't as clear if using just one or two of those practices worked.

Investigations by Baird and others have shown that the supplement galantamine promotes lucid dreaming, probably by fiddling with neurotransmitters involved in REM sleep. But galantamine can be saddled with side effects such as nausea. And although lucidity itself does not appear to spoil sleep quality, the long-term effects of using galantamine are not well-known. "Personally, I wouldn't be mucking around with my neurotransmitters every night," Baird says.

In 2020, Carr and colleagues reported that they'd coaxed 14 of 28 nappers to become lucid in the lab — including three people who'd never before lucid dreamed — no drugs necessary. Before falling asleep, participants learned to associate a cue, such as a series of beeps, with self-awareness. Hearing the same sound again while sleeping reminded



Dream aid For three nights, 121 people combined commonly used strategies for lucid dreaming with one of three doses of galantamine. Those who took higher doses of galantamine were more likely to have lucid dreams. SOURCE: S. LABERGE *ET AL/PLOS ONE* 2018

T. TIBBITTS

them to become lucid. Carr is particularly interested in finding out whether lucid dreaming can help people conquer nightmares, but researchers at Northwestern use the sensory cue strategy to get more lucid emissaries to carry out dream tasks for their experiments.

"Our method is kind of a shortcut," says Northwestern cognitive neuroscientist Ken Paller. It doesn't require a lot of mental training or the grueling sleep interruptions that some other lucid dreaming techniques do.

Another shortcut for researchers is to recruit dreamers from a special slice of the population: people with narcolepsy, who are liable to fall asleep suddenly during the day.

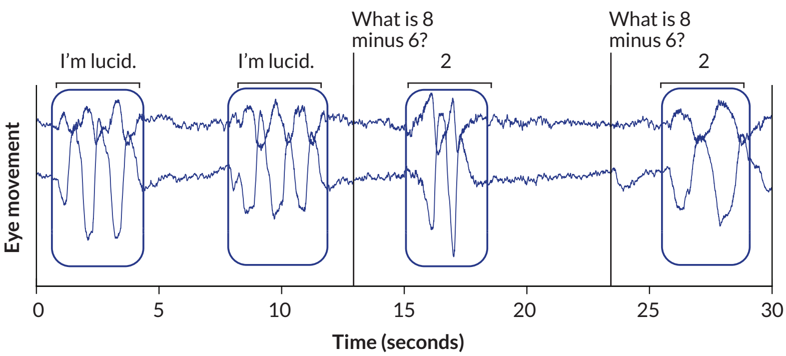
"They're just champions at lucid dreams," says Isabelle Arnulf, a sleep neurologist who heads the sleep disorders clinic at Pitie-Salpetriere University Hospital in Paris.

In 2018, Arnulf's team reported a study where 18 of 21 narcolepsy patients signaled lucidity during lab naps. Even with those impressive numbers, a couple of lucid nappers still couldn't control their dreams well enough to complete their assignment: to do something in a dream that made them briefly stop breathing, such as swimming underwater or speaking. One said after waking that they'd simply forgotten to stop breathing while diving off a cliff, while another said they tried to speak but couldn't get any words out.

Staying lucid and successfully wrangling dream scenarios present challenges for lucid dreamers — and the scientists relying on them. In one study, lucid dreamers instructed to fill a dream room with objects, such as a clock and a rubber snake, ran into

Dream dialog While dreaming, Christopher Mazurek (pictured) signaled the outside world by sweeping his eyes left and right. Electrodes on his face recorded those motions. On the graph below, Mazurek's eye motions that indicate he is lucid appear as three big up-down sweeps. Eye signals answering "2" to researchers' simple math question appear as two big up-down sweeps.
SOURCE: K.R. KONKOLY *ET AL*/*CURRENT BIOLOGY* 2021

Lucid dreamer's eye movements during a mid-dream conversation



problems; the clock spun wildly, or the snake slithered away. In another experiment, lucid dreamers asked to practice throwing darts were waylaid by only having pencils to throw or being pelted with darts by a nasty doll.

"It's a lot harder than just passively lucid dreaming in your bed," says Mazurek, who has participated in several lucid dream studies at Northwestern. "You realize, 'OK, I have to stabilize the dream. I have to remember what the task is. I have to do the task without the dream falling apart.'"

Missions to the moon may be hard, but at least astronauts don't have to worry about forgetting who or where they are, or their spaceship suddenly turning into a banana.

Despite these challenges, lucid dream expeditions are forging ahead — and fast. In fact, an international crew of dreamfarers, including Mazurek, recently embarked on their most ambitious mission yet.

Can you hear me now?

When it comes to getting on-the-ground data, interviewing dreamers in real time is, well, the dream. Instead of just sitting back and watching dreamers do various activities, researchers could ask these agents about their experiences moment to moment, painting the realm of dreams in sharper detail than ever before.

"Reports of dreamed sensations, [such as] tasting certain foods, can be compared with those of actual sensations," Nielsen says. "Similarly, one could test whether sexual pleasure, certain sounds or other types of experiences are accurately simulated." These details, he says, might help "probe the limits and mechanisms of dream production."

Karen Konkoly is especially excited about giving people assignments mid-dream. Say researchers want to know how much dreams help with creative problem-solving. If dreamers are assigned a problem before sleep, they're liable to mull it over as they nod off. "Even if it feels like the lucid dream, maybe it's really the time as you're falling asleep that helped you solve the problem," says Konkoly, a cognitive neuroscientist at Northwestern. Airdropping a puzzle straight into a dream could better isolate the usefulness of that specific part of sleep.

There's a whole medley of theories about why people dream, from honing skills to tapping into creativity to processing memories or emotions. "But if you can't control the dream in real time and then study the outcome, then you never know … if the dream is really doing anything," Konkoly says. So a few years ago, she, Arnulf, Dresler and others decided to find out if people can receive and respond to outside input while dreaming.

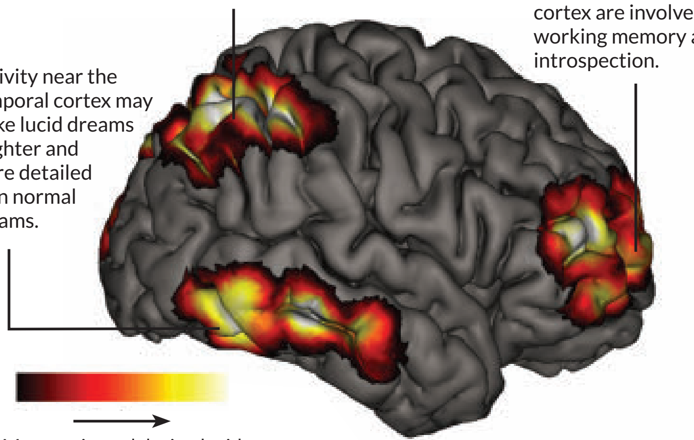
Thirty-six people took snoozes at Northwestern, Arnulf's lab, Dresler's lab or another lab that was in Germany. Once sleepers signaled that they were lucid, researchers spoke yes-or-no questions or math problems in the sleepers' ears. Or, for the Germans, lights flashing different colors conveyed math questions in Morse code. Before conking out, dreamers were told to answer whatever questions they received with eye signals or by smiling and frowning.

"Facial muscles are less inhibited than other muscles during REM sleep," Arnulf explains. Someone smiling in a dream may not make that expression in real life, but electrodes on the face can register tiny corresponding muscle twitches.

Out of 158 attempts to interrogate lucid dreamers, 29 total correct responses came from six different people. Those six ranged from newbie to frequent lucid dreamers, including Mazurek, who heard scientists' questions while dreaming he was in a *Legend of Zelda* game. The rest of the attempts yielded five wrong answers, 28 ambiguous ones and 96 nonresponses.

When Konkoly first saw someone correctly

FROM TOP: K.R. KONKOLY; T. TIBBITTS



Brain power Functional MRI scans of one sleeper's brain during lucid and nonlucid sleep showed that some brain areas (highlighted) may be more active during lucid dreams than during normal ones.

answer a question in their sleep, "my first reaction was to not believe it." But for 26 of those 29 correct responses, a panel of independent sleep experts unanimously agreed that the dreamers were in the throes of REM sleep when they replied. Nearly 400 attempts to reach sleepers who hadn't signaled lucidity netted a single correct response — bolstering the researchers' confidence that correct answers from lucid dreamers weren't flukes. The results appeared in 2021 in *Current Biology*.

"I was astonished," says Robert Stickgold, a cognitive neuroscientist at Harvard Medical School who studies dreams but not lucid ones. "I had no question but that these people are in fact listening and are in fact having lucid dreams at the time of the communication — and that opens up all sorts of possibilities."

Arnulf and others have since asked lucid dreamers to smile or frown as their dreams became more or less pleasant with the goal of understanding how dreamers experience emotion. Another study, not yet published, tracked when lucid dreamers answered or ignored researchers' questions to see how people tuned in and out of the real world while dreaming. Knowing which signals break the dream-reality barrier could help "uncover the mechanism of the brain's disconnection from the external world — which is huge," Baird says. It could even be relevant for other states of unconsciousness, he adds, such as when someone is put under for surgery.

Limits of lucidity

Even if researchers get all the expert lucid dreamers they need to run all their desired experiments, there's still one major sticking point to this whole field of study.

"The biggest issue is how far can you push these results to dreaming in general," Stickgold says. Imagine, for instance, that lucid dreamers get better at a skill by practicing it in their dreams. It's not clear that people who just happen to have normal dreams about doing those activities, without self-awareness, would reap the same rewards. "It's a little bit like recruiting major league baseball players to give you some baseline data on how far people can throw balls," Stickgold says.

Existing data do suggest that lucid dreamers may have access to parts of the brain that normal dreamers don't. The lone case study comparing fMRIs of someone's lucid and nonlucid REM sleep hints that brain areas linked with self-reflection and working memory are more active during lucidity. But those data come from just one person, and it's not yet clear how such differences in brain activity would affect the outcomes of lucid dream experiments.

Some researchers, including Dresler, resist the idea that lucid dreams are profoundly different from nonlucid ones. "Lucid dreaming is not a strict all-or-nothing phenomenon," he says, with people often fluttering in and out of awareness. "That suggests that lucid and nonlucid dreaming are in principle something very similar on the neural level and not two completely different animals."

Perhaps lucidity affects some aspects of the dream experience but not all of them, Baird adds. In terms of how dreams look, he says, "it would be very, very surprising if it was somehow completely different when you become lucid."

A more thorough inventory of the differences in brain activity between lucid and nonlucid dreams might help settle these questions. But even if lucid dreams don't represent dreams in general, Nielsen still thinks they're worth studying. "It is a type of consciousness that has intrigued and amused people for centuries," he says. "It would be important for science to understand how and why humans have this extraordinary capacity for intentional world simulation." ■

Explore more

- Benjamin Baird, Sergio A. Mota-Rolim and Martin Dresler. "The cognitive neuroscience of lucid dreaming." *Neuroscience & Biobehavioral Reviews.* May 2019.

MPI OF PSYCHIATRY

An Electrical Grid Update

How one device could help prepare the grid for a renewable energy future

By Alexandra Witze

As more renewable energy comes online and fossil fuel plants are retired, electrical grids around the world need updates to keep them operating stably.

From Colorado to Washington, from Ohio to Pennsylvania, coal-fired power plants are shutting down. The United States is on track to retire half of its capacity to generate electricity from coal by 2026. That's a remarkably fast decline from coal's peak in 2011 — and a major step in the shift to clean energy and the fight against climate change.

But there's a surprising downside to retiring big, old power plants. These plants help maintain the power grid's stability. As more of them go offline, something else must step up to do that job.

An electrical grid is a complex network involving systems that produce power, like a nuclear power plant or a wind turbine, and systems that store and transmit power, like batteries and transmission lines. A grid can stop functioning for any number of reasons, such as a tree falling on a power line or a heat wave overwhelming the system's capacity. In the United States, electricity pulses through the grid like a heartbeat at a standard frequency of 60 hertz. That frequency can shift if demand increases beyond supply or if something in the system like a large generator goes offline. Even a small interruption in that 60-hertz heartbeat can cause ripple effects that the grid struggles to recover from.

Large power plants are designed to help the grid be resilient to these ripple effects. The inertia of their spinning generators buys time in the event of an unexpected power outage, and they continuously adjust their power output based on the frequency in the grid, keeping everything stable. But a power grid that incorporates large amounts of renewable energy, such as from wind turbines and solar panels, works very differently. It relies on devices known as inverters to convert the direct current, or DC, electricity produced by wind and solar facilities into alternating current, or AC, electricity for the grid. And renewable energy systems involving inverters don't behave like traditional power plants do. "We're dealing with a completely different physical system," says Patricia Hidalgo-Gonzalez, an electrical engineer at the University of California, San Diego.

So researchers have been looking for ways to keep the grid stable as large power plants are retired and renewable energy makes up a larger percentage of U.S. electricity generation. The answer may lie in a special type of inverter, known as grid-forming inverters. These pieces of electrical equipment, which range in size from smaller than a microwave to as big as a shipping container, are specially programmed to work at the interface between something that produces or stores power — like wind turbines, solar panels and batteries — and the grid. Crucially, they are able to control the flow of renewable energy into the grid quickly and responsively, in ways that mimic the control from large power plants.

By adding some grid-forming inverters into an existing power grid, engineers can help replace the functions that are lost when the big plants retire. Grid-forming inverters also have other advantages, such as automatically restarting a grid that has gone offline. That can make society more resilient to the power outages that come with extreme weather fueled by climate change, such as heat waves and hurricanes (SN: 2/15/20, *p.* 22).

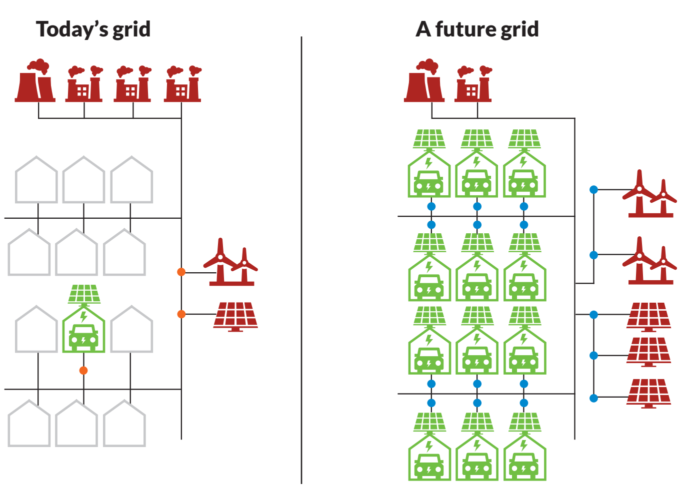
Think of a grid-forming inverter as a mother duck with a bunch of baby ducklings trailing after it, says Dominic Gross, an electrical engineer at the University of Wisconsin–Madison. A grid-forming inverter can inject voltage into a grid and then adjust its frequency according to however much power is flowing through the system. Other sources of electricity flowing into the grid, the baby ducklings, can then synchronize with that grid-forming inverter, just as they did with the flow of electricity that pulsed from power stations.

That gives grid-forming inverters a key role in getting more renewable energy into the power grid. Manufacturers including General Electric, Siemens, Tesla and Hitachi already make these devices, and they have been used for decades in isolated power grids, such as on small islands. Today, their use is expanding rapidly around the world as big power companies turn to the devices to handle the boom in renewable energy.

THE CLIMATE FIX

This article is part of a series of stories on climate change solutions and how people around the world are tackling the biggest challenge of our time.

Grid goals Coal-fired and natural gas power plants are the backbone of today's U.S. electrical grid (left). Wind and solar farms play a smaller role and use grid-following inverters (orange) to get more intermittent electricity into the system. But grid-forming inverters (blue, right) could help make way for a future grid that relies primarily on renewable energy. In the grid of the future, every home could have solar panels, and electric vehicles would have bidirectional charging, allowing them to return energy to the grid. SOURCE: NREL; B. KROPOSKI



OPPOSITE PAGE: JUAN MIGUEL CERVERA MERLO/ALAMY STOCK PHOTO; THIS PAGE: C. CHANG

Adding grid-forming capabilities into renewable energy power systems is an easy first step that can make a dramatic difference in building a robust grid for the future, says Julia Matevosyan, chief engineer at the Energy Systems Integration Group in Austin, Texas. "We really have this window of opportunity now," she says.

If you have solar panels on your house, you probably have an inverter in your garage. Energy companies use similar inverters at wind and solar power farms to convert large amounts of DC electricity into AC electricity to feed into the grid. But most of those are what's known as grid-*following* inverters. They are like the baby ducklings trailing after their mother — they can do a few things on their own but they aren't capable of running the system like an adult duck can.

A grid-forming inverter, though, can sense the changes in the grid and respond in real time to adjust its frequency, which injects more or less power as needed to stabilize the grid. Florian Dörfler, an electrical engineer at ETH Zurich, compares a group of grid-forming inverters in a power grid to a bunch of spinning bicycle wheels connected by an elastic band. If one of the wheels starts to slow a bit for some reason, the elastic band will transfer momentum from the others and bring it back into synchrony with the group.

Who's using grid-forming inverters?

Grid-forming inverters aren't entirely new; they have been used around the world for decades for certain purposes. In the United States, they are mostly in microgrids, small electric power systems supplying isolated areas such as islands or small facilities.

In the 2010s, for instance, a group of researchers and industry professionals built a microgrid that incorporated grid-forming inverters at the Santa Rita Jail in Dublin, Calif. The microgrid used rooftop solar panels, five wind turbines, a fuel cell and battery storage to create a self-contained power system that operated for daily use but could also keep running independently from the main power grid in the event of an outage — crucial to maintaining security. Other microgrids that use grid-forming inverters include a military base on the Hawaiian island of Kauai and the Caribbean island of St. Eustatius.

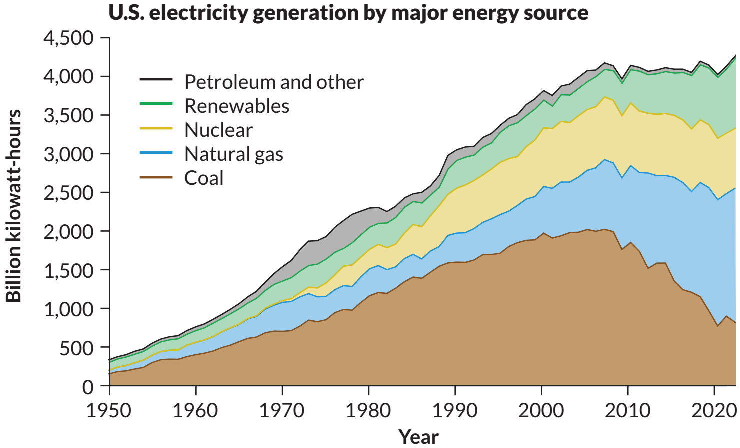
The challenge now is scaling up from those small, self-sustained systems to larger power grids that incorporate a lot of renewable energy. Several nations have begun this effort, adding grid-forming inverters into their systems.

Australia is perhaps the world leader, with three large renewable energy facilities incorporating grid-forming inverters that recently became operational and three more such facilities in the works, for a total of 480 megawatts of power. A couple of these are in South Australia, where wind power has boomed in recent years. In December, the Australian Renewable Energy Agency announced it was investing 176 million Australian dollars (about $118 million) in eight more projects to produce renewable energy using grid-forming technologies. All together those eight projects are designed to generate 2 gigawatts of power — 10 times the nation's grid-forming capacity to date and a "groundbreaking" step in the right direction, Matevosyan says.

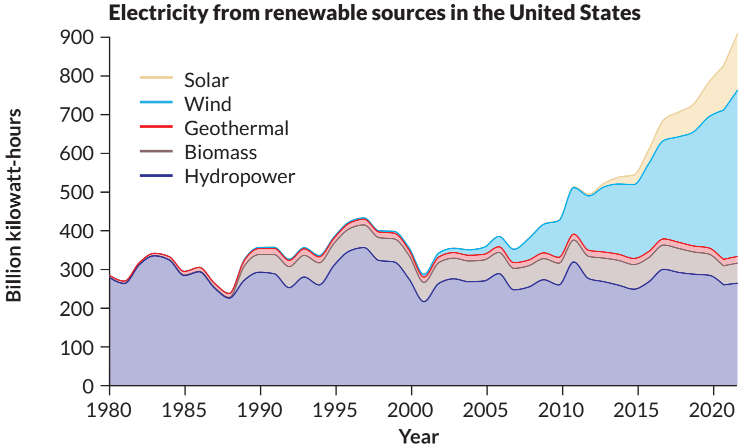
The United Kingdom is also investing in five new projects, including a 300-megawatt facility in Scotland due to be completed in 2024. In contrast, the United States has done little at the national level to encourage the adoption of grid-forming inverters, even as renewable energy production has roughly doubled in the past decade and now accounts for more than 20 percent of the country's electricity generation. "The U.S. is probably 10 years behind the curve," Dörfler says.

Renewable rise
More U.S. electricity is now coming from renewable sources (top graph), with solar and wind energy showing dramatic increases over the last decade (bottom graph). SOURCE: U.S. ENERGY INFORMATION ADMINISTRATION

U.S. electricity generation by major energy source



Electricity from renewable sources in the United States



BOTH: C. CHANG

That may be changing. The U.S. Department of Energy is funding a $25 million effort to work on how to get more grid-forming inverters into the U.S. power system. The consortium, known as UNIFI, for "universal interoperability for grid-forming inverters," is in its second of five years of research. It is led by the National Renewable Energy Laboratory in Golden, Colo., along with the University of Texas at Austin and the Electric Power Research Institute in Palo Alto, Calif.

So far, UNIFI has focused on basic issues such as drawing up suggested guidelines for how companies should build grid-forming inverters. Up until now, manufacturers worldwide have been making their own kinds of grid-forming inverters with little to no coordination among them. In December, UNIFI released draft standards meant to serve as a first step toward a national grid code that includes technical specifications for equipment; a second, updated version is expected by the end of the year.

UNIFI recently brought a handful of grid-forming inverters, acquired from different manufacturers, to NREL's Colorado laboratory. There researchers are testing them in a 1-megawatt power system to see how they fare working in the same grid. A similar UNIFI effort is testing the performance of a larger number of grid-forming inverters made by two different manufacturers in a 20-megawatt system on Kauai.

The goal is to see whether inverters from different manufacturers can be smoothly integrated into a large power grid, and how much programming work it will take to get them to play nicely with one another. "How do you make millions of these things work together, collaboratively, in a large-scale network systems context?" asks Gross, who works with UNIFI. Such tests are just early steps in getting the United States caught up with other countries that already have grid-forming inverters working in their large power grids.

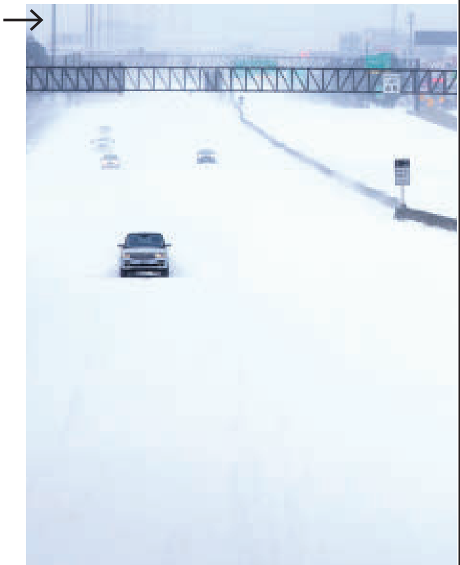
UNIFI hopes to raise the profile of grid-forming inverters and provide guidance to what is currently a Wild West landscape of different companies that manufacture them. But it will have to move fast to make a difference. "We are literally talking about transforming the entire electricity sector in like 15 years," says Ben Kroposki, director of the power systems engineering center at NREL and the organizational director for UNIFI. "It took 140, 150 years to build what we have today. And so that's just a monumental shift in the electric power sector."

Inverters in a typical home solar panel system can cost several thousand dollars, with the cost higher for industrial-scale systems. But grid-forming

Grids on the edge

Electrical grids are showing their age — and they're especially vulnerable to the cascading effects that can come with extreme weather. Here's a look at some recent events that pushed grids to their brink.

February 2021
A deep freeze across much of Texas paralyzed electrical equipment and took much of the state's grid offline, leading to hundreds of deaths.



September 2021
Hurricane Ida knocked out power to more than 1 million people in Louisiana, in part because transmission lines couldn't withstand the hurricane's wind speeds.

May 2022
An intense windstorm across Ontario and Quebec, Canada, toppled power lines and ultimately left nearly a million people without power.

June 2022
A failure at a West Texas power plant triggered more failures across Texas' grid, including knocking 1.7 gigawatts of solar power generation offline.

January 2023
A surge in voltage shut down Pakistan's national grid, leaving more than 200 million people without power.

June 2023
A heat dome over northern Mexico and Texas nearly pushed Mexico's power demand to exceed its supply.

FROM TOP: BRETT COOMER/*HOUSTON CHRONICLE* VIA AP; SEAN KILPATRICK/ THE CANADIAN PRESS VIA AP; K.M. CHAUDARY/AP PHOTO

The Caribbean island of St. Eustatius (a solar farm is shown) depends on a microgrid that uses grid-forming inverters.

equipment isn't necessarily more expensive to produce than grid-following equipment is. Manufacturers charge a bit more to cover their research and development costs, but the difference is minimal for the benefit gained, Matevosyan says. Even as some nations are incentivizing energy companies to put in grid-forming technologies, she says that anyone building grid components today should incorporate them as a matter of course. "It just makes sense to have them grid-forming," she says. "You can future-proof it."

What questions remain?

Even as grid-forming inverters are adopted, there are research questions yet to be answered. One challenge is that it's not yet clear how many inverters in grids of the future will need to be grid-forming. Theoretical calculations suggest that some grids will operate just fine getting 60 to 70 percent of their power from renewable sources using grid-following inverters. But others might crash at just 20 percent and will need to have more grid-forming inverters in the mix, Gross says.

The number for any grid will depend on factors such as the grid's age, stability and geometry. A densely interconnected network of power production facilities such as in Europe might need a much smaller percentage of grid-forming inverters than a long, strung-out network such as that along the Australian coast. The U.S. power grid is actually three separate grids, in the eastern and western parts of the country and in Texas, all with varying inverter needs. And some power operators might choose to disconnect their coal- or gas-fired plants but retain some large nuclear or hydroelectric facilities, which would continue to support the synchrony of the grid and demand fewer grid-forming inverters.

Other research frontiers include figuring out new ways to diagnose and fix problems in the grid. A short circuit in a grid component, for example, can suddenly inject large amounts of current, a surge that traditional power plants can handle automatically by disconnecting the malfunctioning part. Grid-forming inverters cannot tolerate large spikes in current, making it harder to solve these problems in real time. "How to do so efficiently and safely is still a big research question," says Rodrigo Henriquez-Auba, an electrical engineer in Mountain View, Calif., who works with UNIFI.

Some scientists, including Dörfler, are exploring how a power grid with a lot of grid-forming inverters could provide power in new ways. By taking extra steps to optimize how the inverters work together, researchers can move the system closer to what some describe as a virtual power plant—in which many small-scale renewable energy devices effectively function as a single traditional power plant. That might mean programming inverters to quickly draw power out of a battery and inject it to make the grid more robust to unexpected fluctuations. Machine learning techniques may help, by training inverters on real-world data to fine-tune operations.

Of course, there are many other challenges to building the grid of the future, such as figuring out better ways to store electricity from solar and wind farms, how to build the necessary transmission lines and how to speed up the connection of renewable power facilities to the grid, currently backlogged due to regulatory issues.

Hidalgo-Gonzalez says that the electrical grid of the future needs to be stronger and more resilient for everyone. Today's U.S. power grid fosters a lot of societal inequities. It tends to be weak and less reliable, for example, in lower-income communities that are more vulnerable to extreme weather than it is in wealthier communities. In 2021, for instance, Hurricane Ida knocked out power to more than 1 million people in Louisiana, with some lower-income communities not getting it back for weeks.

Renewable energy, bolstered by grid-forming inverters, can play a big role in making the grid more resilient and equitable, Hidalgo-Gonzalez says. "We need to go really fast," she says, "if we want to take climate change seriously." ■

Explore more

- Yashen Lin *et al. Research Roadmap on Grid-Forming Inverters*. National Renewable Energy Laboratory, 2020.

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CONVERSATIONS WITH MAYA

FRANK WILCZEK
Theoretical physicist and Nobel laureate

Maya Ajmera, President & CEO of Society for Science and Executive Publisher of Science News, spoke with Frank Wilczek, a theoretical physicist, author and Nobel laureate. Wilczek has made seminal contributions to fundamental particle physics, cosmology and the physics of materials. His current research focus includes axions, anyons and time crystals, which are concepts in physics that he named and pioneered. Wilczek is an alumnus of the 1967 Science Talent Search (STS), a competition owned and produced by Society for Science. He serves on the Society's Honorary Board.

How did competing in STS influence you?

It was quite an experience for me. I had rarely left my little neighborhood in Queens, N.Y. So traveling to Washington, D.C., was quite an expedition; I had never been on an airplane before. I had the opportunity to meet Glenn Seaborg—a real, living, breathing Nobel Prize winner—and met students from all over the country. The experience was very affirming. The most important gift that I got from STS was confidence.

After STS, you attended the University of Chicago at the age of 15, and you went on to do graduate work at Princeton University at 21. What cultivated your early interest in math and science, and what helped you excel in research and academics at such a young age?

It came naturally to me, so I can't claim too much credit. I was always very interested in big things, abstractions and puzzles. I also received a lot of encouragement in school and grew up during the Cold War, when there was a national focus on STEM education. Scientists were the vanguard of protecting our nation against a big threat.

The memory of World War II and the atom bomb was very fresh in the minds of the adults around me. While I didn't have firsthand knowledge of those things, we did have air raid drills and big scares about nuclear war. Meanwhile, the space race was taking place. Science was in the air, and it was very exciting. My parents also encouraged me every step of the way.

Over the course of your career, you've pioneered multiple concepts in physics. Can you walk us through your experiences exploring some of the universe's greatest mysteries?

Asymptotic freedom, which I discovered with David J. Gross in the 1970s, is best understood in the context of what it accomplished for physics: It was the key to getting to the fundamental theory of what's called the strong force, which is the force responsible for holding together atomic nuclei.

Using very sophisticated instruments and image processing, scientists were able to take a look inside protons and found that protons had an internal structure with smaller particles inside. These particles don't exist as independent objects because they are bound into systems like protons. Inside the protons, they interact very, very little. This is called asymptotic freedom: When they get very close together, they interact very weakly. Before our work, a theory like this was thought to be impossible.

We proposed a fundamental theory of the strong interactions that is now known as quantum chromodynamics. This basic discovery of that strange behavior (asymptotic freedom) and of the theory of the strong interaction was a very major milestone in fundamental physics and is a central part of what's now called the standard model, which has been extremely successful and to this day survives unscathed after several decades of rigorous testing.

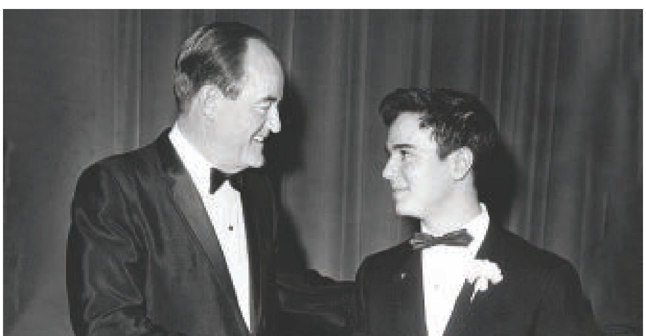
Scientists hold the standard model to very high standards because it's kind of God's last word on how the world works. These are the fundamental equations that are the basis for astrophysics, chemistry, biology and all forms of engineering. When you hold the theory to that high standard, you find there's an annoying flaw in the equations. A particular interaction doesn't match what's expected, which creates a puzzle. The theoretical community widely accepts that you should add some extra symmetry to the theory. That leads to our idea that there should be a new kind of particle, which in 1978 I called the axion, after a laundry detergent, because it cleans up a problem. And I thought axion sounded like it should be a particle.

A surprise that occurred a few years later is that the particle matched the profile of what astronomers call dark matter, which has a density of about six times as much as ordinary matter. It is a striking coincidence, and at present there are difficult but hopeful experiments involving physicists around the world trying to verify that dark matter is made out of axions.

Congratulations on winning the 2022 Templeton Prize, which honors those who harness the power of the sciences to explore the deepest questions of the universe and humankind's place and purpose within it. What does this recognition mean to you in your work?

It means a lot to me because, while I've continued to work on fundamental issues in physics and applications of physics, I have also come back to the questions that in many ways motivated me at the beginning. We didn't discuss this, but there's another thing that fed into my scientific career: When I was a teenager, I grew up in the Roman Catholic Church. I took it very seriously and had the idea that the universe had a purpose. But then as I learned more about science and more about the dogmas of the church, I found that they were very difficult to reconcile.

For many years, I put the questions of meaning and purpose aside. In recent years, as my understanding of the physical world was maturing, I felt the calling to come back to some of those questions. I started exploring that in my writings.


Frank Wilczek (right) shakes hands with then-Vice President Hubert Humphrey during the 1967 Science Talent Search Awards Gala.

I was really moved and touched that the Templeton Foundation recognized that these efforts are worthwhile and worth supporting. As I think about the Templeton Prize, its kind of an analog of the Science Talent Search, which made me feel like I was in the big leagues of science. Now, with this award I feel like I am in the big leagues of wisdom.

Beyond your many discoveries and scientific accomplishments, you've also led a varied career as a writer, including authoring several books and a column for the *Wall Street Journal*. How would you describe your writing process?

My process has evolved over the years. I owe a lot to my high school teachers who used to have us write essays very regularly. In fact, thinking back on it, writing in high school wasn't so different from writing my columns.

My wife, Betsy Devine, was very influential in getting me to write for the public. We wrote together. Our first book was *Longing for the Harmonies*.

What advice do you have for young people today who may be interested in pursuing research and tackling big problems?

Cast a wide net and find what you love. Don't just fall into something and stick with it because that's what your thesis adviser was doing, or that's what appealed to you when you were a 6-year-old. Give the world a chance to speak to you and pay attention to what it is telling you. Weigh what looks promising against the probability of reaching an answer as well as the importance of the problem. That kind of judgment improves with experience.

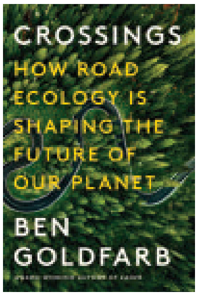
What books are you reading now, and what books inspired you when you were young?

The most recent significant book I read was *A Brief History of Equality* by Thomas Piketty. When I was a child, one book that had tremendous influence on me was *The History of Western Philosophy* by Bertrand Russell.

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

What literally kept me up at night recently was thinking about the dangers of nuclear warfare. The more you study the dynamics of how nuclear wars might start small and grow, and what would happen if there were a significant nuclear exchange, well, it's just appalling and terrifying.

Also, climate change is creeping up on us. The problem is it moves slowly and has enormous inertia. There are key technologies that can help and are becoming more economical. But the politics of making the transition is tricky because there are people who have enormous wealth in the form of fossil fuels, which could be significantly devalued if we transition to clean energy. So there's tremendous resistance to doing the right thing and that's a big problem too.



Crossings
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BOOKSHELF

Journey into the world of road ecology

Nearly 65 million kilometers of roadway crisscross the Earth — enough to encircle the planet more than 1,600 times — and that number will likely double by 2050. These roads have intruded into even the most remote corners of the world, and that has come at a cost: Vehicles are responsible for a staggering number of animal deaths. For instance, 1 million vertebrates are thought to die daily in collisions in the United States alone. Roads also kill indirectly, in part by fracturing migration routes and degrading pristine habitat.

In *Crossings*, journalist Ben Goldfarb delves into the burgeoning field of road ecology and introduces the impassioned, sometimes eccentric scientists who invite us to perceive our roads as animals do to better understand the ecological impacts. Goldfarb journeys alongside these researchers as they bike through Montana and wrestle anteaters in Brazil, squint at roadkill and rhapsodize about the design quirks that engineers can leverage to attract animals to safe overpasses and culverts. Road ecology, many of its proponents say, is a win-win: Building dedicated wildlife crossings, for example, is relatively cheap compared with other infrastructure projects, and minimizing collisions between drivers and animals preserves lives and lowers insurance premiums.

Science News spoke with Goldfarb about roads and how to minimize their harm. The following conversation has been edited for clarity and brevity. *— Amanda Heidt*

How did you get interested in road ecology? It seems very different from your previous book on beavers (*SN: 8/4/18, p. 28*)?
The origins of this book date back to 2013, when I was on a reporting trip about habitat connectivity. I caught wind of wildlife crossings on Highway 93 in northern Montana, and I ended up taking a tour of them with Marcel Huijser, a wonderful road ecologist at the Western Transportation Institute in Montana.

The most powerful moment of that tour was when we moved to the one big wildlife overpass on Highway 93. The sun was going down on this beautiful October evening, and it was just incredibly inspiring to be on top of this piece of infrastructure that humans had built for wild animals. We do so much on this planet to make animals' lives more difficult, and as a conservation journalist, it felt like a form of ecological empathy manifested as a science.

You dedicate a lot of the book to small animals like reptiles, amphibians, insects and fish. Is that where the science led you?
It's where the field of road ecology is going in a lot of ways. A lot of the early history is focused on deer because that's what safety-oriented engineers worry about. But as the field has evolved [to become more focused on conservation than human safety], it's gotten more concerned with less charismatic, less dangerous organisms. They are important to think of because in some ways they're the taxa most harmed by roads.

How has this book changed your perceptions of roads?
One of the biggest takeaways is just how deleterious road noise pollution is. When you read the literature about the health effects and the ecological effects of road noise, you realize that it's truly one of the great unsung public health crises of our time. It's elevating our cortisol levels, raising our blood pressure, and making us more susceptible to cardiac disease and stroke.

You make a lot of comparisons between roads and climate change and the actions that are needed to address them.
The climate movement has evolved a lot over the last decade away from individual blaming and towards indicting larger corporate power structures. The same holds true in the world of road ecology. Most of us have had the experience of hitting wild animals. I've killed animals, unfortunately, and I always feel incredibly guilty about it and complicit in this car culture. But car culture is the product of this very intensive marketing campaign that the whole automotive industrial complex has waged.

Instead of blaming drivers for roadkill, the real answers are these larger systemic solutions. Maybe that's modifying infrastructure to build more wildlife crossings to make highways permeable; maybe it means improved mass transit systems.

You end the book talking about how roads have been leveraged as a tool of oppression against Black and brown communities. Why was it important to include that aspect?
The parallels between the ways that roads impact ecological communities and the ways they impact human communities are striking. Highways are forces of division in both ecosystems and cities, and we humans fall victim to cars, just as wild animals do. But I also wanted to recognize that we're not all harmed equally — roads, especially urban freeways, have been very deliberately weaponized against communities of color throughout the last century. And that's still happening today.

You quote an early U.S. Forest Service employee as saying "roads are such final and irretrievable facts," yet the book argues that roads can be made into "visitors" in a landscape.
We have the capacity to change them. The Forest Service, one of the world's largest road managers, is decommissioning thousands of roads, recognizing that they still have harmful ecological effects. On the other end of the spectrum, you have places like Syracuse, where an urban freeway was punched through the middle of the city, deliberately wiping out a Black neighborhood. This old viaduct will be torn down in recognition of the disproportionate harms that it inflicted on people of color.

It's remarkable to think that everything from tiny dirt roads to this enormous urban freeway are being unmade. Our roads aren't necessarily fatal, permanent mistakes after all. ■

JULY 1, 2023

Diagnosing depression

Traditional screening tools for depression focus on internalizing symptoms, including feelings of hopelessness and sadness. Such surveys may miss depression in boys and men, which more often manifests externally as anger and aggression, irritability and risk-taking, ***Sujata Gupta*** *reported in "The boys are not OK"* (SN: 7/1/23, p. 18)*.*

The Male Depression Risk Scale screens for these and other signs of depression, **Gupta** reported. In a 2020 study, 11 percent of 1,000 Canadian men met the depression criteria on this scale but not on more traditional scales. Reader **Tom Harrison** asked if standard scales could also miss depression in girls and women.

In short, yes, **Gupta** says. "When the Male Depression Risk Scale was developed, researchers included male and female participants. That revealed that some women also reported high irritability and anger, two emotions associated with externalizing behavior, though at a lower rate than men," she says.

Irritability is also a feature of depression among children and adolescents, regardless of gender. That would suggest standard surveys may also miss depression in some subset of girls, **Gupta** says.

Remarkable ants

In Tunisia's flat salt pans, desert ants create towering anthills to help foragers find their way home, ***Soumya Sagar*** *reported in "These desert ants head for the hills"* (SN: 7/1/23, p. 16)*.*

Reader **Jim Schrempp** is fascinated by ants. "Years back, I traced the extent of an ant 'highway' in the street near my home. Each evening, this trail of ants would disappear, only to reappear the next day. I found that they were traveling about a quarter mile between two nests," **Schrempp** wrote. "From their low perspective, the ants must have explored what they think is a gigantic area. It led me to realize that an ant trail on the other side of our village could actually be populated with ants from my street!"

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A mouse's nerves glow with exquisite detail

Dead, see-through mice are nothing new to science. But imaging their insides can be expensive, slow and imprecise. Now, the inner architecture of mice shines in a new light, thanks to a method that makes whole-body imaging cheaper and faster.

Chemically removing cholesterol — a key component of cell membranes — from dead mice creates spongelike holes in tissues without destroying them, researchers report July 10 in *Nature Biotechnology*. That means injected antibodies tagged with fluorescent molecules can move through the holes to infiltrate every corner of the body and bind to proteins of interest, making anatomical features visible under fluorescent light.

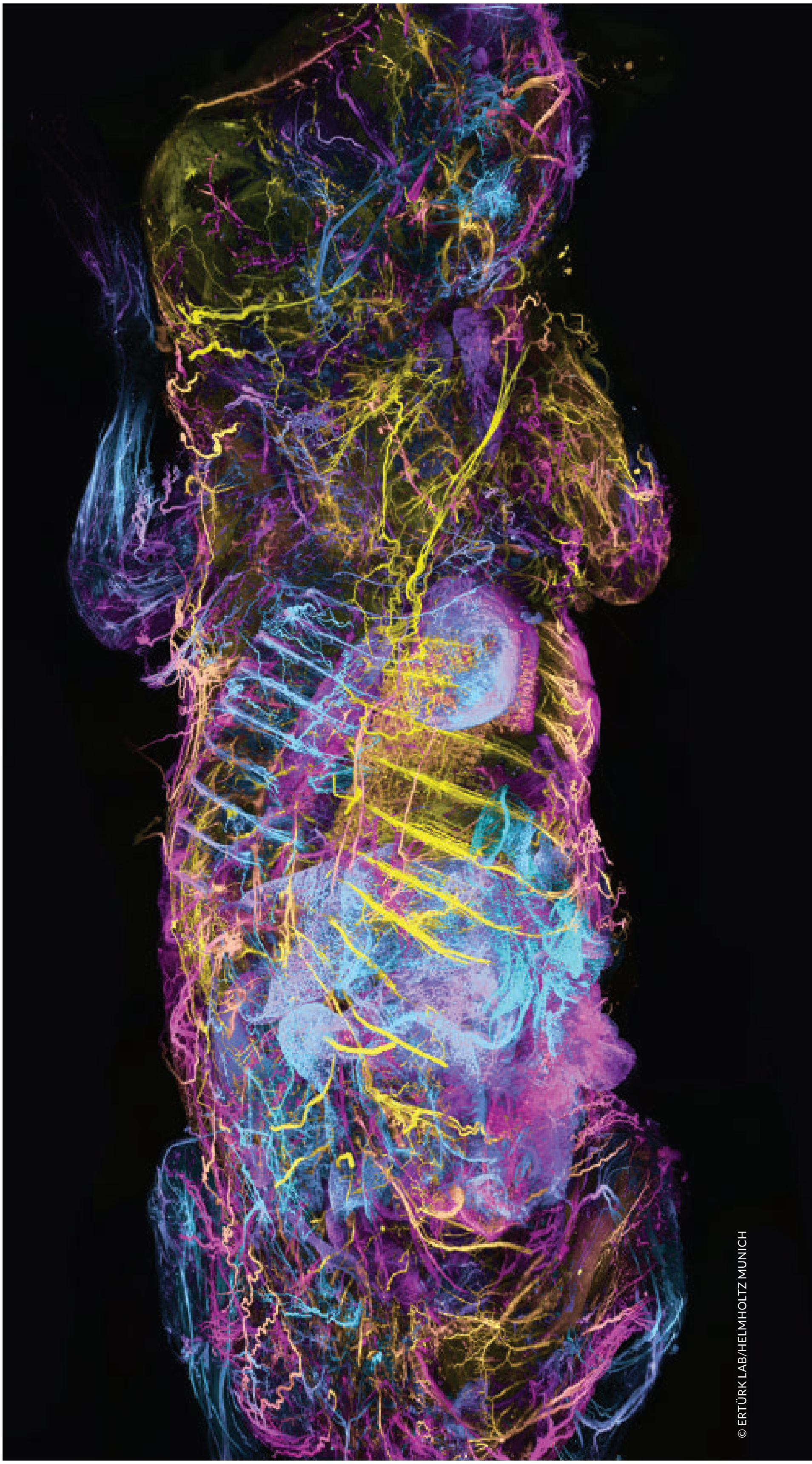
The thorough look under mouse skin helps researchers create bodywide atlases. It's a bit like Google Maps, says Ali Ertürk, a neuroscientist at Helmholtz Munich. But instead of cars recording every street, fluorescent antibodies act as streetlamps to illuminate scientific landmarks.

To make the mice glow, Ertürk and colleagues pumped fluorescent antibodies and cholesterol-dissolving chemicals into dead animals via the heart and blood vessels. After the team used standard techniques to make all the tissues transparent, the mice were ready for their close-ups.

One of the maps depicts the network of nerves in a mouse (right, on its back with its head at the top). Colors show how deep nerve cells are in the animal, from blue (closest to the camera) to pink to yellow (farthest away). Using this technique, Ertürk and colleagues found that mice raised to have no microbes in them at all have underdeveloped nerve networks in their guts compared with normal mice, suggesting the gut microbiome helps nerves develop.

Similar maps of other body networks might help researchers develop computer programs to simulate biological processes in mice and eventually other animals. The programs could, for example, show how a drug travels through blood vessels. Such simulations, Ertürk says, may help scientists move away from doing animal experiments.

— *Erin Garcia de Jesús*



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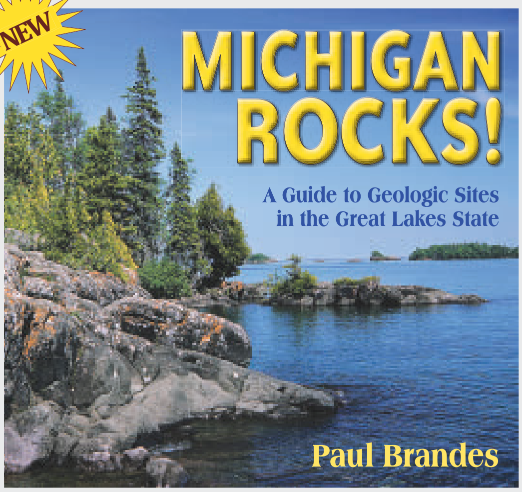

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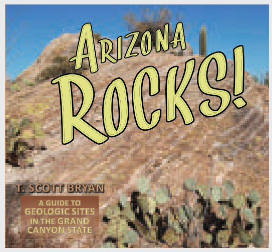

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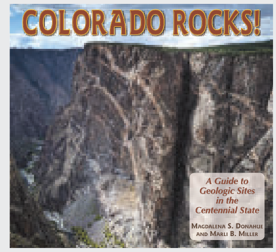

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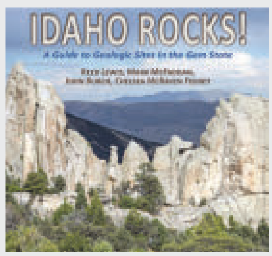

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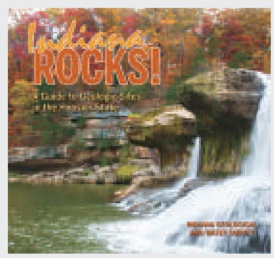

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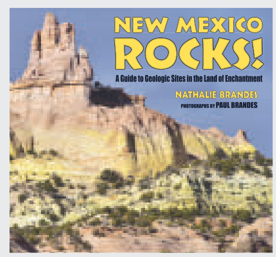

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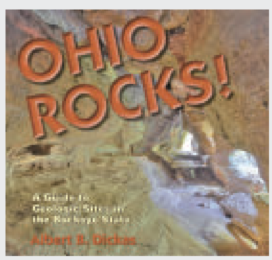

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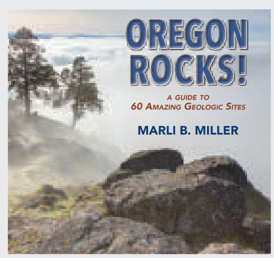

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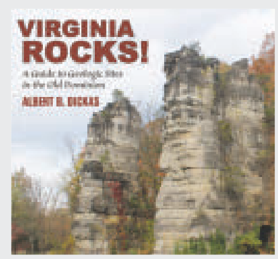

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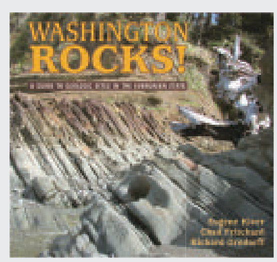

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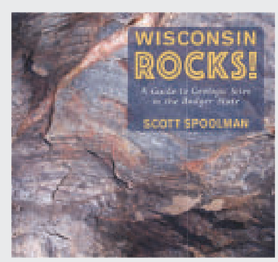

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