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The Power of Viking Women

What new archaeological discoveries reveal

INSIDE

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OCTOBER 2022

VOLUME 327, NUMBER 4

SCIENTIFIC AMERICAN

ON THE COVER

A Viking woman weaves traditional cloth. Studies of textile remains from archaeological sites have revealed that women in Viking and other North Atlantic societies wielded considerable influence as a result of their weaving work. The fabric was used for clothing and other items but also became a form of currency. **Illustration by Chase Stone.**

Photograph by Alastair Philip Wiper

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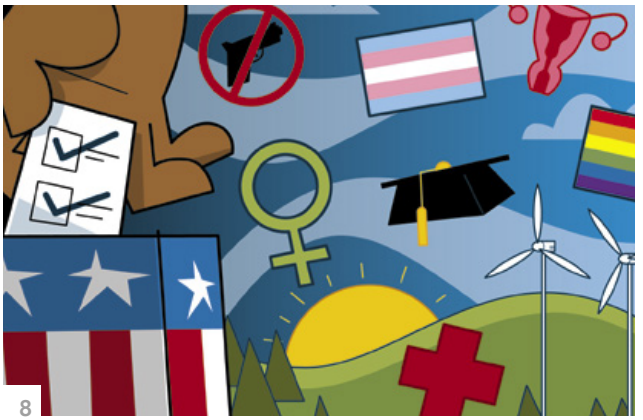
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Laura Helmuth is editor in chief of *Scientific American*.
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Do you have a favorite place to go where you can see the Milky Way? I can't see it from my house, but if I trespass on a nearby public golf course (shh), I can get a good look at our galaxy, as well as any comets that are just visible to the naked eye. Have you ever looked at Saturn or Jupiter through binoculars and seen their moons? You can see them if you keep your hands steady enough and if—if, if, if—the sky is dark enough.

We've made a lot of progress in the U.S. and much of the world in reducing smog and water pollution. Environmental regulations have brought back the bald eagle and are slowly healing the ozone hole. When we understand a problem and work together, we can solve it. And now it's time to solve light pollution.

Astronomers raised the alarm about light pollution—they, like anybody looking up through wobbly binoculars, need dark skies to get a good look at the rest of the universe. Biologists have discovered that light disrupts wildlife in profound ways. Excess light is a waste of energy, and light pollution might harm human health. As science writer Joshua Sokol describes on page 46, smart, science-based policies and better lighting technology can reduce wasted light and let all of us enjoy the sparkling night sky.

Archaeology is having a reckoning, realizing that many of the stories the field has spun out of cultural remains have missed half of past cultures. Research on Vikings has focused on conquest and sailing and tools and wars, which are all fascinating, but only recently have researchers sought to understand work dominated by women in Iceland and Greenland. In this month's cover story starting on page 28, journalist Francine Russo shows how the women's expertise in creating textiles boosted the North Atlantic economy during Viking and medieval times—they literally made the money.

Recognizing patterns is one of the things that humans can generally still do better than algorithms. Mathematician Kelsey Houston-Edwards details on page 36 how algorithms based on topology, or "squishy math," can help identify patterns in all kinds of data, including doughnuts (well, torus-shaped maps) in the brain.

For more reassurance that artificial intelligence is not going to replace human intelligence, at least not yet, author Gary Marcus on page 42 deflates the hype bubble around impressive new AIs. These algorithms seem to know what they're talking about, until you ask the right questions.

The term "gaslighting" comes from a play from the 1930s that was made into a film starring Ingrid Bergman. It has become widespread lately to depict a type of psychological abuse that makes victims doubt their own grasp of reality. On page 56 sociologist Paige L. Sweet shares her research into the social structures and relationship patterns that give gaslighting its often devastating power.

Photographer Alastair Philip Wiper on page 62 takes us inside one of the most advanced fusion research sites: the U.S. National Ignition Facility in Livermore, Calif. As journalist Adam Mann explains, this is where scientists conduct experiments to gauge the status of the nuclear stockpile. It's a chilling reminder that we still have more than enough nuclear weapons to destroy the world and that this would be a good time to resume negotiations for nuclear arms control. SA

Illustration by Nick Higgins

June 2022

"If cognitive neuroscientists spoke more often to their colleagues in philosophy departments, would this breakthrough about how cognition works have happened sooner?"

ZACH SHARP *AUSTIN, TEX.*

MIND AND PERCEPTION

"Constructing the World from Inside Out," by neuroscientist György Buzsáki, is a fascinating and slightly troubling read. What the author explains exceptionally well for a nonscientist reader such as me is how various "outside-in" models of cognition fail in their basic methodological approach: these models have long assumed that the brain must work like a computer, with something akin to a central processor handling the duty of arranging sense data into coherent perceptions. As Buzsáki points out, this entails something like a "homunculus," a separate experiencer sitting in a mental theater and taking in what the brain "shows" it. As his research demonstrates, this approach is an outdated, overly simplistic and now, it seems, experimentally disproved argument about how cognition works. A better model would be one that shows cognition to arise from "inside out," as he says, from the interplay of neurons and action, which in turn means that perception is always bound up with action and is therefore always embodied perception.

What the article fails to mention is that this is not a new idea. There has been long-standing criticism in the philosophy of mind of the very argument Buzsáki attacks: computationalism, the idea that a centralized cognitive "processor" exists in the mind. His conclusions' similarity to philosophical arguments against computationalism is striking. For example, philosopher Hubert Dreyfus's thesis in his 1972 book *What Computers Can't Do* was that cognition cannot be codified in the symbolic language of computers. And he took computationalism to task for assuming that cognition can even occur absent the "background" of lived human experience, the very interplay of neurons and action Buzsáki describes.

The absence of even a brief mention of such debates is yet another symptom of the breakdown of discourse between science and the humanities. While not wishing to diminish the importance of the author's work, I can't help but wonder: If cognitive neuroscientists spoke more often to their colleagues in philosophy departments and if those philosophy departments were more inviting and less insular, would this breakthrough have happened sooner?

ZACH SHARP *Austin, Tex.*

Buzsáki's article reminds me of my dad reproaching me and my siblings by saying, "You look with your eyes, not your hands." I think little kids are compelled to check things out physically by picking them up and feeling and testing them.

JOHN DITRAGLIA *Portsmouth, Ohio*

FIGHTING COVID ON A GLOBAL SCALE

Steven W. Thrasher's piece on how "One Million Dead from COVID Is Not Normal" [Forum] has a major global corollary. The acceptance of the scale of deaths as normal in the U.S. facilitates a view that nothing further needs to be done to fight COVID in the Global South. This global normalization sets aside the science that the virus that causes COVID can mutate anywhere in the world. As I have argued in the report *The Three COVID Crises and Multistakeholderism*, domestic acceptance of high national deaths and of vaccine and antiviral hoarding creates conditions, if not legitimation, for what can best be described as a "silent COVID war" between the Global North and South.

The corollary is that a stand-back-and-take-no-action approach by the North—in the face of well-documented scientific research showing that responding to COVID requires a global campaign—means that the normalization of COVID deaths in the North and the acceptance of a silent COVID war in the South are two sides of the same unhealthy coin. In this sense, the silent COVID war and its devastating impact on the Global South join other silent wars, such as those on climate and hunger, where there is a strong domestic Northern denialism and clear scientific evidence that illnesses and deaths will occur unless there is a coordinated global response.

HARRIS GLECKMAN
Senior fellow, Center for Governance and Sustainability, University of Massachusetts Boston, and research affiliate, Transnational Institute, Amsterdam

PLANETARY GENDER ALIGNMENT

Thank you to Spencer Greenberg and Holly Muir for "Men Aren't from Mars, nor Are Women from Venus" [Mind Matters]. Ever since its publication, I have objected to *Men Are from Mars, Women Are from Venus* and the frequent references to it in movies, television and other media. Ignoring the vast variations in individual personalities, which Greenberg and Muir acknowledge in their discussion, the book generalizes some differences between some men and women—perhaps the types who would read dating guides to begin with—and exploits those differences without recognizing basic commonalities between the two genders. Men and women are two parts of the human whole, and humans are from Earth!

CHARLES WEST *Salem, Va.*

CALLING ALL EXTRATERRESTRIALS

Scientific American is interesting to read because it occasionally brings out disagreements in the scientific community. For example, in "Long-Distance Call" [Advances], Daniel Oberhaus reports on a team led by Jonathan H. Jiang of the NASA Jet Propulsion Laboratory that designed a new potential message intended for extraterrestrials. Oberhaus says that "Jiang and his colleagues propose aiming the message toward a dense ring of stars near the Milky Way's center that are likely to host promising planets."

On the other hand, the September 2018 article "Alone in the Milky Way," by John Gribbin, points out that "stars are packed more densely toward the center, so there are many supernovae, which produce energetic radiation—x-rays and charged particles known as cosmic rays—that is harmful to planets of nearby stars. The galactic center also is home to a very large black hole, Sagittarius A*, which produces intense outbursts of radiation from time to time." Gribbin also mentions gamma-ray bursts that could sterilize the core of the Milky Way and are more common in the inner regions of galaxies.

Let's hope this conflict will be sorted out before time and money are expended.

Frank Ierardi *Gaithersburg, Md.*

ERRATA

In "Constructing the World from Inside Out," by György Buzsáki, the opening illustration should have been credited to Stefania Infante, not Islenia Milien.

"Skin Cancer around the World," by Clara Moskowitz [Graphic Science], should have said that Earth's elliptical orbit, not its tilt, is what causes the Southern Hemisphere to be closer to the sun during its summer than the north is during its summer. And it should have clarified that there are additional reasons New Zealand has stronger ultraviolet radiation than corresponding latitudes in the Northern Hemisphere.

"Discrimination Is Heartbreaking," by Jyoti Madhusoodanan [Innovations In: Health Equity], incorrectly said that Shivani Patel's work has focused on tribal communities in rural India for the past two decades. Her work focuses on community health issues across the country.

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Vote for Science

This Election Day in the U.S., supporting candidates with science-based policies can create a better future

By the Editors

"Elections have consequences," said President Barack Obama in 2009, as he started to press for policies such as affordable health care against Republican opposition. Recently Republican leaders themselves have begun to echo his phrase as red state legislatures ban abortion, prevent the country from taking actions to combat the climate crisis, permit easier access to firearms, and oppose a vigorous public health response to the pandemic. All of that makes the consequences of this fall's vote exceptionally profound.

What these issues have in common is overwhelming scientific support for pursuing one policy direction over another. They share something else, too: a choice between candidates who either follow that scientific evidence or act as if it does not exist. On your Election Day ballot you'll see local and federal candidates who endorse policies based on tested scientific evidence and others who take positions based on unsupported assumptions and biases. The scientific method has brought us vaccines, the Internet, cleaner air and water, and entire new sectors of the economy. Office seekers who use research-based evidence to inform decisions are the ones who will help our country prosper. Those who reject this evidence will increase suffering. The following survey of urgent policy issues highlights the differences:

Reproductive and gender rights. When the Supreme Court overturned *Roe v. Wade* and allowed any state to ban or restrict abortion rights, it let those states force people to undergo the risk of pregnancy against their will. About 50 scientific papers have compared women who received an abortion when they wanted one with women who were turned away. The women denied abortion, followed for several years, had worse physical and mental health. They were also more likely to live below the federal poverty level and be unemployed. Pregnancy itself is far more dangerous than abortion. The U.S. already has a startlingly high rate of maternal mortality, and one study estimates that a national ban would drive up those deaths by 21 percent. Office seekers who support abortion bans ignore such evidence; instead many favor narrow religious doctrine.

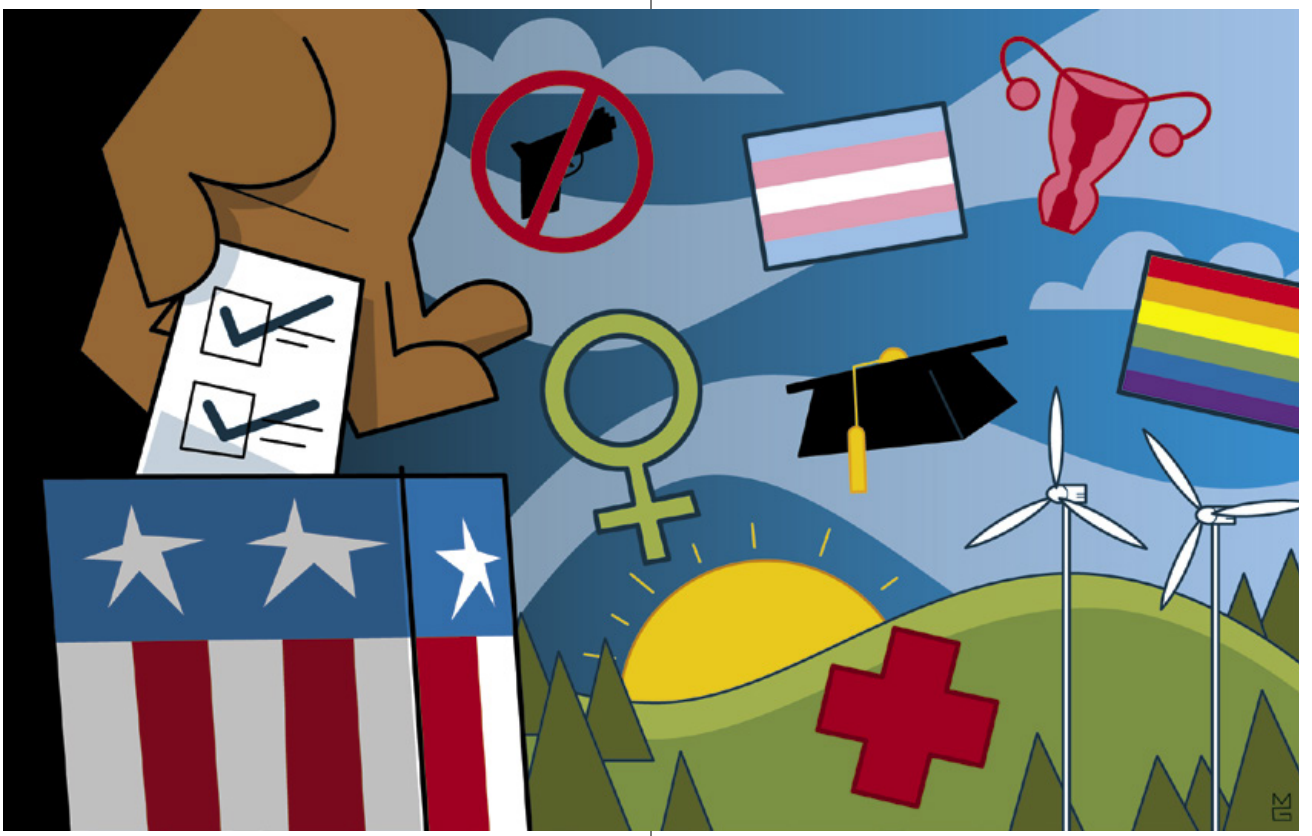
Politicians who oppose gender-affirming health care are just as blinkered. Alabama enacted a law criminalizing such care for transgender youth while Texas directed state officials to investigate such care as child abuse. Florida wants the treatments withheld. These positions ignore the lifesaving effects of these treatments. A 2020 study in the journal *Pediatrics* looked at teenagers who were denied hormone-blocking treatments that temporarily delay puberty while the youth consider their gender. Those teens went on to have a much greater lifetime risk of suicidal thoughts. The effects of this medication are reversible.

Health and the pandemic. This summer Congress passed a budget bill with several key health-care provisions. One was to give Medicare the power to negotiate wildly escalating drug prices with pharmaceutical manufacturers. More than 47 percent of new drugs released in 2020–2021 cost more than $150,000 a year, according to a study in the journal *JAMA;* only 9 percent of new drugs topped that dollar figure as recently as 2013. The bill will put more lifesaving medications in the hands of more Americans, yet Senate Republicans opposed it. They eliminated a specific provision to cap the cost of insulin at $35 per month for people with private insurance. Right now in the U.S., a single dose can cost more than $300, forcing many of the several million Americans with type 1 diabetes to skip doses. And the evidence is clear that affordable health care saves lives. One study showed that states that expanded eligibility for Medicaid, a low-cost health program, saved thousands of people from premature deaths. States that voted against such expansion went in the opposite direction, and people lost years of life.

The U.S. pandemic response has been filled with missteps on all sides. But many conservative Republican-led jurisdictions have been exceptionally hostile to basic public health measures. Despite the large number of studies showing masks reduce transmission of the SARS-CoV-2 virus (the N95 style is the most effective version), these places resisted mask mandates, even as the U.S. climbed to a nationwide toll of more than one million deaths from COVID. Several Republican-led state legislatures introduced laws that took power away from local public health agencies and gave it to state politicians. And officials in Florida, urged on by Governor Ron DeSantis, refused to recommend COVID vaccines for any children or teens. At that time, 1,200 children nationwide had been killed by the virus, and a study had shown vaccines were 94 percent effective at keeping kids aged 12 through 18 out of the hospital. None of the clinical trials of vaccines in children found serious adverse health events.

Gun safety. In the U.S., we are dying from a plague of gunfire: 45,000 people are killed by firearms every year; the most recent numbers show more children and young adults were killed by guns than by cars. While the pace of mass shootings in 2022—at least one incident a day where at least four people were killed or injured—grabs headlines, most of the thousands of victims are shot one or two at a time. The death toll disproportionately hits people of color. Just more than half of the dead are Black men. And deaths do not capture the entire grim story. Approximately 85,000 people were wounded by gunfire in 2017, the most recent year for which these data are available; many of them have pain and disability for the rest of their lives. Still, many politicians, supported by pro-gun lobby groups, want to relax permit rules and make these weapons of mass destruction easier to get.

One false claim repeatedly made by these officials is that more armed good guys will stop more armed bad guys. Senator Ted Cruz of Texas used this disproven refrain after the school



massacre in Uvalde, where in fact many armed good guys (the police) did not stop one bad guy. More to the point, research carried out by investigators at Texas State University using FBI data showed that an armed bystander shot the attacker only 22 times out of 433 active shooter incidents. Even when a "good guy" has a weapon, the carnage is already done. For instance, in a Sutherland Springs, Tex., church shooting, an armed neighbor fired at the assailant but only after 25 people had been killed, including a pregnant woman, and 22 wounded.

When guns are in a home, not out on the street, the research clearly shows that more firearms mean more death and crime. A 2003 study looked at levels of gun ownership among murder and suicide victims. Among gun owners, the odds of becoming a murder victim were 41 percent higher when compared with people who did not keep guns in the house. The odds for dying by suicide were 244 percent higher. That last tragic number is important: of those 45,000 annual firearm-related deaths, nearly 25,000 are suicides.

There are ways to improve gun safety and save innocent lives. These approaches have been studied and demonstrated, and candidates who support them deserve votes. Safe firearm-storage laws should be passed and enforced, for instance. Stricter regulation of gun dealers is an effective measure, as are universal background checks, mandatory licensing requirements, red flag laws, and bans on assault-style weapons and magazines that hold enormous amounts of bullets.

Climate. After being chopped down from trillions to billions of dollars in spending, the Biden administration's climate bill passed, and it does have some significant wins. Chief among them: support for solar panels and wind turbines and funds for clean energy projects in poor communities. But on the state level, some Republican-dominated legislatures are throwing up obstacles to cuts in fossil-fuel use. These reductions, according to scientific consensus, are needed to stop the temperature rise that's driving catastrophic storms, droughts, floods and wildfires in the U.S. Yet West Virginia's attorney general announced plans to sue the federal government if it rules that publicly traded companies have to reveal their levels of greenhouse gas emissions. Several Republican state lawmakers have introduced bills to punish companies if they divest from fossil fuels. And Texas passed a law prohibiting new construction that avoids natural gas as a fuel source.

There are other crucial issues that divide candidates, such as backing state bills that prevent schools from teaching about racism and sexism in American history. Promises to reduce inflation will also get a lot of attention. Take a hard look at these office seekers and their attitudes about policies based on scientific evidence. And then, we urge you, vote for science. SA

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Illustration by Martin Gee

Cities Build Better Biologists

Urban environments naturally train keen observers who are the future of ecology

By Nyeema C. Harris

We often ask humanity to reflect on nature's benefits and on what we can do to promote environmental sustainability. These are noble asks in light of our climate emergency, but reflection is not enough. We need action on multiple fronts.

Urban settings, far from being ecological wastelands, are rife with biological activity. Cities have been described as essential to climate change solutions, but they can also raise the kinds of ecologists that will bring us into a more inclusive biological future.

I am a Black wildlife biologist from Philadelphia. My presence in ecology has challenged assumptions about not only what a biologist looks like but also where a biologist comes from. Throughout the world there are city dwellers like me who have diverse, broad-based skill sets with the potential to make them better biologists.

As an applied ecologist, I travel the world studying the behaviors and interactions of carnivores for their conservation—literally lions, tigers and bears. I bathe in rivers, sleep in tents, poop in holes, get charged at by elephants, jump from helicopters and hike many kilometers a day. The training ground I now provide for young scientists is a far cry from the one I was thrust into when I decided to pursue ecology.

In the U.S., ecology was and is predominantly white and conducted in rural landscapes. I stood out among my peers for not having a history of camping, fishing, hunting or hiking. I had yet to recognize that Philly, with its four seasons and abundance of squirrels, row homes and festivals, was actually my first ecological classroom. There I witnessed feral cats eating birds and rats, people shooing bats from their homes and snakes being killed by lawn mowers. This is as much ecology in action as anything we witness in fields and forests.

City dwellers see the world through a different lens. Our perspective on what a neighbor is gets shaped by the fact that we share space in ways not found in the traditional dichotomy of "natural versus constructed." Urban wild animals exhibit myriad features and behaviors that set them apart from their rural counterparts: they may be bigger, eat more diverse food sources, are active at different times of the day, move differently and have different personalities. Some biologists argue they are even "smarter."

Urban wildlife balances more risks—such as exposure to roads, chemical toxins and diseases from domestic animals—with rewards. Some of those rewards come from humans providing food and from the distribution of our parks and water bodies. Others, particularly for carnivores, are natural resources such as rodents. This dynamic, coupled landscape where nature meets people can also dramatically influence human societies.

Our interactions with nature are ubiquitous. Urbanites' intuition is sharpened by risks—we know a sketchy street, and we lock our doors. Our ability to assess threats and our awareness regarding safety influence our behaviors and choices, much as they do for urban wildlife. This interplay affords us an understanding through proximity.

In our professional lives as biologists, our exposure to diverse communities in cities initiates cultural sensitivities that help to promote inclusivity. When you experience the scarcity and rationing of resources in a crowded city, you understand resource allocation at a deeply personal level. We bear witness to evolution and the wealth of nature's innovation through flowers budding through concrete and birds of prey eating carrion on highways.

Such heterogeneity in cities plants unconscious seeds of appreciation for diversity, tolerance and empathy that can benefit the natural world. The framing of urban areas as degraded, depauperate and deficient leads people to undervalue their inhabitants—wildlife and humans alike. By training more biologists from urban settings, we are creating an agenda that has broader societal relevance. Most of the world's population now accesses green and blue spaces, as well as wildlife, within urban neighborhoods. Nature is no longer only pristine wilderness; it includes sounds of human laughter, trash trucks and sirens.

We urbanites are gritty, resourceful and imaginative. We need more capacity, more participation, more energy and more innovation in science to create solutions to combat environmental degradation and halt biodiversity loss. Identifying this talent across cities presents an easy remedy. SA

Nyeema C. Harris is director of the Applied Wildlife Ecology Lab, an associate professor in the School of the Environment and a Public Voices fellow in the OpEd Project at Yale University.

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Illustration by Erick M. Ramos

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Celebrating the 100th Anniversary with Legal-Tender Morgans

Honoring the 100th anniversary of the last year they were minted, the U.S. Mint struck five different versions of the Morgan in 2021, paying tribute to each of the mints that struck the coin. The coins here honor the historic New Orleans Mint, a U.S. Mint branch from 1838–1861 and again from 1879–1909. These coins, featuring an "O" privy mark, a small differentiating mark, were struck in Philadelphia since the New Orleans Mint no longer exists. These beautiful coins are different than the originals because they're struck in 99.9% fine silver instead of 90% silver/10% copper, and they were struck using modern technology, serving to enhance the details of the iconic design.

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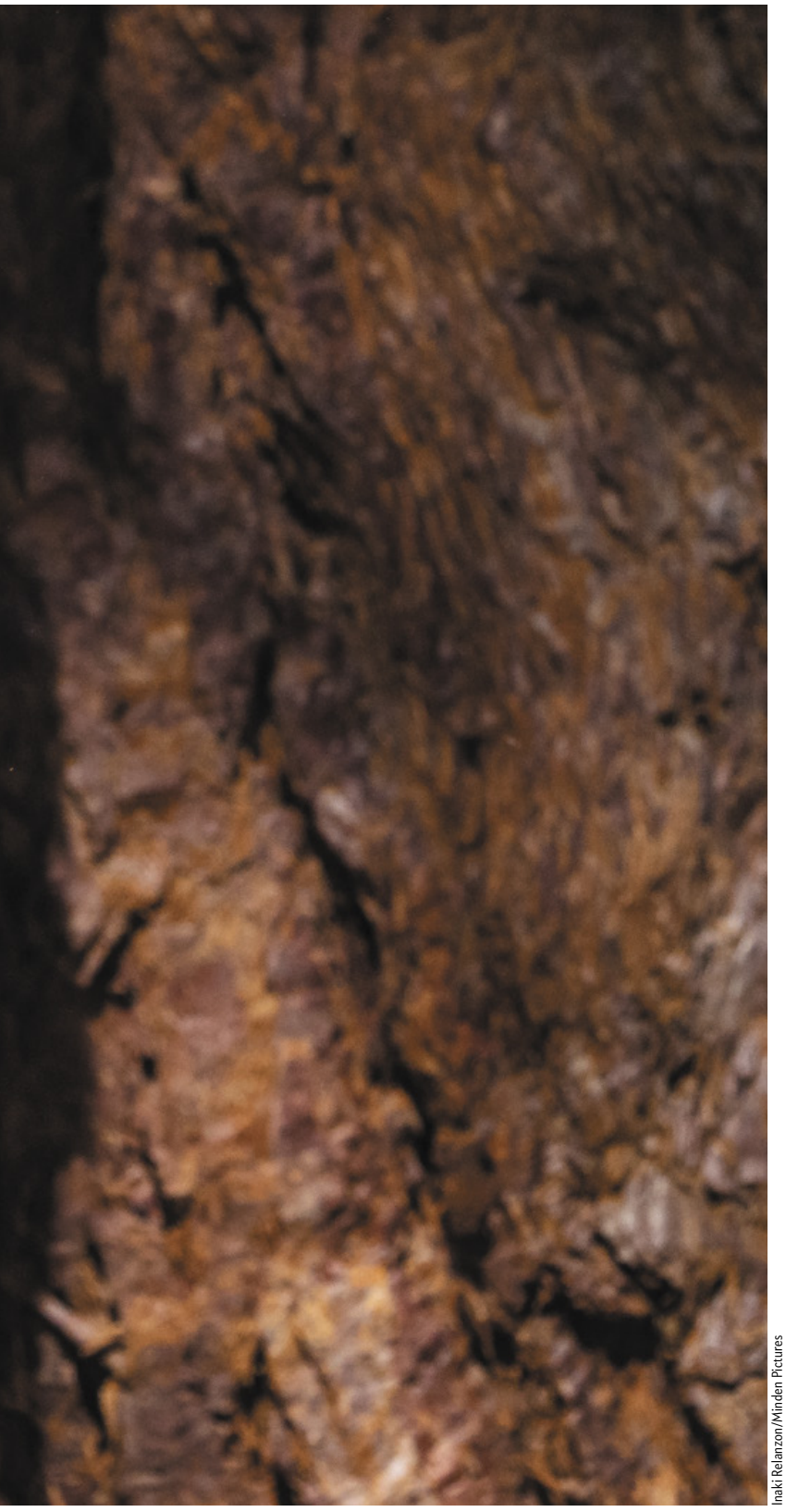
ADVANCES

High-speed video suggests woodpeckers' heads do not cushion their brains from impact.



Inaki Relanzon/Minden Pictures

INSIDE

BIOMECHANICS

Hard Knocks

Woodpecker heads don't absorb shocks—but some crustaceans do

Woodpeckers spend all day hammering their heads on trees, using their beaks to make holes and extracting insects from those holes for a meal. The birds' distinctive drumming and drilling had led researchers to hypothesize that the bone between woodpeckers' beak and brain must absorb shocks to protect them from concussions. But a new study suggests that the head and beak act like a stiff hammer for optimal pecking performance rather than a shock-absorbing system to cushion the brain.

"What this bird has to do during the entire day is dig holes into the wood. It's very important that this business be very efficient," says Sam Van Wassenbergh, an evolutionary biomechanicist at the University of Antwerp in Belgium, who led the new study. If the woodpecker absorbs some of the energy it directs at the tree, then less of that energy is imparted to the trunk, and the bird has to peck even harder to make holes. "So the more you think about it, the less it made sense that there was any shock absorption going on," Van Wassenbergh adds. "But it had to be tested."

In the new study, published in *Current Biology*, the researchers analyzed video of three woodpecker species to track the motion of different parts of their heads on impact with the wood. Rather than seeing the braincase decelerating more slowly than the beak, which could indicate cushioning, they saw the head function like a hammer with little to no dampening of vibrations.

Previous work in the 1970s had considered the bonehead question theoretically, but this study is the first to capture high-speed video to determine how much force is loaded onto the woodpecker's bill and separately onto its brain, says neurobiologist Daniel Tobiansky, who studies woodpeckers at St. Mary's College of Maryland and was not involved in the study.

So how do woodpeckers avoid concussions? The researchers used simulations to calculate the impact on the birds' brains and compared it with thresholds for concussion-causing forces in humans. Because the brains of woodpeckers are much smaller than those of humans, Van Wassenbergh says, they experience much less pres-

sure on sudden impact than human brains do. Based on the models, the forces that woodpeckers' brains sustain are below the danger threshold by a factor of two. So "they could hit the tree at higher speeds and still not suffer a concussion," he says.

But Tobiansky notes that among brain-injured football players, chronic traumatic encephalopathy is most commonly found in offensive linemen who receive repeated, subconcussive shocks. Even impacts that don't cause concussion can harm the brain, so woodpeckers may still need some kind of physiological protection. Tobiansky and his colleagues' work suggests that steroid hormones such as androgens and estrogens may help defend the birds' brains.

In sum, the woodpecker braincase may not be good inspiration for human helmet design. Enter the bigclaw snapping shrimp, which researchers are finding might provide better insight on that front.

The most distinctive feature of this small coastal shrimp is its snapping claw—a weapon the territorial animal uses to battle invaders and defend its home. The claw operates with a latch mechanism that shoots a plunger through a hole at blistering speed. That process creates a jet of water, which boils into a bubble of air caused by low pressure; the bubble then collapses, creating a snapping sound and a brief burst of light. But the primary product of the snapping claw is a high-amplitude pressure wave. When two shrimp engage in combat, each snaps within a centimeter of its opponent, trying to intimidate the other in a hydraulic game of chicken. These pressure waves can inflict brain damage.

Researchers writing in *Current Biology* recently probed the snapping shrimps' secret to coping with the constant onslaught. The shrimp are equipped with a transparent, gogglelike structure, known as an orbital hood, which covers their eyes and protects their brain from the pressure waves.

"There's been tons of work on the evolution of weapons and relatively little work on 'How do you defend against them?'" says Melissa Hughes, who studies snapping shrimp at the College of Charleston in South Carolina and was not involved in the study. In this case, the question is particularly interesting because the snap can harm the shrimp itself as well as its opponent. "So you need double protection—protection from others coming at you but also from your own use of the weapon," she explains.

The researchers observed that when orbital hoods were surgically removed, shrimp exposed to shock waves became disoriented and lost motor control of their limbs, sometimes permanently—an indicator of brain damage. Intact animals showed normal behaviors. Measuring the pressure inside and outside of the orbital hoods using tiny sensors, the researchers found that on average the hoods cut the shock waves' magnitude in half. "When we have an animal that has their helmet on, it's pretty effective at dampening those shock waves, so we get less energy reaching the brain underneath the hood," says University of Tulsa biologist Alexandra Kingston, the study's lead author.

Further investigation suggested that a shock wave forces water out through the bottom of the orbital hood, thus transferring its energy to water expelled down and away from the animal instead of traveling through its tissues.

Understanding how these tiny helmets work could inspire equipment to protect humans from traumatic brain injuries, including those from shock waves, the researchers say. Woodpeckers and snapping shrimp "seem to risk brain damage all day, every day," says Daniel Speiser, a visual ecologist at the University of South Carolina and senior study author. The physiological and biomechanical tricks used to protect the animals' brains, scientists hope, may inspire new medical or engineering solutions to prevent human brain injuries, too. —*Viviane Callier*

INVASIVE SPECIES

Ceramics Cleaner

Aquatic invader could filter wastewater

"Devilfish" catfish, also called suckermouths, are native to South America but have spread to four other continents. These freshwater invaders outcompete native species and eat their eggs, even damaging fisheries. But in *Scientific Reports*, researchers in Mexico showed the pests could be unexpectedly useful: when ground into a paste, they can help filter ceramics industry wastewater.

The ceramic tile sector alone produces at least 16 billion square meters of product a year. Manufacturing facilities go through large quantities of potable water, and a biological cleaning system like this one could allow reuse instead of letting that water drain away.

Collagen from the fish's connective tissues, when combined with an iron-rich salt, works as a coagulant: the mix destabilizes tiny bits of waste compounds so they amass into bigger globs that can be strained out. The scientists found this process removed 94 percent of solids from industrial ceramics wastewater, and it reduced an indicator of organic materials in the water by 79 percent. The researchers say their fish mix is less toxic than other available coagulants—a toxicity that discourages some manufacturers from filtering ceramic waste at all.

Aman Verma/Getty Images

"Most of the time ceramic waste is left to dry in the sun, and later the mud is disposed of or used as fill material," says environmental scientist Miguel Mauricio Aguilera Flores of the National Polytechnic Institute of Mexico, who led the study. "People mistrust reusing the water in any of their activities because of fears of toxicity arising from currently available chemical coagulants, so at present the water resource is lost."

The mixture is simple to prepare, but Aguilera Flores says getting enough biomass for industrial use might be a limiting factor. Trapping wild devilfish could support modest demand, he says, but to scale up, they might ultimately need to be farmed—carefully.

"Effluent management from any industry is a serious issue, and the ceramic manufacturing industry is no exception," says Eileen De Guire, technical content and communications director at the American Ceramic Society. "Taking advantage of an invasive species seems to be a creative way to use one waste problem to solve another." —*Gary Hartley*

MATERIALS SCIENCE

Mistletoe Sticks Around

The festive parasite makes an intriguing biological glue

Many people today associate mistletoe with holiday kisses. But for centuries the plant was known more for its remarkable stickiness; ancient Greeks and Romans used gooey mistletoe berries for applications ranging from bird traps to skin ulcer ointment. Now biochemists are investigating whether mistletoe's clinginess can provide a natural alternative to synthetic glues.

For the parasitic mistletoe plant, stickiness is essential. Inside each berry are seeds coated in a mucuslike substance called viscin. After a bird gobbles up and digests a berry, it expels globs of seeds in strands of this substance, which drape over tree branches and glue the seeds in place. The mistletoe then embeds itself into the tree, siphoning water and nutrients from its host.

To determine what makes this natural adhesive so tacky, McGill University chemical biologist Matt Harrington and researchers at the Max Planck Institute of Colloids and Interfaces in Potsdam harvested mistletoe plants growing on apple trees in Germany. Using tweezers, they pulled the stringy viscin from the berries for a closer look.

In a study published in *PNAS Nexus*, the team found that viscin's structure sets it apart from other adhesives. Whereas many synthetic glues start as puddles of sticky chemicals, viscin is made of stiff strands of cellulose that help it hold firm. These strands are encased in a humidity-sensitive coating that keeps the substance extremely malleable: Under humid conditions, a viscin thread about a half centimeter long can be stretched to over two meters in length. When it dries, the goo stiffens like cement. "This multifunctional, humidity-responsive nature is what blew my mind," Harrington says.

The researchers found that viscin is strong—it supported weights 50 times heavier than mistletoe seeds—and it is also quite versatile. Viscin is adapted to adhere to bark and feathers, but the team found that it sticks to just about anything, including skin. (Wetting hands covered in viscin doesn't remove the compound, Harrington says, but rubbing them together generates enough warmth and moisture to loosen its grip.)

The scientists say viscin could be used as a biodegradable agent to seal fresh wounds. They tested viscin on cuts made to a piece of pork from a local butcher shop; once the viscin dried, it kept the gashes sealed, even when force was applied.

According to Juliann Aukema, a researcher at the USDA Forest Service who studies mistletoe ecology and was not involved in the study, this alternative to petroleum-based synthetic glues could revitalize the ancient importance of mistletoe. "There's this wealth of mistletoe knowledge that we had and lost," Aukema says. "And we're relearning it now in 2022."

—Jack Tamisiea

Nigel Cattlin/Minden Pictures

BIOLOGY

From Drab to Fab

The hidden splendor of moth wings revealed in a new light

Moths' drab gray and brown coats may not capture our imaginations as much as their colorful butterfly cousins do, but according to a recent study, that's more a failure of human eyesight than of moths themselves.

By photographing the wing scales of 82 moths from 26 different species using a camera that captures an extra wide spectrum of light, researchers viewed the insects in the infrared: wavelengths of light too long for humans to see. In infrared, the buff and beige wings we are used to seeing flutter around outdoor lights take on vibrant, iridescent colors, the researchers reported in the *Journal of the Royal Society Interface*.

Each moth's left half is shown in true color, and the right shows an enhanced view based on infrared wavelengths.

From "Potential for Identification of Wild Night-Flying Moths by Remote Infrared Microscopy," by Meng Li et al., in *Journal of the Royal Society Interface*, Vol. 19, No. 191; June 22, 2022

Beyond exposing moths' beauty, the new data also revealed species-specific structural differences in how the insects' wings reflect and scatter infrared light. The diversity of these infrared features—which come from microscopic scales that cover moth wings—could eventually help scientists identify moth species using lidar (light detection and ranging), a tool that emits and senses infrared light.

Scientists already use radar to count moths in the field. But species details could

MARINE ENVIRONMENT

Pickled History

An ultradense saltwater pool on the ocean floor hides pristine records of past disasters

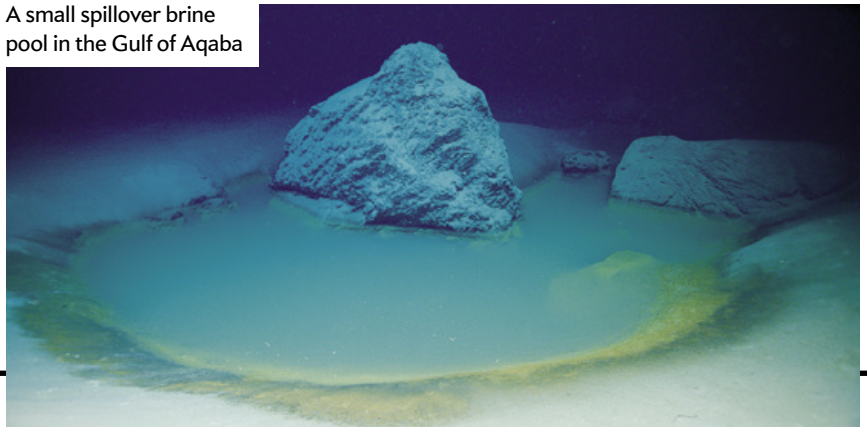
A brine pool is a rare and bizarre anomaly of nature: water so dense with salt that it won't mix with seawater and forms a clearly defined "lake" on the ocean floor, becoming a toxic environment where few organisms survive. Now researchers have discovered a unique brine pool in an arm of the Red Sea that preserves sediments revealing a pristine, 1,000-year history of flash floods, tsunamis and earthquakes.

Brine pools form in places where a sea was cut off from other oceans in the deep past and evaporated, leaving behind subsurface salt deposits. The newly found pool, situated in the Gulf of Aqaba between Saudi Arabia and Egypt, is the closest to shore of any known brine pools in the Red Sea. Because it is just 1.2 miles from land, it has trapped sediments from the coast for centuries—and its salty hostility to life inhibits biological disturbances.

"Any sedimentary layers that are laid down at the bottom of the brine are exquisitely preserved," says University of Miami marine geologist Sam J. Purkis. "Nothing touches them."

Purkis and his colleagues discovered the pool in 2020, using a remotely operated vehicle during a research mission run by the nonprofit OceanX. The briny water looks like an eerie haze, outlined by a rind of salt-loving microorganisms around the pool's perimeter. Despite its inhospitability, shrimp and eels lurk around the pool's edges, darting briefly into the ultrasalty water to snag small creatures that have ventured in and been stunned by the brine.

So far the researchers have drilled 1,200 years' worth of sediments from the floor of the pool. "It's the memory of the experiences of that place," says Beverly Goodman Tchernov, a marine geoscientist at the University



A small spillover brine pool in the Gulf of Aqaba

From "Discovery of the Deep-Sea NEOM Brine Pools in the Gulf of Aqaba, Red Sea," by Sam J. Purkis et al., in *Communications Earth & Environment*, Vol. 3, No. 146; June 27, 2022

help scientists keep track of the creatures' varying nocturnal migrations, which serve as major food sources for birds and other animals.

Radar entomologist Alistair Drake of the University of New South Wales in Australia notes the potential limitations of lidar for moth monitoring. "The thing about lidar is it has a very narrow beam," says Drake, who was not involved in this study. The radar beams used to detect insects can be 60 to 100 feet across, big enough to capture lots of individual organisms flying past, whereas lidar beams span only a few inches—about the size of a single hawk moth. "So we don't really know whether the vertical-pointing lidar beam is going to produce enough insect crossings to be useful."

To test the proposed moth-spotting method, study lead author Meng Li, an optics expert researching tools for remote detection of insects at Lund University in Sweden, and her team are evaluating how well lidar captures the different moths around their study site. "We've been monitoring since April with radar and lidar and a trap," she says. "So if there is a big migration of certain moths, it will appear in all three."

—*Daniel Lingenhöhl* and *Sasha Warren*

of Haifa, who was not an author on the study.

The sediment layers include muddy, silty deposits from roaring rivers called wadis that form in the desert during once-every-quarter-century rains. One layer, dating back about 500 years, may correspond to an underwater landslide that Purkis and his team previously discovered remnants of in the Red Sea.

The team also found coarse sediments likely transported by tsunamis. A relatively recent layer may be related to a 1995 magnitude 7.2 earthquake, which caused 13-foot waves in an Egyptian port town. Examining the sediments suggests that similar tsunamis caused by earthquakes or landslides may occur about every 100 years, the researchers reported in *Communications Earth & Environment*.

The northern coast of the Red Sea has long been sparsely populated, Goodman Tchernov says, but that is changing rapidly. Drawing on his brine pool findings, Purkis has talked with Saudi Arabian officials about the geological risks of building in that region. "The key here," he says, "is awareness and planning."

—*Stephanie Pappas*

Sharon Fisher/Natural History Museum of Los Angeles County

PALEONTOLOGY

Mystery Digit

Walking on all fours helped shape the panda's "thumb"

A bear that roamed what is now China about six million years ago is the oldest bamboo-eating panda ancestor yet found—and it had the same stubby pseudo thumbs that jut from the wrists of today's pandas alongside their five fingers. Fossils of the new species suggest such "thumbs," which helped the animals grip and strip bamboo, maintained their peculiar shape to facilitate the beast's four-legged locomotion.

The fossils, found in the province of Yunnan and described in *Scientific Reports*, also push back the date that pandas' ancestors likely transitioned from eating meat to chomping bamboo—from two million to six million years ago. "Giving up on a carnivorous diet means trading the volatile life of a carnivore for quiet consumption of the plentiful bamboo," says paleontologist and study lead author Xiaoming Wang of the Natural History Museum of Los Angeles, adding that it was "not a bad deal."

Although the fossils dug from the province's Zhaotong Basin included only teeth and some limb bones from the bear, these were distinctive enough for Wang and his colleagues to identify the fossils as belonging to an early member of the panda lineage called *Ailurarctos*. A wrist bone in the collection, with its proto-thumb, stands out among the remains. "Its morphology is really close to that of the living panda," says Juan Abella Pérez of Miquel Crusafont Catalan Institute of Paleontology in Barcelona, who was not involved in the new study.

Why didn't this nubby outcropping eventually evolve into a longer, larger false thumb to better grasp a meal? The researchers propose that treading on all fours was the key constraint: If the panda's thumb were larger, Wang and his colleagues suggest, the appendage could have interfered with walking or faced a high risk of breaking. There was no way for pandas' false thumbs to evolve to be larger or more complex without the bears becoming bipedal or otherwise getting the appendage out of the way. In a sense, this makes the evolution of the panda's thumb all the more impressive. The distinctive structure was constrained by the need to move as well as to eat, an evolutionary compromise rather than an ideal structure for grabbing long sticks of bamboo. —*Riley Black*

ECOLOGY

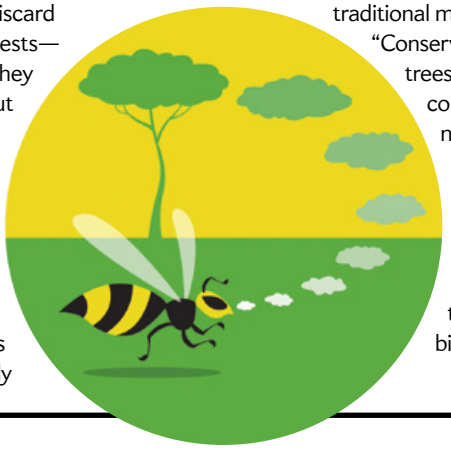
Helpful Hornets

Plants call on predators to rescue their seeds

A hornet senses a chemical distress signal from an agarwood tree and zips over, hoping to devour a customary meal of attacking caterpillars. But when it arrives, there are no caterpillars, and it has to settle for agarwood seeds—which the duped insect carries away, unwittingly helping the tree reproduce. A new study in *Current Biology* says this is the first-known case of a plant deploying such defensive chemicals to spread its seeds.

The agarwood species *Aquilaria sinensis* is native to tropical China. When caterpillars start eating its leaves, the leaves respond with a type of defense found in many plants: they release compounds called herbivore-induced plant volatiles, or HIPVs, to attract hungry predators. "Most plants have these [HIPVs]," says Jessamyn Manson, an ecologist at the University of Virginia, who was not involved with the new research.

In the study, researchers used chemical analyses and field experiments to demonstrate that agarwood fruit can also produce compounds found in HIPVs—even in the absence of a caterpillar assault. This quickly draws various types of hornets, which feed on fleshy, nutrient-rich blobs called elaiosomes attached to the seeds. The hornets tend to discard the seeds near their nests—shaded areas where they can germinate without drying out. In direct sunlight, the seeds die within hours.



The study illuminates an infrequently studied phenomenon. "Rapid seed dispersal is overlooked," says study co-author Gang Wang, an ecologist at Xishuangbanna Tropical Botanical Garden of the Chinese Academy of Sciences. Seed dispersal by hornets is particularly mysterious. Although ants—hornets' relatives—are estimated to spread seeds for more than 11,000 plants, the study notes, documented cases of hornets themselves doing so are rare.

These results have conservation implications, too, for a region where local people eat hornet larvae and use agarwood—which is threatened by habitat loss—for traditional medicine practices. "Conservation of agarwood trees has to link with the conservation of hornets," Wang says. Manson agrees. "We can't just protect a plant and hope for the best," she says. "We need to understand its biological community." —*Darren Incorvaia*

Illustrations by Thomas Fuchs

ENVIRONMENT

Conservation Connections

Mapping the world's animal travel routes

To access new mates and food sources, wild mammals must often venture between protected areas. Conservationists have long advocated designating "wildlife corridors" to make this easier and safer—but the most crucial routes' locations, and whether conditions within them support or hinder these journeys, have been largely unknown until now.

A recent study in *Science* found that more than 65 percent of such passages where movements are most concentrated remain unprotected. Reducing certain human pressures, the study authors note, could be even more effective at boosting connections than adding protected territory between existing refuges.

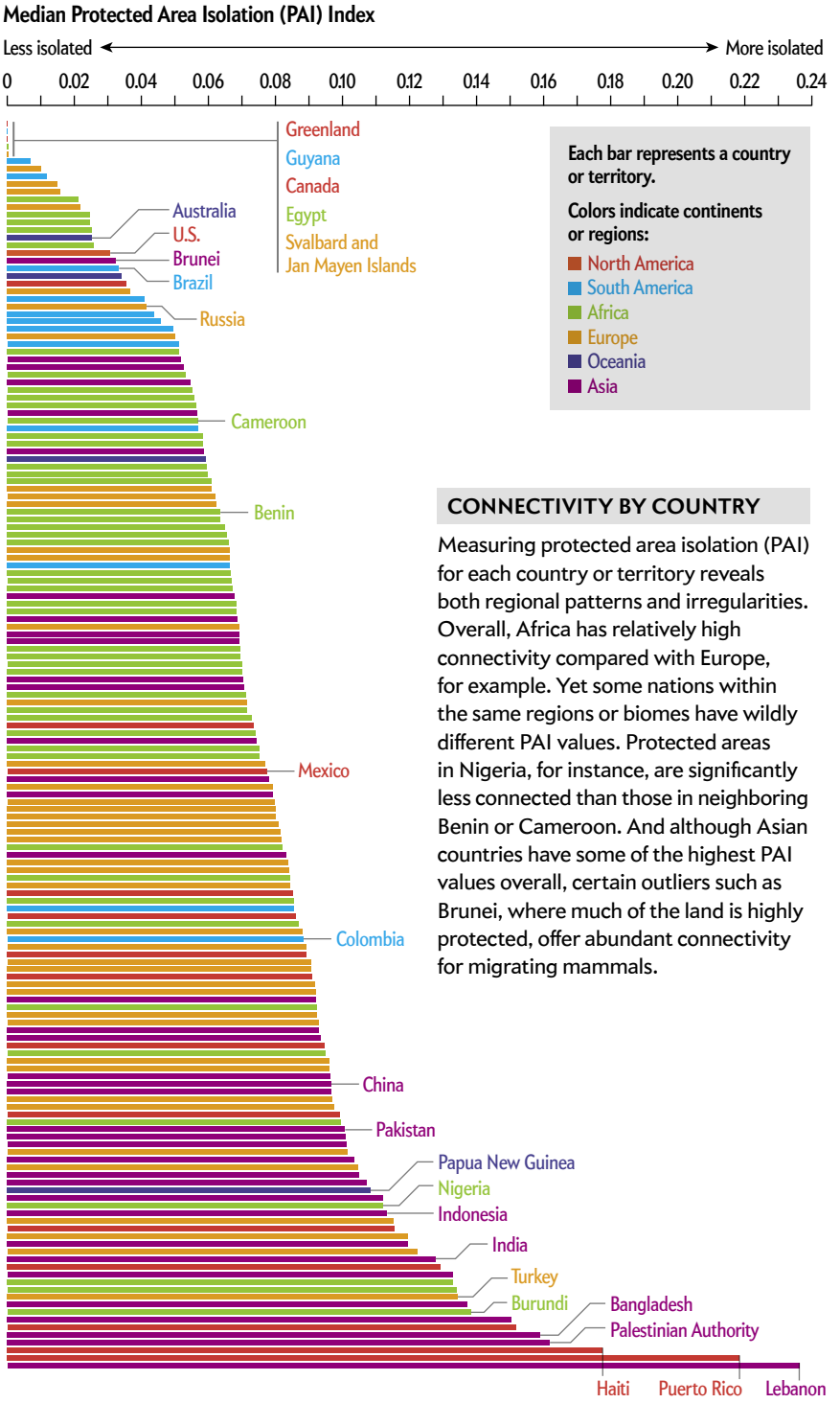
The scientists examined data on the movements of 624 individual mammals from 48 species, from South American jaguars to African giraffes, using a methodology called circuit theory to create a global map of pathways between protected areas. Most previous studies simply evaluated whether these areas were connected at all. The new study also scrutinized conditions along these mammal pathways, including routes through land used by humans for homes, crops, forestry or livestock.

The team then evaluated whether protected areas were well connected to or isolated from others—information land managers could use to safeguard mammals threatened by habitat loss and degradation. "We need to maintain those populations and make sure that protected areas don't become islands in a sea of human land uses," says University of British Columbia conservation scientist Angela Brennan, the study's lead author.

The scientists found that reducing a region's overall human footprint by half, through steps such as minimizing agricultural use and integrating trees and shrubs into livestock areas, could increase connectivity on average by 28 percent. They also found that conserving 50 percent more land would boost connectivity by 12 percent. Together both methods could enhance protected areas' connectivity by 43 percent.

The study uses "real data and strong analytical approaches to help us understand connectivity," says Michigan State University ecologist Nick Haddad, who was not involved in the work. "Just improving the landscapes that are there even if people are on the land, and making them more accessible to animals, can increase the connections between protected areas."

—Susan Cosier



CONNECTIVITY BY COUNTRY

Measuring protected area isolation (PAI) for each country or territory reveals both regional patterns and irregularities. Overall, Africa has relatively high connectivity compared with Europe, for example. Yet some nations within the same regions or biomes have wildly different PAI values. Protected areas in Nigeria, for instance, are significantly less connected than those in neighboring Benin or Cameroon. And although Asian countries have some of the highest PAI values overall, certain outliers such as Brunei, where much of the land is highly protected, offer abundant connectivity for migrating mammals.

Source: "Functional Connectivity of the World's Protected Areas," by Angela Brennan et al., in *Science*, Vol. 376; June 3, 2022 (*data*)

Graphic by Amanda Montañez

ASTRONOMY

Science in Images

By Fionna M. D. Samuels

The first images released from the James Webb Space Telescope (JWST), which launched last December after an arduous construction process, reveal new views of the cosmos in exquisite, never-before-seen detail. There will be a lot to learn from JWST during its mission, from how galaxies evolve to the composition of exoplanet atmospheres.

The data from this telescope have already started going public. Eventually all of its measurements will be available for anyone to use. "Anybody can actually go and explore the universe; we're not keeping any secrets here," says Susan Mullally, deputy project scientist for JWST at the Space Telescope Science Institute in Baltimore. That's the wonderful thing about NASA projects: the data are open access. "Science is a very open process," Mullally says. "It's through a collective knowledge that we reach our understanding of our place in the universe."

This photograph of a stellar nursery about 7,600 light-years away in the Carina Nebula shows massive young stars enrobed in swirling gas and dust. It was taken by JWST's Near-Infrared Camera (NIRCam), which can capture previously hidden features within and behind the occluding material. The youngest stars appear as red pinpricks of light in the cloud. High-energy ultraviolet radiation—the same kind of light that causes sunburns on Earth—and stellar winds from hot newborn stars eroded some of the surrounding material, sculpting what astronomers dub the Cosmic Cliffs. What appears to be white steam rising from the "cliffs" is in fact hot dust and ionized gas streaming away as the ultraviolet radiation interacts with the nebula. This is just a small part of the edge of a bubblelike offshoot of the whole Carina Nebula, which stretches across more than 200 light-years of space. In comparison, this image shows a region only about 16 light-years across.

These first gorgeous pictures and data are just a small piece of what the team running JWST hopes will come out of the mission. "This was just a demonstration," Mullally says, adding that the observatory will release equally huge amounts of data every day. As scientists begin to drink from the JWST firehose, she anticipates a plethora of interesting new information to be discovered about our universe. Some findings will confirm what we already suspect, whereas other discoveries may be paradigm shifting. "Keep your eye out," she says. "This is just the beginning."

To see more, visit ScientificAmerican.com/science-in-images

NASA/ESA/CSA/STScI

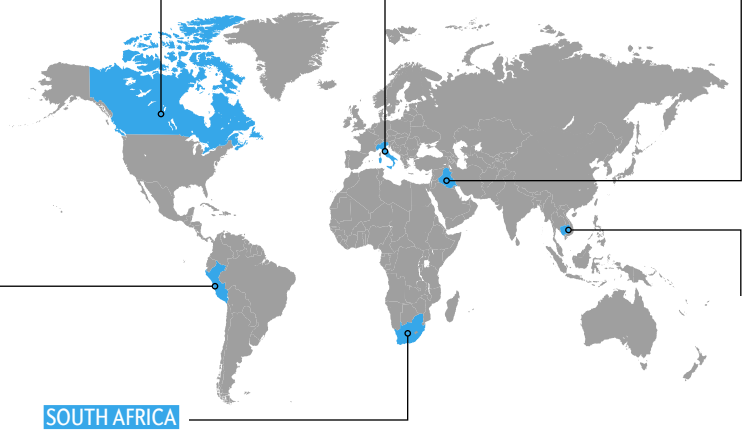
Quick Hits

By Sasha Warren

CANADA
Researchers used key photos from amateur astronomers to help explain a mysterious red glow appearing alongside the Northern Lights. It is likely caused by electrons—a by-product of the protons that trigger the typical green aurora—raining onto Earth's magnetic field.

ITALY
Pollen and plant fragments from wine jars in the San Felice Circeo harbor reveal that ancient Roman winemakers used local grapes but imported pine tar from hundreds of miles away to seal the jars—and maybe to flavor the wine.

PERU
Analysis of 700,000 years of sediment from an Andean lake shows that tropical mountain glaciers in the Southern Hemisphere grow and shrink in sync with ice sheets in the Northern Hemisphere, despite local differences in climate and sunlight. They are shaped by greenhouse gases, Earth's orbit and other global factors.



IRAQ
A 3,400-year-old city re-emerged from the Tigris River during a drought this year. Archaeologists used the dry spell to further explore the ruins, finding well-preserved clay walls, cuneiform tablets and a multistory storage building.

CAMBODIA
A 661-pound endangered giant stingray from the Mekong River may be the largest freshwater fish ever caught. The roughly 13-foot-long behemoth has been fitted with a tracker and transmitter to examine the ray's migration and behavior.

SOUTH AFRICA
A new sediment-dating method, less affected by the scrambling of rock layers over time, has shown that fossils of early prehumans found near Johannesburg are one million years older than previously thought—potentially old enough to add a new branch to the human evolutionary tree.

For more details, visit www.ScientificAmerican.com/oct2022/advances

GENETICS

Elephant-Assisted Oncology

How a key cancer-fighting gene keeps elephants tumor-free

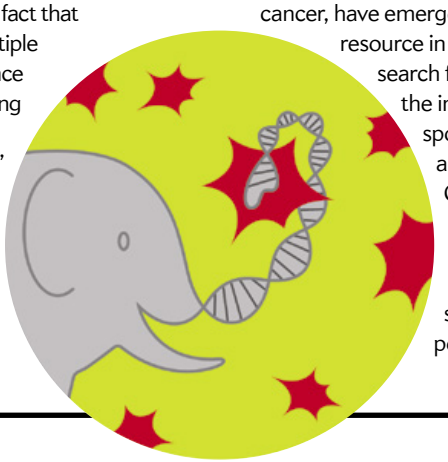
Scientists call it Peto's paradox: cancer is caused by gene mutations that accumulate in cells over time, yet long-lived animals that have lots of cells, such as elephants and whales, hardly ever get it. Why?

For elephants, at least, part of the answer may be the gene commonly known as *p53,* which also helps humans and many other animals repair DNA damaged during replication. Elephants have an astounding 20 copies of this gene. Those copies, each with two variations called alleles, produce a total of 40 proteins, compared with humans' (and most animals') single copy producing two proteins.

New research in *Molecular Biology and Evolution* delves into how elephants' many copies offer cancer-fighting advantages. The work "opens many new possibilities to study how cells protect themselves from a damaged genome, both in elephants and in humans," says study co-author Robin Fåhraeus, a molecular oncologist at France's National Institute of Health and Medical Research.

In mammals, *p53* plays a crucial role in preventing mutated cells from turning into tumors. It works by pausing replication and then either initiating repair or causing cells to self-destruct if the damage is too extensive. Without action from *p53,* cancer can easily take hold: in more than half of all human cancers, the gene's function has been lost through random mutations.

The scientists virtually modeled and examined elephants' 40 p53 proteins, finding two ways the gene could help elephants avoid cancer. First, the fact that elephants possess multiple copies lowers the chance of *p53* no longer working because of mutations. Additionally, elephants' *p53* copies activate in response to varying molecular triggers and so respond to damaged cells differently, which likely gives an edge when detecting and weeding out mutations.



These "remarkable" results imply that elephants have a spectrum of means through which *p53* can operate, says Sue Haupt, a cell biologist at the Peter MacCallum Cancer Center in Australia, who was not involved in the work. This points to "exciting possibilities for exploring powerful new approaches to cancer protection in humans," she adds.

Fåhraeus and his colleagues are now following up on these results using blood samples from an African elephant at the Vienna Zoo. They are exploring how its p53 proteins interact with damaged cells and other key molecules and plan to compare those findings with results from human cells.

"Elephants, with their low incidence of cancer, have emerged as a surprising resource in human cancer research for understanding the intrinsic cellular response to DNA damage," says Fox Chase Cancer Center virologist Virginia Pearson, who was not involved in the study. "This is an important publication."

—Rachel Nuwer

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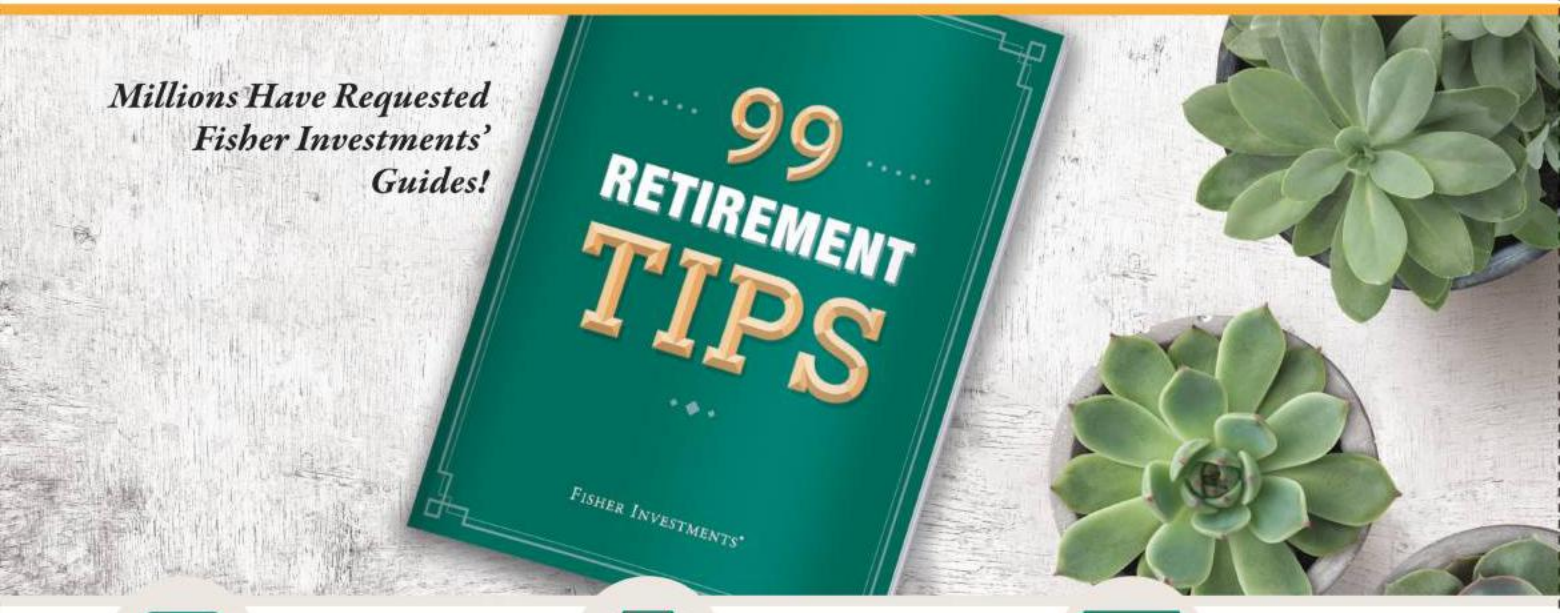

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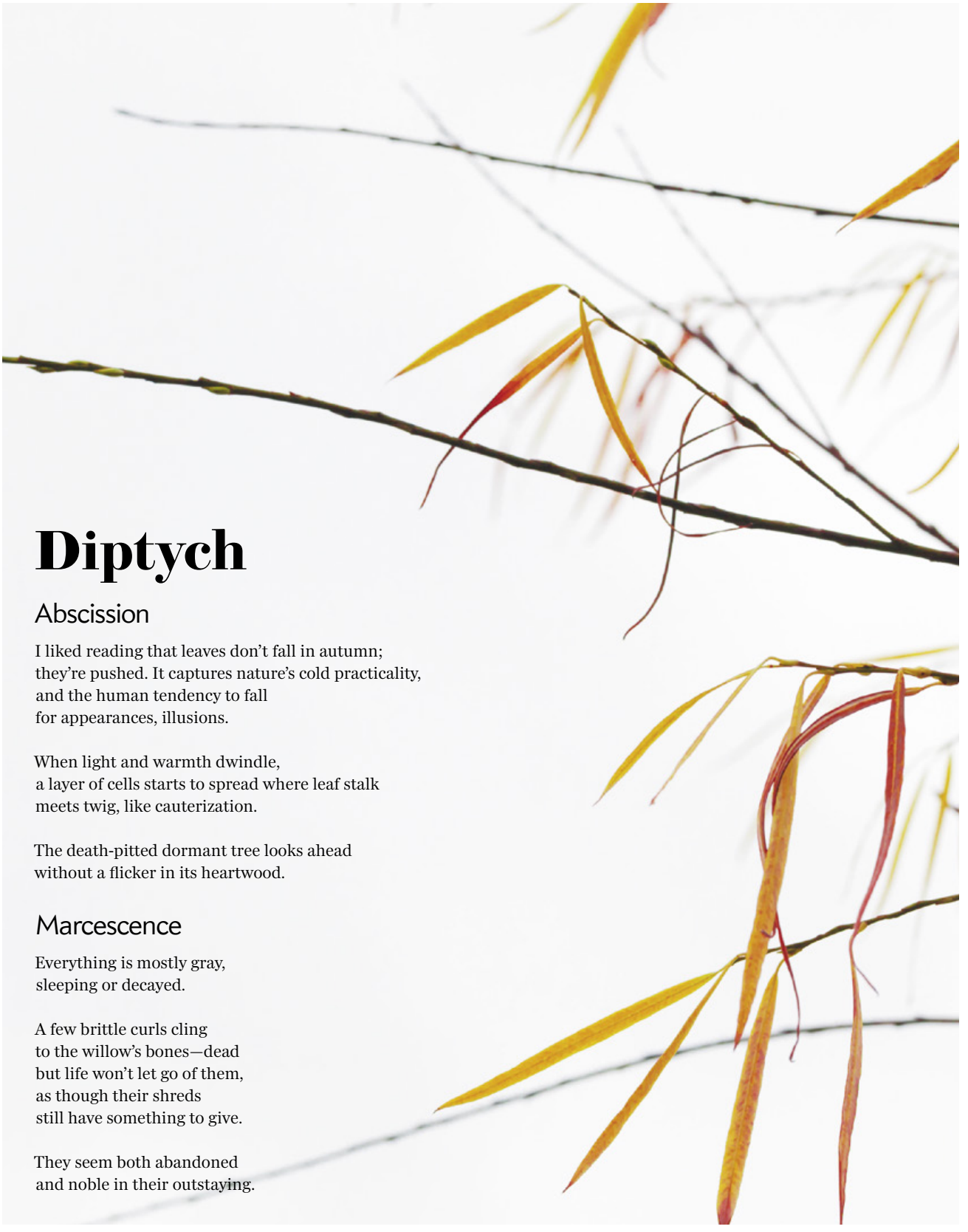
Nicola Healey lives in Buckinghamshire in England, and her poems have been published widely in U.K. journals, including *The Poetry Review, Poetry Ireland Review, The London Magazine* and *Wild Court*.



Diptych

Abscission

I liked reading that leaves don't fall in autumn;
they're pushed. It captures nature's cold practicality,
and the human tendency to fall
for appearances, illusions.

When light and warmth dwindle,
a layer of cells starts to spread where leaf stalk
meets twig, like cauterization.

The death-pitted dormant tree looks ahead
without a flicker in its heartwood.

Marcescence

Everything is mostly gray,
sleeping or decayed.

A few brittle curls cling
to the willow's bones—dead
but life won't let go of them,
as though their shreds
still have something to give.

They seem both abandoned
and noble in their outstaying.

Eugene Sergeev/Alamy Stock Photo

Claudia Wallis is an award-winning science journalist whose work has appeared in the *New York Times, Time, Fortune* and the *New Republic.* She was science editor at *Time* and managing editor of *Scientific American Mind.*

A Rising Risk in Pregnancy

Gestational diabetes, already on the upswing, surges in the pandemic

By Claudia Wallis

Among the most common complications of pregnancy is a high level of glucose in the blood, a condition known as gestational diabetes mellitus (GDM). Because it usually goes away after birth, GDM was not always seen as a serious concern, although the excess sugar often produces very large, hard-to-deliver newborns. "For a long time it was not regarded as a real disease," says clinical epidemiologist Cuilin Zhang of the National University of Singapore. That has changed after multiple studies, including some by Zhang, linked the condition to a long-term risk of chronic diabetes for the mother and of obesity for the child.

This summer the first-ever national analysis of trends in gestational diabetes conducted by the Centers for Disease Control and Prevention brought alarming news. Between 2016 and 2020 the prevalence jumped 30 percent, affecting nearly 8 percent of U.S. pregnancies in 2020. Some increase was expected, says Elizabeth Gregory, a CDC health scientist and co-author of the report: "We know that risk factors, including overweight and obesity and older maternal age, have been increasing over time." For those reasons, the condition has been rising globally. What was unexpected was a giant jump in a single year: GDM was up 13 percent in 2020, as opposed to about 5 percent in each of the previous four years.

The CDC report did not examine the reasons for the 2020 surge, but the COVID pandemic is an obvious culprit. "Decreased physical activity, weight gain and other lifestyle factors during lockdowns are known to impact gestational diabetes," Gregory points out. An Italian study of 1,295 women, published earlier this year, supports this idea. It found that the incidence of GDM nearly tripled during lockdown periods—rising from 3.4 percent prelockdown to 9.3 percent. Pregnancy weight gain averaged 20.5 pounds during Italy's strict lockdowns versus 14.5 pounds prepandemic. A higher body mass index (BMI) was linked to greater risk.

Other contributing factors, Zhang says, could be a poorer diet—more snacking and less fresh produce—stress, inability to exercise and depression. Work by Zhang and her former colleagues at the National Institutes of Health showed that depression is associated with a higher risk of GDM, particularly in nonobese women.

The CDC analysis found that gestational diabetes rose in nonoverweight women as well as those with a high BMI. Those of non-Hispanic Asian origin had by far the highest incidence (14.9 percent); non-Hispanic Black women had the lowest (6.5 percent). Asian people in general tend to develop type 2 diabetes—a form in which the body does not use insulin effectively—at a lower BMI than do people of other ethnicities, and the same appears to be true with gestational diabetes. Learning why and what interventions might help was a key reason Zhang recently relocated to Singapore to head up her university's new Global Center for Asian Women's Health.

Women with gestational diabetes face about seven times the average risk of developing type 2 diabetes later in life, along with increased chances of cardiovascular disease. It is not clear whether GDM causes these ailments or if individuals who are vulnerable to GDM also have an underlying vulnerability to type 2 diabetes and heart disease. For the baby, there is a short-term danger of birth injury as a result of large size and a longer-term elevated risk of obesity and impaired glucose tolerance.

Zhang and others have shown that early intervention can reduce the likelihood of gestational diabetes. A 2016 study done in Finland, for example, found that a healthy diet and exercise regimen during pregnancy cut the incidence of GDM by 39 percent among participants who had a history of the ailment or who were obese. Evidence suggests that beginning such a regimen early in pregnancy—or better yet, before becoming pregnant—works best. Unfortunately, most pregnant patients are not tested for diabetes until the sixth or seventh month. Those with obesity or other risk factors are supposed to be screened much earlier, but that recommendation may not be widely followed by physicians, says obstetrician-gynecologist Veronica Gillispie-Bell of Ochsner Health Center–Kenner in New Orleans.

For low-income women who do not receive routine medical care, "pregnancy may be their first opportunity to find out if they have diabetes," says Gillispie-Bell, who helps to lead Louisiana's efforts to reduce its high rate of maternal mortality. And the rise in GDM adds yet another element to an ongoing crisis in maternal and reproductive health. SA

Illustration by Thomas Fuchs

A NEWFOUND EAR FOR THE SECRETS OF THE **STARS**

Jørgen Christensen-Dalsgaard pioneered ways to use sound waves in stars to reveal their internal dynamics. We asked him what they revealed about life in the universe, the formation of galaxies and the ultimate fate of our planet

In the summer of 1975, Jørgen Christensen-Dalsgaard became obsessed with the idea of seeing inside the sun. He was at a conference where an astronomer presented data that suggested our home star was alternately expanding and contracting. "I immediately thought that the waves that produce these oscillations must go all the way through the center of the sun," he says.

If so, he realized, astrophysicists would have a powerful new tool to monitor reactions in the solar core, where nuclear fusion converts solar mass into radiant energy.

Although the 1975 data turned out to be an artifact, later observations of the sun showed that Christensen-Dalsgaard's instincts were spot on. Astrophysicists have studied internal sound waves to study the structure, evolution and dynamics of the sun's interior—and that of thousands of distant stars as well.

Astronomers had first spotted the solar surface oscillating in the 1960s. Not long after, Roger Ulrich, now a professor emeritus of astrophysics at the University of California, Los Angeles, laid out the equations that explained why the sun shimmers as it shines. "I solved them the way you would calculate the tone of an organ pipe," he recalls.

Ulrich's theoretical work validated the idea that hot gases within the sun bubble toward the solar surface and sink as they cool, generating waves that resonate inside the sun, much as air made to vibrate in an organ pipe generates waves that resonate to produce specific tones. Since the behavior of sound waves varies with the properties of the medium they're traveling through, Ulrich realized that studying a star's sound waves could reveal the makeup and dynamics of the star's interior.

Ulrich and Christensen-Dalsgaard, an asteroseismologist now at Aarhus University in Denmark, then worked for years to promote the establishment of ground-based telescope networks and, later, space-based telescopes precise enough to detect visible signs of sound waves inside the sun and distant stars. That data allowed asteroseismologists a powerful tool to measure the mass, gravity, chemical makeup, rotation and age of thousands of stars, revealing insights into the evolution of the Milky Way itself.

"Those data are something we will continue to work on for a very long time," says Christensen-Dalsgaard, who shares the 2022 Kavli prize in astrophysics with Ulrich and asteroseismologist Conny Aerts of KU Leuven, Belgium, for their pioneering work in helio- and asteroseismology.

Here, Christensen-Dalsgaard pokes holes in our current understanding of stellar interiors—including that of our own sun—and ponders Earth's fate, our galaxy's history and the possibility of extraterrestrial life.

What happens inside a sun-like star when it burns up its hydrogen and evolves into a red giant?

As a star becomes a red giant, its outer layer expands and cools, while its helium core contracts. You would expect the rotation of this contracting core to speed up—just as a figure skater spins faster when she pulls in her arms. But in these red giant stars, the core does not rotate as rapidly as our models would predict. Something is slowing it down, perhaps magnetic fields. But how these fields arise, how they interact with the matter in stars, and how they evolve over the lifetime of a star—these are all open questions. The answers could affect our understanding of the evolution of the massive stars that will become supernovae and create a lot of the elements in the universe.

Will Earth ultimately be swallowed by the sun?

We don't yet know. In the very late stages of solar evolution, the sun will expand greatly in size. At the same time, it will be losing mass. This means that Earth will drift farther away from the sun. How rapidly the sun loses mass compared with how rapidly it expands will determine whether Earth ends up swallowed or whether it manages to hang on out there. Either way, in five billion years the sun is going to be very much brighter than it is now, so Earth is not going to be a very nice place to live.

How did the Milky Way evolve—and what's next for our galaxy?

Going back maybe seven billion years, there is evidence that a fairly large galaxy merged with the Milky Way. We can see streams of stars that joined after the bulk of the galaxy was formed. One way we see this is by looking at what the stars are made of: their composition holds the secrets of the environment where the stars were formed. We can also see how they move in the sky and determine how old they are.

Mergers are still going on in the present universe. Two Magellanic Clouds are probably going to merge with the Milky Way in a billion years or so, and the Andromeda galaxy is also going to merge with the Milky Way, maybe a few billion years down the line. In these merger events, you see regions of very rapid star formation where the two galaxies overlap. Although it happens on a timescale of a few hundred million years, it's quite dramatic.

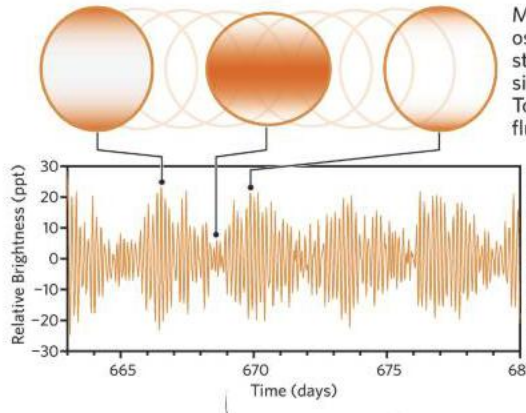
Could there be life elsewhere in the universe?

Thanks to the Kepler mission, we've found Earth-like planets in the "Goldilocks zone"—not too warm, not too cold. We haven't found very many, and some are around stars that are very different from the sun. We want to look for more Earth-like planets in the right place around a star that's not too different from the sun. Then we want to look at the atmosphere of those exoplanets to look for molecules that indicate the presence of life. Oxygen, for instance. Knowing that life has evolved elsewhere in universe would be huge. One might then imagine that at least somewhere in the universe there's intelligent life.

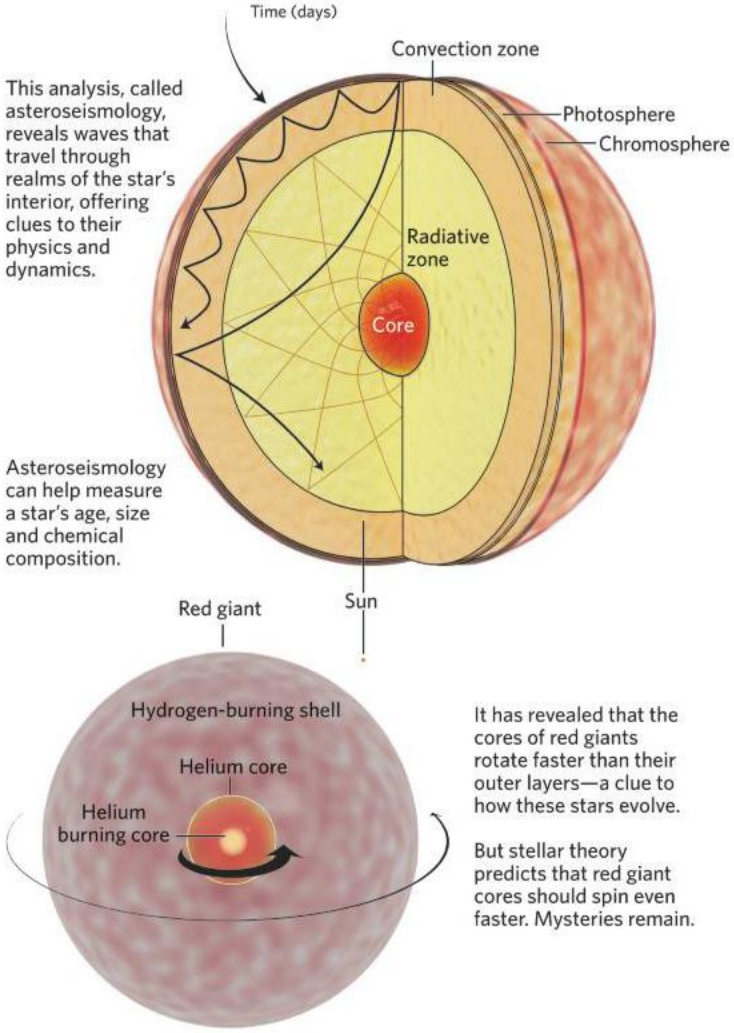
To learn more about the work of Kavli Prize laureates, visit kavliprize.org.

TUNING IN TO THE HEART OF A STAR

By tracking fluctuations in a star's brightness, scientists can determine the oscillations that cause them, revealing the physics at work in different realms of the star's interior.



Sources: J. Christensen-Dalsgaard; C. Aerts/ Physics Today 68(5), 36 (2015), AIP Publishing



THE KAVLI PRIZE

ARCHAEOLOGY

The Power of Viking Women

Analyses of ancient North Atlantic textiles show that Viking and medieval women wielded considerable cultural and economic influence

By Francine Russo

Illustration by Chase Stone

Francine Russo is a veteran journalist specializing in social sciences and relationships. She is author of *Love after 50: How to Find It, Enjoy It, and Keep It* (Simon and Schuster, 2021).

ARCHAEOLOGY HAS A REPRESENTATION PROBLEM. FOR MOST OF THE TIME that scholars have been probing the human past, they have focused mainly on the activities of men to the exclusion of women. There are a couple reasons for this bias. One is that the kinds of artifacts that tend to preserve well are made of inorganic materials such as stone or metal, and many are associated with behaviors stereotypically linked to men, such as hunting. Another reason is that early archaeologists were mostly men and more interested in men's work than in women's. As a result, our understanding of past cultures is woefully incomplete.

In recent years archaeologists have sought to fill that gap in our knowledge, in part by taking a closer look at traditionally ignored remains such as textiles, which had long been dismissed as trivial. Cloth rarely survives the centuries because it decomposes easily except under ideal preservation conditions. But even in a fragmentary state, it contains a wealth of information about the people who made and used it.

Michèle Hayeur Smith, an anthropological archaeologist at Brown University, has been at the forefront of efforts to glean insights from ancient cloth, scouring archaeological sites and museum collections for textiles that could illuminate the lives of women in early North Atlantic societies. Her work has shown that the Vikings never would have expanded their known world without the women's work of weaving.

Hayeur Smith's study of early North Atlantic textiles took off from the basement storage area of the National Museum of Iceland, its rows of metal shelving bursting with boxes and bags of dirt-covered cloth. She first visited in 2009 to inspect the museum's collection of remains from the Viking Age and later periods. "It was literally thousands of fragments," she says. Yet they were just sitting there, hardly examined by anyone.

Hayeur Smith grew up surrounded by fabrics her anthropologist mother collected from around the world. In her 20s Hayeur Smith earned a fashion degree in Paris. She knew that the way people in the past clothed themselves and wove everything from currency to cloaks could reveal a great deal about a lost culture, especially its women. In the 1990s, as a Ph.D. student at the University of Glasgow, she'd devoted herself to studying Viking women's dress and ornament, typically from artifacts found in burial sites. Inspired by her first glimpse of the wealth of textile remnants in the museum's storeroom, Hayeur Smith eventually decided to uncover the lives of the ordinary women who stood weaving at their looms.

Ever since then, she has been analyzing textiles spanning 900 years of history, starting with the Viking settlement of Iceland in C.E. 874. She has pored over thousands of soil-encrusted fragments dense with information about the women who made the fabric. Her resulting studies of that museum's neglected collection of little brown scraps, as well as many other specimens of ancient Viking and later North Atlantic fabric, are among the first to prove the old guard wrong about the importance of cloth and women in ancient societies.

Textiles *trivial?* In my Zoom interview with her, Hayeur Smith, blond hair spilling to her waist, calling to mind a Valkyrie, speaks in a voice ringing with conviction: "No. Textiles and what women made were as critical as hunting, building houses and power struggles," she says. In the Viking and medieval eras, women

LEGAL CLOTH known as *vaðmál* was recovered from late 17th-century archaeological deposits at the site of Gilsbakki in western Iceland. Gilsbakki was the seat of Viking Age and medieval chieftains from around C.E. 900 to C.E. 1210.

were the basis of the North Atlantic economy, and their cloth allowed people to survive the climate of the North Atlantic.

HIDDEN FIGURES

IN POPULAR CULTURE, Viking women are seen through the eyes of the era. In the 1950s they were portrayed as weak and subservient to men. In the 1970s they were sexualized. In recent shows such as *Vikings* and *The Last Kingdom,* they are depicted as shield-maidens or warriors.

Until Hayeur Smith began her work, the real lives of Viking women were largely unknown to science. According to archaeologist Douglas Bolender of the University of Massachusetts Boston, who studies the Viking Age and the medieval North Atlantic, the basic outline of Viking society came from the Icelandic sagas. Those book-length narrative accounts were set down more than 300 years after the events they describe. And the authors, who were men as far as we know, were Christianized people writing about their "pagan" ancestors.

Viking women have long been stereotyped in archaeology as performing primarily domestic tasks: child-rearing, cooking, weaving and making clothing. Written accounts and archaeological evidence confirm that they were weavers. Yet for years at a time during their husbands' absences for raids or trading expeditions, women ran the farms and engaged in trade, Hayeur Smith says.

"There's some truth" to the idea that we've found women's work less interesting, says archaeologist Thomas McGovern of the City University of New York. McGovern, whose full white beard evokes an Old Testament patriarch, entered archaeology in the 1970s. "Mostly it was old white guys," he recalls. Since then, however, the field has changed for the better, he says, with far more women and diversity generally.

Yet traditional views of women still color researchers' interpretations of evidence, says archaeologist Marianne Moen of the Museum of Cultural History in Oslo. A Viking expert who studies gender in the archaeological record, she says that she regularly sees how the meaning of artifacts is distorted by preconceptions of what they must signify. For example, a grave filled with a warrior's weapons at the Viking site of Birka in Sweden was long thought to be a man's final resting place until DNA evidence proved it was a woman's.

Alexandra Sanmark of the University of the Highlands and Islands in Perth, Scotland, an authority on Vikings and medieval archaeology, agrees. A man buried with scales is seen as a merchant, she says, but a woman buried with scales must be a merchant's wife, despite ample evidence that women conducted trade.

WRITTEN IN CLOTH

HAYEUR SMITH DECIDED to seek out North Atlantic women in the work of their hands. So little has been known about them until now, she says, "because it was men analyzing this from the perspective of men and medieval law codes written by men. Nobody had gone and looked at the actual stuff made by women."

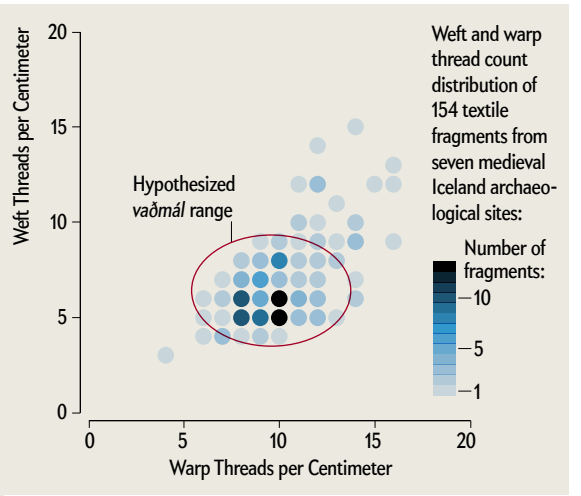
She did not begin her textile analysis completely from scratch. There had been a few studies of textiles, most notably by the late Elsa Guðjónsson, whose work was foundational for Hayeur Smith. Guðjónsson, however, had been able to study only "a handful" of archaeological pieces of fabric from the mountain of artifacts in the Iceland museum's collection, Hayeur Smith says. And Guðjónsson's work, like that of other textile analysts, focused mainly on technical details such as thread counts, weave types, fleece varieties, embroidery stitches and tools used to make them to understand the techniques of weaving.

For Hayeur Smith, the technical details were important, but she had a different goal: to create what she calls a "social archaeology" of the culture through which she could uncover the lives of the women who created the cloth. For this purpose, she focused on the everyday "homespun"—plain woolen fabric—made by ordinary women, who left no elaborate graves on their farms throughout the North Atlantic. Their only memorials are the textiles they wove on their warp-weighted looms.

Hayeur Smith demonstrated the Vikings' style of weaving at an event organized by the Haffenreffer Museum of Anthropology at Brown in 2020, a recording of which is available on YouTube. A wood horizontal bar resting on two vertical ones holds the separate vertical warp threads, which are weighed down taut by volcanic stones of the kind that dot the shores of Iceland. Holding a heddle rod to separate the warp threads, she draws the continuous horizontal weft thread in and out of one or more warp threads. By varying the number of warp threads, weavers could create common Icelandic patterns, mostly basic weaves known as twills and tabbies.

Before about C.E. 1000, the loom would have been set up in a *dyngja,* a weaving hut, says University at Albany archaeologist Kevin Smith, Hayeur Smith's husband, who has excavated similar structures in Iceland. These pit houses, he explains, are dug down 1.5 to three feet deep, sometimes with turf walls above the pit and sometimes with wood walls that would have provided a space high enough for people to stand and work. With a stone-framed hearth in one corner to offer warmth and light, these small buildings—no more than nine by 15 feet in size—would have provided an intimate space fitting a loom and perhaps three women, spinning, weaving and sharing stories.

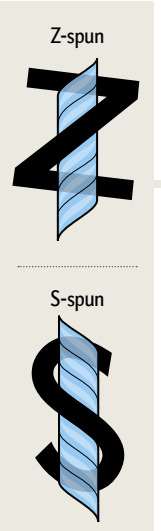
Hayeur Smith made several trips to the museum's basement laboratory in 2010, examining specimen after specimen under a microscope, counting warp and weft threads, taking note of such characteristics as the spin direction of yarn, the kind of fiber used and the weave type. As she worked, Hayeur Smith entered her data and extracted small samples for further analysis and testing, including a type of radiocarbon dating called accelerator mass spectrometry.



For the next several years she studied fabric remains from museum repositories in Iceland, Greenland, the Faroes, Scotland and Norway. Wielding her digital caliper, she measured the diameter of the cloth fibers and the sizes of the remnants. For each specimen, she meticulously recorded the age, site of origin and manufacturing details such as warp threads per square centimeter.

Somewhere between the first and second year of this endless and "filthy" job, soil all over her fingers, Hayeur Smith had her eureka moment. "Look," she shows me on a video call, holding her book open to a graph and pointing to a thick cluster of circled icons. "The more sites I checked, the more I saw this pattern. Viking Age textiles were colorful and varied, but in medieval times, there is a complete shift into standardized cloth."

Regular modern cloth, Hayeur Smith explains, could vary from 75 to 300 warp threads, but in Iceland and only in Iceland, from the 12th through 17th centuries, every textile from every site fell into a tight range of four to 15 warp threads. In addition, the spin direction of the yarn—clockwise (Z-spun) versus counterclockwise (S-spun)—shifted almost completely from Z-spun warp and weft to S-spun in the weft in the 11th century. All these details are specifications for legal cloth, called *vaðmál.* "Women were making the money!" she says.



CLOTH CURRENCY

ICELAND'S BUDDING ECONOMIC SYSTEM was based on Norway's. Certain commodities—cloth, cows, butter, grain—were legally assigned a value based on their equivalent value in silver. Toward the end of the Viking Age, however, homespun woolen cloth be-

Source: *The Valkyries' Loom: The Archaeology of Cloth Production and Female Power in the North Atlantic,* by Michele Hayeur Smith. University Press of Florida, 2020 (*chart reference*)

Graphics by Jen Christiansen

came much more important as a form of exchange in Iceland than in Norway. Scholars believe this shift may have resulted from such factors as a scarcity of silver after the Vikings stopped raiding, population growth, and the colony's burgeoning wool production. "Although its value was still measured, in theory, against silver, this cloth … came to be legally regulated as an exchange good in and of itself," Hayeur Smith notes in her 2020 book *The Valkyries' Loom: The Archaeology of Cloth Production and Female Power in the North Atlantic*. The name *vaðmál,* she explains, is a combination of the Old Norse words *vað* ("stuff" or "cloth") and *mál* ("measure"), meaning "cloth measured to a standard." It is frequently mentioned as a measure and medium of exchange in Icelandic legal texts, as well as sales accounts, church inventories and farm registers, from the 1100s into the 17th century.

Women made all of the *vaðmál*. In fact, they were churning out huge quantities of it as both a unit of currency and a commodity to be sold near and far. *Vaðmál* could be used to pay taxes and tithes, but it could also be traded or sold for making clothes and other necessities. It was especially in demand in England, which produced its own luxury fabrics but needed great quantities of Iceland's cheap durable homespun to clothe peasants, the urban poor and common soldiers.

It's a modern idea that work done at home is "domestic" and lesser because it doesn't produce money, Moen says. In the North Atlantic world, "home was where work was done." In fact, as Hayeur Smith points out, *vaðmál* was a major income-generating product.

Scholars knew about *vaðmál* in an "abstract" sort of way, Hayeur Smith says, because it was precisely defined in the medieval law books. But the legal texts never mention the women weaving it, she points out. And nobody checked the cloth remains to see whether they conformed to the specifications in the legal texts.

In tandem with her textile analysis, she examined the legal texts—most of which had, thankfully, already been translated from Old Norse into modern English. Through painstaking inspection, she confirmed that the cloth Icelandic women wove conformed exactly to these standards: a 2/2 twill (a tweed), Z/S-spun, woven with four to 15 warp threads per centimeter. The cloth was also supposed to measure two "ells" in width and six ells in length (a little more than one yard wide and three yards long in modern measurements). Based on the fragments she analyzed, the Icelandic cloth "can be assumed to be about this size or bigger." That unit of cloth was equal to a certain weight of silver. "Everyone assumed the economy was a male thing," Hayeur Smith says. In fact, it was not the men but the women making the decisions.

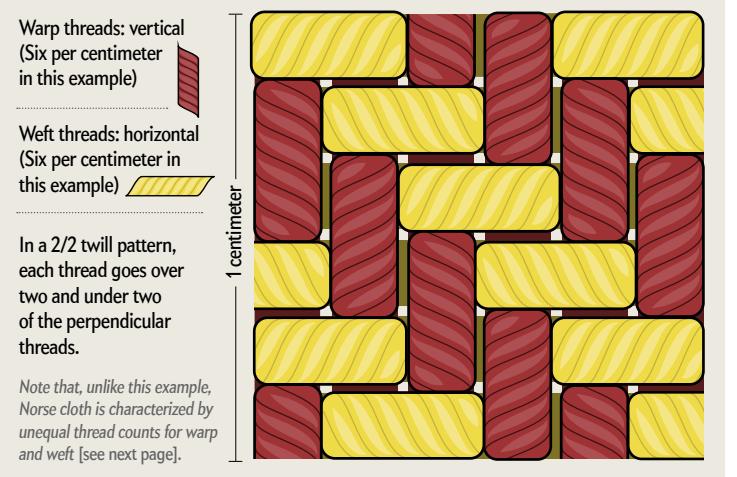
She suggests that women either created the specifications themselves or collaborated with men to do it. "It's hard to know what they were thinking," Hayeur Smith admits. "What's clear in looking at the time involved and the tools is that every able-bodied female in a household would have been involved." Indeed, at a certain level, "they may have controlled a lot of the narrative on these legal guidelines," she says. "It's not the men sitting there writing books … because [men] didn't go near weaving," she says.

LOOMING TABOOS

HAYEUR SMITH GROUNDS THIS assertion partly on evidence from poetic and mythological sources, including the Icelandic sagas, which provide clues to deep-seated attitudes toward women and weaving in the Viking Age and beyond. The power of women is expressed in the *Darraðarljóð* from Njáls saga, says Karen Bek-Pedersen, an expert on female aspects of Viking religion at Aarhus University in Denmark. In the saga, a soldier at the dawn of a battle has a vision in which he peeks into a *dyngja* and sees 12 Valkyries, Odin's female warrior spirits. They set up a loom and start weaving, using men's viscera as parts and threads. As they weave, they describe—and determine—the bloody defeat to come, Bek-Pedersen explains. She quotes this stanza:

The fabric is warped
with men's intestines
and firmly weighted
with men's heads;
bloodstained spears serve
as heddle rods,
the shed is ironclad,
and pegged with arrows.
With our swords we must strike
this fabric of victory

Poems from the sagas probably predate the sagas themselves, Bek-Pedersen says. Filled with metaphor, alliteration, rhythm and rhyme, they are hard to alter and easy to remember, making them likely



to have been passed down through oral tradition.

The *dyngja,* Bek-Pedersen observes, can be seen as a space "charged with a feminine energy that reaches beyond the abilities of ordinary human women." In the literary canon, she says, men who hang out there and gossip with the women are portrayed as cowards or villains and invariably come to a bad end.

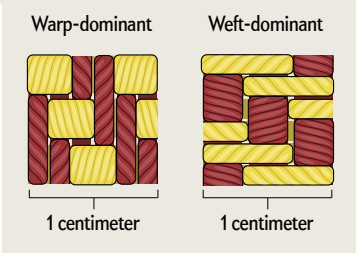
The fact that the *dyngja* was a space men shunned weighs heavily in Hayeur Smith's appraisal of women's power in cloth-making. Men feared that if they entered, they would lose their masculinity or even their lives. After Scandinavia turned Christian around C.E. 1000, looms were brought into the main living area of the *skáli,* the longhouse. Weaving would have been carried out in a separate area or room, with the taboos about this women's craft most likely undiluted. These taboos became a critical factor in women's power as their cloth turned into a major driver of the Icelandic economy.

CLOTH AND CLIMATE

IN 2011 HAYEUR SMITH met McGovern in a Chinese restaurant on the Upper East Side of Manhattan for what must have looked to an outside observer like a peculiar hand-off. McGovern had brought some fragile remains from an excavation he and his team had carried out a couple years earlier at a site called Tatsipataa in southwestern Greenland. The workers had scooped up the textile bits separately from the bones he was studying, and he was happy to give them away, wondering what she could possibly learn from them. When he handed them over, he recalls thinking, "Well, good luck with this!"

Hayeur Smith was on a quest to find out why the cloth made by Greenland's women diverged so much from the cloth made by Iceland's female weavers. Greenland had been settled in C.E. 986 entirely by Icelanders. They were followers of Erik the Red, who'd been exiled from Iceland for manslaughter. The Greenlanders' cloth started out identical to the Icelanders' warp-dominant fabric but eventually shifted to contain more threads in its weft than its warp.

In the early 2000s the late Else Østergård, a textile expert at the Danish National Museum, proposed an explanation for the shift. Holding up her lovingly tattered copy of Østergård's 2004 volume *Woven into the Earth,* Hayeur Smith says Else thought it possible that Greenlandic women's weaving innovations might be a response to climate change during a period of cold climate known as the Little Ice Age. In Greenland, the first dramatic drop in temperatures started around roughly 1340 and continued with fluctuations through the mid-15th century, when its colonies disappeared, to the 1900s.



Hayeur Smith set out to test Østergård's hypothesis against the archaeology, starting with the evidence from Tatsipataa. McGovern's specimens turned out to be "phenomenal," she says. Excavated under controlled conditions from a well-documented series of layers of remains, they were brimming with information about changes in weaving, when these changes occurred—and, quite possibly, *why.* Collaborating with McGovern's doctoral student Konrad Smiarowski, Hayeur Smith reviewed their excavation plan, a depiction of how the artifact layers were deposited over time. It indicated that the weft-dominant cloth appeared somewhat later in time.

By dating the Tatsipataa cloth remains, Hayeur Smith was able to correlate the ratio of weft to warp threads in each sample with published records of climate data. As Østergård had hypothesized, weft-dominant cloth did indeed increase as temperatures dipped in the 1300s. "It matched up perfectly with the climate data!" she says.

Still, as exciting as that finding was, "it was just one site," Hayeur Smith says. To prove that women were adapting their weaving to climate change, she had to collect remains from all over Greenland during different time periods.

In September 2014 Hayeur Smith's pursuit of women in textiles brought her to what had once been an old trading house on Greenland's Nuuk Harbor, where she could watch icebergs float by. Built by 18th-century Danish-Norwegian missionary Hans Egede, the building was now used by the Greenland National Museum and Archives to host research teams. But she was the only researcher there. At night the storms battering the house and the groaning beams evoked a sense of uneasiness that challenged her scientific outlook. Later she would learn from locals that this abode, situated beside a graveyard for smallpox victims, was widely regarded as haunted.

She laughs at her fears as she recounts them in 2022 from her cozy home office in Pawtucket, R.I., which is filled with artwork and portraits of her French Canadian and American great-grandfathers in antique oval frames. In the Nuuk museum and, during another trip that same year, in the National Museum of Denmark in Copenhagen, Hayeur Smith inspected some 700 cloth specimens from multiple archaeological sites across Greenland. She returned to Nuuk in 2017 to study even more samples. With all the dating she did, plus Østergård's, she was able to track the evolution of weft-dominant cloth and correlate it with the years of climate change. "I *confirmed* [it was] climate change," she says.

Flicking her long hair back from her face, Hayeur Smith points to a graph in her book. "Look, that's the climate data." She draws my attention to an arrow that goes down to the year 1320. "That's when you see weft-dominant cloth," she says. That type of

cloth becomes widespread between 1300 and 1362.

After those dates, the weaving of weft-dominant textiles intensifies. Previously a minor type of cloth, "it becomes the most common textile produced in Greenland," she wrote in *The Valkyries' Loom*. It was "almost certainly" a response by local weavers in Greenland in this medieval era to cope with colder temperatures. Hayeur Smith had found her women. "I could see in the piece of cloth," she says, her voice buzzing with excitement, "the actual deliberate decision-making that women were doing, like *it's getting cold; let's change the way we weave our cloth*. It's almost unheard of that you get to see people's direct actions and thought processes" so far in the past.

POWER SHIFTS

EVENTUALLY, THOUGH, NATURAL, political and economic forces combined to strip Icelandic and Greenlandic women of the power they possessed as a result of making the all-important cloth. By around 1450 the Little Ice Age, among other factors, had destroyed the Greenland Norse colony, and plague and political upheaval had roiled the Kingdom of Norway.

In 1603 Danish authorities under King Christian IV imposed a royal monopoly on trading and strictly required all imports and exports to go through Denmark, reducing Iceland's freedom to trade. At this point, although Iceland continued to use *vaðmál* as currency and export it until the late 17th century, fish replaced the cloth as Iceland's primary export starting in the 14th century.

Imitating the English, whose male weaving guilds had produced fine cloths on foot-powered treadle looms since the 1300s, the Danes trained North Atlantic men to weave on these faster looms. They set up production workshops in locations around Iceland, including Reykjavik. They gave women spinning wheels, a much more efficient way to create yarn than the traditional spindle whorls used on the drop spindle. The Danes also encouraged women to knit—a skill they'd learned in the 1500s—responding to a market demand for knitted exports. In addition, they imported fabric from Denmark to Iceland. Women could buy it to make clothing, saving them the relentless labor of weaving. In taking these measures, the Danes essentially pushed women out of the mainstream of weaving.

Nevertheless, as Hayeur Smith found in the archaeological record, women continued to weave their homespun cloth on their farms. Fragments of the textile have surfaced at 17th- and 18th-century sites throughout Iceland, including its wealthiest ecclesiastical center, Skálholt. She believes people used it as a statement of national identity in the face of Danish rule and the new laws imposing a transformation of the women's 900-year-old tradition of textile production. "I see it as resistance," she says.

Yet the Danes—and the growth of industrialization—eventually prevailed. By the early 1800s, Hayeur Smith says, no one even knew how to weave on the old looms. And women were worse off for it. Once textiles could be made so much faster on machines than by hand, they came to be associated with things considered "frivolous or peripheral to our daily lives or of interest and important mainly to women as their primary consumers," she observes in *The Valkyries' Loom*. "It was in part the Industrial Revolution that sealed the fates of women as second-class citizens and ensured that Western society would become so vehemently patriarchal."

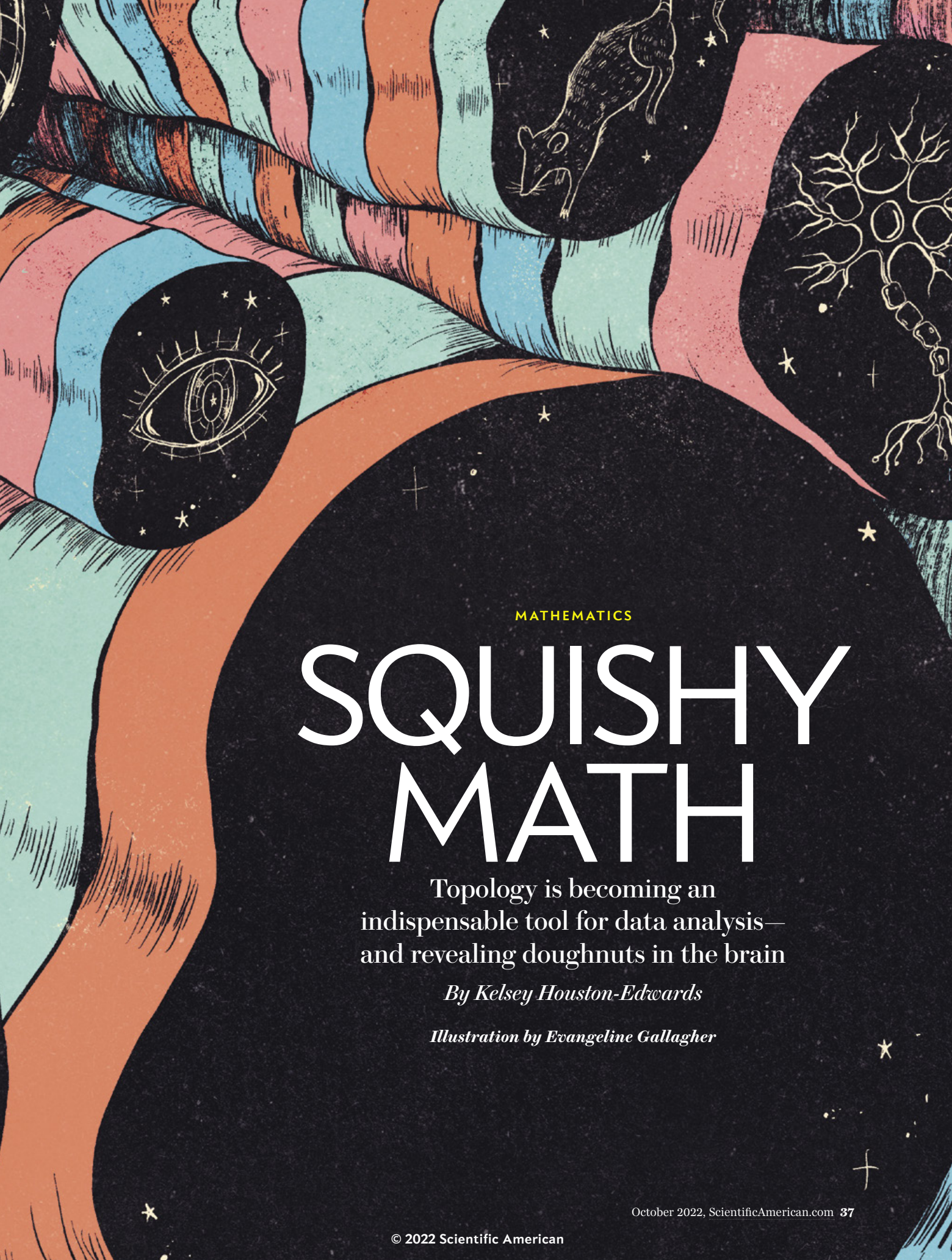
Hayeur Smith remains committed to the pursuit of the tales only cloth can tell. As the once dubious McGovern observes, "after her publications, nobody's going to look at textiles the same way again." SA

MICHÈLE HAYEUR SMITH examines archaeological deposits at Gilsbakki spanning 1,000 years—from the early 10th century to the early 20th century.

FROM OUR ARCHIVES

The Caveman's New Clothes. Kate Wong; November 2000.
Greenland's Vanished Vikings. Zach Zorich; June 2017.

scientificamerican.com/magazine/sa



MATHEMATICS

SQUISHY MATH

Topology is becoming an indispensable tool for data analysis—and revealing doughnuts in the brain

By Kelsey Houston-Edwards

Illustration by Evangeline Gallagher

Kelsey Houston-Edwards is a mathematician and journalist. She formerly wrote and hosted the online show *PBS Infinite Series*.

BENJAMIN ADRIC DUNN, A DATA SCIENTIST AT THE Norwegian University of Science and Technology, shows me a picture of unevenly spaced dots arranged vaguely like the rocks at Stonehenge. The overall pattern is clear—at least, to a human. "When we look at this, it's obviously a circle," he says. But an algorithm would likely struggle to recognize this simple shape. "It very often misses the big picture."

Many scientific processes involve loops, or repetitions. A computer's inability to see these relationships is a problem for scientists who want to identify circular patterns within huge masses of data points. Data are often visualized as dots floating in space, like stars in the night sky. A dot might represent a physical location, like the two numbers for longitude and latitude marking where a ship is on the high seas. Genes can likewise be plotted in a mathematical space of many dimensions—hundreds sometimes—so that two genes with similar DNA sequences will be represented by nearby points. The significance of a circular pattern within the data depends on context. Circles in a ship's position might indicate that it is lost, whereas circles within genetic data may demonstrate an evolutionary relationship.

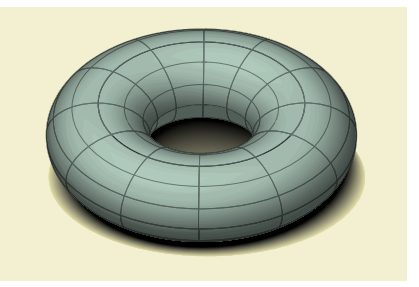
Often these starry skies of data points are too complex and high-dimensional to study with the naked eye. To detect circles, researchers require a set of instructions precise enough for a computer to understand. But many standard techniques for data analysis are based on a type of mathematics known as linear algebra, which studies straight lines and flat planes. To hunt out loops, researchers are instead turning to topological data analysis (TDA), which offers a radically different perspective.

In contrast to the relatively simple and rigid structures that characterize linear algebra, TDA is grounded in topology, a branch of mathematics that studies pliable, stretchy shapes. Because its practitioners assume that all shapes are arbitrarily flexible, topology is often called rubber sheet geometry.

Like the formation of constellations from stars, topological data analysis helps mathematicians build revealing shapes from scattered dots. Researchers begin by using the data points as nodes or joints in a virtual scaffolding, building complex structures that may extend through hundreds of dimensions. The resulting picture contains much of the essence of the original data but in a more tangible form. They study these structures using a topological perspective—looking for features that are preserved even if the scaffolding is stretched or bent.

Topology's usefulness in data analysis lies in its ability to reveal qualitative, rather than quantitative, properties. It identifies the aspects of the structure that persist even if there are random errors, or noise, in the underlying measurements. Noise often jiggles the underlying data, but the topology remains the same—revealing robust features of the system. "There are lots of instances in the real world where the data given to you are squishy," says Robert Ghrist, a mathematician at the University of Pennsylvania. "So you've got to use squishy math."

Mathematicians and scientists are now working together to find unusual topological shapes in a vast range of data, representing anything from biological processes with daily rhythms to the structure of drug molecules. Perhaps the most intriguing of these investigations pertain to brain structure. Mathematicians have used topology to explore how neurons interact across extended areas of the brain, reacting to different surroundings and stimuli. In collaboration with neuroscientists, Dunn recently found that certain brain cells use a torus, the mathematical name for the surface of a doughnut, to map their environment.

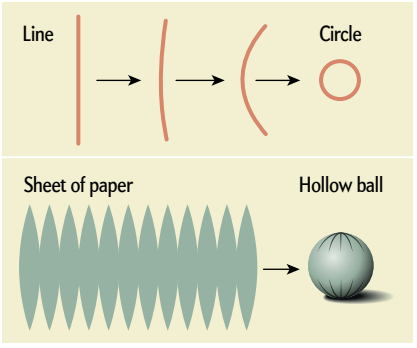


Graphics by Jen Christiansen

DOUGHNUTS AND COFFEE CUPS

EVEN THOUGH topologists contort rubber sheets for a living, they are very careful to preserve the number of holes in them. They never punch a new hole or press closed an existing one. There's a classic math joke that a topologist can't tell the difference between a doughnut and a coffee cup: they both have one hole.

Topologists classify holes based on their dimension. A closed loop, like the numeral 0, has a one-dimensional hole because it is formed by gluing together the ends of a one-dimensional line. Starting with a two-dimensional plane, like a sheet of paper, and taping up the edges will yield something like a hollow ball, which has a two-dimensional hole.

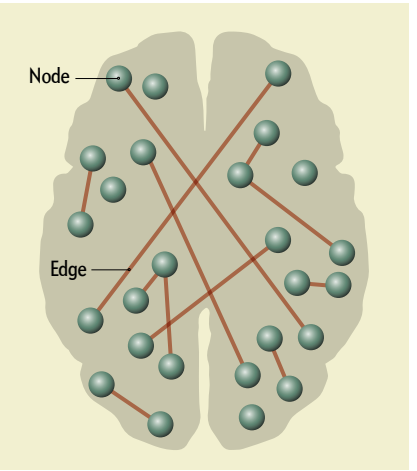


Higher-dimensional shapes can have higher-dimensional holes. By analogy with the one- and two-dimensional holes, for example, a three-dimensional hole is formed by "closing up" a three-dimensional space, like a cube. But this process can be seen only from a four-dimensional perspective, outside of most people's—likely anyone's—reach.

Some shapes have multiple holes of different dimensions, such as an inflatable ball with an attached handle that a child sits and bounces on. The hollow center of the ball is a two-dimensional hole, whereas the solid handle forms a one-dimensional hole. Topology has many precise methods to count holes in higher-dimensional shapes—an ability that turns out to be helpful in studying the brain's neuronal activity.

Neuroscientist Olaf Sporns of Indiana University thinks of the brain as a massive transportation network. The roads and infrastructure are built from the neurons and their connecting synapses. The brain's electrical and chemical signals drive along these streets. "The physical roads constrain the traffic patterns that you can observe dynamically on top," Sporns says. The traffic patterns change as we move and think.

As we squint at a diagram of the brain, it might look like a collection of points, representing neurons. Some of them are connected by lines, indicating a synapse between those particular neurons. Mathematicians refer to this structure as a graph: a collection of nodes connected by edges. The graph flattens the biological



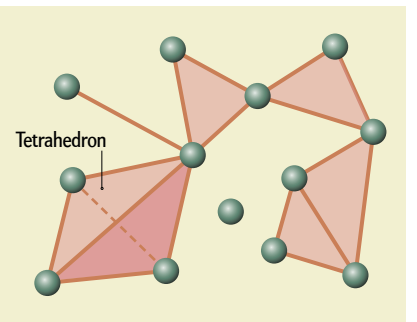
complexity of the brain, but it retains the overall shape of the circuits. Such a trade-off is typical when creating a mathematical model, which weighs simplicity and analyzability against usefulness.

The graph of neuronal connections is a weblike mess: neurons are abundant and richly interwoven. In 2017 Kathryn Hess, a mathematician at the Swiss Federal Institute of Technology in Lausanne, tackled this complication by doing something that is initially surprising: she made the graph more complicated. She analyzed data from the Blue Brain Project, a massive computer simulation of the activity of a rodent neocortex, a part of the brain involved in higher-order functioning. The computer model contains representations of the individual neurons, which are connected to other simulated neurons via synapses. These links, as well as when they are likely to fire, are determined by basic biological principles and by experimental data from laboratory rodents.

The simulation can show the traffic patterns of the brain—the neurons firing in response to a stimulus. Unlike the aerial view of the real brain, however, the simulation can be paused, giving scientists a freeze frame showing which synapses are firing in response to a given stimulus. It is easy to convert this static image into a graph because it indicates the data points, as well as the lines between them: two neurons are connected if a synapse linking them is firing. From this picture, Hess constructed something that mathematicians refer to as a simplicial complex, transforming the simple graph into a voluminous shape.

A simplicial complex is built from triangles of different dimensions. In the Blue Brain graph, for example, three neurons with all three synapses between them transmitting signals formed the vertices of a hollow triangle. To expand this structure into a simplicial complex, the mathematicians colored in this hollow triangle with a solid, two-dimensional triangle. Similarly, they filled in larger clusters of connected neurons with higher-dimensional analogs of triangles. For example, a tetrahedron, a solid three-dimensional pyramid with four triangular faces, would fill in a group of four neurons firing together.

The maximum number of neurons that Hess and others observed firing as a group was eight, so the largest piece of this simplicial complex was a seven-dimensional triangle. Many elements overlapped, forming a multidimensional sculpture: a triangle might jut out of a tetrahedron and meet another triangle at a point. Moreover, the



mathematicians and scientists examined not just one but a series of freeze frames, taken after simulating a gentle stroke of the rodent's whiskers. They converted each of these maps into a simplicial complex and analyzed how its shape changed in time using the tools of topology.

Immediately after receiving the stimulus, the simplicial complexes grew like a massive Lego construction, adding in pieces of higher and higher dimensions until the sculpture reached the maximum of three or four dimensions, depending

Some holes appear and then disappear, but the stubborn holes—those that survive through a range of scales—point to the most essential features of the data.

on the stimulus. Then the whole thing rapidly disappeared. "You have these increasingly complex structures that are being created by the stimulus until it just all collapses," Hess says.

To a topologist, three lines connected to make a triangle are the same as a hollow circle because one shape can be bent into the other. Because the simplicial complexes that Hess and her co-workers built from the simulated rodent brains are seven-dimensional, they can have holes in up to seven dimensions. Their analysis showed that as the shape grew, the number of holes increased. At its peak, the structure contained a surprisingly large number of two- and three-dimensional holes—many more than a random simplicial complex or one built from a different biological process would yield. The specific pattern of holes revealed a high level of organization in the neuronal response; this complexity may indicate a fundamental feature of thought processes.

STUBBORN HOLES

MORE OFTEN, HOWEVER, data are represented by isolated points floating in an abstract mathematical space, with no obvious, preordained connections. To apply TDA, mathematicians need to figure out how to connect them. But there are many possible ways to link stars into a constellation. To find these implicit pictures, mathematicians use a technique known as persistent homology. Topologists analyze a succession of simplicial complexes built at various scales to find the essential features of the data cloud.

To make the first simplicial complex, they cast the widest net possible, connecting every point to every other point to form a dense mesh. Filling in this web with solid forms yields a high-dimensional simplicial complex with few discernible features. But the mathematicians need to compare this complex with others formed by connecting the data at smaller scales. So, next, they cast a narrower net over the same data, connecting only nearby points. Now they have a sparser web, which they use to construct a second simplicial complex. Because this mesh contains fewer data points, its simplicial complex contains shapes of lower dimensions. The researchers repeat the process with a series of smaller nets. "At every scale you're going to have a different snapshot of what that complex looks like," says Ranthony Ed monds, a mathematician at the Ohio State University.

Each simplicial complex is a possible constellation formed with the same scattered data dots. Topologists study this spectrum of shapes—recording, in particular, the number of holes in each dimension. They are especially interested in holes that persist through many different scales. Some holes briefly appear and then disappear, but the stubborn holes—those that survive through a range of scales—point to the most essential features of the data. TDA can thus reduce a complex mess of data to a simple list of stubborn holes, in much the way that a JPEG photo file compresses an image. "It's a way of paring down the data to the stuff that really matters so that we have something much more workable," Ghrist says.

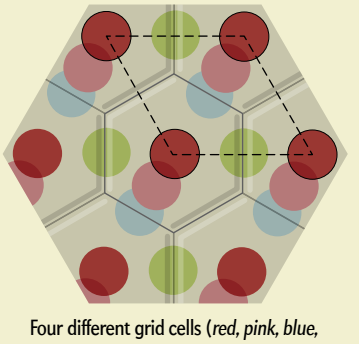
Sometimes the holes identified in this way have direct interpretations. Mathematician Jose Perea of Northeastern University and a team of computational biologists used persistent homology to find periodic biological processes—those that repeat at regular intervals. Examples include the metabolic cycle of yeast or a mouse's circadian clock. "What is recurrence or repetition?" Perea asks. "Geometrically it should be like you're traversing some sort of loop in the space of the thing that you're looking at jzdm."

TDA has also helped researchers de sign new drugs. These compounds are often found by tweaking the molecular structure of existing drugs. But the structure of molecules is extremely complex and difficult to analyze, even for machine-learning algorithms. To design novel drugs, computers need to work with simplified representations of the existing molecules. There are many ways to do this, but a team led by Guowei Wei of Michigan State University chose to reduce molecules to their "topological signatures." This is the description of the chemical based on its topological characteristics—essentially the collection of information gained through persistent homology, such as the number of stubborn holes in each dimension.

BRAIN LOOPS

THE MOST INTRIGUING application of TDA might be at the most basic level of brain organization—a single type of neuron. In 2014 John O'Keefe and research partners May-Britt Moser and Edvard Moser received the Nobel Prize in medicine for discovering, respectively, place cells and grid cells, types of neurons that activate when an animal is in specific locations. They act as sensors for position, says Carina Curto, a mathematician at Pennsylvania State University.

Each grid cell in a rat's brain lights up when it is in several places within its environment. To figure out the relationship between the grid cells and the rat's location, neuroscientists picked a single grid cell to study. They drew a dot on a computer model of the floor, marking where the rat was each time that cell activated. As the rat moved freely about the square box, a regular and repeating pattern of dots emerged, of a kind that mathematicians describe as a hexagonal lattice. The dots on the lattice represented all the locations where that particular grid cell lit up. They repeated this process with multiple grid cells, marking each one in a different color. The dots corresponding to each grid cell had the same overall geometric pattern but were offset from one another, covering the box like busy tiling.

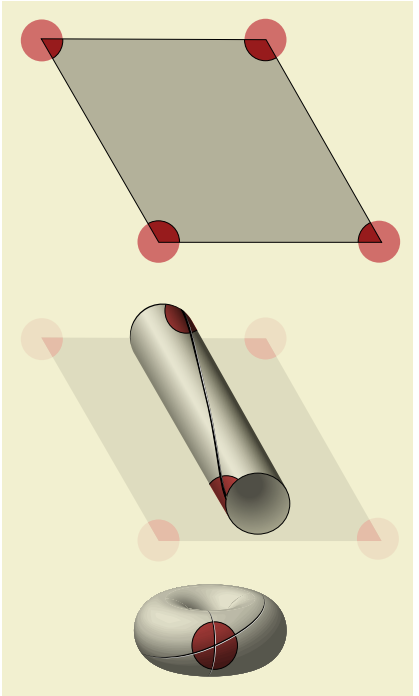


Four different grid cells (*red*, *pink*, *blue*, and *green*); each activates in a repeating pattern of regions.

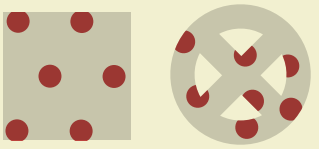
Source: "What Can Topology Tell Us about the Neural Code?" by Carina Curto, in *Bulletin of the American Mathematical Society*, Vol. 54, No. 1; January 2017 (*reference*)

Neuroscientists wanted to understand exactly how the grid cells represented spatial locations—in essence, they were looking for the template that produced the hexagonal pattern. For example, imagine a circular rubber stamp with various cartoon characters printed on it. As you roll out the stamp, it will create a line. The image of Mickey Mouse will appear at regular intervals along the line. But all those images came from the same location on the original rubber stamp. It's easy to imagine rolling out a stamp, but the reverse question is more challenging: How do you produce the template stamp from the pattern that it created?

In the tiling of colored dots representing where the rat was when each grid cell fired, four neighboring red dots formed the corners of a slanted rectangle known as a parallelogram. Just like the repeated images of Mickey Mouse, all the red dots of the same color corresponded to a single grid cell. So topologists identified all the red dots, folding the parallelogram into a doughnut shape using an operation they refer to as "gluing." First, they glued together two opposing sides of the parallelogram, forming a cylinder with two red dots: one on the top and one on the bottom. Next, they bent the cylinder, gluing together the two ends to form a torus. In this way, the four red corners of the parallelogram become a single point on the doughnut. Exactly one dot of every other color will show up on the torus. Thus, just like the circular stamp was the template for the line of cartoons, a torus is the correct map for how grid cells represent the floor of the box.



Neuroscientists could see this pattern when the rat was running around a box. But it was harder to visualize the pattern when the rat moved around other test fields, like a bicycle wheel with spokes and a central hub. Each grid cell was still firing in multiple positions, but scientists were not confident about the underlying map. The arrangement of dots was not obviously structured.

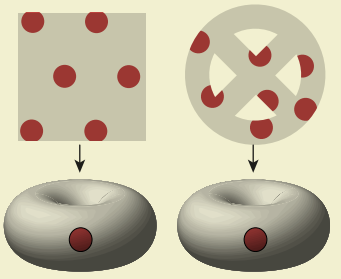


Simplified view of a grid cell firing pattern when a rat runs around a box, which displays a regular pattern (*left*), and when a rat runs about a wheel-shaped arena, which does not display an obvious pattern (*right*).

In a February 2022 *Nature* paper, a team of mathematicians and neuroscientists, including Dunn, used grid cells to test a theory called continuous attractor networks, which predicts that certain neurons are wired together in a specific pattern—and the pattern does not change even if the animal is in a different situation. To test the theory of continuous attractor networks, researchers needed to determine whether the grid cells always form a torus, no matter what environment the rat finds itself in. They were searching for tori in messy neurological data—the perfect job for TDA.

This time, instead of marking the positions in a box where a single grid cell fired, the researchers studied the collective activity of an entire network of grid cells. At regular intervals they recorded the state of the network using a string of 0s and 1s, which indicated whether each grid cell was active or not. From a mathematician's perspective, this long string is a point in a very high-dimensional space. In effect, as the researchers recorded the state of the system at different instants, they were accumulating high-dimensional data points. These points describe the way patterns of grid cell activation evolve in time, but the data are too complicated to study with the naked eye.

After using some standard techniques to simplify the data, the team computed the persistent homology of the system by connecting the data points at different scales and examining the resulting simplicial complexes. As before, the data formed a torus when the rat was running about a box. But the real test was when the researchers derived data from a rat running around a wheel-shaped arena. To their delight, it again formed a torus.



Both the box and wheel-shaped grid cell firing patterns mapped to a torus.

The researchers were even able to collect data from a sleeping—possibly dreaming—rat. Again, they found a torus, a shape that persisted regardless of the rat's environment or state of being, a finding that supports the theory of continuous attractor networks. The doughnut shape seems to be intrinsic to how grid cells represent space.

Many of these applications of topological data analysis are only possible because of powerful new computational tools. "None of this would have happened if people hadn't seriously started building algorithms," says Vidit Nanda, a mathematician at the University of Oxford. "If it's not effective, if it doesn't scale well, then nobody wants to use it, no matter how beautiful the theory is."

Thanks to these technologies, the uses of topology, which until recently seemed to be no more than an abstract, if amusing, branch of mathematics, are burgeoning. "The applications are getting stronger and stronger," says Gunnar Carlsson, a mathematician at Stanford University and one of the pioneers of TDA. "We've really crossed the chasm." SA

FROM OUR ARCHIVES

The Math of Making Connections. Kelsey Houston-Edwards; April 2021.

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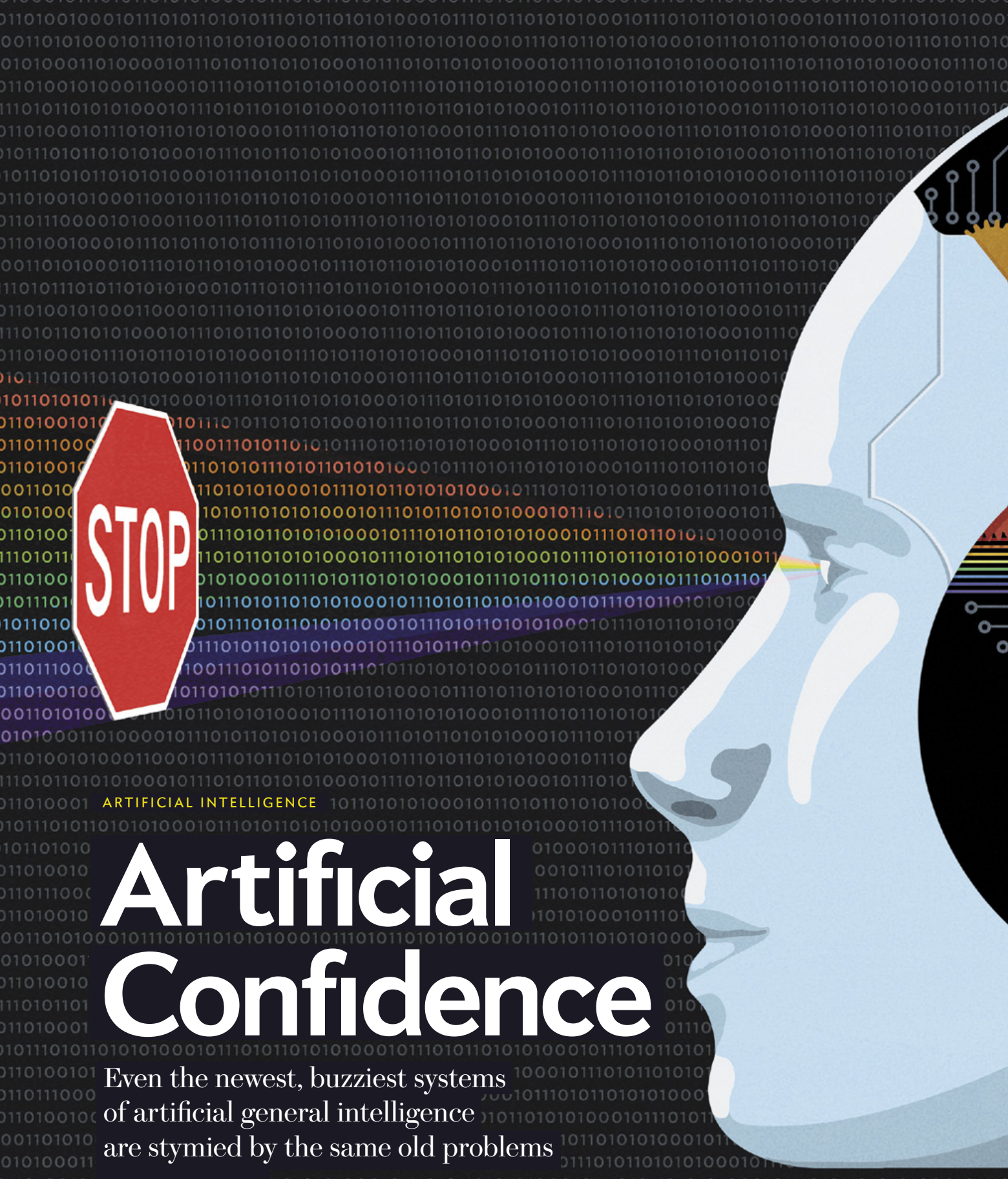


ARTIFICIAL INTELLIGENCE

Artificial Confidence

Even the newest, buzziest systems of artificial general intelligence are stymied by the same old problems

By Gary Marcus

Illustration by Michael Glenwood

Gary Marcus is a scientist, best-selling author and entrepreneur. His most recent book, co-authored with Ernest Davis, is *Rebooting AI* (Vintage, 2019).

TO THE AVERAGE PERSON, IT MUST SEEM as if the field of artificial intelligence is making immense progress. According to some of the more gushing media accounts and press releases, OpenAI's DALL-E 2 can seemingly create spectacular images from any text; another OpenAI system called GPT-3 can talk about just about anything—and even write about itself; and a system called Gato that was released in May by DeepMind, a division of Alphabet, reportedly worked well on every task the company could throw at it. One of DeepMind's high-level executives even went so far as to brag that in the quest to create AI that has the flexibility and resourcefulness of human intelligence—known as artificial general intelligence, or AGI—"the game is over."

Don't be fooled. Machines may someday be as smart as people and perhaps even smarter, but the game is far from over. There is still an immense amount of work to be done in making machines that truly can comprehend and reason about the world around them. What we need right now is less posturing and more basic research.

AI is making progress—synthetic images look more and more realistic, and speech recognition can often work in noisy environments—but we are still likely decades away from general-purpose, human-level AI that can understand the true meanings of articles and videos or deal with unexpected obstacles and interruptions. The field is stuck on precisely the same challenges that academic scientists (including myself) having been pointing out for years: getting AI to be reliable and getting it to cope with unusual circumstances.

Take the recently celebrated Gato, an alleged jack of all trades, and how it captioned an image of a pitcher

hurling a baseball (*above*). The system's top three guesses were:

A baseball player pitching a ball on top of a baseball field.

A man throwing a baseball at a pitcher on a baseball field.

A baseball player at bat and a catcher in the dirt during a baseball game.

The first response is correct, but the other two answers include hallucinations of other players that aren't seen in the image. The system has no idea what is actually in the picture, beyond the rough approximations it draws from statistical similarities to other images. Any baseball fan would recognize that this is a pitcher who has just thrown the ball and not the other way around. And although we expect that a catcher and a batter are nearby, they obviously do not appear in the image.

Likewise, DALL-E 2 couldn't tell the difference between an image of a red cube on top of a blue cube versus an image of a blue cube on top of a red cube. A newer system, released this past May, couldn't tell the difference between an astronaut riding a horse and a horse riding an astronaut (*opposite page*).

When image-creating systems like DALL-E 2 make mistakes, the result can be amusing. But sometimes errors produced by AI cause serious consequences. A Tesla on autopilot recently drove directly toward a human worker carrying a stop sign in the middle of the road, slowing down only when the human driver intervened. The system could recognize humans on their own (which is how they appeared in the training data) and stop signs in their usual locations (as they appeared in the training images) but failed to slow down when confronted by the unfamiliar combination of the two, which put the stop sign in a new and unusual position.

Unfortunately, the fact that these systems still fail to work reliably and struggle with novel circumstances is usually buried in the fine print. Gato, for instance, worked well on all the tasks DeepMind reported but rarely as well as other contemporary systems. GPT-3 often creates fluent prose but struggles with basic arithmetic and has so little grip on reality it is prone to creating sentences such as "Some experts believe that the act of eating a sock helps the brain to come out of its altered state as a result of meditation." A cursory look at recent headlines, however, wouldn't tell you about any of these problems.

The subplot here is that the biggest teams of researchers in AI are no longer to be found in the academy, where peer review was the coin of the realm, but in corporations. And corporations, unlike universities, have no incentive to play fair. Rather than submitting their splashy new papers to academic scrutiny, they have taken to publication by press release, seducing journalists and sidestepping the peer-review process. We know only what the companies want us to know.

In the software industry, there's a word for this kind of strategy: "demoware," software designed to look good for a demo but not necessarily good enough for the real world. Often demoware becomes vaporware, announced for shock and awe to discourage competitors but never released at all sfkw.

Chickens do tend to come home to roost, though, eventually. Cold fusion may have sounded great, but you still can't get it at the mall. AI will likely experience a winter of deflated expectations. Too many products, like driverless cars, automated radiologists and all-purpose digital agents, have been demoed, publicized—and never delivered. For now the investment dollars keep coming in on promise (who wouldn't like a self-driving car?). But if the core problems of unreliability and failure to cope with outliers are not resolved, investment will dry up. We may get solid advances in machine translation and speech and object recognition but too little else to show for all the premature hype. Instead of "smart" cities and "democratized" health care, we will be left with destructive deepfakes and energy-sucking networks that emit immense amounts of carbon.

Although deep learning has advanced the ability of machines to recognize patterns in data, it has three major flaws. The patterns that it learns are, ironically, superficial not conceptual; the results it creates are hard to interpret; and the results are difficult to use in the context of other processes, such as memory and reasoning. As Harvard University computer scientist Les Valiant noted, "The central challenge [going forward] is to unify the formulation of … learning and reasoning." You can't deal with a person carrying a stop sign if you don't really understand what a stop sign even is.

Imagen

For now we are trapped in a "local minimum" in which companies pursue benchmarks rather than foundational ideas. Current engineering practice is far ahead of scientific skills: these departments focus on eking out small improvements with the poorly understood tools they already have rather than developing new technologies with a clearer theoretical ground. This is why basic research remains crucial. That a large part of the AI research community (like those who shout, "Game over") doesn't even see that is, well, heartbreaking.

Imagine if some extraterrestrial studied all human interaction only by looking down at shadows on the ground, noticing, to its credit, that some are bigger than others and that all shadows disappear at night. Maybe it would even notice that the shadows regularly grew and shrank at certain periodic intervals—without ever looking up to see the sun or recognizing the 3-D world above.

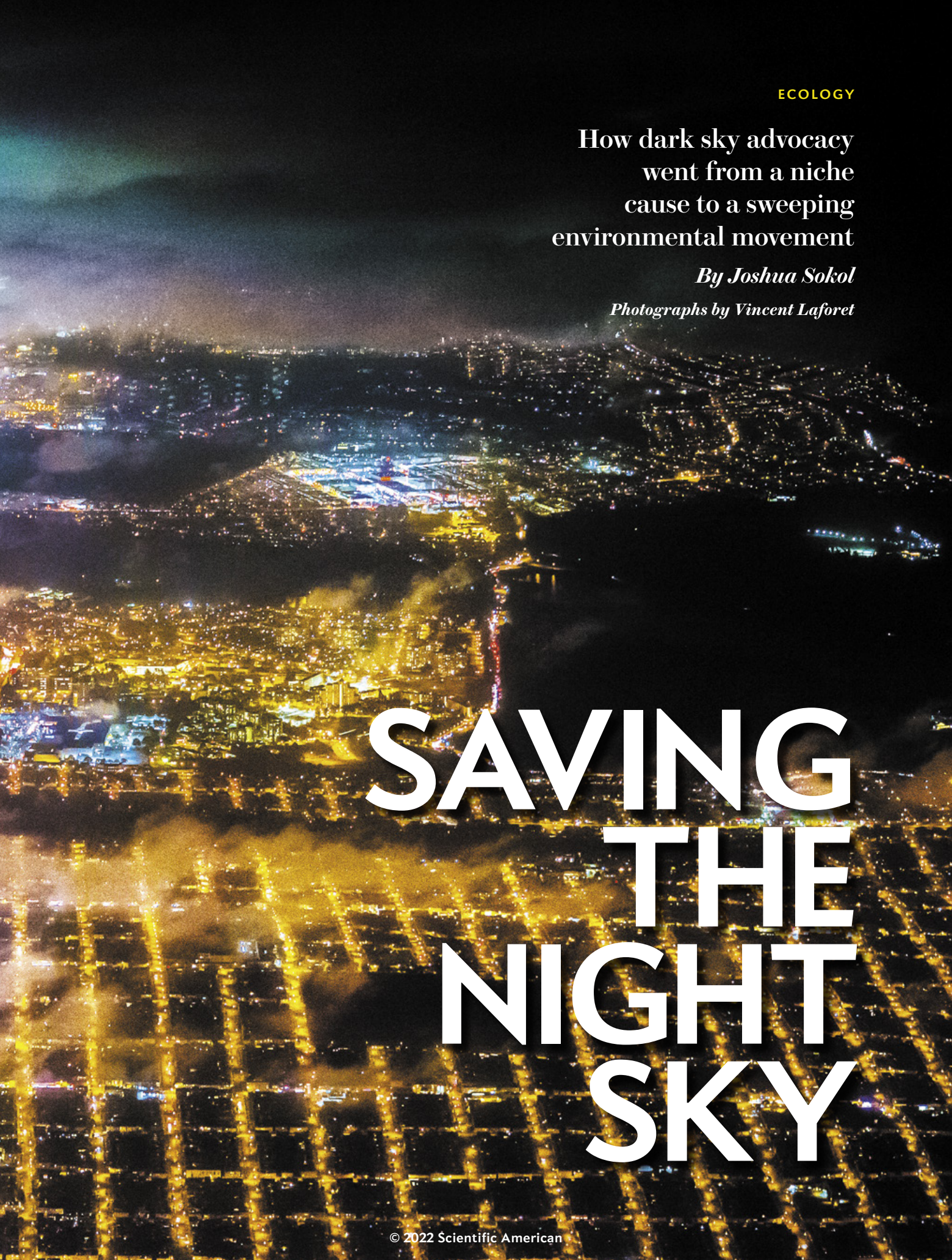
It's time for artificial-intelligence researchers to look up from the flashy, straight-to-the-media demos and ask fundamental questions about how to build systems that can learn and reason at the same time. SA

FROM OUR ARCHIVES

Will Artificial Intelligence Ever Live Up to Its Hype? John Horgan; ScientificAmerican.com, December 4, 2020.

scientificamerican.com/magazine/sa

AERIAL VIEWS of cities at night, such as this photograph of San Francisco, show both the allure of artificial light and the challenge of reducing it.



ECOLOGY

How dark sky advocacy went from a niche cause to a sweeping environmental movement

By Joshua Sokol

Photographs by Vincent Laforet

SAVING THE NIGHT SKY

Joshua Sokol is an award-winning freelance science journalist whose work has appeared in *Science*, the *Atlantic*, the *New York Times*, and many other publications. He lives in Raleigh, N.C. His reporting on the environmental status of the night sky was supported by a 2021 fellowship from the Alicia Patterson Foundation.

DARKNESS WAS FALLING AT KITT PEAK NATIONAL OBSERVATORY OUTSIDE TUCSON, Ariz. At this hour Michelle Edwards, the observatory's associate director, would usually be inside prepping for a night on the telescope. But on this evening last December she stood alongside me in the twilight, watching two worlds collide. As the stars came out, electric lights dotting the landscape below turned on, too, leaving a diminished Milky Way arcing above the brighter civilization. "Holy crap," Edwards said, taken aback by the enormous city glow.

Tucson was a bright bubble eating the eastern sky and the shoulder of Orion. A snake of lesser lights—Interstate 10—wriggled out from the glow, winding 100 miles north toward the glare of Phoenix. To the south, across the Mexican border, loomed another luminous half-circle from the lights of Nogales.

All that light is an existential threat to high-grade stargazing on Kitt Peak. Over the decades astronomers have taken urgent steps to slow or even reverse its spread. For them, the boundary of each glowing dome was a battle line, expanding or shrinking with each skirmish won or lost; the imperfect darkness overhead was a testament to local policy and millions of collective actions—or collective shrugs and proliferations of gleaming billboards and streetlights.

Yet the glow keeps spreading. Under skies so filled with stray photons, it takes twice as long to resolve an astronomical target as it typically would, one Kitt Peak astronomer told me a few hours after sunset. Intense wildfires linked to global warming (such as one that swept the summit half a year after my visit) may pose more obvious risks to the telescopes there, but the subtle, pernicious effects of ever brighter nights could eventually become an even bigger threat to astronomy.

Species spiraling into oblivion, a few extra parts per million of carbon dioxide in the air, sea life gobbling up microplastics—many of our era's ecological calamities are hard to see with unaided eyes. Not so with light pollution, even though astronomers looking through telescopes may have been the first to really notice it. Its impacts are not limited to astronomy, of course. Over the past decade biologists have discovered that wasteful nighttime lighting drastically disrupts animals, plants and the ecological relationships that knit the world together. These effects reach across entire regions of the globe, far outside of cities. "You need to think about it much more like we might think about plastic pollution or some of the climate change effects," says Kevin Gaston, a prominent U.K.-based conservation biologist at the University of Exeter.

Researchers still maintain that we can reduce light pollution without much sacrifice. As new research reveals the scope of the problem, possible fixes become clearer as well. Light pollution is something we can understand and manage, like smokestack emissions or factory wastewater. The sooner we act, the better. Satellite measurements suggest that more than three in five Europeans and four in five North Americans live under skies too light-swamped to allow them to see the Milky Way. Other analyses show Earth's artificially lit surface area bloating outward by about 2 percent a year, transforming the remaining map of true night into Swiss cheese. And although recent LED technology has made lighting cheaper and more energy-efficient than ever, consumers don't seem to be pocketing those savings and reducing carbon emissions. Instead humanity seems to be switching on even more lights.

It doesn't have to be this way. Dark, star-filled skies

can once again become the rule rather than the exception, easing the burden on already struggling ecosystems while restoring some celestial wonder into ordinary human lives. Legislation aiming to achieve as much is already being drafted on multiple continents. Any solution, however, depends on questions more social than scientific: Can we sustain the necessary research to properly define and address light pollution? How much nighttime lighting do we really need? And most crucially, maddeningly—does anyone care?

TO GIVE SCIENTISTS AND THE REST OF US some credit, it has always been hard to assess the ecological implications of bathing the world in an eternal false twilight. To some creatures, a lamp is a siren call; to others, it's a repulsive force field. Light's timing, wavelength, direction and intensity, as well as the eyes of the beholder, all matter, and unlike mercury in tuna or DDT in bald eagles, photons don't leave behind a lasting measurable chemical trace. Taken together, though, studies on at least 160 species provide ample evidence that artificial lights send the natural world a bewildering array of ill-timed signals—Wake up! Hide! Hunt! Fly this way! Change your metabolism!

One morning in May of last year, I drove out to a cattle farm in rural North Carolina to meet Murry Burgess, a graduate student at North Carolina State University who had strung up little Christmas lights over swallow nests built in the rafters of a barn. She went up on a ladder, pulled out what looked like squirmy, stubble-feathered dinosaurs one by one, and subjected each chick to a battery of tests while clutching it gently in her warm palms. The parents didn't know to move their nests away from the lights, she said, and the light took a toll on their babies' bodies. Compared with neighboring chicks growing up under no lights, coming of age under just one tiny bulb had made these birds stunted and underweight. "It's crazy how light goes all the way in deep into their cells," Burgess told me.

What harms individual baby barn swallows also operates on the scale of entire species, even ecosystems. Offshore, artificial light can cause reef-building corals that grasp toward the surface to stop spawning all at once, turning what should be synchronized explosions of fresh life into useless, mistimed puffs of eggs and sperm. In the U.S. alone, somewhere between several hundred million and one billion birds die every year after thwacking into windows, many of them beckoned by interior lights.

Insects especially are facing dire consequences. Moths keep flapping into lightbulbs for reasons scientists still don't quite understand. Cricket calls are becoming decoupled from the rhythms of night and day. In the British countryside, research shows caterpillar populations plummeting in roadside hedgerows illuminated by LED streetlights. Light pollution is almost certainly hastening the so-called insect apocalypse, the planet's declining portfolio of bug biomass, although little research has focused on this grim end point.

Light pollution ripples through multiple domains of life. In one 2017 experiment, scientists with night-vision goggles watching cabbage thistle plants confirmed that ambient light deterred nocturnal pollinating insects from making their rounds. Daytime pollinators couldn't make up the deficit, so the plants bore less fruit, suggesting that the effects of brightening nights could eventually show up in supermarket aisles. And while nocturnal light can lead the insects we like to lose conviction, it can fill those we despise with passionate intensity: the mosquito *Aedes aegypti,* which causes a staggering 400-million-odd infections such as dengue and Zika a year, seems encouraged to bite more in the presence of artificial light, as does another mosquito species that spreads West Nile virus.

Artificial lights send the natural world a bewildering array of ill-timed signals—Wake up! Hide! Hunt! Fly this way! Change your metabolism!

Such observations used to be documented one organism at a time in specialist journals, unconnected to a broader research program. But in the late 1990s a pair of grad students and self-described environmental "troublemakers" in Los Angeles began building up a dossier of these kinds of stories. Catherine Rich, a lawyer turned ecologist-in-training, got accepted to several Ph.D. programs, but when she went looking for an adviser who would let her study the effects of light pollution on wildlife, she found no takers. "I would hear things like 'you might not get any results,'" she says. But Rich and her now husband Travis Longcore stuck with the issue and organized what would prove to be a seminal academic conference on the subject.

In their 2002 conference, a 2004 review paper and a subsequent book, Longcore and Rich steered clear of another, parallel field of research—the ongoing exploration of what living in a brighter outdoors and brighter-still indoor world does to human health. (We know light exposure at night is associated with myriad problems, ranging from the obvious, like sleep disruption, to the more surprising, like higher breast cancer risk, but it isn't clear yet how much of this is from outdoor light pollution versus our glowing screens and indoor fixtures.) Even so, journalists and the public began to pick up on the idea that light pollution was real pollution, ecologically speaking. By 2011 high-powered European ecology laboratories such as Gaston's picked up the topic and began cranking out their own results and meta reviews of the literature. As of this year, Longcore and Rich's review paper has been cited more than 1,500 times.

Many of these results involve the easiest kind of light pollution to picture: a single, intense light source shining at you with the harsh glare of LED headlights on a new-model SUV. More recently, however, others have focused on the subtler, more encompassing light-bubble effect I saw from Kitt Peak. The latest, most painstaking ecological findings show that these levels of ambient light pollution have biological consequences, too, even with no specific light sources in sight.

A series of recent experiments, conducted in tanks and under domes bobbing in a German lake, showed that bright skies alone can cause sagging levels of melatonin—a hormonal messenger of darkness—and alter reproductive hormones in Eurasian perch. A separate paper last year showed that whiter nights disoriented dung beetles in South Africa, which look toward the Milky Way to guide themselves in the humble but essential task of burying poop in the savanna. Yet another 2021 study, led by Longcore, showed similarly low thresholds of light on stretches of California beach can prevent plovers from roosting and fish called grunion from throwing themselves ashore to spawn.

All this matters because domes of light from skyglow are visible for hundreds of miles across state and international borders, and studies show they lure migratory birds and insects at regional scales. Even in the rare corners of the planet these domes haven't yet reached, organisms already seem attuned to the faintest changes in lighting. Over winter in the Arctic Ocean, for example, plankton rise and fall each day despite the sun never breaching the horizon. Artificial light from fishing or mining could also scramble that system.

There is no real, organized "pro-skyglow" opposition on the other side of all this funneling money to politicians or pumping out contrarian studies. The problem, scientists assert, is that current lighting trends are driven by unquestioned development and millions on millions of oblivious human decisions. Setting aside regions left in the dark by poverty and neglect, precious few communities have managed to slow down light's advance.

Two weeks before my sojourn at Kitt Peak, I stood shivering in the late-night chill beneath the ponderosa pines around Lowell Observatory in Flagstaff, gazing up at a lunar eclipse. As Earth's shadow slid across the face of the moon, the black of bare sky deepened, and the stars popped brighter, as if a photo editor were fiddling with the vista's contrast levels.

The most memorable part of the whole experience, though, was the downward view overlooking Flagstaff. Almost no illumination besides individual stoplights shined back up. You could blink and convince yourself you were overlooking a sleepy coastal hamlet, not a mountain town of more than 75,000 hoping to snag tourists on their way to the Grand Canyon. It looked like a little corner of modernity had somehow taught itself to close its eyes and fall asleep.

To date, the most successful defenses of dark skies have been mounted in places where astronomers could rally around facilities with economic value. In 1958, around the same time Rachel Carson got the tip that spawned *Silent Spring* and modern environmentalism, astronomers at Lowell Observatory began to worry about spinning searchlights used in advertising spoiling their view of the sky. In response, Flagstaff put the world's first light-pollution ordinance on the books. Arizona—not exactly a place famous for collectivist, big-government policies—has been the heartland of the dark sky movement ever since.

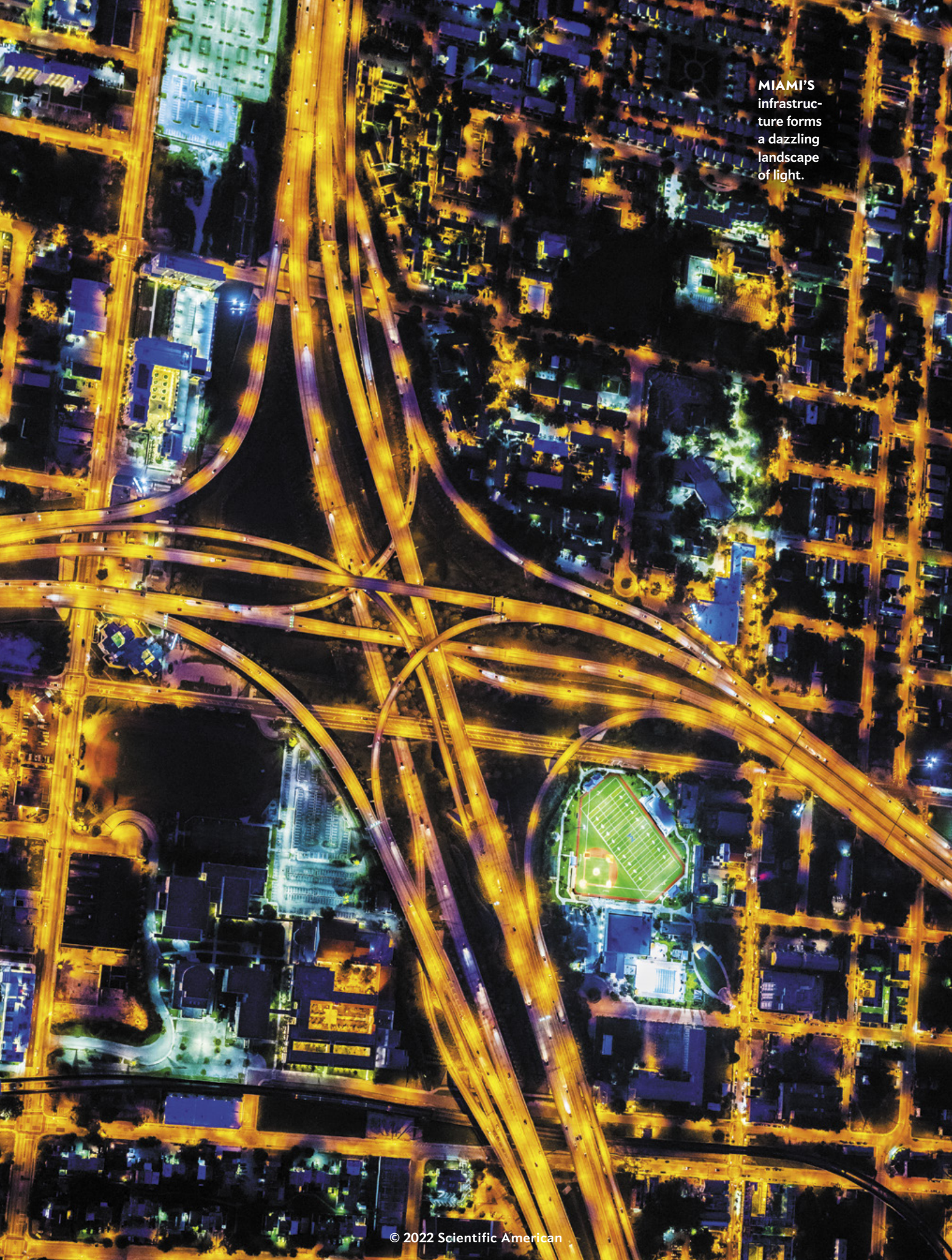
Two years earlier, a few hundred miles to the south, astronomers and tribal guides from the surrounding Tohono O'odham nation had ridden on horseback to the top of Kitt Peak, exchanging Western and Indigenous star stories by a campfire at the summit. Soon the federal government leased the land from the tribe in perpetuity, and bigger and better telescopes bloomed on the mountaintop.

As light pollution in nearby Tucson ballooned, Kitt Peak astronomers found allies such as Tim Hunter, a doctor who had grown up seeing the Milky Way through elms in the Chicago suburbs, then watched helplessly as artificial light dimmed the galaxy just like Dutch elm disease rotted the trees. Together Kitt Peak astronomer David Crawford and Hunter formed the International Dark Sky Association (IDA) in 1988, hoping to build a broader coalition that included their allies in Flagstaff.

Over the years, as advocates watched darkness retreat, the tools and techniques required to track it advanced. Light-pollution modeling progressed from pen-and-paper equations to computerized ray-tracing simulations. Sophisticated wide-angle cameras made it easier to measure skyglow from the ground, and satellite images started showing spidery webs of light spreading across the globe. The general trend was, and remains, dismal: the better researchers can study the problem, the worse it appears to be.

The IDA and its affiliated researchers reject the assumption that light pollution must intensify as cities grow. Usually crime prevention is the municipal excuse for banishing the night. But how well does this work? Perhaps the most definitive evidence that light suppresses crime comes from an experiment begun in 2016 in which criminologists lugged nearly 400 basketball hoop–sized lighting towers into public outdoor spaces in New York City housing developments. Powered by their own portable fuel generators, the blue-white fixtures were left on from sunrise to sunset—and outdoor crimes around the light towers at night dropped by about 45 percent.

But dark sky researchers point out that these towers were far brighter than mere streetlights. They also note the ethically dubious nature of any anticrime policy that relies on subjecting majority-minority communities to prison yard–esque floodlights all night long. Indeed, across the continental U.S., the burden of light at night, like other known pollutants, falls harder on less powerful groups: according to a 2020 study from



MIAMI'S infrastructure forms a dazzling landscape of light.

researchers at the University of Utah, Black, Hispanic and Asian American neighborhoods tend to be about twice as illuminated as white ones.

Road safety is another common rationale for the proliferation of lights at night. But here, too, scientists argue that brightness standards are driven by convention, not science. In 2018 lighting researchers from England and the U.S. scanned regulations in Europe and North America. "There appears to be little, if any, credible empirical support for light levels recommended in much current road lighting guidance," they concluded.

Other lighting choices come down to industries and individual people, many of whom remain unreached or unmoved by the issue. Spend any time in dark sky circles, and you'll hear talk of a curse: a moment of revelation, of veil lifting, when you suddenly see bad, wasteful lighting and then can't unsee it. (Mine came on a walk in my Raleigh, N.C., neighborhood, when I realized a richer, whiter "historic" stretch of blocks had dimmer amber streetlights, and the adjacent historically Black neighborhood had harsher white fixtures.)

Many activists have also taken that curse as a call to action. The day after watching the lunar eclipse in Flagstaff, I sat down with Chris Luginbuhl in the city's Dark Sky Brewing Company. Playing along, he ordered a "Circadian Rhythm." That on-the-nose brew had run out, though, so he settled for a brown ale.

Luginbuhl, a former astronomer at the nearby U.S. Naval Observatory who has worked to protect Flagstaff's skies for four decades, knows the field of dark sky science and its progress better than almost anyone. He and his coalition are "like the John Muir character," one colleague told me, "kind of nutty but superpassionate." Streetlights here are a dim orange because, as Luginbuhl explains, blue-tinged light is more disruptive to most animals at night (humans included), as well as to nearby astronomical observatories. That's because bluer, shorter-wavelength photons scatter more readily in the air, creating a localized fog of light.

Nursing his beer, Luginbuhl praised his town as a paragon, a proof of concept that other communities could emulate. In 2017 the U.S. National Park Service deployed an ultrasensitive panoramic camera outside both Flagstaff and the similarly sized city of Cheyenne, Wyo., which does not have comparable dark sky ordinances. Cheyenne was 14 times brighter than Flagstaff, and the bubble of trapped light around it was eight times bigger. Luginbuhl says his strategy has been simply to show people the stars and convince them that being able to see them is a matter of choice—that there is no zero-sum conflict pitting growth against wilderness. "Do I think that stars will win out over light? Almost every time," Luginbuhl says. "They're mind-bending, and everybody needs to have their minds bent."

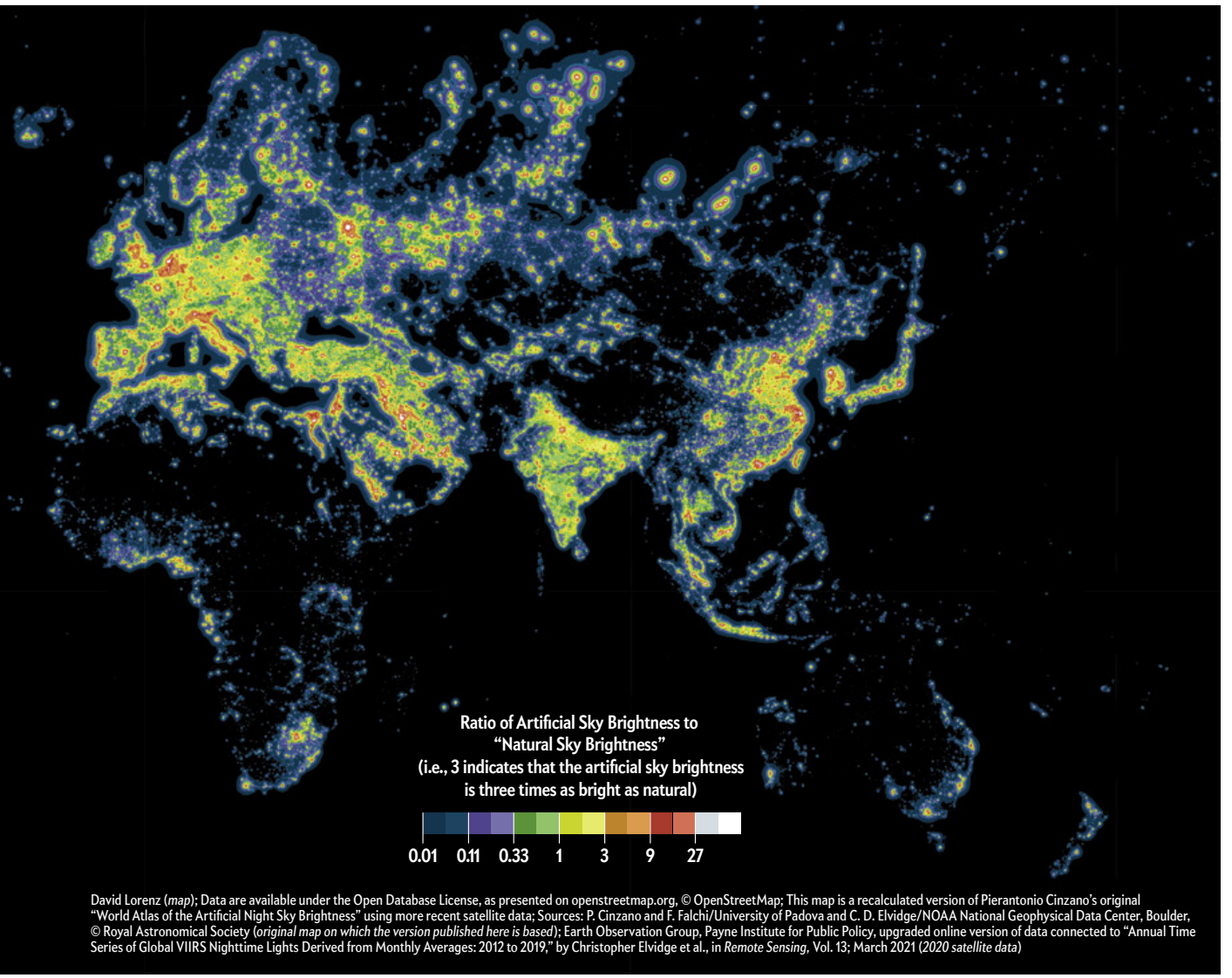
IN THE SPRING OF 1942 Nazi Germany sent U-boats slinking across the Atlantic to prey on American shipping lanes. Cargo sank by the ton, drowned bodies washed ashore, and it soon became clear that the submarine gunners were picking off ships at night by watching for their dark silhouettes against skyglow over the coast.

Elected officials and chambers of commerce in cities such as Miami were pressured to dim lights and turn off glitzy outdoor displays. Clearly, this light pollution had literal life-or-death stakes. For three months, though, community leaders dragged their heels, subverting a collective response, citing economic concerns. The carnage offshore ultimately moved President Franklin D. Roosevelt to issue an executive order that compelled coastal blackouts, and U-boat attacks waned as defensive patrols were stepped up and communities for many miles inland restricted their use of nighttime lights, even taping over car headlights. All this is within living memory: my late grandmother, a teenager at the time, told stories about how serious it felt to keep the lights off that summer in Wrightsville Beach, N.C.

"It's like, oh, my God," says Christopher Kyba, a physicist and dark skies advocate at the GFZ German Research Center for Geosciences in Potsdam. Even back

Bright Skies, Dark Futures

Derived from Earth-observing satellite data, global maps of nighttime artificial lighting such as the one here can be used for many purposes—from estimating economic development to evaluating suitability for stargazing from any point on the planet. Because of the environmentally disruptive effects of even low illumination levels, however, such maps can also reveal where lighting most threatens fragile creatures and ecosystems—and where, for now, they still find refuge.



David Lorenz (*map*); Data are available under the Open Database License, as presented on openstreetmap.org, © OpenStreetMap; This map is a recalculated version of Pierantonio Cinzano's original "World Atlas of the Artificial Night Sky Brightness" using more recent satellite data; Sources: P. Cinzano and F. Falchi/University of Padova and C. D. Elvidge/NOAA National Geophysical Data Center, Boulder, © Royal Astronomical Society (*original map on which the version published here is based*); Earth Observation Group, Payne Institute for Public Policy, upgraded online version of data connected to "Annual Time Series of Global VIIRS Nighttime Lights Derived from Monthly Averages: 2012 to 2019," by Christopher Elvidge et al., in *Remote Sensing*, Vol. 13; March 2021 (*2020 satellite data*)

then, "the U.S. government knew how to control skyglow! We're not waiting for some breakthrough technology." Smarter, more data-driven guidance on unnecessary lighting can exist; presumably the collective will to act on it can, too.

Barring that, it's easy to imagine the planet's wealthier regions cranking out ever more wasted light powered by wasted carbon, evaporating the remnants of true night like water from a drying lake bed and subjecting life on Earth to an additional stressor in a world increasingly full of them. Or—and this is also eminently possible—we can come to notice wayward light as we would a neighbor's garden sprinkler accidentally set to water the street. With enough restraint, the Milky Way can shine once more above bustling human communities.

Pressure to dim the lights is building. Multiple U.S. states are reviewing proposed dark sky–friendly legislation. Campaigns to turn off lights during bird migration season are spreading all over the country; in Texas cities such as Dallas and Houston, for example, more than 100 downtown buildings dimmed their lights this past spring. And since 2001, when the IDA started recognizing places where dark skies are being preserved—Flagstaff, of course, was first on the list—nearly 200 such sites have been certified around the globe.

Even bolder policies are unfolding in Europe. In France, a law passed in 2019 bars businesses from leaving decorative lights and signs illuminated all night. In Germany, which has developed a legal action plan to reverse insect declines, controlling light pollution is considered to be a major goal. On the technology front, LED makers, sensing an unmet need, are adding dark sky–friendly, downward-pointing, long-wavelength fixtures to the market. And the Holker Lab in Berlin—the ones behind those fancy lake experiments on skyglow—have developed prototype lights that don't emit the wavelengths disruptive to most insects. "The crazy thing about this problem," ecologist Jesse Barber of Boise State University told me, echoing a sentiment common throughout dark sky circles, "is it's so damn fixable."

IT'S HARD TO CARE FOR what you've never seen. The Milky Way—a glitter bomb of awe that all our grandparents and all preceding humanity could witness whenever they wanted—is the biggest reward for limiting light pollution. But unlike residents of the American West, who can summon its appearance with modest reductions in light, people in the more densely populated, brighter eastern U.S. can't gain even a subpar view of our galaxy without hours-long drives to isolated pockets of darkness. There are other perspectives to consider, though.

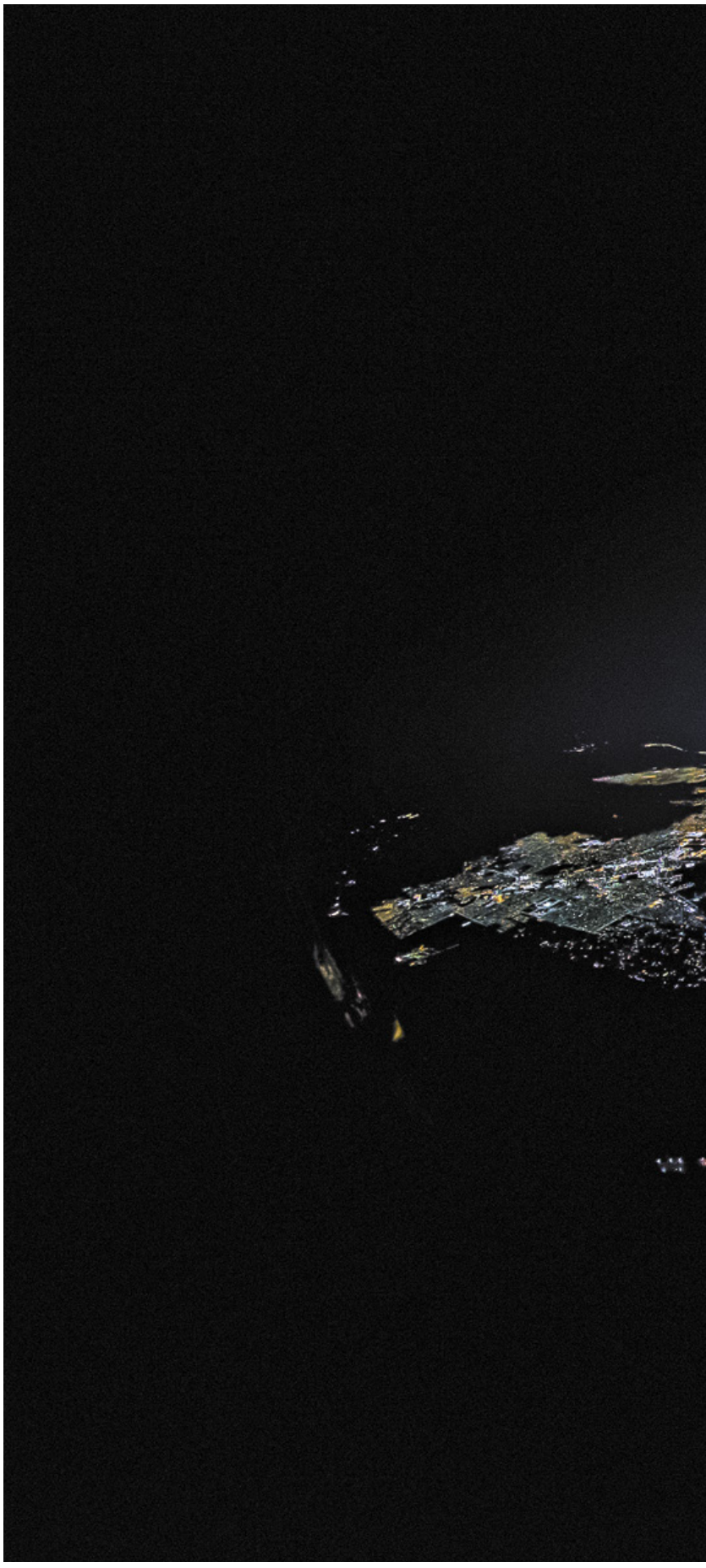
Recently I learned of a quiet little wonder left in my own world: a species of ghost firefly was discovered haunting old pine stands near my home in the Piedmont of central North Carolina. The males of this species keep their lights on for up to 30 seconds at a time, scrawling faint, floating messages, and the females sit still below, gleaming back up silent, greenish answers.

In 2021 citizen scientists spotted populations of this firefly in some of the state's most urbanized counties, where, of course, they had been all along. They easily could have been paved over to extinction before anyone noticed. The entomologist searching for the species, Clyde Sorenson of North Carolina State, even stumbled onto a population in his very own backyard. "I've been living there for 25 years," he told me, sheepishly.

Desperate for a little reenchantment myself, I pulled up in his driveway one evening this past spring. We set out into the adjoining woodlot, wearing headlamps and crunching through leaves as a bullfrog bellowed in the background. This being a new species, we didn't know the exact time of year to expect it or the right weather. We did know darkness was necessary.

Fireflies, obviously, are sensitive to levels of light, the medium in which they communicate. Studies show ambient light pollution obstructs firefly courtship to the extent that some species don't even bother to try. As we walked that night, errant rays—from our phones, streetlights through the trees, the neighbor's security floodlight—kept needling their way back in, illuminating all the fireflies' likely hiding spots.

But then we saw three huddled females scintillating like misplaced stars, glowing from a shadowy crevice of glare-blocking leaf litter. Their bodies were the size of grains of rice. I leaned in close, and each firefly's star divided into two emerald dots, two side-by-side light organs cranking out their own feeble wattage into the scattered remnants of the dark—a broadcast they continued for about half an hour, until that evening's shift ended, and they winked out. SA



FROM OUR ARCHIVES

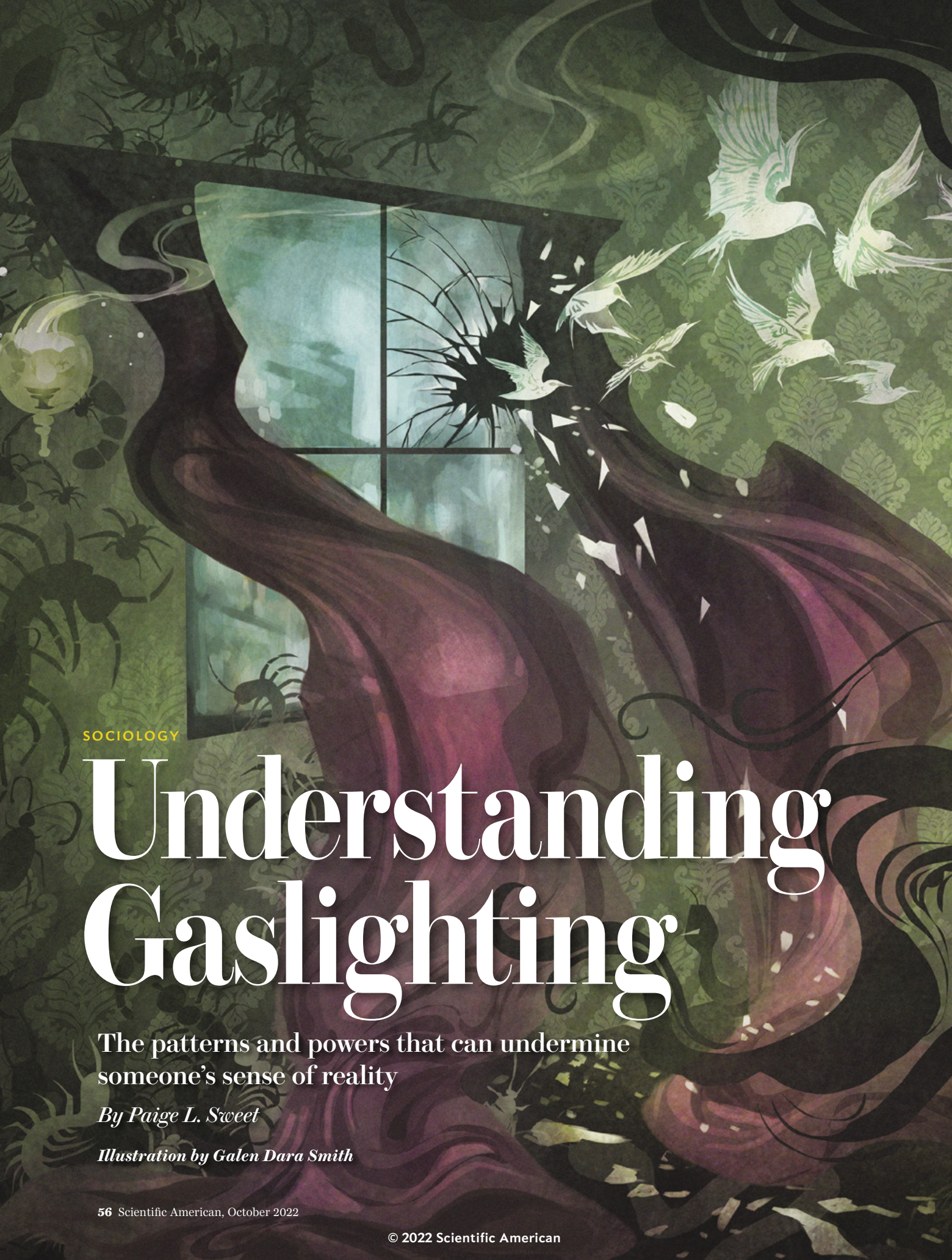
New Map Shows the Dark Side of Artificial Light at Night. Lee Billings; ScientificAmerican.com, June 10, 2016.

The End of Night. Joshua Sokol; February 2018.

Light Blight. Steve Mirsky; February 2020.

scientificamerican.com/magazine/sa

A TYPICAL STARLESS SKY over Las Vegas, one of the brightest nighttime cities on Earth.



SOCIOLOGY

Understanding Gaslighting

The patterns and powers that can undermine someone's sense of reality

By Paige L. Sweet

Illustration by Galen Dara Smith

Paige L. Sweet is an assistant professor of sociology at the University of Michigan and author of *The Politics of Surviving* (University of California Press, 2021).

DURING HER 12-YEAR MARRIAGE, "CHANDRA" SAYS, HER HUSBAND ROUTINELY CHEATED and then told her she was "crazy," "jealous" and "paranoid" when she produced evidence of his affairs. He often used the word "irrational," historically a term used to demean women. Chandra worked, went to school and provided all of the care for their children, yet her husband convinced her that she needed him. He would, for instance, intentionally delay paying bills and then blame her when the lights were shut off—a strategy of financial control that made her feel dependent on him. During an hour-long Zoom interview as part of my research, Chandra repeatedly described her ex-husband as a gaslighter.

After ending the call with Chandra (a pseudonym to protect her privacy and safety), I jotted down notes: confusion, unequal caregiving responsibilities, shame, credibility loss, gender-based insults, verbal abuse. Her experiences are typical of the stories I've collected about gaslighting over the past few years. Over time the way Chandra's ex-husband called her "crazy" and accused her of "overreacting" made her doubt herself as a reliable witness to her own experiences.

But this effect was not produced in a vacuum. Chandra was socially isolated from her friends and family. She was experiencing financial stress as well as a lack of support around balancing child care with her jobs. These vulnerabilities made her less able to resist her husband's manipulations, and she became psychologically exhausted and entrapped. Chandra questioned her perception of reality, her memory and her ability to interpret events. She wondered if she *was* crazy.

Gaslighting is broadly defined as a type of psychological abuse that makes someone seem or feel "crazy." It resembles other forms of psychological abuse and can be thought of as a subset of this broader category. We know that psychological abuse, and "crazy making" in particular, is a core feature of domestic, or intimate partner, violence. It functions in part by convincing victims that what they are experiencing is not real or important and then blames them for their experience.

The result is what sociologist Kathleen Ferraro has called the "surreality" of abusive relationships or what scholar and activist Beth E. Richie refers to as a "hostile social environment." The word itself comes from a 1930s play called *Gas Light* that was turned into a 1944 film starring Ingrid Bergman. In it, the protagonist's husband secretly dims and brightens the gas-powered indoor lights and insists she is imagining it, making her believe she is insane.

Over the past decade the term has become astronomically popular. Partly this is a result of the success of the #MeToo movement, which illuminated how victims of sexual violence and harassment are systemically doubted and discredited when they go public. Commentators have also used it to describe the mind-bending denials of reality coming out of the White House during the Trump presidency. The term "gaslighting" has exploded online among Twitter, Instagram and TikTok users interested in mental health, as well as among political and culture writers and popular psychologists.

But even though everyone seems to be talking about gaslighting, this type of abuse is just starting to be studied using systematic social scientific data. Although we tend to think of gaslighting as a problem between two people in a relationship, it also unfolds as part of an unequal social context. Gaslighting feeds off social vulnerabilities and stereotypes. It entrenches existing power imbalances while fostering new ones. The term is also increasingly used to describe structural racism, sexism, homophobia and ableism. Scholars and activists have used the term "racelighting," for instance, to name racial microaggressions that undermine the experiences of people of color and the ideologies that cover up these behaviors; a 2021 policy report described race-based gaslighting as "institutionalized in the social fabric."

Social theorists and writers from marginalized backgrounds have long insisted that social power works by trying to convince us that everything is normal while the conditions surrounding us are discriminatory and oppressive. As psychiatrist Ann Crawford-Roberts and her colleagues argued in 2020, watching George Floyd's

murder by a police officer and then being told his death was the result of preexisting medical conditions is "structural gaslighting." Our task as sociologists is to follow the elusive, topsy-turvy ways in which social domination operates. We must follow what sociologist Avery Gordon calls the "spells of power" and the way patterns of noncredibility are established. By taking gaslighting seriously, we can learn about the relation between macro-level inequalities and the "micro" forms of silencing and disempowerment that people experience in their everyday lives.

DANGEROUS RELATIONSHIPS

AS A SOCIOLOGIST, I'm interested in the social conditions and intimate dynamics that allow gaslighting to occur. In 2021 I set out to use in-depth qualitative research to figure out what makes gaslighting such an immiserating force. To find interview participants, I posted ads on social media defining gaslighting loosely as someone trying to make you "seem or feel crazy." This recruitment strategy allowed anyone who defined their experiences as "gaslighting" to participate, no matter where or how they experienced it.

After conducting 122 interviews over six months and analyzing the patterns that make up this form of abuse, I became most intrigued by the social contexts where we find gaslighting, and its relation to inequalities around gender, sexuality, class, ability and race. Unsurprisingly, gaslighting does not involve just one of these axes of identity—rather people experience gaslighting intersectionally, meaning that factors such as age, race, gender and sexuality all matter for the way people's realities are distorted, questioned or denied.

Based on my sample, there appear to be four central relationships or contexts in which gaslighting typically occurs: domestic violence; intimate partners who are not otherwise abusive; parents and other family members; and institutional gaslighting, primarily in the workplace. These forms of gaslighting rely on different dynamics—for example, domestic violence situations often include verbal abuse, whereas workplace gaslighting often has to do with racial discrimination. But they all involve power imbalances. This matters because it teaches us to ask different questions. Not, "Why did this person do that and what should the victim do in response?" But rather, "Who is establishing power and authority and how?" What follows are examples of these four contexts.

The experiences of "Selah" typify the domestic violence type of gaslighting. Selah's ex-husband questioned her sanity for years, telling her she needed medication and that her family thought she was "unstable." He once called a crisis mental health team to the house, claiming Selah was suicidal and couldn't be left alone. After Selah left him and got her own apartment, her husband broke in while she was at work and made himself comfortable. When Selah arrived home, he pretended that nothing was amiss and asked what they were having for dinner. He distorted Selah's reality (she had left him) by insisting on his own reality (they were still together). He peppered subtle threats throughout their conversation and wouldn't let her leave the house to get groceries.

This was part of a years-long pattern: Selah's husband stalked and harassed her each time she tried to leave, until eventually she fled in secret to a domestic violence shelter halfway across the country. This abuse had a sinister quality that made it difficult for Selah to describe what was happening. After all, what's wrong with your husband coming over and asking what's for dinner? As Selah explained, "They live in an alternate reality. And they want you to live there with them."

Around 30 percent of the people I interviewed identified their parents as their primary gaslighters. "Audrey" feels that her mother doesn't take her mental health problems seriously, insisting that Audrey's depression and anxiety are not "real," that she's just being "lazy," a "drama queen" and "overreacting." Audrey has been hospitalized for her mental illness, has attempted suicide, and receives government assistance because her symptoms make her unable to work. Still, Audrey worries that no one will believe her symptoms are real. Audrey told me: "Maybe I *am* a loser. Maybe I have really poor character. Maybe I'm just whiny."

Although we tend to think of gaslighting as a problem between two people in a relationship, it also unfolds as part of an unequal social context.

Because of these fears, Audrey delays treatment and minimizes her symptoms. Her experiences exemplify a type of gaslighting that tends to start in childhood and persist over long periods. This gaslighting often involves a parent denying a child's experiences in a way that exacerbates isolation and self-doubt. Here Audrey's mother controls resources (housing, finances) and wields a significant amount of emotional power over Audrey, a kind of authority rooted in the parent-child relationship.

When "Maya" tried to get her boss to stop telling sexually inappropriate jokes at work, he accused her of "overreacting." Things got worse, and when she put in her two weeks' notice, she was asked to leave and not come back. After she filed for unemployment and claimed in the request for unemployment compensation that it was a toxic work environment, he—a lawyer—contested her claim with a 500-page document asserting that she had laughed at his jokes, so how could they be offensive? In other words: she must be making it up. He claimed that Maya had gone "bar hopping" during the pandemic, endangering the safety of her co-workers, even though Maya had been pushing for masking at work. "Everything that I was doing to

try and keep myself safe, he would twist it around … to appear that I was doing something nefarious or out of malevolence." As the only nonwhite person in her office, Maya felt that he used stereotypes of people of color as aggressive to make her out to be a danger to the office.

"Alex," whose fiancé gaslit her while they were in college, was not fearful of her partner. Unlike the other examples given here, their relationship appeared to be equal. But Alex was constantly made to blame herself for her partner's actions, and a power imbalance quickly emerged. Alex's partner would cheat on her and then deny it was happening. When Alex questioned her, she would say that Alex was "jealous" and "possessive" and ask why Alex didn't value friends and "chosen family" as much as she claimed to. Alex felt confused and guilty; she stopped eating and sleeping. She started a journal in which she wrote down things her partner said to keep a record, fearful that her partner would undermine her memories.

Shame is central to gaslighting because it keeps victims trapped in the exhausting cycle of defending themselves against assaults on their integrity.

Alex described herself as "dazed" and "numb" during the relationship. She explained that it was hard to identify this experience as "gaslighting" because there was no clear gender-based power differential between her and her same-sex partner. Alex's experiences typify gaslighting in relationships that are not otherwise abusive, such that the manipulations were subtle and indirect but nonetheless made Alex doubt her ability to interpret reality. Unlike in Selah's case, verbal abuse, extreme control, threats and physical intimidation were not part of the equation. Instead Alex's partner gained power in the relationship by using Alex's own values against her, insisting Alex was being "jealous," a trait they both believed was toxic. She argued that Alex should be disappointed in herself.

What ties these stories together? Although strategies of abuse vary between cases, they all depend on the mobilization (or creation) of a power imbalance against the victim. The material effects of gaslighting may be more extreme in some cases (Selah received threats to her life; Maya had to leave a job in the middle of a pandemic), but what remains consistent is that controlling resources and narratives is key to how power imbalances are established and reproduced.

PATTERNS OF MANIPULATION

OUR FIRST TASK, then, is to reframe the way we think sociologically about abuse: gaslighting, like other forms of intimate violence, is not an incident but a process. Through my research, I've found that gaslighting typically unfolds as denial or distortion, isolation, shame, and attacks on credibility. The basic pattern is to deny or occlude, then flip the script. This pattern holds whether the perpetrator of gaslighting is a parent, friend, partner, mentor or boss.

When gaslighting is severe and affects victims' lives in lasting ways, this pattern occurs in a context of isolation and as part of a power imbalance between the gaslighter and the victim. That imbalance may be the result of widespread social inequalities—for example, between male and female partners or between a white boss and a Black employee. Or it may be naturalized in the family, such as the age and authority differential between parent and child. This is what understanding gaslighting with sociological tools allows us to see: mental manipulation typically relies on existing social patterns of domination.

The classic film example of gaslighting suggests that an abuser intentionally distorts his partner's sense of reality. My research shows that gaslighting may be unintentional—for example, Audrey doesn't think her mother gaslights her on purpose. But it can also involve denial of another's reality. When Selah's ex showed up at her house and pretended everything was normal, he was denying the reality that she had left him. Alex and Chandra's ex-partners both denied clear evidence of affairs and then disoriented Alex and Chandra with accusations of jealousy. Maya's boss denied her experiences of harm in the workplace, distorting her responses to his jokes. Denying someone's reality and distorting interpretations of past events are key to all forms of gaslighting.

Disorientation and denial are most effective if they take place in a context of isolation. For example, although Alex's partner did not "isolate" her in the extreme way that many abusers do, the gaslighting occurred while she and her partner were out of the country, where Alex felt alone and out of sorts.

"Imani," a domestic violence victim, explained that she became isolated because her abuser turned her against her own family. "He would make me think they're not good for me…. I wouldn't go down there [to visit family] anymore. [He would say] 'Why would you want to be around somebody that wasn't there for you?'" Imani started to believe that her partner was the only one who loved her, that the rest of the world was against her. She no longer wanted to socialize; she didn't even want to go outside. Imani's experiences show how gaslighting turns inward. She came to believe she wanted the isolation.

This is important because isolation prevents victims from hearing a counternarrative to what's happening in the relationship. For example, as part of institutional gaslighting, Maya's boss accused her of unethical work practices and forced co-workers to surveil her communications, leaving her alienated and her colleagues suspicious. Domestic violence and institutional gaslighting tend to involve the most extreme forms of isolation.

Isolation, as one of my interviewees put it, is the "breeding ground" for gaslighting.

Gaslighting also works by instilling shame, which makes victims feel that the abuse is their fault. "Summer" explained that her partner likes to provoke her into fights. He needles her with insults and stories of his relationships with other women, whom he says are better than her at cooking, at sex, at being a mom. He waits until she starts crying and yelling. "And he stood there, and he goes, 'You're acting really crazy right now, and I do not understand why,'" Summer recalled. "And I was like, oh, my gosh, it's finally happening to me... I'm tearing things off the wall … I just could not take it anymore…. And then [he had this] look, pitiful, on his face. He's like, 'I was just trying to have a conversation with you.'"

Here Summer's boyfriend, who has strangled Summer and threatened her with guns, flipped the situation to make her out to be unstable and violent. He then used her intense shame about "going psycho" to threaten that he would tell others about how she acted. Shame is central to gaslighting because it keeps victims trapped in the exhausting cycle of defending themselves against assaults on their integrity.

Shame also weakens a victim's credibility with themselves and others. The result is what feminist philosophers call "testimonial injustice," wherein prejudice causes people to withhold credibility from someone's narrative. Summer's abuser told his family that she is the one who beats him and lies about it. This strategy of "credibility slashing" is effective even though he is on probation for domestic violence.

Attacks on victims' credibility often work by appealing to community values, as when "Elyse's" ex-husband told friends and family that she was acting "ungodly" and out of character after filing for divorce. Making a victim seem unstable in trusted social networks exacerbates isolation.

Victims experience attacks on their credibility across types of gaslighting, although the form of those credibility attacks is specific to the institutional and social context in which gaslighting occurs. These attacks matter for legal proceedings such as divorce (for Elyse) and unemployment filing (for Maya). Attacks on credibility also diminish victims' ability to trust themselves, to know that what they are experiencing is real. Victims often come to feel that no one will believe them, making them doubt themselves as reliable witnesses.

TAKING GASLIGHTING SERIOUSLY

DESPITE THE CONSEQUENCES of this abuse, "gaslighting" has the makings of a flash-in-the-pan buzzword. The term has plenty of skeptics, especially among academics and commentators who argue that it lacks clarity and is overused. "Gaslighting" is indeed used in fast and loose ways in popular culture, without the rigor of social scientific research to back it up. It's often wrapped up in self-help culture, which can perpetuate messages that focus on individuals' actions and reinforce victim blaming. Sometimes it's conflated with simple lying or with other kinds of emotional abuse such as humiliation.

I agree with many of these criticisms. But mostly I'm relieved that we now have a language to talk about psychological abuse and its links to oppressive structures such as racism and ableism. Learning the term "gaslighting" gave Chandra, a 50-year-old Black woman, a container for identifying real patterns of abuse and discrimination. She's in a happier marriage now, but her happiness has been hard won: By leaving her ex-husband, seeking out higher-paying jobs, and working with counselors to identify her ex's abusive behaviors, she was able to regain her autonomy. If people such as Chandra are using "gaslighting" to make sense of confusing and harmful experiences, I think we have a net positive here. After all, there's nothing precious about a made-up word from a movie—so why not use it to name confusing forms of injustice and to argue for more equal social relationships?

Undeniably, gaslighting is a harmful type of psychological abuse that preys on people's social vulnerabilities. High rates of psychological abuse reported more generally suggest that researchers should pay closer attention to gaslighting and its lasting effects on victims' lives, whether or not physical violence is also present. One of the clearest patterns to emerge from my research is that the effects of gaslighting are worse for people who lack social networks and structural protections.

Some of those supports are things policy makers could choose to provide. For example, when people have access to a living wage, child care, and safe housing, they are less dependent on bad jobs and abusive partners. Would Chandra have stayed with her gaslighting husband for 12 years if she had access to money and child care? Would Audrey's mother's gaslighting be so effective if Audrey's disability benefits paid enough that she could live on her own? People who experience gaslighting around their material vulnerabilities are particularly at risk of staying in bad relationships longer.

Robust social networks of friends, family and neighbors also matter. Generally, the people I interviewed who were able to leave gaslighting relationships quickly had people they could rely on to validate their realities and give them positive counternarratives about their self-worth. Gaslighting is harmful not only because it draws from and exacerbates social inequalities but because it becomes internalized in a context of isolation, making one question one's sense of self. Coming to doubt oneself as a reliable interpreter of the world does significant damage. But context matters. If social networks and community support are protective, we can rely on one another to prevent or reverse the worst effects of gaslighting. SA

FROM OUR ARCHIVES

George Floyd's Autopsy and the Structural Gaslighting of America. Ann Crawford-Roberts et al.; ScientificAmerican.com, June 6, 2020.

scientificamerican.com/magazine/sa

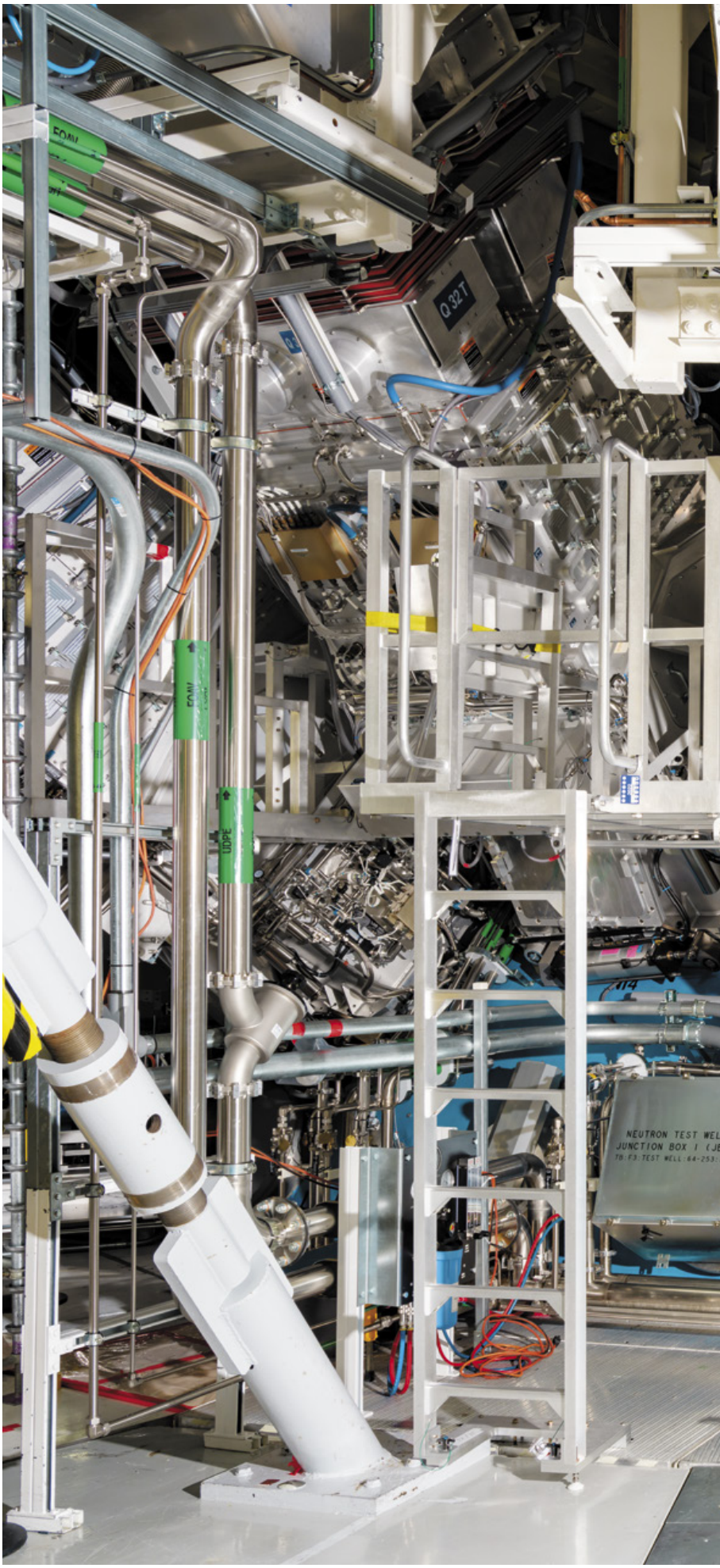
DEFENSE

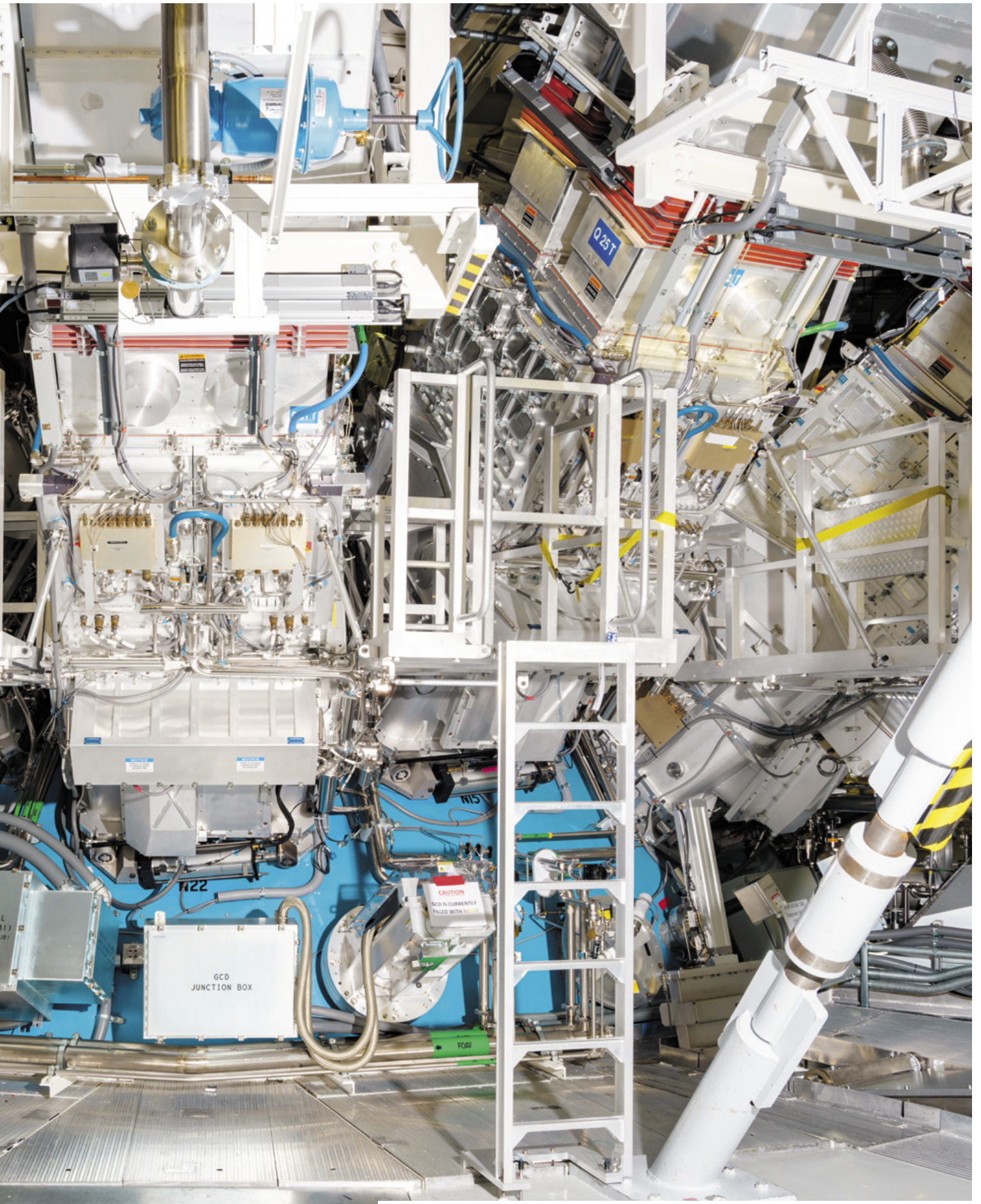
TESTING NUKES

The National Ignition Facility is designed to ensure that the U.S. arsenal will work

By Adam Mann

Photographs by Alastair Philip Wiper





THE TARGET CHAMBER of the National Ignition Facility (*painted blue*) houses a minuscule pellet of plutonium or other materials. Lasers hit the target from all sides, precipitating a fusion reaction. Such experiments enable researchers to gauge the performance of the U.S. nuclear arsenal.

Alastair Philip Wiper is internationally recognized for his photographs of industrial and scientific constructions. His most recent book is *Unintended Beauty* (Hatje Cantz, 2020).

Adam Mann is a journalist specializing in astronomy and physics. His work has appeared in *National Geographic*, the *Wall Street Journal*, *Wired*, and elsewhere.

GET INSIDE, STAY INSIDE AND STAY TUNED—THAT'S WHAT the New York City Emergency Management team asked citizens to do last July in case of a thermonuclear attack. "All right? You got this," assured the upbeat announcer in a video clip.

The reaction was swift and scathing. "The reality is, if this comes to pass, you don't 'got this,'" tweeted the International Campaign to Abolish Nuclear Weapons. "In the hours and days to follow there will be no way to respond." Yet the return of such public service announcements points to an unsettling reality: nuclear war is once again possible.

In 1995, after the Soviet Union had dissolved and fear of a nuclear exchange had receded, world powers indefinitely renewed the Non-Proliferation Treaty (NPT), a 1970 agreement to prevent new states from obtaining nuclear weapons and to induce those that already had them to disarm. A year later the U.S. signed the Comprehensive Nuclear-Test-Ban Treaty (CTBT), intended to prohibit "any nuclear weapon test explosion or any other nuclear explosion" anywhere in the world. These treaties did not stop U.S. efforts to ensure the readiness of its nuclear arsenal, however. Under the Stockpile Stewardship and Management Program, created in the wake of the CTBT, the nation spends $15 billion a year to research and test nuclear material, much of it at the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory in California.

Construction on this massive fusion research facility, the size of a sports stadium, began in 1997 and took more than a decade to complete. The NIF possesses 192 laser beam lines, each more than 100 meters long. The lasers are aimed in pulses of 20 billionths of a second and 500 trillion watts—roughly 1,000 times U.S. power usage at any given instant—at minute samples of plutonium and other substances. Compressed by pressures of more than 100 billion times Earth's atmosphere, the target implodes, generating a fusion reaction with temperatures more than seven times hotter than the center of the sun.

These and other experiments provide information on materials science and fusion energy. Most important, however, the data they yield, along with information from nuclear tests conducted before the ban, are fed into sophisticated simulations that conduct virtual thermonuclear explosions in a supercomputer.

NIF researchers say such experiments are necessary to understand how the U.S.'s more than 5,000 nuclear warheads, most of

which were produced in the 1980s, will behave in the event of a thermonuclear exchange. "The ultimate goal is to never use these things," says Mark Christopher Herrmann, deputy program director for Fundamental Weapons Physics at Lawrence Livermore. "But we want to assure our allies that we've got their backs and make sure our adversaries know that if they ever need to be used, they will work as intended and have devastating consequences." Detractors question, however, the need to spend billions of dollars on such a program. Tests have shown that exist-

AN ARRAY of 96 laser beam lines, each more than 100 meters long, is matched by an identical array (*not shown*) on the other side of the target.

ing atomic bombs should remain viable for at least the next 70 years, with some weapons lasting closer to 100 years without significant degradation.

Photographer Alastair Philip Wiper is documenting the diverse applications of nuclear physics and exploring the ways in which people experience the loaded word "nuclear." He has photographed the Large Hadron Collider at CERN near Geneva, the ITER and JET fusion reactors, and medical and other facilities that involve nuclear reactions. This is his first documentation of a reactor that conducts nuclear weapons research. SA

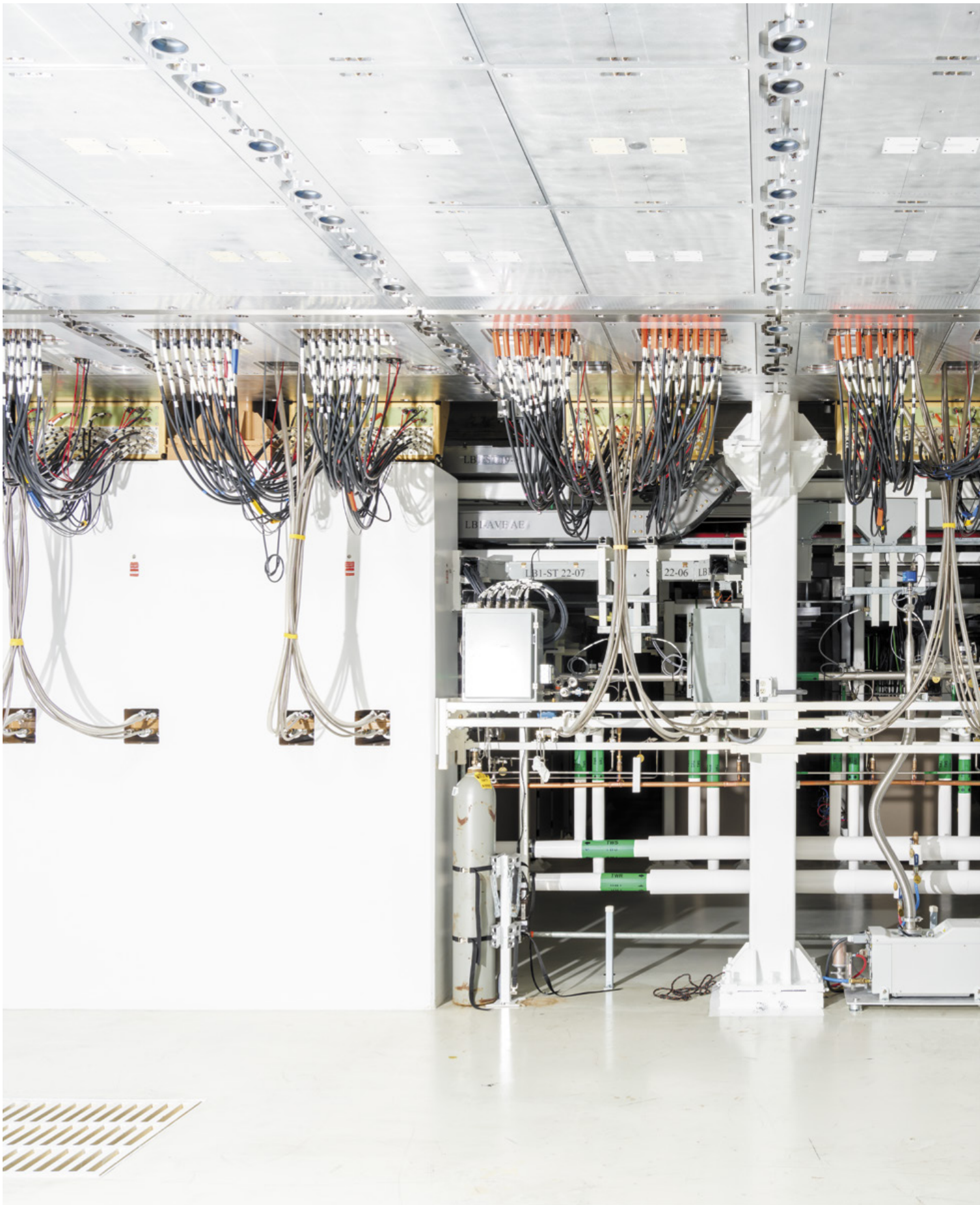
FROM OUR ARCHIVES

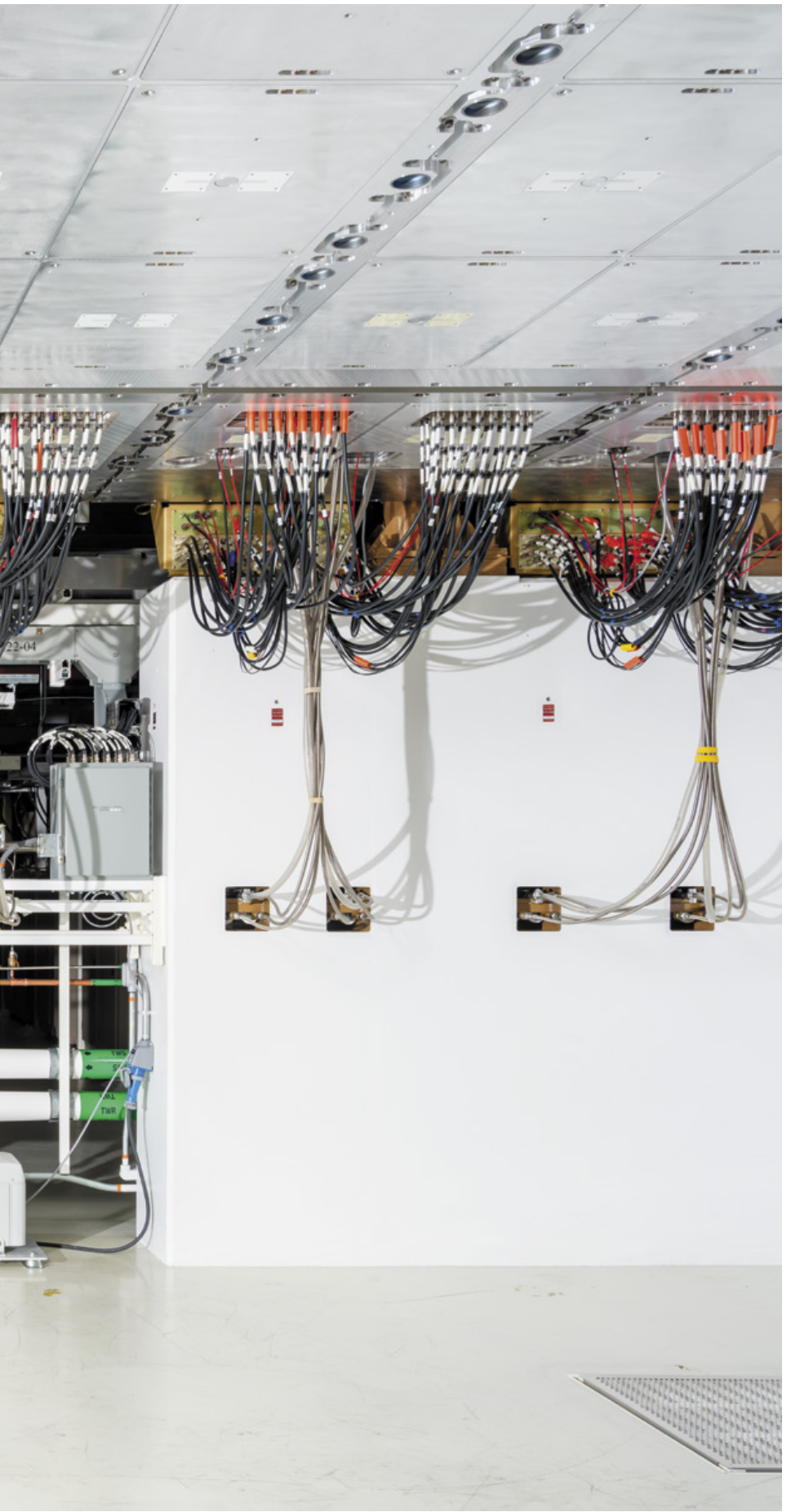
Measuring Beauty. Guy Wilkinson; November 2017.

scientificamerican.com/magazine/sa

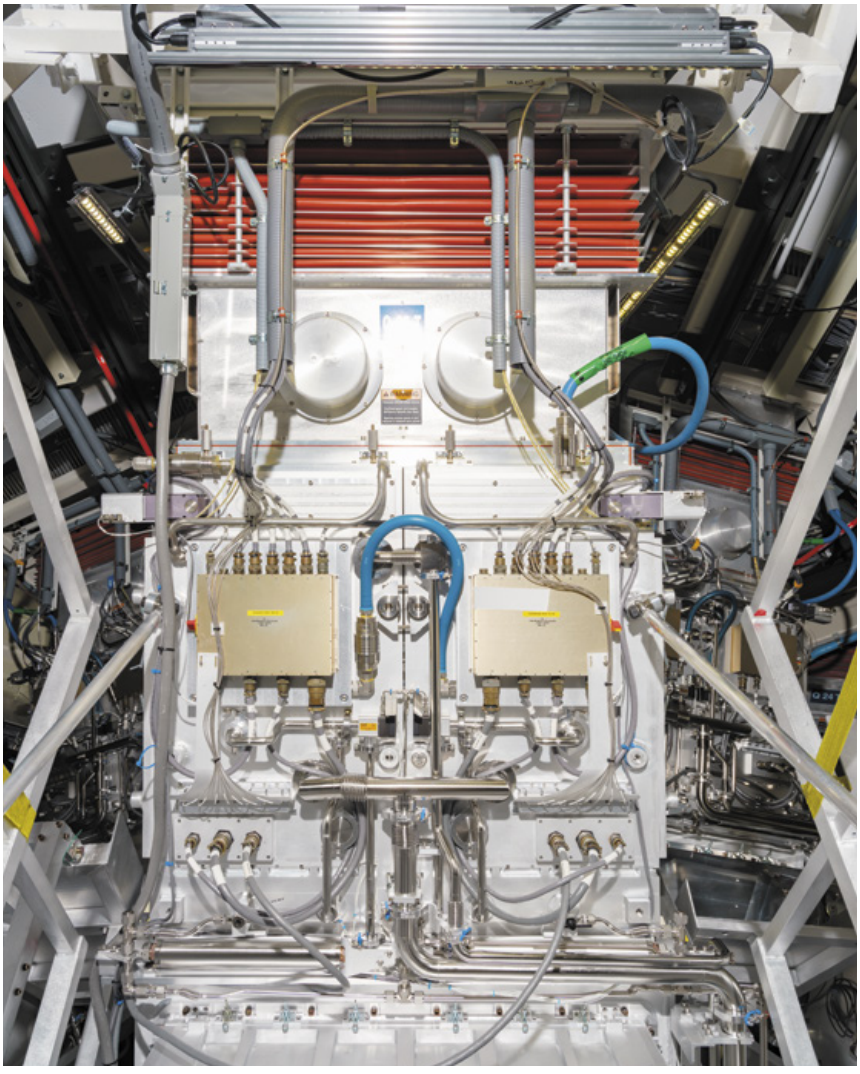
INSIDE THE LASER BAY, high-voltage instruments control the propagation of the laser beams through the amplifiers.

PULSES OF HIGH-POWERED LASERS originate in the master oscillator room (*left*). An oscillator generates low-energy laser pulses, which are modulated and amplified by 48 independent systems.





OPTICAL SWITCHING technology enables the laser pulses to be sent back and forth through the amplifiers to efficiently increase their power.



NEAR THE TARGET, each of 48 optical assemblies checks the lasers for quality, alters their frequency and focuses them into the target chamber.

THE EXTERIOR of the target chamber is shown from within the target bay. Clean environments are essential for handling the optical instruments.


Hemant Kakkar is an assistant professor of management at Duke University's Fuqua School of Business.
Niro Sivanathan is a professor of organizational behavior at London Business School.

When Dominant Leaders Go Wrong

Highly assertive managers may foster a selfish culture that hurts companies

By Hemant Kakkar and Niro Sivanathan

"Competitive," "decisive," "action-oriented," even "intimidating": many people invoke these words to describe good leaders. Indeed, several studies suggest extroverted, dominant individuals are perceived as competent, influential leaders in industry and politics. Think of the late former General Electric CEO Jack Welch, Amazon founder Jeff Bezos or Tesla CEO Elon Musk.

But dominant individuals can have shortcomings as well. Such leaders sometimes insist their way is the only way, or they intimidate others rather than taking steps to discuss, debate or consult with colleagues. And that has serious downsides for the companies, organizations and nations that they lead.

In our recent research, we examined some of the unintentional negative consequences of a dominant leadership style. Across eight studies, we explored how such leaders can inadvertently reduce cooperation among their employees by fostering a competitive climate. Past research shows that societies and organizations flourish when members help one another, share information and engage in collective problem-solving. But dominant leadership can stifle those activities. We argue that's because a leader's hyperindividualist approach can foster a zero-sum mindset in which people believe they can progress only at the expense of others.

First, we looked at political leadership, comparing democracies and dictatorships. Although some democratic leaders are aggressive, dictators exhibit extremely dominant behavior. They subjugate others to serve their own best interests. Given our hypothesis that dominance may foster a highly competitive culture, we wondered whether citizens in dictatorships engage in more zero-sum thinking than those in democracies. To test that idea, we examined data from 70 countries surveyed between 1981 and 2014 through the World Values Survey, which seeks to understand people's social, political and cultural beliefs. Residents reported their agreement with such statements as "people can only get rich at the expense of others." We also looked at their helping behaviors, including how highly they rated the importance of caring for their neighbors. We found that citizens of countries governed by dictators reported greater zero-sum mindsets and were less likely to help others when compared with residents of democracies.

For our second study, we designed an experiment to directly test whether dominance influences how people think about cooperation and competition at work. We recruited male and female professional actors and filmed them in a series of videos. The performers introduced themselves as managers and described their leadership approach to new workplace subordinates. One of these approaches was dominance: leaders described their tendency to be authoritative and decide what is best for the team. The other approach was what we call the prestige style: leaders emphasized how they valued others' input and an egalitarian approach.

We then recruited about 600 participants who watched one of these videos (either a male or female leader in the dominance or prestige condition). Afterward, they rated how much they agreed with statements related to zero-sum thinking and how likely they would be to engage in helping behaviors—such as listening to a coworker's problems—if they worked for the boss whose video they had just seen. We found that participants who had watched a dominant leader were more prone to express a zero-sum mindset and less likely to help others, compared with participants who had just watched a prestige leader. Gender had no effect: dominant men and women as bosses reduced helpfulness and increased zero-sum thinking among participants.

Finally, we tested whether this finding could be replicated with actual working groups. We surveyed 249 employees in 50 teams, along with their supervisors, at companies in India. We began by asking employees about their leader's tendency to influence based on dominance and about their own zero-sum mindset. Six weeks later supervisors rated their employees' helping behaviors. Employees supervised by a dominant leader reported greater zero-sum thinking. And as their supervisors subsequently revealed, these employees displayed fewer helping behaviors.

Although a number of leadership books and popular coaching manuals celebrate the effectiveness of a confident, decisive leader, our work underscores how this approach may backfire. Managers need to be aware that an assertive or forceful approach could reduce cohesiveness and collaboration. Organizations, meanwhile, should be careful about the people they promote. SA

Illustration by Alice Yu Deng

MAKE THE HEALTHY CALL

Stand Up To Cancer
and Optum®
want to help you reduce
your risk of cancer so...
TAKE THE PLEDGE
to get screened and
learn more about
cancer prevention.
And while you're at it,
don't forget the sunscreen.

To learn more and
get helpful resources, visit
TakeAHealthyStand.org

Stand Up To Cancer Ambassadors
DAN HICKS &
PAUL AZINGER

Photo By
FRED SIEGEL

STAND UP TO CANCER | Optum

Stand Up To Cancer is a division of the Entertainment Industry Foundation (EIF),
a 501(c)(3) charitable organization.

NONFICTION

The Uncertainty Paradox

Doubt can help us understand our world—or it can be used to delay change

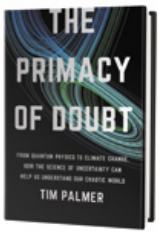
Review by Brian Kahn

Certainty is the currency of politics and social media, where boiling down complex issues into simple, bite-sized nuggets is now the norm. In his new book, *The Primacy of Doubt,* climate physicist Tim Palmer argues that the science of uncertainty is woefully underappreciated by the public even though it is central to nearly every field of research. Embracing uncertainty and harnessing "the science of chaos," he says, could help us unlock new understandings of the world, from climate change to emerging diseases to the next economic crash.

The first section is a dense discussion of major questions and concepts in physics that illustrates how, among other things, systems can go from a stable state to a wildly chaotic one with little warning, but the book picks up speed when Palmer gets specific with accessible, everyday examples. The sharpest chapter is a crash course on how to predict the weather, a process Palmer helped to modernize. He explores the history of the forecast, starting with the first public storm warning in 1861 that used data from telegraphic stations from around the U.K. and taking us to ENIAC, the first programmable electronic computer.

Such efforts paved the way for the probabilistic forecasts used today, which predict the chance of rain in a given hour and provide the "cone of uncertainty" for hurricane tracks. This backstory puts our weather apps in a new light: if we required certainty to make choices, these tools wouldn't exist.

Palmer is also a major contributor to improving climate models and is among the researchers who won the 2007 Nobel Prize for authoring the Intergovernmental Panel on Climate Change reports. His chapter on the topic, however, is a mixed bag. It excels in explaining evolving areas of research where reducing uncertainty is vital to figuring out just how bad things could get, such as whether clouds will speed up or slow down warming. Palmer proposes some interesting avenues for making the most of—and in some cases resolving—uncertainty, notably calling for a "CERN for climate change" that would focus on modeling how rising carbon dioxide and natural shifts in the climate will interact regionally over the next couple of decades (rather than globally over the course of the century). Doing so could help predict, for instance, long-term droughts in Africa's Sahel region, giving governments and humanitarian agencies a head start to stave off famine.



The Primacy of Doubt: From Quantum Physics to Climate Change, How the Science of Uncertainty Can Help Us Understand Our Chaotic World by Tim Palmer. Basic Books, 2022 ($30)

But Palmer struggles to frame both the uncertainties of climate change and the severity of its effects. He tees up the chapter (subtitled "Catastrophe or Just Lukewarm?") by defaulting to a both-sides approach: Are the "maximalists" right to suggest we're in an emergency and should decarbonize as much and as quickly as possible, or are the "minimalists" right in suggesting that uncertainty is grounds for delaying action? The truth, he writes, is somewhere in the middle.

Palmer notes that doubling atmospheric carbon dioxide alone would warm the planet by one degree Celsius. (That's without factoring in feedback loops it might cause, such as the loss of ice cover or more water vapor in the atmosphere, which would further turn up the heat.) This is, he says, "perhaps not something to make a big deal of."

But look at a planet that is already one degree warmer today than in preindustrial times, and the view is quite alarming. That incremental shift has fueled unprecedented heat waves on every continent, set the American West ablaze with ferocious intensity, and led to deadly deluges in areas that have never experienced such extreme back-to-back rainfall. Further, the most recent IPCC report, which Palmer urges his readers to reference, paints an increasingly dire picture that would seem to support a more maximalist view. Camille Parmesan, an ecologist at the University of Texas at Austin and one of the lead authors on that report, said in February 2022 that "we're seeing adverse impacts are being much more widespread and being much more negative than expected in prior reports."

The Primacy of Doubt makes a compelling case for either reducing uncertainty or operating with confidence in the "reliability" of the uncertainty that remains. But it can obscure the much bigger picture of climate *action.* It's impossible not to ponder how overlooking such nuances might sit with readers prowling for reasons to brush off the urgency of new climate policies.

Scientific American columnist Naomi Oreskes and historian of science Erik M. Conway's book *Merchants of Doubt,* along with exhaustive journalistic and academic investigations, has shown how the fossil-fuel industry, conservative politicians and a tiny cadre of scientists have played up uncertainty with the intent to delay meaningful carbon regulation in the U.S. Palmer acknowledges this with a blithe neutrality, saying "we should be just as wary of inflation of uncertainty as of attempts to make predictions more certain than can be justified." In doing so, he inadvertently brushes off the reality that uncertainty is too often used against society rather than to its benefit.

Brian Kahn is an award-winning writer and editor. He is the climate editor at the tech site Protocol.

Illustration by London Ladd

ANTHOLOGIES

Radical Banality

Women writing science fiction in the 1970s didn't need pulpy adventure to thrill and sting

The first volume of Library of America's "The Future Is Female" series collected science-fiction stories penned by women from the era of pulp fiction to the year of the moon landing. It closed with a knockout 1969 Ursula K. Le Guin story that dared to suggest our Space Age future might be an alienating drag. Le Guin's "Nine Lives" digs into the loneliness of astronauts and clones alike, suggesting that advanced tech and interplanetary adventure could make actual human connection all the more rare. It imagined not just what the future might look like but how we might feel in it.

That framing doubles down in volume two, also edited by Lisa Yaszek, which finds women writing sci-fi in the 1970s blasting off on topics of sex, power, the banal routines of domestic life, and whether civilizations can ever achieve true equality. Whereas "Nine Lives" still centered on men and offered pulp thrills, the avowedly feminist stories here (including a Le Guin classic about the aged leader of an anarchist revolution looking back as her movement bears fruit) focus on women whose choices are circumscribed by societies that are pointedly like, or pointedly unlike, our own.

The results still jolt, 50 years later. Set in a 2021 where humanity is facing a dire overpopulation problem, Doris Piserchia's "Pale Hands" is narrated by the cleaner of government masturbation stalls. Joanna Russ's "When It Changed," a Nebula Award winner, finds a planet where women have thrived without men for 30 generations suddenly reintroduced to what a newly arrived male astronaut calls "sexual equality." ("Seals are harem animals," he says, "and so are men.") In the kickoff story, "Bitching It," Sonya Dorman imagines the bored rutting of housewives in a world where women behave like alpha dogs in heat and men must passively take it.

Other works in this bold collection delve into the put-on hotness of what we now know as influencer culture, such as in the prescient "The Girl Who Was Plugged In," by pseudonymous James Tiptree, Jr. Both Joan D. Vinge's "View from a Height" and Cynthia Felice's "No One Said Forever" detail everything a woman must give up to be free to embark on old-school adventures. And by dramatizing a sci-fi author's effort to write a story that grows richer the more it draws from her own life, Eleanor Arnason's "The Warlord of Saturn's Moons" makes explicit these authors' mission to claim the genre for impassioned self-expression. In their hands, the future's not just female, it's personal. —*Alan Scherstuhl*

The Future Is Female! Vol. 2: The 1970s: More Classic Science Fiction Stories by Women
Edited by Lisa Yaszek.
Library of America, 2022 ($27.95)

IN BRIEF

A Traveler's Guide to the Stars

by Les Johnson. Princeton University Press, 2022 ($27.95)

What will it take to explore a distant star within 100 years? To illuminate the momentousness (and ethics) of sending humans light-years from home,

NASA scientist Les Johnson helps us digest mind-boggling numbers—the distance between stars, the energy required to travel that far—while laying out the opportunities and limits of existing technologies. Whether we get there by solar sails or ion thrusters or nuclear bombs, the advances we make in pursuit of interstellar travel will likely also change the way we live on Earth. After all, we wouldn't have electricity or cell phones "if our predecessors had not conducted science for the sake of science." —*Fionna M. D. Samuels*

Nineteen Ways of Looking at Consciousness

by Patrick House. St. Martin's Press, 2022 ($26.99)

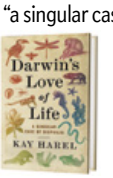
This book, thankfully, does not attempt to explain what consciousness is, how it arises, or why. Neuroscientist Patrick House instead sketches an outline

for how we might look at who we are from the inside out through wittily rendered observations plucked from neuroscience, quantum mechanics, and beyond. Recurring examples—such as the curious case of a teenager's laughter during brain surgery—provide a sense of the questions that might help us understand how our cells collectively conjure our selves. As befits a phenomenon that still evades a unifying theory, House's collage forms a picture of our minds that is far more nuanced, and more perplexing, than the sum of its parts. —*Sasha Warren*

Darwin's Love of Life: A Singular Case of Biophilia

by Kay Harel. Columbia University Press, 2022 ($26)

In these gentle but stirring essays, writer Kay Harel happily diagnoses Charles Darwin with "a singular case of biophilia," or profound love of



life, that engenders empathy, creativity and an intuitive sense of truth. Harel posits biophilia as the root of Darwin's genius and the influence behind everything from his love of dogs and fascination with the insect-eating *Drosera* plant to his rejection of mind-body dualism and his sense that estimations of the earth's age would one day align with the time span of evolution. Harel's focus on the confluences of Darwin's life rather than its conflicts offers a refreshing take on his legacy. —*Dana Dunham*

Naomi Oreskes is a professor of the history of science at Harvard University. She is author of *Why Trust Science?* (Princeton University Press, 2019) and co-author of *Discerning Experts* (University of Chicago, 2019).

An Unsustainable Partnership

Stanford University mistakenly acts as if the fossil-fuel industry will help it—and the rest of us—tackle the climate crisis

By Naomi Oreskes

Stanford University is betting big on Earth's future. It is launching a giant new initiative, the Doerr School of Sustainability, that was kick-started with a $1.1-billion donation by Bay Area venture capitalists John and Ann Doerr.

With that kind of money, you might think the Stanford school could easily protect its integrity and independence by declining money from the businesses that have done more than any other to threaten planetary stability: the fossil-fuel industry. This is what many faculty, students and alumni would like it to do. But the dean-elect, Arun Majumdar, has said industry gifts are welcome.

Majumdar previously led the Stanford Precourt Institute for Energy, which has long accepted fossil-fuel money, including a $20-million grant from Shell in 2019. Like administrators in other universities (including my own), Majumdar insists that we must "engage" with the very industry that gave us the climate and sustainability crisis.

Many university leaders hold the view that "there's no such thing as tainted money, except 't'ain't enough.'" If the money is put to good use, they suggest, it doesn't matter where it came from. But "good use" is precisely the issue. Funding strongly influences what kinds of scientific questions are asked and what kinds of answers are deemed plausible, credible and worthy of further pursuit. Ample scientific evidence demonstrates that the interests of funders influence academic findings, even when researchers strive to be objective. The clearest example is tobacco, where studies funded by the tobacco industry are much less likely to find clear evidence of harm than independent studies. This is why many prominent medical journals do not accept papers with tobacco funding.

It's not just that individual studies get biased. Entire research programs are framed in ways that are consistent with what funders are interested in and are likely to fund in the future. Stanford historian of science Paul Edwards has called this "mutual orientation." He showed how scientists who worked closely with U.S. Air Force sponsors came to internalize their patron's concerns, and these concerns guided their investigations. My own work on U.S. Navy funding of cold war oceanography confirms this pattern: projects perceived as low naval priorities were simply not pursued. (One of these was research into human-made climate change.)

My point here is that funding doesn't just influence what we do, it also influences how we think. Navy support of marine science led to an expansive understanding of the ocean as a physical medium—a better grasp of currents, marine sound transmission and deep-sea geology. But it also pushed marine scientists to look at the ocean as a place of warfare rather than an abode of life. The way we think depends in part on the company we keep.

This is where Stanford is going wrong. The fossil-fuel industry and its allies have worked to confuse the American people about the reality and severity of climate change. They have attacked the natural scientists who proved that climate change was caused by carbon pollution and the social scientists who exposed the obstructive role the industry has played. They have fought to preserve fossil-fuel subsidies while claiming to believe in free markets. They have even lobbied against market-based solutions, such as carbon pricing and emissions trading. Their insistence that our economies—both national and household—cannot survive without fossil fuels has been an attempt to limit our thinking about energy.

The chances that we can solve the climate crisis with more fossil fuels and more atmospheric carbon pollution, mitigated somewhat by carbon capture and storage—a technology that is far from proved and extremely expensive—are low. Yet that is what the industry is pushing and with a few exceptions intends to continue to do: to develop and sell more oil and gas, which will put yet more carbon dioxide and methane in the atmosphere.

Stanford wants to solve a problem in partnership with the people who not only created it but continue to compound it. So consider this: Would you enlist unreformed drug dealers to help eliminate drug abuse? I know I wouldn't. SA

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Illustration by Yunyi Dai

50, 100 & 150 YEARS AGO

INNOVATION AND DISCOVERY AS CHRONICLED IN *SCIENTIFIC AMERICAN*

Compiled by Mark Fischetti

OCTOBER

1972 No Life on the Moon

"It seems increasingly likely that we are not alone in the universe. There may be millions of inhabited planets like our own. It is a prime goal of science to search for life or its remnants elsewhere. The samples returned from the moon have provided the first opportunity to test our life-detection methods on samples that have been carefully collected and protected from terrestrial contamination, thereby avoiding the bitter controversy surrounding the analysis of meteorites. This first search has now been completed. No life-forms, living or dead, have been found in the lunar samples after intensive studies with sophisticated techniques capable of revealing any biochemicals or their derived products in amounts exceeding a few parts in a thousand million."

Unintentional Pregnancies

"The modernization of U.S. contraceptive practices has been a major factor in the remarkable decrease in the U.S. birthrate during the past decade. The birthrate dropped from 23.7 per 1,000 of population in 1960 to 17.3 in 1971 and was below 16 per 1,000 in each of the first five months of this year. According to Charles F. Westoff of Princeton University, codirector of the 1970 National Fertility Study, about four out of five couples practicing contraception in 1970 were 'highly protected from the risk of unintentional conception.' This high level was being experienced 'probably in substantial part due to the efforts of public and private family planning programs.'"

1922 Smelly Gas Is Safe Gas

"Manufactured natural gas is not so odorous, and the danger of asphyxiation from it [in the home] is consequently great. Professor Yandell Henderson of Yale University proposes to introduce into the gas supply a strong odor which would betray even a slight leak long before there was danger from it. The odor used is that of mercaptan, which we commonly associate with the skunk, one of the most powerful odors known. Burning the gas causes a chemical change in the mercaptan so that it is no longer odorous. Thus as long as the gas supply system is working properly there will be no inconvenience. But if even a small amount of gas is allowed to escape without burning, that fact will be quickly detected."

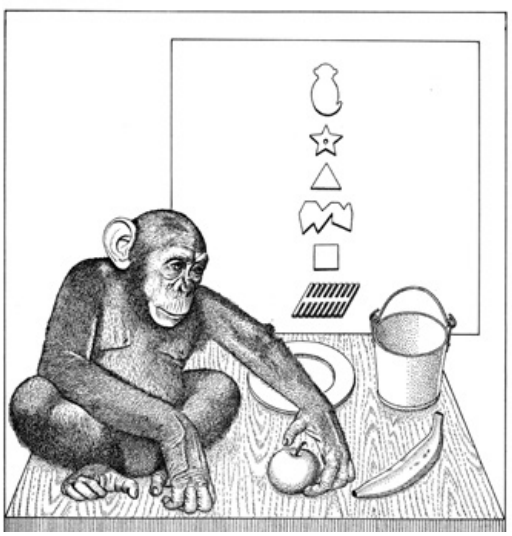
Hypnosis Eases Surgery

"By the hypnotic process, the patient is hypnotized directly before an operation. The anesthetic is administered slowly, so that the narcosis condition creeps into the hypnotic state. As soon as the operation is over the narcosis ends, but the hypnotic condition continues. Only two-thirds to three-fifths of anesthetic ordinarily necessary is used, with the result that the poisoning effect, brought about by ether, for example, is much reduced. The patient is not nearly so much distressed. There is no nausea. The continuance of the hypnotic state for several hours and even days allows the patient to recover from the immediate after-effects of the operation, which are always accompanied by acute pain and mental distress. It avoids the use of drugs, which must be given to the patient frequently to overcome the severe strain on outraged nerves."

1972

1922


1872



1972, CHIMP COMPREHENSION: "Sarah the chimpanzee, after reading the message 'Sarah insert apple pail banana dish' on the board, performed the appropriate actions. To make the correct interpretation to put the apple in the pail and the banana in the dish (not the apple, pail and banana in the dish), she had to understand sentence structure rather than just word order."

1872 Black Ink from Plants

"Botanists are endeavoring to introduce in Europe a plant of New Granada, which will be a valuable acquisition to manufactories of ink. The juice or sap which it yields, and to which is given the name *chanhi,* is at first of a reddish tint, but in a few hours becomes intensely black. It may be used without any preparation. The *chanhi* corrodes steel pens less than ordinary ink, and better resists the action of time and chemical agents. It is said that, during the Spanish domination, all public documents were required to be written with this ink; written otherwise, they were liable to damage by sea water."

Instant News

"A correspondent, J.W.K. in Colorado, makes the following alarming suggestion: 'Why not have a whole city furnished simultaneously with the latest telegraphic news upon the instant of its arrival, by means of a steam whistle or whistles, or a gigantic speaking machine, instead of waiting for it to go through the tedious process of typesetting, printing, folding and distribution by the carrier? The old way is too slow, even with carriers on horseback as we have here in Denver.'"

Scientific American, Vol. 227, No. 4; October 1972

Text by Madhusree Mukerjee | Graphic by Daisy Chung

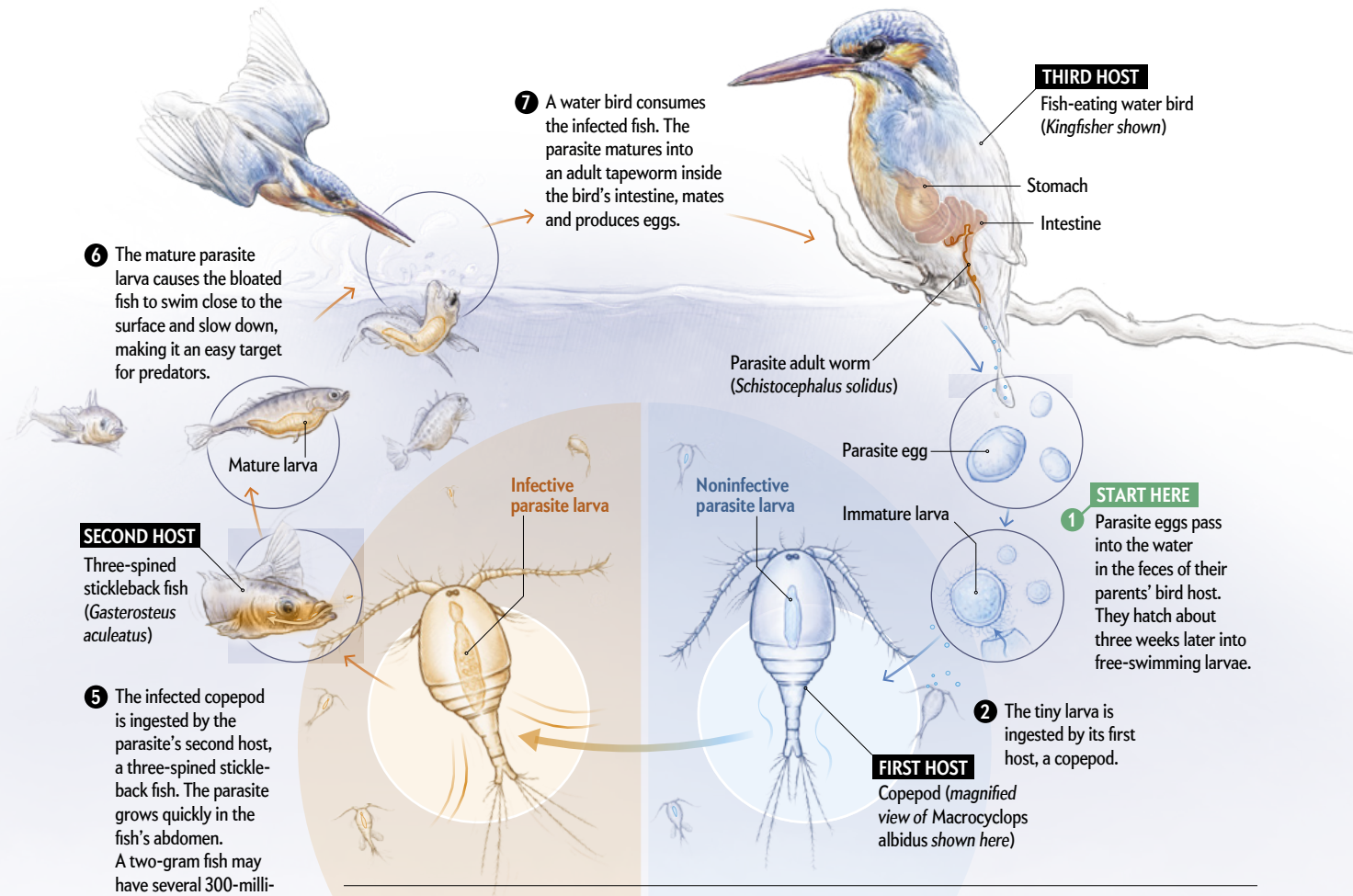
An Improbable Life Cycle

A parasite manipulates the behavior of at least one of three hosts to travel from water to air—and back

Parasites give new meaning to the cliché "eat or be eaten." Often their life cycle can be completed only if they are ingested by a host—multiple times for some—making the odds of their survival seemingly minuscule. To improve their chances, certain parasites manipulate their hosts' behavior to make it more likely the eater will get eaten.

The parasitic cestode *Schistocephalus solidus* requires a much larger host—specifically, a three-spined stickleback fish—to grow in and then a bird to breed in. But the parasite's larvae, less than a millimeter long, are too small to be eaten by the fish.

Instead a larva must first be ingested by a copepod, a crustacean akin to a tiny shrimp. When ready for its next host, the larva makes the copepod twitch. If all goes well (for the parasite), a three-spined stickleback then eats the copepod. Inside the fish, the larva grows enormously, making the poor stickleback gasp at the water's surface, where it is likely to get snacked on by a bird. Inside the bird, the parasite matures and mates, sending its eggs back to the water through the bird's poop. And so the cycle begins again.



Parasitologist Nina Hafer-Hahmann studied the cestode *S. solidus* at the Max Planck Institute for Evolutionary Biology in Plön, Germany. She showed that the parasite directly manipulates its copepod host's behavior and that this ability is heritable.

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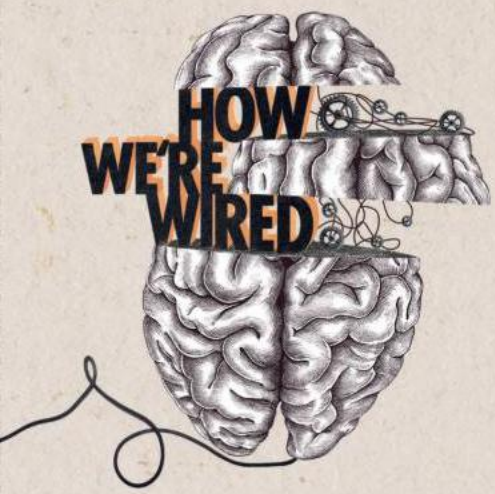

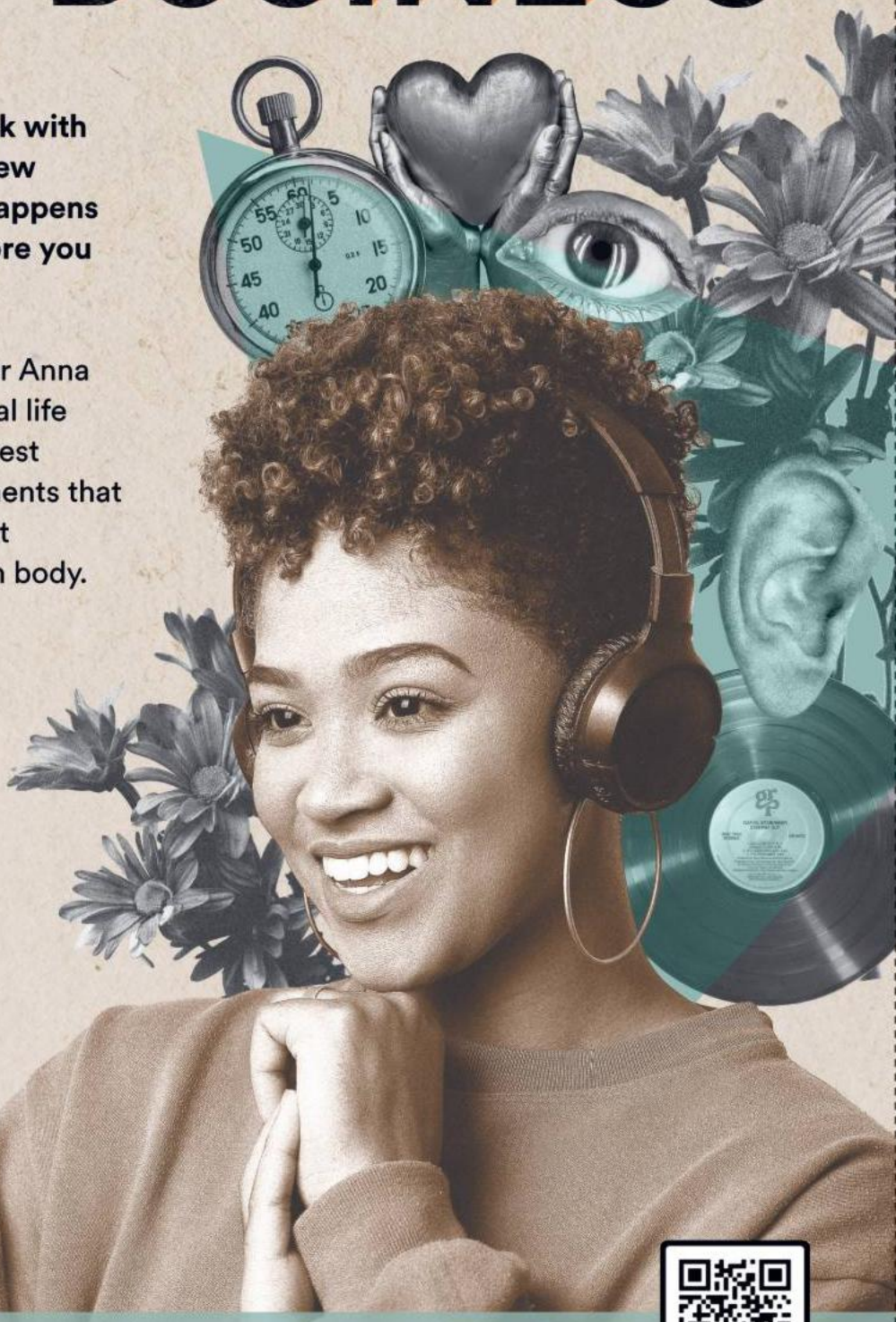

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