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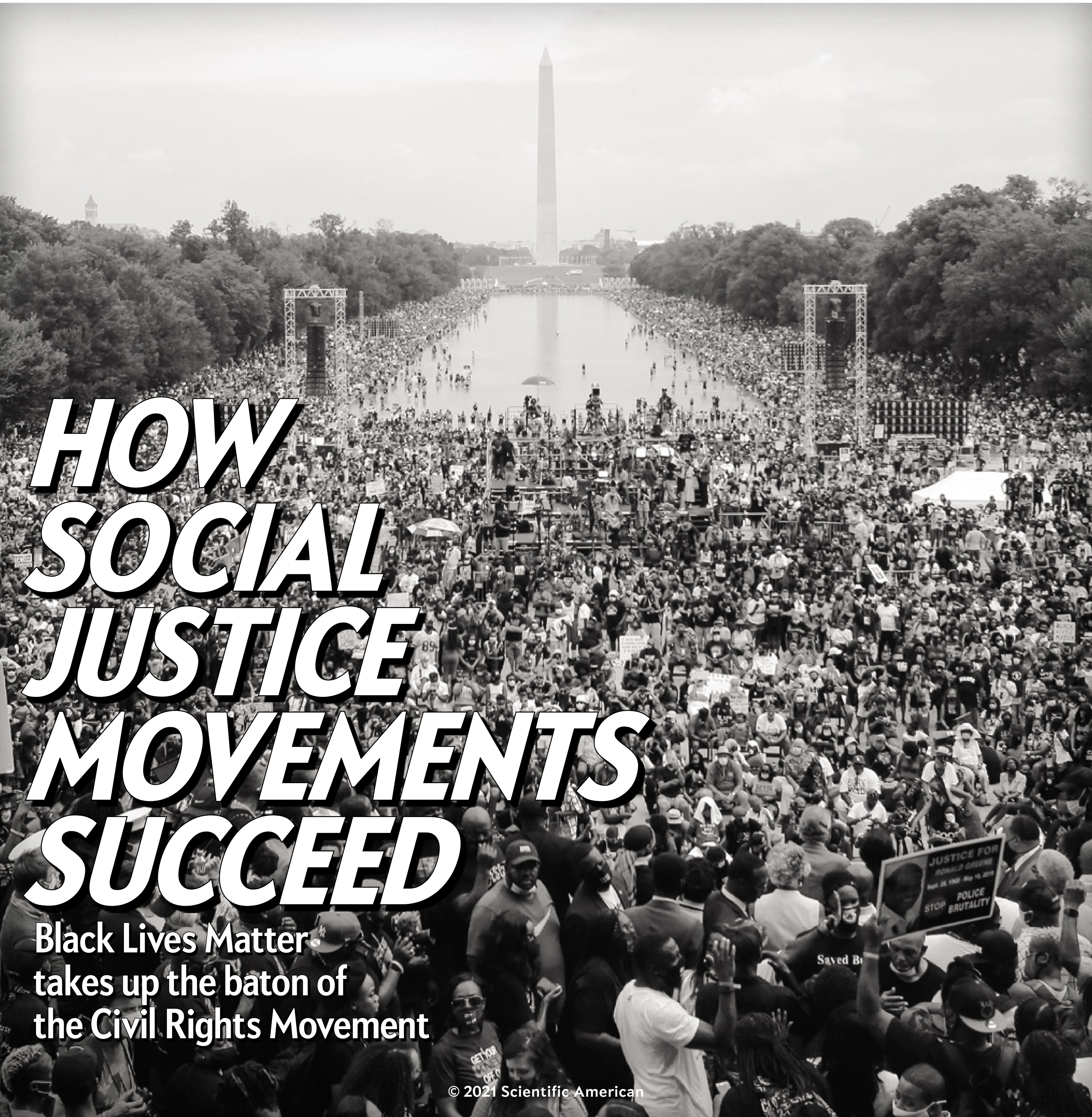

HOW SOCIAL JUSTICE MOVEMENTS SUCCEED

Black Lives Matter takes up the baton of the Civil Rights Movement

MARCH 2021

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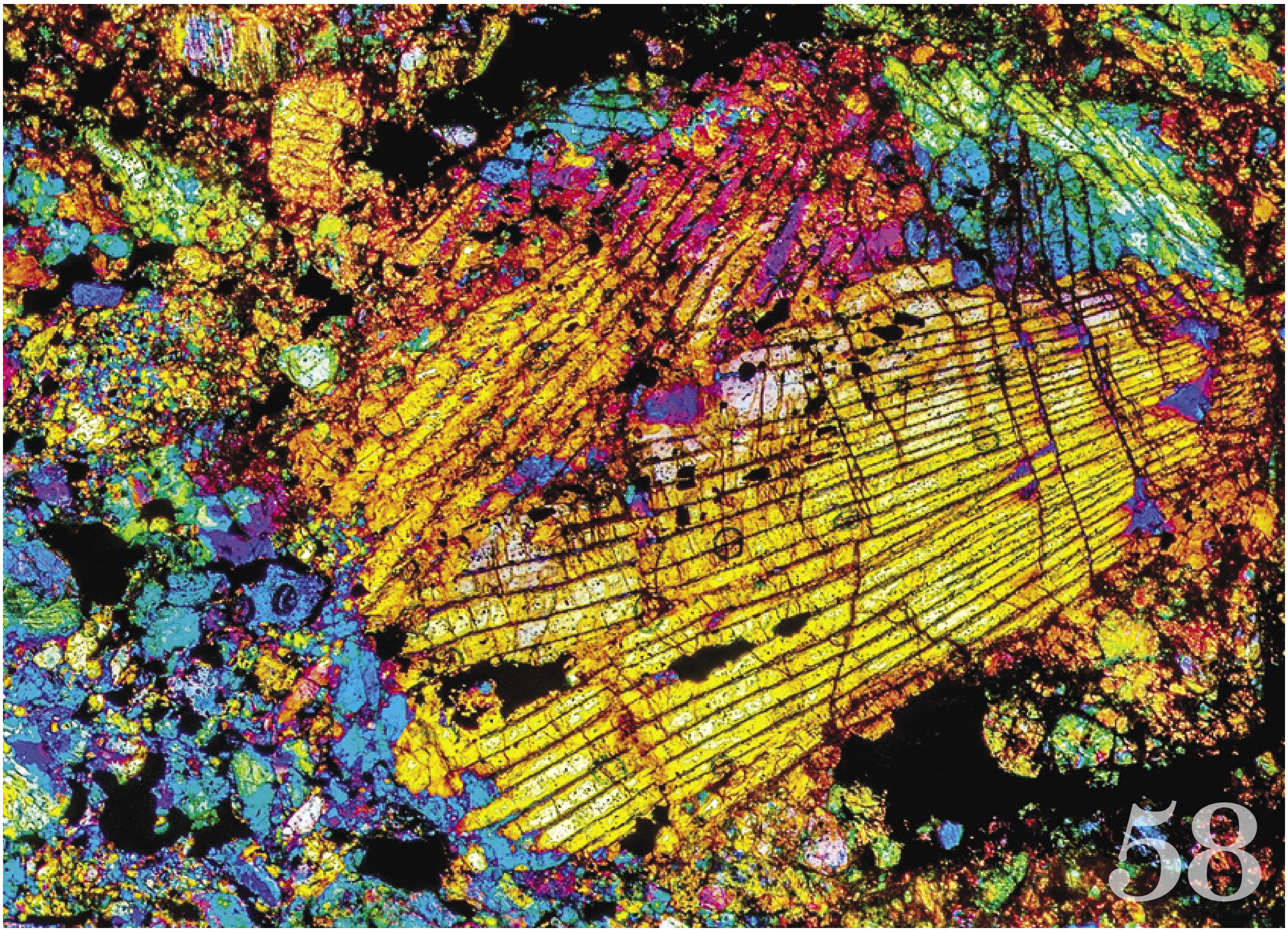

ON THE COVER

A Black Lives Matter protest last August at the National Mall in Washington, D.C., honored the 57th anniversary of the historic March on Washington during the Civil Rights Movement. Successful movements require organization, strategy, and material and cultural resources that largely emanate from within the community experiencing injustice. **Photograph by Mel D. Cole.**

ALFRED PASIEKA *Science Source*

SCIENTIFIC AMERICAN

11

12

72

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FROM THE EDITOR

Laura Helmuth is editor in chief of *Scientific American.* Follow her on Twitter @laurahelmuth

Power of Protest

What we're learning about how solar systems and civilizations developed

In our powerful cover story this month, sociologist Aldon Morris explains how social justice movements succeed. When the Civil Rights Movement began, some social scientists were dismissive of activists and described protests as unthinking mobs. Morris and his colleagues conducted immersive interviews with leaders of the Civil Rights Movement and similar struggles against injustice around the world and found that meticulous planning, cultural resources, discipline and creativity powered the movements, along with emotions ranging from righteous indignation to empathy and love. The Black Lives Matter movement has taken the baton from the Civil Rights era, and as Morris points out, "these struggles necessarily (and excitingly) continue to evolve faster than social scientists can comprehend them." Turn to page 24.

One of the first great cities of the world was established about 7000 B.C.E. and lasted for 2,000 years. Çatalhöyük wasn't organized around marketplaces or monuments; people who lived there were homebodies who conducted work and rituals within their houses, which they entered through the ceiling. Beginning on page 66, author Annalee Newitz (who also writes fantastic science-fiction novels) shares what archaeologists have learned about the metropolis, including what people there ate and how they warmed their beds.

Astronomers are getting close to identifying the first exomoons—moons orbiting exoplanets in distant solar systems. They have a few candidates already, and science writer Rebecca Boyle explains, on page 38, how they are honing their instruments to detect subtle signals of a moon's influence on its host planet. Our own moon stabilizes our climate and influenced how life evolved—and exomoons could show us whether such a partnership is common throughout the galaxy.

Last December the Hayabusa2 spacecraft completed its complex and ambitious mission to bring samples of an asteroid back to Earth. The pieces of the asteroid Ryugu could answer stubborn questions about the origins of our solar system, including how chondrules were made. These seedlike "droplets of fiery rain" are found in most meteorites, and astronomers have been speculating for centuries about how they were created: by lightning, or shock waves, or planet formation. On page 58, science writer Jonathan O'Callaghan shares the theories and the excitement about understanding these mysterious tiny drops.

Many of us at *Scientific American* are birders, some for decades and some who have taken up the hobby during the pandemic. The more you learn about birds, the more fascinating they are, and much of what we know about their migrations, life spans, and breeding and wintering ranges comes from a century of bird banding. Senior editor and newly converted birder Kate Wong, with graphic artist Jan Willem Tulp and illustrator Liz Wahid, highlights the discoveries that have come from this simple methodology (*page 52*). The research is ongoing—if you ever see a bird (alive or dead) with bands on its legs or wings, please report the band's code to the U.S. Geological Survey.

We hope you're faring as well as possible through the COVID pandemic and are able to get access to a vaccine soon if you haven't already. As the catastrophe enters its second year, science writer Melinda Wenner Moyer, on page 46, shares some evidence-based advice for coping through long-term disasters. We're really looking forward to publishing future stories about how the world recovers from all the challenges to physical, economic and mental health. SA

Illustration by Nick Higgins


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November 2020

"It's demoralizing that a century after the 1918 pandemic, I have to ask: What have we learned?"

SHANNON LEIGH O'NEIL *VIA E-MAIL*

FORGOTTEN TRAGEDY

I read "The Pandemic We Forgot," Scott Hershberger's article on the 1918 influenza pandemic, and noted your call for stories at the end of the online version about ancestors who experienced it.

Among the 675,000 people in the U.S. who lost their lives 102 years ago were nearly all of my great-grandmother's immediate family. Both of her parents and a brother died. Her first husband and their one-year-old daughter died the same day in October 1918 and were buried together in the same coffin. At the age of only 22, she was pregnant with her second child, a son who would never know his father. She also had to raise her younger siblings who survived.

This happened in Oklahoma, a state that is currently dealing with spikes of COVID-19 and very sporadic mask compliance—with no statewide mandate in place. It's demoralizing that a century after the 1918 pandemic, I have to ask: What have we learned?

SHANNON LEIGH O'NEIL *via e-mail*

The collective "forgetting" of the 1918 pandemic Hershberger describes rang true for me and my family. My 91-year-old grandmother told me that her father (my great-grandfather, Georg Monsen) survived the pandemic but that his older brother, the older brother's wife and their two kids all died of it. I've been alive for four decades and am close to my grandmother, but I never heard any of this history until now. Plus, she said that her father had hearing loss for the rest of his life because of the effects of that flu, as did other members of the family who had it but survived. This all took place in western Norway, where my grandmother is originally from.

TABITHA GRACE MALLORY
Henry M. Jackson School of International Studies, University of Washington

My grandfather died in the second wave of the pandemic on September 24, 1918. He was 26 and otherwise very healthy. My grandmother was deeply affected by his death, and she always seemed to believe that she could have done more to save him. This made her deeply anxious about the health of everyone in the family and especially me, as I was given his name. I always hid any cold that I had from her. In lots of ways, my grandfather's death reverberated through the generations. His name was Samuel Rubinson, born August 15, 1892.

SAMUEL GUTTENPLAN
Professor emeritus of philosophy, Birkbeck, University of London

Regarding the lack of collective memory, I had the same question when I heard of the pandemic and discovered my grandmother had died during it. It was the only family story ever told about her. Gone at 38, leaving five small children. My father was nine years old. My 2010 book *Influenza and Inequality: One Town's Tragic Response to the Great Epidemic of 1918* covers the epidemic in one small town: Norwood, Mass. It has dozens of personal stories from survivors, families and descendants.

I believe that this lack of collective memory is linked in large part to the population of victims: the majority were young, foreign-born and poor. Like today, those who could afford to stay home and avoid infection were the privileged. Then, as now, it was marginal communities—those who lived and worked in hazardous environments and lacked medical access—who were struck down. Who was going to memorialize young poor immigrants? Let us hope today's victims will not be so invisible and easily forgotten.

PATRICIA J. FANNING *Professor emeritus of sociology, Bridgewater State University*

My dad would have been about 16 years old when the 1918 influenza both took his own father's life and sickened him. I was a child when he told me that, as the disease faded, "all [his] hair fell out." In 1920 my father—with, by then, an abundant resupply of hair—entered the U.S. Naval Academy. No doubt at least some of his classmates were also influenza survivors. I'm inclined to believe that in the process of bonding with one another, they would have shared their "collective memories" of experiencing "the flu."

At age 75, I'm at the tail end of those who were spared by vaccination from the terrible scourges of smallpox, tetanus and diphtheria. But we had to risk the complications of illnesses now rarely seen in the developed world: measles, rubella, chicken pox, mumps, polio. Such experiences have certainly generated moments of collective memory.

ELIZABETH R. HATCHER *Topeka, Kan.*

EDITORS' NOTE: Read unabridged versions of these letters and several others about people whose ancestors were affected by the 1918 flu pandemic at www.scientificamerican.com/1918-pandemic-letters

SPACE WAR TRASH

In "Orbital Aggression," Ann Finkbeiner discusses options for avoiding conflicts in space. But she does not address the question of whether any such space war would be inherently *self-defeating*. Even if a war in Earth orbit was entirely one-sided, with the "enemy" not retaliating, the creation of large amounts of new orbiting debris from deliberate satellite destruction could become self-propagating. An attacker could find access to orbital space denied to all countries, including itself, because of an ever escalating cascade of debris-satellite collisions—making any space war a mutual-assured destruction of the orbital environment.

MARK PROTSIK *San Jose, Calif.*

MASK MISTAKE?

In “Scientists: Use Common Sense” [Observatory], Naomi Oreskes criticizes the World Health Organization for initially advising people not to wear masks in response to COVID-19 in April. She gives two reasons the WHO did so: (1) A medical mask shortage would result for critical care workers. (2) Masks would give people a false sense of security. I concur with Oreskes in rejecting 2. But 1 was a powerful argument at the time. If an N95 mask manufacturer could get a higher price from pharmacies or other customers than it could from hospitals, what does she think would have happened?

Fortunately, the problem was solved—at least here in Los Angeles County, where our local officials wisely recognized that wearing any mask, even a simple cloth one, would help and organized local garment manufacturers to turn them out. Yet at present, with the start of the third wave and companies openly selling N95 masks to the public, we might be back in trouble again. I hope this doesn't happen. But I also note that a responsible U.S. federal government could have prevented it.

D. S. Burnett
California Institute of Technology

DATA AND DECEPTION

Your recent editions have had a number of articles about misinformation. I would like to introduce the notion that data precede information, whether it constitutes misinformation or not. As any scientist can attest, there are good and bad data. Good data are obtained by careful control of conditions and demonstration of reproducibility. Bad data can arise from sloppiness, confirmation bias or intentional falsification. Information of any kind arises from analyzing data; misinformation arises from bad data or a distorted analysis of good data.

There are an enormous number of sources of intentionally bad data created to entrap people. How can our society step back from the edge? Science in the U.S. is taught as a series of facts to be accepted unquestioningly. Instead children need to be taught the clear, critical thinking that underlies the scientific enterprise. Many of the most egregious bits of misinformation are, on inspection, stupid. Far too many Americans have no capacity to identify “stupid.”

Arthur Moss *Wilmington, Del.*

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Biden's Nuclear Challenge

He must take immediate action to reduce the risk of atomic war

By the Editors

When Joe Biden was sworn in as the 46th U.S. president on January 20, he inherited major crises, including a raging pandemic, a planet gripped by escalating climate change, a ravaged economy and a nation riven by hyperpartisanship, worsened by what amounted to an attempted coup inspired by his predecessor. But it is an older existential threat, the fearsome power of nuclear weapons, that should still be the most terrifying. Immediately after his inauguration, the new president gained official control over the "nuclear football," a 20-kilogram satchel containing launch codes and strike options for unleashing the nation's vast atomic arsenal on his sole authority, at a moment's notice. But the intricate international web of agreements and strategies used to restrain this world-destroying power—held by other countries as well as the U.S.—has become dangerously frayed.

Some 9,500 warheads are currently in military service among the world's nine nuclear-armed states, with over 90 percent held by the U.S. and Russia. Just a minuscule fraction of that alarming total could bring about millions of deaths, unfathomable suffering and a new Dark Age from which recovery would not be guaranteed. And unlike the most significant impacts of climate change, which manifest over decades and centuries, the devastation from nuclear warfare could unfold in mere minutes and hours.

This modern-day sword of Damocles has hung over humanity's head for generations, held at bay by diplomacy, carefully orchestrated international agreements and the chilling zero-sum game of mutually assured destruction. Yet today, after years of neglect if not outright opposition by those who believe nuclear warfare can be "winnable," those intertwined threads of safety are worn, loose and about to come apart. Treaties to limit the proliferation and use of nuclear weapons have expired, more nations than ever before are poised to develop new arsenals, and potential destabilizing factors such as antiballistic missile defense systems and novel hypersonic weapons platforms continue to multiply.

The Biden administration can take several steps to tiptoe back from the brink of disaster while maintaining national security. The first should be Biden's fulfillment of his campaign promise to extend the New Strategic Arms Reduction Treaty (New START), the sole remaining arms-control agreement with Russia, set to expire on February 5. It is a vital component in curtailing each nation's existing nuclear forces and the possibility of a new nuclear-arms race. More broadly, extending the treaty should be part of a much needed attempt to improve the perilous state of U.S.-Russia relations—exemplified by Russia's recent, massive cyberattack on U.S. institutions, including the federal agencies charged with maintaining the national nuclear stockpile. Such efforts could serve as a model for dialogues with other nuclear-armed nations, especially China, which could in turn yield a wider range of solutions to the vexing problem of how to denuclearize North Korea.

And Biden should make good on his promise to reenter the Joint Comprehensive Plan of Action, also known as the Iran nuclear deal, an agreement from which then President Donald Trump withdrew the U.S. in 2018. The 2015 deal sought to extend Iran's "breakout time"—its capability to produce bombs from enriched fissile material—from a few months to at least a year. But after Trump reinstated severe sanctions, Iran resumed vigorous uranium enrichment. The assassination of Iran's top nuclear scientist last November and substantial congressional opposition to the deal all set high barriers to the U.S. rejoining. Nevertheless, the consensus view among arms-control experts is that the agreement is the least-worst option for ensuring a nuclear-free Iran.

Yet if such efforts are met with intransigence from Congress—a not unlikely event—Biden should take unilateral actions designed to reduce risks and bolster international cooperation. Drawing down the nation's number of deployed strategic weapons; reevaluating its byzantine "command and control" systems; and declaring a "no first use" policy for nuclear weapons—something U.S. presidents have so far been unwilling to do—all fall within his purview. Most consequentially, however, Biden should order sweeping changes to what is now the president's sole authority for launching nuclear weapons. He should insist that it be made in consultation with executive branch officials and congressional leaders, a step that can be taken without weakening deterrent ability, arms-control experts say. If this move were eventually formalized through federal legislation, it could be the most meaningful act of Biden's presidency toward ensuring a safer world. SA

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Illustration by Martin Gee


Nick Pyenson is a research geologist and curator of fossil marine mammals at the Smithsonian Institution.


Alex Dehgan is co-founder and CEO of Conservation X Labs.

The U.S. Needs Scientists in the Diplomatic Corps

They have expertise, problem-solving skills and international credibility

By Nick Pyenson and Alex Dehgan

Benjamin Franklin might have been on the short list for a Nobel Prize if there had been such a thing during his lifetime. The amazing breadth of his contributions stands out even today: he worked in areas ranging from the science of electricity to the wave theory of light to demography, meteorology, physical oceanography and even behavioral science. Franklin was also the first U.S. ambassador to France. His reputation as a scientist galvanized his popularity in Europe and helped him secure France's support for the fledgling nation.

Franklin's example is a reminder that we need scientists for today's challenges in diplomacy and development and not just because of their expertise—we need them because their skills, networks and ways of thinking about problems represent the best of what America can offer the world.

Over the past 75 years our academic institutions, the majority of our most innovative companies and the public at large have benefited from sustained and directed investment in research by the federal government. The vision of what the government could undertake when the risks were too great for any other entity was informed by a post–World War II mindset about the role of science in American life. Since the 1940s taxpayer dollars have supported a broad portfolio of basic research that has undergirded long-term American prosperity and security, including faster and more efficient airplanes, the Internet, genomics, weather satellites, vaccines, and so much more.

As a result, the U.S. has an untapped reservoir of talent to bring to its international relations. America's scientists have high-level technical expertise and creative problem-solving abilities. The best of them have a facility for communicating complex ideas and social networks that are important for public diplomacy, and the U.S. will need diplomats with an abundance of these assets. Moreover, the credibility of the upcoming generation of American scientists will be invaluable on the world stage: even though international opinion of the country has reached record lows, U.S. science and ingenuity are still deeply respected.

Even with a richness of talent, we still need more opportunities to integrate scientists into the front lines of U.S. embassies and missions abroad. Programs such as the fellowships offered by the American Association for the Advancement of Science can place postdoctoral scientists throughout the State Department and the U.S. Agency for International Development (USAID) to address pressing problems in diplomacy and development. Scaling up this type of program would have a significant impact in these areas. At USAID, the Partnerships for Enhanced Engagement in Research have built hundreds of collaborative programs to date, in conjunction with American scientific agencies, aimed at building long-term engagements and connections across the wider scientific community.

Science-focused diplomacy works because science is a distributed, global enterprise with products that can be replicated and verified and that can inspire. It can create the scaffolding that allows our official relationships to thrive by providing trust, transparency and engagement that would otherwise be hard to achieve. Many foreign scientists trained in the U.S. climb to leadership roles in their home countries. Engaging through science can form bridges over divisions in geography, religion, culture and language, and it can help other countries meet real needs—especially when emerging threats fail to respect political boundaries. Finally, as global connections make national economies increasingly intertwined, science diplomacy can create avenues that sustain competitiveness and promote economic growth in the U.S.

Given the protracted challenges on the horizon for U.S. foreign policy, science provides a path through the planetwide crises we are facing, and it also gives our country a way to put its best foot forward. After all, many of the values that scientists share are also historic American values.

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Illustration by Dawn Yang

ADVANCES

The first octopus genome sequenced was from a California two-spot octopus (*species pictured here*).


JOEL SARTORE

INSIDE

- An AI trains to spot an invasive lanternfly's eggs
- Copycat cetaceans may outsmart orcas
- Car-sized boulders heaved by a tsunami hide among island vegetation
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BIOLOGY

A Model Octopus

Big-brained cephalopods could help reveal the evolution and neurobiology of intelligence, complexity, and more

Humans are more closely related to dinosaurs than they are to octopuses. Our lineage split from that of cephalopods—the spineless class that includes octopuses, squids and cuttlefish—half a billion years ago. Octopus brains lack any of the major anatomical features of vertebrate brains, and most of the animals' neurons are distributed across their arms rather than in their head.

Yet octopuses are extremely intelligent, with a larger brain for their body size than all animals except birds and mammals. They are capable of high-order cognitive behaviors, including tool use and problem-solving, even figuring out how to unscrew jar lids to access food. Increasingly, some researchers are suggesting octopuses' combination of smarts and sheer difference from humans could make them an ideal model for inferring common rules governing complex brain function, in addition to revealing novel neurological workarounds cephalopods have evolved.

Scientists have often turned to animals, among them *Drosophila* fruit flies, zebra fish and *Caenorhabditis elegans* nematodes, to gain biological insight and understanding. But of all the widely studied "model species" that are easy to raise in the laboratory, rodents such as mice have been most instrumental in understanding how the brain works.

"The advantage of the mouse is that its brain is remarkably similar to the human brain, whereas the advantage of the octopus is that it's remarkably dissimilar," says Gül Dölen, a neuroscientist at Johns Hopkins University. Comparing and contrasting these systems with our own, she says, "gives you that logical power of reduction." Nematodes and fruit flies are also very dissimilar to humans, she notes, but octopuses eclipse these fellow invertebrates in terms of complexity. Recognizing the unique opportunity cephalopods provide as vastly different yet highly sophisticated creatures, Dölen and other neuroscientists are rooting for them to become the field's newest model organism.

Using octopuses to gain insight into our own species was originally proposed in the 1960s by neurophysiologist J. Z. Young. The idea moved within reach in 2015, when scientists sequenced the first octopus genome, for the California two-spot octopus. "A whole genome opens up huge levels of information you didn't have before," says Clifton Ragsdale, a neurobiologist at the University of Chicago, who co-authored the octopus genome study in *Nature.*

As was the case with other model species, publishing the octopus genome paved the way for critical modes of investigation, the researchers say. These include using genetic engineering to probe how the brain works, zooming in on where specific genes are expressed, and exploring evolution by calculating differences between octopus genes and those of other species.

"We're at a really exciting moment for working with these remarkable animals," says Caroline Albertin, an evolutionary developmental biologist at the Marine Biological Laboratory in Woods Hole, Mass., and lead author of the genome study. "There's just a vast ocean of research and questions that we need to explore."

Toward that end, researchers have begun developing cephalopod versions of the same molecular tools that those working with mice or flies take for granted. Last summer in *Current Biology,* Albertin and her colleagues described the first cephalopod gene knockout (inactivating a gene to study what it does). Now the same team is working on gene knock-ins that will, for example, let scientists insert activity indicators into octopus cells. This process will let them study the animals' neural activity in real time, says Marine Biological Laboratory researcher Joshua Rosenthal, who co-authored the knockout study. "Once we get that next step," he says, "I think the community is just going to start exploding."

Research is already accelerating. In 2018 Dölen and co-author Eric Edsinger dosed octopuses with MDMA and found that although they are typically antisocial, they respond to a drug-induced flood of the neurotransmitter serotonin the same way humans do: they relax and become more sociable. Through genome analysis, the scientists also confirmed that octopuses possess the same serotonin transporters that MDMA binds to in vertebrates. As reported in *Current Biology,* this finding suggests that sociality could involve a molecular

TECH

Lanternfly Invasion

A new algorithm could spot the insect's eggs and curtail their rapid spread

Since it was first noticed in 2014 in Berks County, Pennsylvania, the spotted lanternfly—a one-inch-long plant hopper that resembles a moth and is native to China—has been wreaking havoc on East Coast lumber, tree fruit and wine industries. It has spread to many counties in Pennsylvania, plus parts of New Jersey, Delaware, Maryland, Virginia, West Virginia and New York.

The invasive, plant-killing insect can lay its eggs on almost any surface, including vehicle exteriors. These egg masses "are most concerning because they can go very far, by hitchhiking," says Maureen Tang, a chemical and biological engineer at Drexel University. Tang's new project uses crowdsourced photographs of the egg masses to

The spotted lanternfly is proliferating quickly across the U.S. East Coast.

mechanism rather than being rooted in specific vertebrate brain regions.

Other labs are investigating how octopus arms sense and interact with their environment with minimal input from the brain. Last fall researchers reported in *Cell* that specialized receptors in octopus suckers detect chemicals on surfaces they contact, enabling them to taste by touching. "This is an example of how we need to consider studying life in all shapes and sizes to really understand how molecular and cellular adaptations give rise to unique organismal features and functions," says Nicholas Bellono, a molecular and cellular biologist at Harvard University and senior author of the *Cell* study.

Scientists will soon have even more resources to draw on. In 2016 the Marine Biological Laboratory launched a cephalopod breeding program to culture research animals. Albertin and program manager Bret Grasse are now working with Dölen and other colleagues to sequence the genome of *Octopus chierchiae*—a golf ball– to tangerine-sized Central American species that is the leading candidate for an octopus model organism. *O. chierchiae*'s small size would make it ideal for raising in a lab, and unlike a number of other octopus species, scientists have figured out how to breed it.

Cephalopods will no doubt bring more insights into fundamental biology. Technological breakthroughs could follow, too. Materials researchers are interested in the animals' skin for its incredible camouflage ability, for example, and computer scientists may someday draw on octopuses' separate learning and memory systems—one for vision and one for tactile senses—for new approaches to machine learning.

Octopuses could also inspire biomedical engineering advances. Rosenthal is studying cephalopods' incredibly high rates of RNA editing, which could someday lead to new technologies to erase unwanted mutations encoded in human genomes. Ragsdale is investigating how octopuses quickly regenerate their arms, nerve cords and all; this might one day contribute to therapies for humans who lose limbs or have brain or spinal cord damage. "Biology has pretty much figured out a solution to almost everything," Rosenthal says. "We just have to find it." *—Rachel Nuwer*

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train a sophisticated scanning algorithm for pinpointing them.

Adult lanternflies feast on more than 70 plant species and leave behind so-called honeydew droppings, which attract wasps and other stinging insects and which breed a black, sooty mold that can significantly damage plants. The mature lanternflies die in the cold, but the masses of between 30 and 50 eggs, which look like a grayish putty, release a new generation in the spring.

Once fully trained on thousands of photos, the image-processing algorithm will let scanning devices detect significant infestations in real time, says Drexel mechanical engineer Antonios Kontsos, who is building the algorithm. The system will first be put to work in high-risk locations such as rail and shipping yards, where storage containers often sit around for long periods and it is difficult and dangerous for a human to check underneath them for egg masses, Tang says. The lanternflies' favorite tree, *Ailanthus altissima,* tends to grow near railroad tracks.

People already scan for signs of pests using drones with computer vision; these drones fly over crops and treescapes to check for significant damage. But Tang says her team's type of discrete, close-up egg-detection system is new.

"We've seen a lot of ingenuity come from spotted lanternfly [research], and this is another great example," says Heather Leach, who studies these insects at Pennsylvania State University and is not involved in the initiative. Any methods that help to reduce the bug's spread, especially in regions where it has not yet been established, offer a better chance at controlling it, Leach says.

The team aims to finish the algorithm and start using it to search for eggs before the bugs begin emerging. Egg masses are much easier to contain than jumping nymphs or swarming adults, notes Karen Verderame, curator of entomology at the Academy of Natural Sciences of Drexel University. Researchers will first target top-priority spots using a portable scanning device that can look for egg masses in visible, infrared and ultraviolet light, Kontsos says. He anticipates someday using a version of this device in a "precision-agriculture framework"—installing it on a drone for efficient, large-area scans. *—Claire Marie Porter*

GETTY IMAGES

SPACE EXPLORATION

Going Back

Astronaut Jessica Watkins could be among the first to return to the moon

NASA plans to go back to the moon—but unlike the Apollo missions of a half-century ago, the agency's Artemis program is designed to send humans on longer-duration journeys, to land at the lunar south pole, and potentially even to build and populate a base there. The first crewed landing could take place as early as the mid-2020s. Last December the space agency announced the 18 astronauts who are working to make Artemis a reality; Jessica Watkins, who joined the astronaut corps in 2017, is among them. As a planetary geologist and a former member of the science team for NASA's Mars Curiosity rover, Watkins is a leading candidate for future lunar missions and could become the first woman and first person of color to walk on the moon. *Scientific American* spoke to Watkins about Artemis, why the moon, and why to send humans at all. An edited transcript of the interview follows.

—*Lee Billings*

Why is it important to send people to the moon? What draws you to it, personally?

There are a lot of different reasons to go back—scientific, economic, you name it—but one for me is this idea of having something we can all engage with that brings us together. After the past year we've had—as a country, as a world—to have something positive that we can all support is really important. And there's still a lot to be learned about and from the moon. Going to a different landing site than we did in the Apollo days, bringing upgraded technologies there—that will really increase our knowledge and understanding of the moon, Earth and the solar system as a whole.

You used to work on the Curiosity Mars rover, so you know this all too well: Some people want to skip the moon in favor of going straight to Mars. What might convince them otherwise?

Mars was my first love, for sure. And going back to the moon serves as a steppingstone to help us get toward Mars. So it's not an either-or. One of the really interesting things about going to the lunar south pole is that because of the orbital dynamics and geometry, you end up with these permanently shadowed regions there. And in these [areas], you have access to craters with the potential to have preserved volatiles—things like water ice—that are obviously very interesting from a scientific standpoint but also can be used as resources as we start to think about building a lunar base.

Why not just send robots?

This question of "robots versus humans" is similar to the "moon versus Mars" conversation, in the sense that they build on each other and it is not a mutually exclusive situation at all. We need both. Sending robots is cheaper and easier in the sense that you don't have a [human] in the loop. In human interplanetary exploration, we can send robots out before we arrive, to help us decide on a landing site, to give us preliminary data to drive our scientific questions that we'll then have humans go out and try to answer. [But] based on my experience with Curiosity, a rover is just much slower. Whereas a human being—as soon as we step onto a surface, we can get to work almost instantaneously, making decisions about where to go to find answers to questions.

Every Apollo astronaut was a white man in his 30s or 40s. Why is the diversity of Artemis's astronauts important?

It's important that the Artemis team be diverse, first of all, because a diverse team is a strong team. The astronaut corps (as well as all of NASA) is made up of people with diverse skill sets, strengths, backgrounds and experiences—and relying on each of those individuals' expertise will enable the collective success of the Artemis missions. The whole truly is greater than the sum of its parts. It's also important because representation does matter. It was absolutely beneficial to me as a young girl to have role models to look up to who looked like me and for them to go before me and create a path for me to pursue my dreams. I hope that the Artemis team can do that for the next generation of explorers and inspire them to follow their dreams as well.

ROBERT MARKOWITZ NASA

ANIMAL BEHAVIOR

Whale Mimics

Australian pilot whales might copy orca calls

Southern long-finned pilot whales are marine mammals with a lot to say—and they may use vocalizations to outsmart a deadly foe.

Cetaceans such as whales, dolphins and porpoises communicate through sound to find food and mates, to navigate and to interact socially. Their vocalizations vary between species and within communities. The animals can mimic artificial noise such as sonar, but nobody had previously recorded them matching other cetaceans' sounds. A new study, however, found overlap in the cetacean sound book.

Researchers listened to 2,028 vocalizations of long-finned pilot whales off the coast of Australia, the first time sounds from the species in this region have been comprehensively described. They were surprised to hear 19 instances of vocalizations that resembled those of orcas—the whales' oceanic rivals. "We found some calls that are, to the human ear, identical to the killer whale calls in the same area," says Christine Erbe, director of the Center for Marine Science and Technology at Curtin University in Perth and co-author of the study, published in *Scientific Reports*.

Pilot whales and orcas, the two largest species of delphinid, are often seen in the same environments and are similar sizes, and both live in social groups with strong cohesion, says Charlotte Curé, a bioacoustics researcher at CEREMA Lab in France, who was not involved in the study. Orcas compete for food with long-finned pilot whales and are potentially their predators.

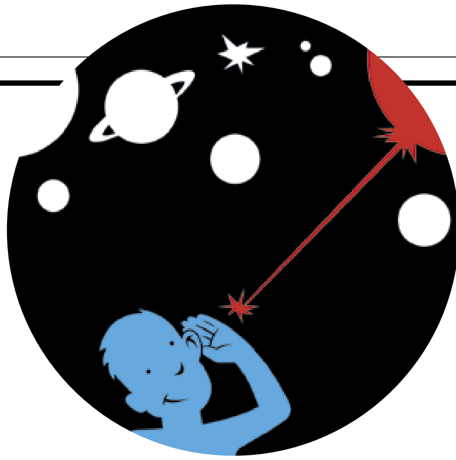
Evidence from orca stomachs shows they do occasionally eat pilot whales. But pilot whales can mob and chase orcas away, the only cetaceans seen defending themselves from the apex predator in this way.

Mimicry could serve as an additional defense: "One hypothesis is that if they use similar sounds, they may not be recognized as prey," Erbe says. Pilot whales scavenging or eating orcas' food remnants might go unnoticed if they use orcalike calls. "This is all underwater, where light travels really poorly," she adds. "So these animals rely on sound for detecting their prey and predators and for navigating." Long-finned pilot whales have shown an ability to distinguish between orca calls with different meanings; Curé suggests that instead of tricking orcas, the callers could instead be demonstrating a new orca sound to other group members.

Additional work would confirm whether mimicry is actually occurring. Researchers could pair their listening data with direct observations of the animals' interactions in the wild or perhaps even play orca sounds and watch the whales' reactions.

But if a future experiment used predatory sounds, it would need to be done very carefully. "A reaction to a predator can be very strong," Curé says. "In some protected areas, you are not allowed to do more than two predatory playbacks per year."

—Doris Elín Urrutia



OPTICS

Traveling Photons

A laser-based system could boost deep-space data transfer

A new laser technology could improve the quality of deep-space communication, making it easier for humans to push the boundaries of the final frontier.

Much of today's space communication relies on radio signals. But these diffract and broaden as they travel, as does light or any other electromagnetic wave. A radio beam fired from the moon to Earth "would typically diverge to the size of a continent," says Peter Andrekson, a photonics researcher at Chalmers University of Technology in Sweden and co-author of a new study in *Light: Science and Applications*. In contrast, he notes, "a laser beam would diverge to a two-kilometer radius or so."

Catching enough of a spacefaring radio signal from somewhere like Mars requires a really big dish. NASA's widest receivers stretch 70 meters across, says Bryan Robinson, an optical communications engineer at the MIT Lincoln Laboratory, who was not involved in the study: "It's like a football field that's on a gimbal pointing to Mars."

Laser communication could work with receivers about 20 centimeters across—the size of a personal pizza—and condensed laser beams can carry much more information than radio. But laser signals are transmitted at a lower power level, and processing them once they are received requires a daunting level of amplification.

The researchers' new receiver manipulates interactions between photons to magnify an incoming signal without reducing its quality, a technique called phase-sensitive amplification (PSA). This approach is "very interesting," Robinson says, because today's amplifiers add distorting "noise." The experimental PSA system was sensitive enough to receive an unprecedented 10.5 gigabits of information per second, noise-free, through a lab setup that mimics the vacuum of deep space and adds diffraction to simulate distance. The next challenge will be to overcome distortion caused by Earth's atmosphere.

In 2013 the Lincoln Laboratory and NASA successfully tested another type of laser transmission between a spacecraft and Earth. That method used a photon-counting receiver, which tallies individual light particles as they strike a detector. It is extremely efficient for transmitting data, which can be numerically encoded—but the counter works only at –454 degrees Fahrenheit. PSA receivers operate at room temperature.

Despite the challenges, refining optical communications systems such as these would be "a pretty big deal," says planetary scientist Tanya Harrison, who was not involved with either project. Harrison is mapping Mars by satellite and has been frustrated with the limitations of radio transmissions. Radio data currently travel from Mars to Earth with all the speed and fidelity of an early-1990s modem. A satellite orbiting the Red Planet, Harrison says, "can take an order of magnitude more data than it's able to actually send back. Basically we could be doing a lot more science if we had optical communications." —*Joanna Thompson*

GEOLOGY

Tsunami Boulders

An island's mysterious rocks were likely deposited by giant waves

The dense vegetation of Isla de Mona, an uninhabited speck in the Caribbean, hides car-sized boulders studded with corals. Scientists first reported spotting them in the early 1990s, but the strange rocks slipped back into obscurity before anyone investigated their origin. Now researchers have revisited these behemoths and concluded that massive tsunami waves, launched by an underwater landslide, heaved them from the sea.

Many of the boulders are visible from the air, but most are difficult to reach from the ground, says Bruce Jaffe, an oceanographer at the Pacific Coastal and Marine Science Center in Santa Cruz, Calif. He recalls picking his way around the island's poisonous plants, including one that can cause blistering and temporary blindness. "We've talked about going back with hazmat suits," he says.

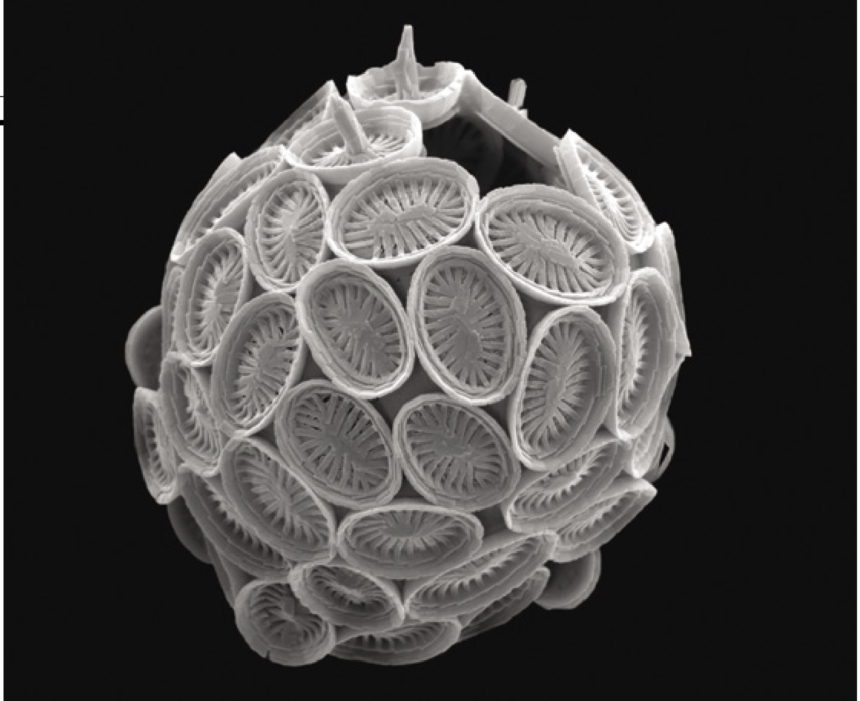
During two trips, the researchers visited more than 50 boulders. The largest was more than eight meters long, and the rocks were strewn over a wide area up to 800 meters inland. A storm probably would not have deposited them so far from the shoreline, Jaffe says; a powerful tsunami must have been involved. Ricardo Ramalho, a geologist at the University of Lisbon, who was not involved in the research, agrees: "I would find it surprising if it was the work of a storm," he says.

Team member Pedro Israel Matos Llavona, a geoscientist at the University of Massachusetts Amherst, pored over maps of the nearby seafloor and found evidence of something that could have triggered such a tsunami: a jagged depression nearly four kilometers wide, the relic of a long-ago underwater landslide. Matos Llavona simulated the landslide and found it would have sent 10-meter-high tsunami waves crashing onto Isla de Mona—with enough force to heave many-ton boulders far inland. The researchers presented these results at the 2020 American Geophysical Union Fall Meeting.

Next the team plans to pinpoint more of these boulders by flying a drone to detect the heat that they emit after a day in the sun. The researchers suggest that tracing how the rocks are scattered may help scientists detect tsunami signatures elsewhere. —*Katherine Kornei*

WILSON R. RAMIREZ

Illustration by Thomas Fuchs



A modern coccolith has holes that help with locomotion.

FROM "ALGAL PLANKTON TURN TO HUNTING TO SURVIVE AND RECOVER FROM END-CRETACEOUS IMPACT DARKNESS," BY SAMANTHA J. GIBBS ET AL., IN *SCIENCE ADVANCES*, VOL. 6, NO. 44; OCTOBER 30, 2020

PALEOBIOLOGY

Predatory Algae

When the sun disappeared, tiny coccoliths became hunters

An asteroid strike 66 million years ago not only devastated the dinosaurs but almost reset life in the oceans back to a primitive soup of simple microorganisms. What prevented ocean ecosystems from totally collapsing, scientists hypothesize, may have been shell-covered algae that could feed on other organisms but maintained the ability to photosynthesize. This skill would preserve the foundation of the marine realm's complex food webs through a long dark spell.

The predatory plankton belonged to a family of armored, algaelike organisms called coccolithophores, or coccoliths. They have been around for about 200 million years, and many forms still bob along as ocean plankton today. But their survival was especially significant in the wake of the mass extinction at the end of the Cretaceous period, when debris from the asteroid's impact and wildfire ash blotted out the sun for two years. Life experienced a prolonged "impact winter" when photosynthesis all but ceased.

"The food webs in the ocean have photosynthesis as their foundation, just like the land, but in the ocean the photosynthesis is carried out by microscopic bacteria and algae," says University of Southampton paleontologist Samantha Gibbs, lead author of a new study in *Science Advances*. Coccoliths were among these energy converters in the Cretaceous, and about 90 percent of coccolith species went extinct after impact.

Lacking light for their energy needs, Gibbs says, "the handful of survivor species were able to turn to food capture and ingestion." Small holes in coccolith fossils indicate that the survivors possessed whiplike flagella that let them move and stalk other organisms. The researchers tracked hunter algae's prevalence in the fossil record and modeled the organisms' evolution to show how they could have survived and adapted to the sun's disappearance—and then its return, when they proliferated again.

Experts have long wondered how photosynthesis-using organisms such as coccoliths endured without sunlight. "This is a really exciting finding that goes a long way to explaining an apparent paradox in the extinction," says University of Texas at Austin paleontologist Christopher Lowery, who was not involved in the study.

The model may explain changes in other organisms as well. Small creatures called foraminifera, or forams, also took a hit from the impact but persisted. They were armored, too, and those that survived evolved spines. The spines would have worked together with miniature tentacles to help forams grab larger prey, Lowery says, bolstering the idea that other single-celled organisms also adapted their feeding style.

Eventually coccolith survivors picked up photosynthesis again, revitalizing the ocean's food webs when light returned. Tiny, hungry algae helped to save the seas. —*Riley Black*

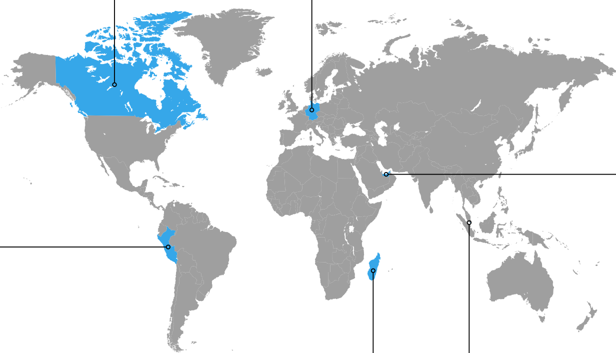
IN THE NEWS
Quick Hits
By Sarah Lewin Frasier

CANADA
Researchers reconstructed the mitochondrial genome of a mummified wolf pup buried in permafrost for more than 50,000 years. They found that the way it is related to both North American and Eurasian wolves suggests the populations maintained a connection over an ancient land bridge.

GERMANY
Divers found a Nazi "Enigma" encoding machine at the bottom of the Bay of Gelting, possibly thrown overboard to keep it away from an enemy. Archaeologists will spend a year restoring the World War II–era device.

UNITED ARAB EMIRATES
A study of dead camels' stomachs revealed that 1 percent contained large clumps formed of plastic bags, the biggest of which weighed nearly 64 kilograms. These so-called polybezoars can release toxins, and they cause camels to starve because their stomachs are too full for food.

PERU
A study found that epigenetic changes (chemical modifications that control DNA activity) help Quechua people who spent their childhood in the Andes Mountains endure high altitudes.



MADAGASCAR
A newly discovered orchid species that looks like a decaying paper bag has been named the ugliest orchid in the world by the Royal Botanic Gardens, Kew. It is among 156 plants and fungi described by the organization's researchers in 2020.

SINGAPORE
For the first time, a country's regulatory authority—the Singapore Food Agency—has approved the sale of a lab-grown meat. The "chicken" chunks, grown in a bioreactor, are produced by U.S. company Eat Just.

For more details, visit www.ScientificAmerican.com/mar2021/advances

TRANSPORTATION
Off the Rails
Will trackless trams gain traction in the U.S.?

Joe Ciresi used to drive about 30 miles into Philadelphia for work every day. "It took anywhere from an hour and a half to three hours, depending on traffic," he recounts. "I said, 'This is insanity.'" Now a Pennsylvania state representative, Ciresi has been thinking about how to reduce the number of cars on the road. Recently he and his staff were looking at public transport options and encountered a video about trackless trams created by Peter Newman, a researcher at the Curtin University Sustainability Policy Institute in Perth, Australia.

Public transportation is essential to reducing gridlock and emissions on highways and in cities, Newman says. But trains require extensive infrastructure spending, and historically buses have been unpopular because of potentially bumpy and traffic-slowed rides. Now, however, new technology can let buslike vehicles run on roads for a ride resembling the more popular experience of rail travel—without rails. Newman describes one example already running in China: a self-driving electric bus with optical sensors that let it follow a white line painted on the road. Its hydraulic suspension system, a type often used in trains, eases jolts.

A trackless tram in Yibin, China, follows painted guides.

"What impressed me in China was that the ride quality was ... equivalent to what I had experienced on a modern light rail, where everything is fixed on a steel track," Newman says. To emphasize the technological advances making these souped-up buses more pleasant to ride, Newman advocates officially calling them "trackless trams." He is working to bring them to Perth and says they are being studied or tried out in Zimbabwe and Qatar. "I think you'll find that in the next decade [the idea will] take off very quickly," he says.

Trackless trams avoid the need for expensive rail systems, but they do require some changes to infrastructure. "Most of the cost of these new systems that we're building is in that cost of constructing the right of way," says Yale Wong, a transportation researcher at the University of Sydney. In Ciresi's area of Pennsylvania, for example, creating a dedicated trackless tram lane would mean modifying about a dozen overpasses for the specialized vehicles. Wong notes that these changes could also support a dedicated bus route—but "people just don't like buses." He suggests that a form of transit associated with rails (and with shiny new technology) has a better chance of earning the public's enthusiasm.

That is why Ciresi hopes to demonstrate trackless trams in the U.S. before pushing for infrastructure changes. "We do a test run, maybe for five miles … and we find out if this is worth the investment," he says. "I think, as Americans, we like to see the product and be able to hold, touch, feel and give our opinion of it." —*Sophie Bushwick*

CRRC

Anna Leahy directs the M.F.A. in Creative Writing program at Chapman University in Orange, Calif., where she also curates the Tabula Poetica reading series and edits the international *Tab Journal*. She is author of *Tumor* (nonfiction) and the poetry collections *Aperture* and *Constituents of Matter*.

STATES OF MATTER

For any liquid, there are two ways to arrive:
condensation or melting, a gas finding
shape or a solid losing it. For any liquid,
leaving depends on pressures
and one of two ways out: to evaporate
is to lift from its own surface,
the bonds broken, the substance cooling
with each molecular departure;
to boil is to reach the elemental
point of no return, through and through.
For a solid, there's another trick to changing states
by skipping the liquid in-between:
the ablation of glaciers by wind that eats snow,
the whiff of mothballs from the closet,
arsenic like a hint of garlic in the air—
or in reverse, frost or soot or rime,
the coalescence of vapor, no longer suspended.
The mind is said to do this, too: to turn
one energy into another, like desire into art
to save oneself in another state of being.

DON KOMARECHKA

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.*

7 Ways to Tackle COVID Vaccine Hesitancy

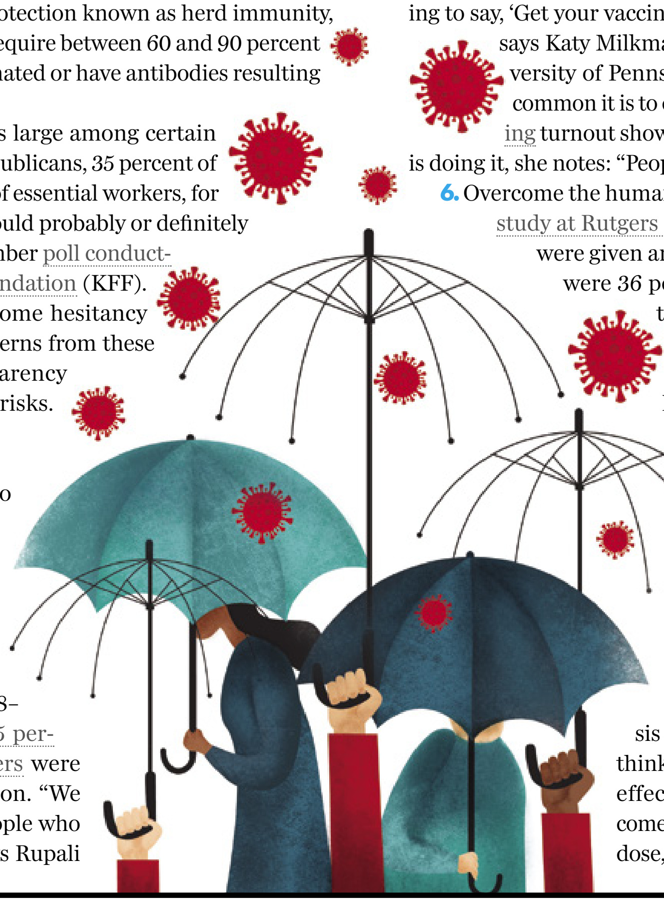
Use trusted messengers, remove barriers, and other research lessons

By Claudia Wallis

Like billions of people around the world, I am eagerly awaiting my turn for a COVID vaccine. But not everyone shares my enthusiasm. My sister-in-law, an alternative health practitioner, says she doesn't trust "Big Pharma" to have formulated safe shots. She prefers to fortify her immune system with supplements and a healthy lifestyle. "I avoid all vaccines," she told me.

She is not alone. By now the term "vaccine hesitancy" has entered everyday pandemic discourse, joining "flatten the curve" and "social distancing." Polls in December 2020 suggested that about 30 percent of Americans harbor doubts about COVID vaccinations. If that number holds steady, unvaccinated people could form a deadly reservoir of the SARS-CoV-2 virus, able to restart outbreaks. We need a level of protection known as herd immunity, which experts estimate will require between 60 and 90 percent of the population to be vaccinated or have antibodies resulting from infection.

Vaccine reluctance looms large among certain subgroups: 42 percent of Republicans, 35 percent of Black adults and 33 percent of essential workers, for varying reasons, said they would probably or definitely refuse the vaccine in a December poll conducted by the Kaiser Family Foundation (KFF). Experts say efforts to overcome hesitancy should address specific concerns from these groups and include transparency about vaccine benefits and risks. Here are seven key ideas:



1. It's not necessary to change the minds of committed anti-vaxxers; they are just a tiny slice of the population, and we can reach herd immunity without them. Consider, for example, that in the 2018–2019 school year, only 2.5 percent of U.S. kindergartners were exempted from vaccination. "We are more interested in people who might be ambivalent," says Rupali Limaye, a health communication scientist at the Johns Hopkins Bloomberg School of Public Health.

2. Facts alone will not persuade skeptics. A 2014 study of adults who worried that vaccination might cause autism—a debunked idea—found that corrective facts had no impact on their intentions to vaccinate a child. The information actually hardened negative views among those most opposed. "A more convincing approach is to address the lack of trust or reach people with trusted messengers rather than trying to throw facts and science at people," says Brendan Nyhan, lead author of that study and a professor of government at Dartmouth College.

3. Some minority groups, such as Black and Native Americans, have strong historical reasons to view health authorities with suspicion. Experts favor working closely with civic and faith leaders, admired athletes and other trusted figures within those groups. This technique was first developed to promote practices that prevent HIV/AIDS among gay men and has since been adapted for other purposes and populations.

4. Low levels of vaccination, particularly among low-income communities, often reflect practical barriers. Offering extended hours for immunizations and ensuring that the public knows there is no cost are two ways to improve the rates, says Samantha Artiga, director of racial equity and health policy at KFF.

5. Talk about how popular the vaccine is. "It might be tempting to say, 'Get your vaccine because half of Americans won't,'" says Katy Milkman, a behavioral scientist at the University of Pennsylvania, but that "emphasizes how common it is to decline the vaccine." Research on voting turnout shows it is more effective to say everyone is doing it, she notes: "People follow perceived norms."

6. Overcome the human tendency to procrastinate. A 2009 study at Rutgers University showed that people who were given an opt-out appointment for a flu shot were 36 percent more likely to be vaccinated than folks who were sent a link to schedule it themselves. Once the new vaccines are widely available, Limaye suggests health providers can say to patients who come in for other, more routine reasons, "Let's go ahead and get that COVID shot."

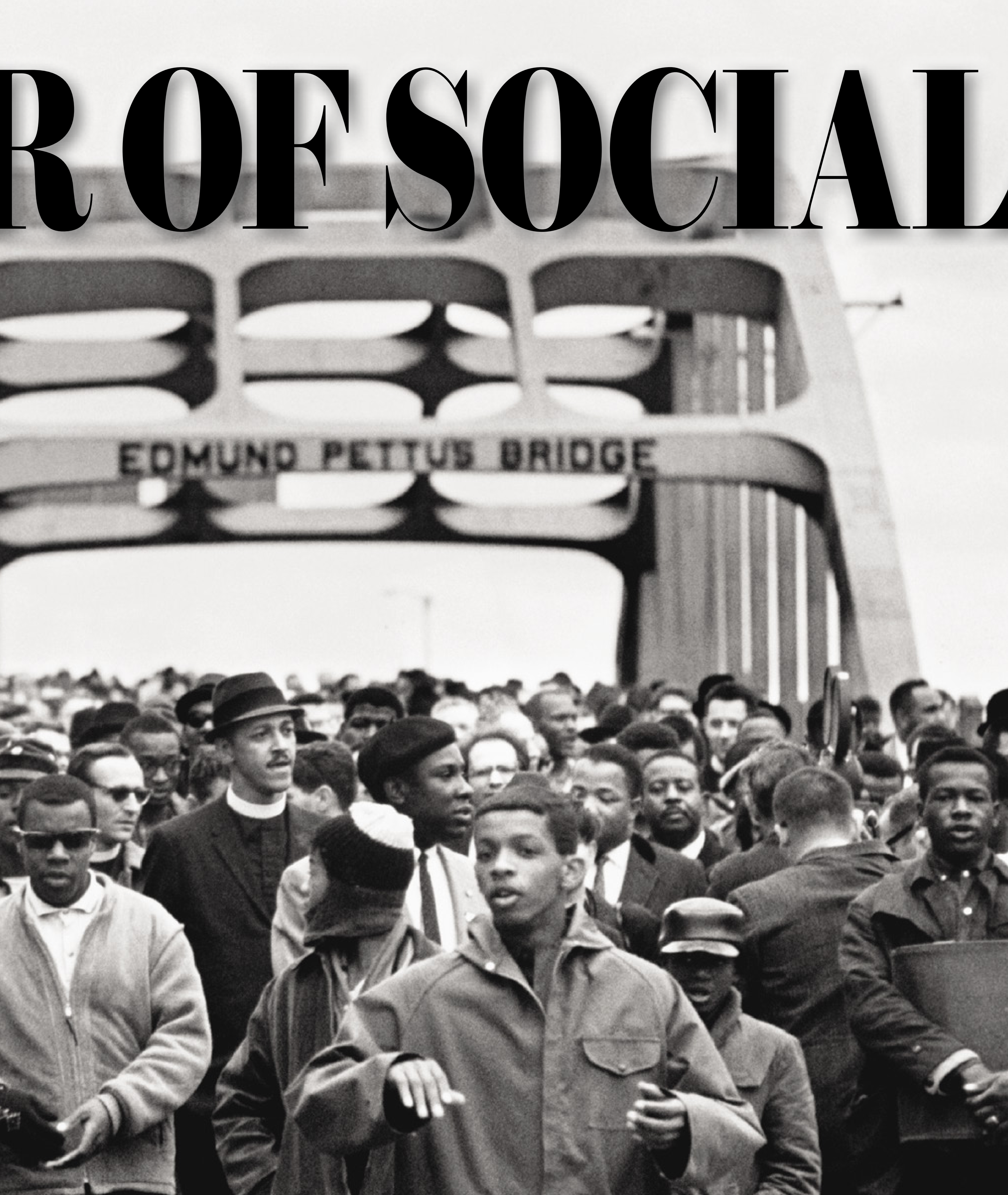
7. For forgetful types, simple reminders—by text or voice message—can be powerful. A 2019 study showed that frequent daily reminders to complete drug treatment for tuberculosis greatly improved outcomes. "You'd think that would be irritating, but it was effective," Milkman says. So when it comes time for that second COVID vaccine dose, she suggests, "Let's nag people." SA

Illustration by Fatinha Ramos

THE POWE

CIVIL RIGHTS supporters march from Selma to Montgomery in Alabama on March 9, 1965, in a campaign to register Black voters. Days earlier a similar group of nonviolent protesters had been brutally beaten by state troopers at the Edmund Pettus Bridge. This time Martin Luther King, Jr., who led the march, avoided confrontation and asked the campaigners to kneel and pray at the site of the attack before walking back to Selma, in an effort to morally pressure President Lyndon B. Johnson to extend federal protection to the peaceful protest.

R OF SOCIAL



JUSTICE MO

BLACK LIVES MATTER activists march across the George Washington Bridge in New York City on September 12, 2020, to protest systemic injustices, including the killings of Black people by police.

OVEMENTS

PRECEDING PAGES: FLIP SCHULKE *Getty Images;* THIS PAGE: JASON D. LITTLE

SOCIOLOGY

Black Lives Matter takes the baton from the Civil Rights Movement

By Aldon Morris

ONE EVENING NINE YEARS AGO 17-year-old Trayvon Martin was walking through a Florida neighborhood with candy and iced tea when a vigilante pursued him and ultimately shot him dead. The killing shocked me back to the summer of 1955, when as a six-year-old boy I heard that a teenager named Emmett Till had been lynched at Money, Miss., less than 30 miles from where I lived with my grandparents. I remember the nightmares, the trying to imagine how it might feel to be battered beyond recognition and dropped into a river.

The similarities in the two assaults, almost six decades apart, were uncanny. Both youths were Black, both were visiting the communities where they were slain, and in both cases their killers were acquitted of murder. And in both cases, the anguish and outrage that Black people experienced on learning of the exonerations sparked immense and significant social movements. In December 1955, days after a meeting in her hometown of Montgomery, Ala., about the failed effort to get justice for Till, Rosa Parks refused to submit to racially segregated seating rules on a bus—igniting the Civil Rights Movement (CRM). And in July 2013, on learning about the acquittal of Martin's killer, Alicia Garza, Patrisse Cullors and Opal Tometi invented the hashtag #BlackLivesMatter, a rallying cry for numerous local struggles for racial justice that sprang up across the U.S.

The Black Lives Matter (BLM) movement is still unfolding, and it is not yet clear what social and political transformations it will engender. But within a decade after Till's murder, the social movement it detonated overthrew the brutal "Jim Crow" order

Aldon Morris is Leon Forrest Professor of Sociology and African American Studies at Northwestern University and president of the American Sociological Association. His landmark books include *The Origins of the Civil Rights Movement* (1986) and *The Scholar Denied: W.E.B. Du Bois and the Birth of Modern Sociology* (2015).

in the Southern states of the U.S. Despite such spectacular achievements, contemporary scholars such as those of the Chicago School of Sociology continued to view social movements through the lens of "collective behavior theory." Originally formulated in the late 19th century by sociologist Gabriel Tarde and psychologist Gustave Le Bon, the theory disdained social movements as crowd phenomena: ominous entities featuring rudderless mobs driven hither and thither by primitive and irrational urges.

As a member of what sociologist and activist Joyce Ladner calls the Emmett Till generation, I identify viscerally with struggles for justice and have devoted my life to studying their origins, nature, patterns and outcomes. Around the world, such movements have played pivotal roles in overthrowing slavery, colonialism, and other forms of oppression and injustice. And although the core methods by which they overcome seemingly impossible odds are now more or less understood, these struggles necessarily (and excitingly) continue to evolve faster than social scientists can comprehend them. A post-CRM generation of scholars was nonetheless able to shift the study of movements from a psychosocial approach that asked "What is wrong with the participants? Why are they acting irrationally?" to a methodological one that sought answers to questions such as "How do you launch a movement? How do you sustain it despite repression? What strategies are most likely to succeed, and why?"

JIM CROW

SOCIAL MOVEMENTS have likely existed for as long as oppressive human societies have, but only in the past few centuries has their praxis—meaning, the melding of theory and practice that they involve—developed into a craft, to be learned and honed. The praxis has always been and is still being developed by the marginalized and has of necessity to be nimbler than the scholarship, which all too often serves the powerful. Key tactics have been applied, refined and shared across continents, including the boycott, which comes from the Irish struggle against British colonialism; the hunger strike, which has deep historical roots in India and Ireland and was widely used by women suffragettes in the U.K.; and nonviolent direct action, devised by Mahatma Gandhi in South Africa and India. They led to the overthrow of many unjust systems, including the global colonial order, even as collective behavior theorists continued to see social movements as irrational, spontaneous and undemocratic.

The CRM challenged these orthodoxies. To understand how extraordinary its achievements were, it is necessary to step into the past and understand how overwhelming the Jim Crow system of racial domination seemed even as late as the 1950s, when I was born. Encompassing the economic, political, legal and social spheres, it loomed over Black communities in the Southern U.S. as an unshakable edifice of white supremacy.

Jim Crow laws, named after an offensive minstrel caricature, were a collection of 19th-century state and local statutes that legalized racial segregation and relegated Black people to the bottom of the economic order. They had inherited almost nothing from the slavery era, and although they were now paid for their work, their job opportunities were largely confined to menial and manual labor. In consequence, nonwhite families earned 54 percent of the median income of white families in 1950. Black people had the formal right to vote, but the vast majority, especially in the South, were prevented from voting through various legal maneuvers and threats of violent retaliation. Blacks' lack of political power enabled their constitutional rights to be ignored—a violation codified in the 1857 "Dred Scott" decision of the Supreme Court asserting that Black people had "no rights which the white man was bound to respect."

Racial segregation, which set Black people apart from the rest of humanity and labeled them as inferiors, was the linchpin of this society. Humiliation was built into our daily lives. As a child, I drank from "colored" water fountains, went around to the back of the store to buy ice cream, attended schools segregated by skin color and was handed textbooks ragged from prior use by white students. A week after classes started in the fall, almost all my classmates would vanish to pick cotton in the fields so that their families could survive. My grandparents were relatively poor, too, but after a lifetime of sharecropping they purchased a plot of land that we farmed; as a proud, independent couple, they were determined that my siblings and I study. Even they could not protect us from the fear, however: I overheard whispered conversations about Black bodies hanging from trees. Between the early 1880s and 1968 more than 3,000 Black people were lynched—hung from branches of trees; tarred, feathered and beaten by mobs; or doused with gasoline before being set ablaze. This routine terror reinforced white domination.

But by 1962, when I moved to Chicago to live with my mother, protests against Jim Crow were raging on the streets, and they thrilled me. The drama being beamed into American living rooms—I remember being glued to the television when Martin Luther King, Jr., delivered his "I Have a Dream" speech in 1963—earned the movement tens of thousands of recruits, including me. And although my attending college was something of an accident, my choice of subject in graduate school, sociology, was not. Naively believing that there were fundamental laws of social movements, I intended to master them and apply them to Black liberation movements as a participant and, I fantasized, as a leader.

As I studied collective behavior theory, however, I became outraged by its denigration of participants in social movements as fickle and unstable, bereft of legitimate grievances and under the spell of agitators. Nor did the syllabus include the pioneering works of W.E.B. Du Bois, a brilliant scholar who introduced empirical methods into sociology, produced landmark studies of inequality and Black emancipation, and co-founded the National Association for the Advancement of Colored Peoples (NAACP) in 1909. I was not alone in my indignation; many other social science students of my generation, who had participated in the movements of the era, did not see their experiences reflected in the scholarship. Rejecting past orthodoxies, we began to formulate an understanding of social movements based on our lived experiences, as well as on immersive studies in the field.

VOTING RIGHTS activists march 54 miles from Selma to Montgomery in 1965. The third attempt to reach Montgomery succeeded on March 25 with the protection of the federal government. The heroism and discipline of the protesters, who endured violent attacks without retaliation or retreat, enabled the passage of the Voting Rights Act that August.

BUYENLARGE *Getty Images*

BUS BOYCOTT

IN CONDUCTING my doctoral research, I followed Du Bois's lead in trying to understand the lived experiences of the oppressed. I interviewed more than 50 architects of the CRM, including many of my childhood heroes. I found that the movement arose organically from within the Black community, which also organized, designed, funded and implemented it. It continued a centuries-long tradition of resistance to oppression that had begun on slave ships and contributed to the abolition of slavery. And it worked in tandem with more conventional approaches, such as appeals to the conscience of white elites or to the Constitution, which guaranteed equality under the law. The NAACP mounted persistent legal challenges to Jim Crow, resulting in the 1954 Supreme Court decision to desegregate schools. But little changed on the ground.

How could Black people, with their meager economic and material resources, hope to confront such an intransigent system? A long line of Black thinkers, including Frederick Douglass, Ida B. Wells and Du Bois, believed that the answer could be found in social protest. Boycotts, civil disobedience (refusal to obey unjust laws) and other direct actions, if conducted in a disciplined and nonviolent manner and on a massive scale, could effectively disrupt the society and economy, earning leverage that could be used to bargain for change. "Nonviolent direct action seeks to create such a crisis and foster such a tension that a community which has constantly refused to negotiate is forced to confront the issue. It seeks so to dramatize the issue that it can no longer be ignored," King would explain in an open letter from the Birmingham jail.

The reliance on nonviolence was both spiritual and strategic. It resonated with the traditions of Black churches, where the CRM was largely organized. And the spectacle of nonviolent suffering in a just cause had the potential to discomfit witnesses and render violent and intimidating reprisals less effective. In combination with disruptive protest, the sympathy and support of allies from outside the movement could cause the edifice of power to crumble.

The Montgomery bus boycott in 1955, which inaugurated the CRM, applied these tactics with flair and originality. It was far from spontaneous and unstructured. Parks and other Black commuters had been challenging bus segregation for years. After she was arrested for refusing to give up her seat, members of the Women's Political Council, including Jo Ann Robinson, worked all night to print thousands of leaflets explaining what had happened and calling for a mass boycott of buses. They distributed the leaflets door to door, and to further spread the word, they approached local Black churches. A young minister named King, new to Montgomery, had impressed the congregation with his eloquence; labor leader E. D. Nixon and others asked him to speak for the movement. The CRM, which had begun decades earlier, flared into a full-blown struggle.

The Montgomery Improvement Association, formed by Ralph Abernathy, Nixon, Robinson, King and others, organized the movement through a multitude of churches and associations. Workshops trained volunteers to endure insults and assaults; strategy sessions planned future rallies and programs; community leaders organized car rides to make sure some 50,000 people could get to work; and the transportation committee raised money to repair cars and buy gas. The leaders of the movement also collected funds to post bail for those arrested and assist participants who were being fired from their jobs. Music, prayers and testimonies of the personal injustices that people had experienced provided moral support and engendered solidarity, enabling the movement to withstand repression and maintain discipline.

Despite reprisals such as the bombing of King's home, almost the entire Black community of Montgomery boycotted buses for more than a year, devastating the profits of the transport company. In 1956 the Supreme Court ruled that state bus segregation laws were unconstitutional. Although the conventional approach—a legal challenge by the NAACP—officially ended the boycott, the massive economic and social disruption it caused was decisive. Media coverage—in particular of the charismatic King—had revealed to the nation the cruelty of Jim Crow. The day after the ruling went into effect, large numbers of Black people boarded buses in Montgomery to enforce it.

This pioneering movement inspired many others across the South. In Little Rock, Ark., nine schoolchildren, acting with the support and guidance of journalist Daisy Bates, faced down threatening mobs to integrate a high school in 1957. A few years later Black college students, among them Diane Nash and John Lewis of Nashville, Tenn., began a series of sit-ins at "whites only" lunch counters. Recognizing the key role that students, with their idealism and their discretionary time, could play in the movement, visionary organizer Ella Baker encouraged them to form their own committee, the Student Nonviolent Coordinating Committee, which started to plan and execute actions independently. Escalating the challenge to Jim Crow, Black and white activists began boarding buses in the North, riding them to the South to defy bus segregation. When white mobs attacked the buses in Birmingham and the local CRM leadership, fearing casualties, sought to call off the "Freedom Rides," Nash ensured that they continued. "We cannot let violence overcome nonviolence," she declared.

The sophisticated new tactics had caught segregationists by surprise. For example, when the police jailed King in Albany, Ga., in 1961 in the hope of defeating the movement, it escalated instead: outraged by his arrest, more people joined in. To this day, no one knows who posted bail for King; many of us believe that the authorities let him go rather than deal with more protesters. The movement continually refined its tactics. In 1963 hundreds of people were being arrested in Birmingham, Ala., so CRM leaders decided to fill the jails, leaving the authorities with no means to arrest more people. In 1965 hundreds of volunteers, among them John Lewis, marched from Selma to Montgomery in Alabama to protest the suppression of Black voters and were brutally attacked by the police.

The turmoil in the U.S. was being broadcast around the world at the height of the cold war, making a mockery of the nation's claim to representing the pinnacle of democracy. When President Lyndon B. Johnson formally ended the Jim Crow era by signing the Civil Rights Act in 1964 and the Voting Rights Act in 1965, he did so because massive protests raging in the streets had forced it. The creation of crisis-packed disruption by means of deep organization, mass mobilization, a rich church culture, and thousands of rational and emotionally energized protesters delivered the death blow to one of the world's brutal regimes of oppression.

FRAMEWORKS

AS I CONDUCTED my doctoral research, the first theories specific to modern social movements were beginning to emerge. In 1977 John McCarthy and Mayer Zald developed the highly influential resource mobilization theory. It argued that the mobilization of money, organization and leadership were more important than the existence of grievances in launching and sustaining movements—and marginalized peoples depended on the largesse of

BLACK STUDENTS from Saint Augustine College sit at a lunch counter reserved for white customers in Raleigh, N.C., to challenge racial segregation in February 1960. Many participants in these protests were assaulted or arrested.

ROSA PARKS refused to relinquish her seat to a white man on a bus in Montgomery, Ala., in December 1955, triggering the Civil Rights Movement of the 1950s and 1960s.

more affluent groups to provide these resources. In this view, the CRM was led by movement "entrepreneurs" and funded by Northern white liberals and sympathizers.

At roughly the same time, William Gamson, Charles Tilly and my graduate school classmate Doug McAdam developed political process theory. It argues that social movements are struggles for power—the power to change oppressive social conditions. Because marginalized groups cannot effectively access normal political processes such as elections, lobbying or courts, they must employ "unruly" tactics to realize their interests. As such, movements are insurgencies that engage in conflict with the authorities to pursue social change; effective organization and innovative strategy to outmaneuver repression are key to success. The theory also argues that external windows of opportunity, such as the 1954 Supreme Court decision to desegregate schools, must open for movements to succeed because they are too weak on their own.

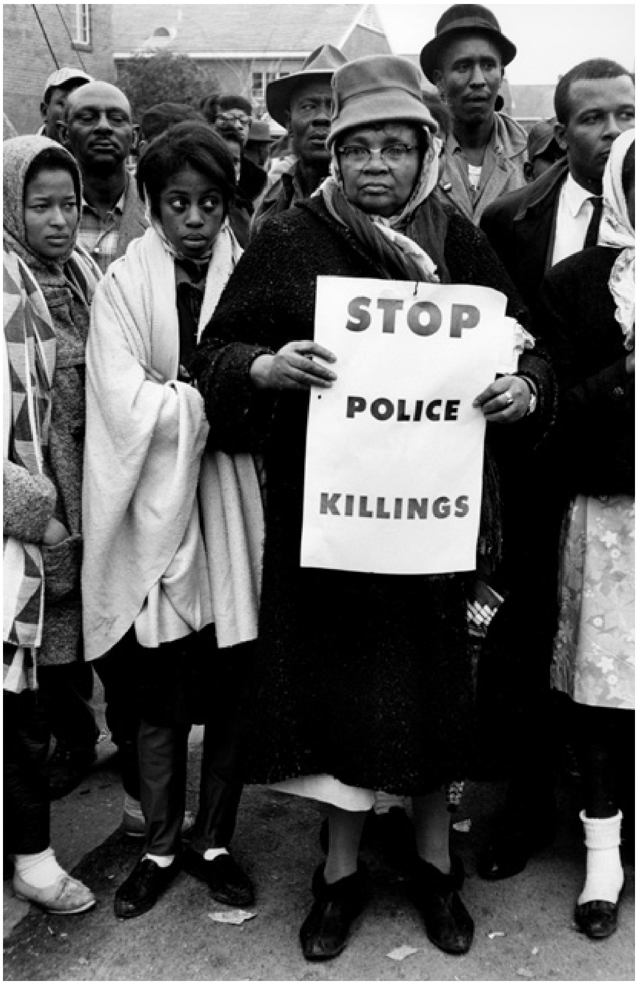
Thus, both theories see external factors, such as well-heeled sympathizers and political opportunities, as crucial to the success of movements. My immersive interviews with CRM leaders brought me to a different view, which I conceptualized as the indigenous perspective theory. It argues that the agency of movements emanates from within oppressed communities—from their institutions, culture and creativity. Outside factors such as court rulings are important, but they are usually set in motion and implemented by the community's actions. Movements are generated by grassroots organizers and leaders—the CRM had thousands of them in multiple centers dispersed across the South—and are products of meticulous planning and strategizing. Those who participate in them are not isolated individuals; they are embedded in social networks such as church, student or friendship circles.

Resources matter, but they come largely from within the community, at least in the early stages of a movement. Money sustains activities and protesters through prolonged repression. Secure spaces are needed where they can meet and strategize; also essential are cultural resources that can inspire heroic self-sacrifice. When facing police armed with batons and attack dogs, for example, the protesters would utter prayers or sing songs that had emerged from the struggle against slavery, bolstering courage and maintaining discipline.

The indigenous perspective theory also frames social movements as struggles for power, which movements gain by preventing power holders from conducting economic, political and social business as usual. Tactics of disruption may range from nonvio-

OPPOSITE PAGE: BETTMANN *Getty Images*; THIS PAGE: UNDERWOOD ARCHIVES *Getty Images*

POSTER at a Selma-to-Montgomery march in 1965 protested the killings of Black people by police.



MORE THAN 200,000 people participated in the March on Washington on August 28, 1963, where King articulated the aspirations of millions with his famous "I Have a Dream" speech.

STEVE SCHAPIRO *Getty Images* (top); HULTON ARCHIVE *Getty Images* (bottom)

BETTMANN *Getty Images*

BAYONETS wielded by police officers halt unarmed protesters seeking to reach city hall in Prichard, Ala., in June 1968, months after King's assassination in Memphis, Tenn., in April.

JUSTIN AHARON

GEORGE FLOYD'S murder by a police officer in Minneapolis, Minn., on May 25, 2020, triggered the largest protests in U.S. history, including this one in New York City the following June.

GRIEVOUS INJURIES sustained by 25-year-old Freddie Gray of Baltimore, Md., during his arrest on April 12, 2015, sparked this standoff in front of a police station. Gray died the day after the protest.

CHANTING “Wake up, wake up! This is your fight, too!” a demonstrator summons bystanders to a Black Lives Matter protest in Brooklyn, N.Y., on June 12, 2020.

DEVIN ALLEN *(top)*; JUSTIN AHARON *(bottom)*

"GET YOUR KNEE OFF OUR KNECKS" was the slogan for a protest at the National Mall on August 28, 2020, the 57th anniversary of the historic March on Washington led by King. The event honored the Civil Rights Movement while acknowledging the challenge of eradicating systemic racial and economic injustice in the U.S.

JOSHUA RASHAAD McFADDEN

lent measures such as strikes, boycotts, sit-ins, marches and courting mass arrest to more destructive ones, including looting, urban rebellions and violence. Whichever tactics are employed, the ultimate goal is to disrupt the society sufficiently that power holders capitulate to the movement's demands in exchange for restoration of social order.

Decades later cultural sociologists, including Jeff Goodwin, James Jasper and Francesca Polletta, challenged the earlier theories of resource mobilization and political process for ignoring culture and emotions. They pointed out that for movements to develop, a people must first see themselves as being oppressed. This awareness is far from automatic: many of those subjected to perpetual subordination come to believe their situation is natural and inevitable. This mindset precludes protest. "Too many people find themselves living amid a great period of social change, and yet they fail to develop the new attitudes, the new mental responses, that the new situation demands," King remarked. "They end up sleeping through a revolution." But such outlooks can be changed by organizers who make the people aware of their oppression (by informing them of their legal rights, for example, or reminding them of a time when their ancestors were free) and help them develop cultures of resistance.

Collective behavior theorists were right that emotions matter—but they had the wrong end of the stick. Injustice generates anger and righteous indignation, which organizers can summon in strategizing to address the pains of oppression. Love and empathy can be evoked to build solidarity and trust among protesters. Far from being irrational distractions, emotions, along with transformed mental attitudes, are critical to achieving social change.

BLACK LIVES

ON APRIL 4, 1968, I was having "lunch" at 7 P.M. at a Chicago tavern with my colleagues—we worked the night shift at a factory that manufactured farming equipment—when the coverage was interrupted to announce that King had been assassinated. At the time, I was attracted by the Black Panthers and often discussed with friends about whether King's nonviolent methods were still relevant. But we revered him nonetheless, and the murder shocked us. When we returned to the factory, our white foremen sensed our anger and said we could go home. Riots and looting were already spreading across the U.S.

The assassination dealt a powerful blow to the CRM. It revived a longstanding debate within the Black community about the efficacy of nonviolence. If the apostle of peace could so easily be felled, how could nonviolence work? But it was just as easy to murder the advocates of self-defense and revolution. A year later the police entered a Chicago apartment at 4:30 A.M. and assassinated two leaders of the Black Panther party.

A more pertinent lesson was that overreliance on one or more charismatic leaders made a movement vulnerable to decapitation. Similar assaults on leaders of social movements and centralized command structures around the world have convinced the organizers of more recent movements, such as the Occupy movement against economic inequality and BLM, to eschew centralized governance structures for loose, decentralized ones.

The triggers for both the CRM and BLM were the murders of Black people, but the rage that burst forth in sustained protest stemmed from far deeper, systemic injuries. For the CRM, the wound was racial oppression based on Jim Crow; for BLM, it is the devaluation of Black lives in all domains of American life. As scholar Keeanga-Yamahtta Taylor and others point out, when BLM was emerging, over a million Black people were behind bars, being incarcerated at more than five times the rate of whites. Black people have died at nearly three times the rate of whites during the COVID-19 pandemic, laying bare glaring disparities in health and other circumstances. And decades of austerity politics have exacerbated the already enormous wealth gap: the current net worth of a typical white family is nearly 10 times that of a Black family. For such reasons, BLM demands go far beyond the proximate one that the murders stop.

The first uprisings to invoke the BLM slogan arose in the summer of 2014, following the suffocation death of Eric Garner in July—held in a police chokehold in New York City as he gasped, "I can't breathe"—and the shooting of Michael Brown in Ferguson, Mo., in August. Tens of thousands of people protested on the streets for weeks, meeting with a militarized response that included tanks, rubber bullets and tear gas. But the killings of Black adults and children continued unabated—and with each atrocity the movement swelled. The last straw was the murder of George Floyd in May 2020 in Minneapolis, Minn., which provoked mass demonstrations in every U.S. state and in scores of countries. Millions of Americans had lost their jobs during the pandemic; they had not only the rage but also the time to express it.

By fomenting disruptions across the globe, BLM has turned racial injustice into an issue that can no longer be ignored. Modern technology facilitated its reach and speed. Gone are the days of mimeographs, which Robinson and her colleagues used to spread news of Parks's arrest. Bystanders now document assaults on cell phones and share news and outrage worldwide almost instantaneously. Social media helps movements to mobilize people and produce international surges of protests at lighting speed.

The participants in BLM are also wonderfully diverse. Most of the local CRM centers were headed by Black men. But Bayard Rustin, the movement's most brilliant tactician, was kept in the background for fear that his homosexuality would be used to discredit its efforts. In contrast, Garza, Cullors and Tometi are all Black women, and two are queer. "Our network centers those who have been marginalized within Black liberation movements," the mission statement of their organization, the Black Lives Matter Global Network, announces. Many white people and members of other minority groups have joined the movement, augmenting its strength.

Another key difference is centralization. Whereas the CRM was deeply embedded in Black communities and equipped with strong leaders, BLM is a loose collection of far-flung organizations. The most influential of these is the BLM network itself, with more than 30 chapters spread across the U.S., each of which organizes its own actions. The movement is thus decentralized, democratic and apparently leaderless. It is a virtual "collective of liberators" who build local movements while simultaneously being part of a worldwide force that seeks to overthrow race-based police brutality and hierarchies of racial inequality and to achieve the total liberation of Black people.

WHAT THE FUTURE HOLDS

BECAUSE SOCIETIES ARE DYNAMIC, no theory developed to explain a movement in a certain era can fully describe another one. The frameworks developed in the late 20th century remain relevant for the 21st, however. Modern movements are also struggles for power. They, too, must tackle the challenges of mobilizing resources, organizing mass participation, raising consciousness, dealing with repression and perfecting strategies of social disruption.

BLM faces many questions and obstacles. The CRM depended on tight-knit local communities with strong leaders, meeting in churches and other safe spaces to organize and strategize and to build solidarity and discipline. Can a decentralized movement produce the necessary solidarity as protesters face brutal repression? Will their porous Internet-based organizational structures provide secure spaces where tactics and strategies can be debated and selected? Can they maintain discipline? If protesters are not executing a planned tactic in a coordinated and disciplined manner, can they succeed? How can a movement correct a course of action that proves faulty?

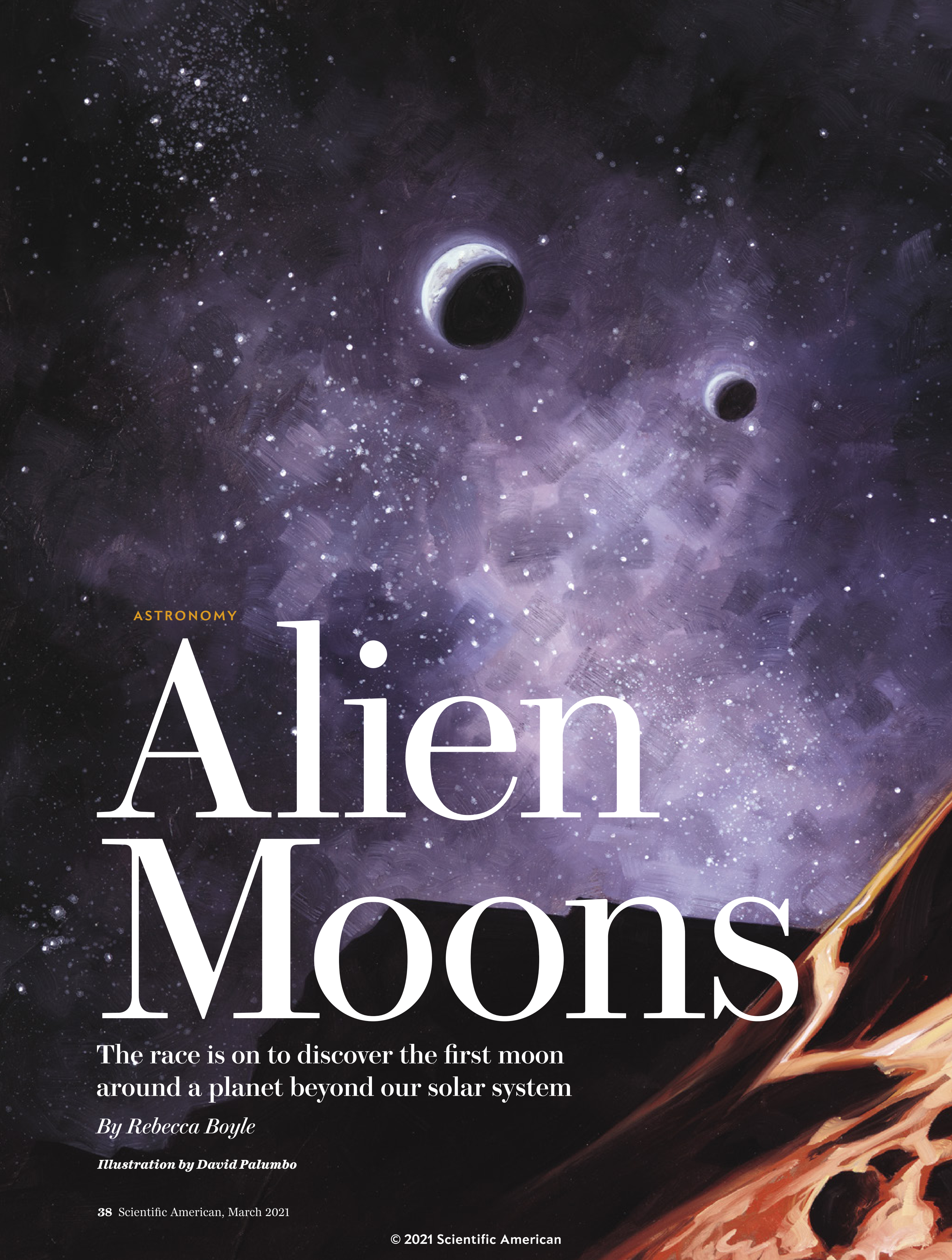
Meanwhile the forces of repression are advancing. Technology benefits not only the campaigners but also their adversaries. Means of surveillance are now far more sophisticated than the wiretaps the FBI used to spy on King. Agents provocateur can turn peaceful protests into violent ones, providing the authorities with an excuse for even greater repression. How can a decentralized movement that welcomes strangers guard against such subversions?

Wherever injustice exists, struggles will arise to abolish it. Communities will continue to organize these weapons of the oppressed and will become more effective freedom fighters through trial and error. Scholars face the challenge of keeping pace with these movements as they develop. But they must do more: they need to run faster, to illuminate the paths that movements should traverse in their journeys to liberate humanity.

FROM OUR ARCHIVES

Born Unequal. Janet Currie; October 2020.

scientificamerican.com/magazine/sa



ASTRONOMY

Alien Moons

The race is on to discover the first moon around a planet beyond our solar system

By Rebecca Boyle

Illustration by David Palumbo

Rebecca Boyle is an award-winning freelance journalist in Colorado Springs, Colo. Her forthcoming book *Walking with the Moon* (Random House) will explore Earth's relationship with its satellite throughout history.

IN 1655 DUTCH ASTRONOMER CHRISTIAAN HUYGENS SET UP A REFRACTOR TELESCOPE OF HIS own construction and aimed it at Saturn. He thought the planet was encircled by a single solid ring and planned to observe its tilt, which astronomers knew changed over several years. Instead he saw something unexpected in his viewfinder: a giant moon, now called Titan. Saturn became the third planet, after Earth and Jupiter, known to have a satellite. Even if Saturn's rings were rare, moons in our solar system were apparently commonplace.

In 2007 a network of automated telescopes observed a star about 433 light-years away in the constellation Centaurus. The star dimmed noticeably for at least 54 days, with its feeblest light measured around April 29. In 2012 astronomers determined that this star hosted a huge, Saturn-size gaseous planet orbited by a spectacular array of 37 rings. Just as Saturn does, this world known as J1407b has a gap in its ring system. Scientists suggested the gap may indicate a moon with roughly the mass of Earth.

Until the end of the 20th century, the only known planets were the seven worlds with which Earth shares the sun. This situation changed with the earliest exoplanet discoveries in the late 1990s and was completely overturned starting in 2009, when the Kepler space telescope opened its lens. We now know that the cosmos is peppered with planets, that there are far more planets than stars, and that these worlds come in almost every imaginable size, location and type. Arguably for the first time since the days of Galileo Galilei, discoverer of Jupiter's largest moons, and astronomers such as Huygens himself, humans are seeing our place in the universe with fresh eyes. We have yet to find a distant planet that looks just like home or to confirm that an exoplanet is orbited by a moon of its own. But we are getting closer.

Astronomers began speculating about exomoons in the early 2000s, after several exoplanets began winking into distant starlight, and searches since 2018 have turned up a few promising candidates. Locating a moon outside our solar system would mark another reorientation of our cosmic perspective. We will learn whether moons are ubiquitous or rare; whether they are usually large or small, compared with their planets; whether they often form along with their planets or are created in later cataclysms; and whether they come in groups or typically fly solo. We will be able to understand whether our solar system is unique and whether Earth and its solitary, huge moon stand alone.

"Every time we see an exoplanet, I think it's a mirror on our own history," says Alex Teachey, a postdoctoral researcher at the Academia Sinica Institute of Astronomy and Astrophysics in Taiwan and co-discoverer of a possible exomoon of the exoplanet Kepler-1625b. "In what ways are we common and in what ways are we uncommon? Just as we started seeing with exotic exoplanet systems, we could be surprised in what we see with exomoons as well."

THE PERKS OF A MOON

EARTH REMAINS UNIQUE, in this solar system and everywhere else we have looked so far. It is the only planet known to harbor life. It is the only planet whose active innards sculpt its outer face, in the form of plate tectonics, a process that itself plays a role in the dispersal and evolution of life. It is the only planet with an atmosphere thick enough to support liquid water, a climate that has remained stable for millennia and a just-right distance from its sun that keeps it warm but not too hot. These conditions exist at least in part because of Earth's moon.

The moon's role in Earth's history goes back to the very beginning, some 4.5 billion years ago, when a planet the size of present-day Mars collided with the infant Earth. The cataclysm left behind an incandescent, oblong Earth and a boiling moon. The moon has been cooling and moving away from Earth ever since. The planet became more spherical as the moon began to

recede, and Earth's crust flexed under the resulting tidal force. The early crust deformed, possibly causing the onset of tectonics. The moon's recession also slows Earth's spin, lengthening our day by almost two milliseconds every century.

The moon's heft is significant relative to Earth's; our planet's mass is only 81 times greater than that of our satellite, a ratio many times smaller than for the other moons of our solar system. Saturn, for instance, outweighs Titan 4,200-fold. The moon's pull guards Earth's axis, keeping the planet near a constant 23.5-degree tilt with respect to the sun. This configuration protects Earth's climate over millennia, as opposed to Mars, which lacks sizable moons and thus wobbles on its axis between zero and 60 degrees at the extremes every few million years—a change that drives dramatic climatic shifts. The moon provides the primary influence over Earth's tides, which shape coastlines and the life in the oceans. Our moon's tides most likely played a role in evolution, shepherding the first plants and tetrapods from the salty marshes of the coasts and onto land.

The moon is more than a silent, spectral satellite; it is a world unto itself, which Earth's occupants have both used and contemplated since the first sighted beings looked skyward. Earth would not be Earth without the moon. Neither would the oceans, or poetry, or religion, or science, or any of us.

If Earth's singular past provides any prologue, exoplanets might be different without moons, too. Unmooned exoplanets might be lifeless rocks, doomed to tilt like Mars through the millennia, freezing or boiling and preventing atmospheres and life from holding on. Exomoons themselves, if they exist, might even be better places for life than their planets. The search for life beyond our solar system may need to focus on planets with the possibility of moons and even on the moons themselves.

Although Huygens could not have known it, his Titan, an orange ball of haze dotted with methane and ethane rivers and lakes, is quite planetlike. It would not be hospitable to us or any life we would recognize, but it contains liquid and an atmosphere, meaning it contains a chance for mixing of ingredients and a chance for life. Saturn, with its intense gravity and clouds of ammonia, would never be a safe haven for life; the same scenario exists for Jupiter, practically a half-star with absurd radiation belts and gas layers that would be fatal to us. But the same cannot be said of their moons.

"Because of our solar system, we know Jupiters can have significantly large moons that can have water," says Chris Fox, a graduate student at Western University in Ontario. "If you have a Jupiter in the habitable zone of its star, you could see a moon that is like Earth, and the moon may have life. Given the number of moons that

EARTH'S MOON, seen here from the International Space Station, has shaped the history of our planet and helped make it habitable for life.

NASA

there [likely] are, maybe life on moons is even more common than life on planets."

Exomoons, in other words, may be habitable themselves, and they might help make their host planets habitable, too. Finding them will bring us closer to understanding those worlds as well as our own.

AN INTRIGUING CANDIDATE

ASTRONOMERS SUSPECTED the cosmos was full of worlds and their moons long before the Kepler telescope saw its first light. In 1999 Paola Sartoretti and Jean Schneider, now both at the Paris Observatory, became the first to propose searching for exomoons using the transit method.

If a star and its planets are arrayed on a flat plane as viewed from Earth—as if you were looking at the solar system from the side rather than the top down—the star will appear to dim for a brief period because a planet has moved in front of it. This eclipselike frontal pass is called a transit. When transits repeat on a regular schedule, you can usually be confident an orbiting planet is causing the dimming. The Kepler telescope used this method to find planets for a decade. Sartoretti and Schneider argued that moons orbiting at wide distances from their host planets would be detectable in this way, too, if the moon were beside the planet at the time of the transit. A host star could dim more than usual or could even dim twice if the moon's orbit was sufficiently distant from the planet. If you were standing on the planet during the transit, for widely separated moons, the moon's phase would have to be near first or last quarter; a full moon or new moon, when the moon is directly opposed to the star, would not make a discernible dent in the planet's transit.

Even if exomoons orbited close to their host planets, making a secondary dimming implausible, astronomers might still detect moons by looking at how a planet's repeating transit pattern appears to change over time, Sartoretti and Schneider suggested. Often transits recur with metronomelike precision. But sometimes they are a little off, with a transit beginning or ending just a bit earlier or later than scientists predict—an effect called transit timing variation. This can happen because other planets orbit the star and tug on one another, but it can also happen when a planet is hosting a large moon.

To understand why, it helps to understand that Earth's moon does not orbit our planet exactly. Rather both bodies orbit their mutual center of mass, called a barycenter. The barycenter is still located on Earth because the planet is more massive than the moon. (To be precise, the barycenter is located *in* Earth, in the mantle, offset from Earth's gravitational center.) As a result, Earth wobbles very slightly as it orbits the sun. This wobble is one thing Sartoretti and Schneider recommended looking for.

In 2017 Teachey and David Kipping, an astronomer at Columbia University, sifted through data from the Kepler telescope to look for any indications of a moon interfering with the star's light. They analyzed some 300 planets, hoping to find a population of moons. They found just one candidate: Kepler-1625b.

They applied for time on the Hubble Space Telescope and were surprised when they got it, both recalled. Then they studied the Hubble data for a year, with part of that time spent learning how to use them. When Kipping and Teachey finished their analysis, their Hubble observations showed that the planet's transit began sooner than it should have, implying a moon was by its side. The planet's transit time varied by about 20 minutes in five years of data. "We know there's something pushing that planet around," Kipping says, "and we think it's a moon."

Teachey and Kipping posted their paper to a preprint server in early 2018, and it was ultimately published in October 2018 in *Science Advances*. They say the evidence supports the existence of a Neptune-sized moon around Kepler-1625b, which itself is many times the size of Jupiter. Kipping and Teachey stopped short of claiming a discovery. "I think people were frustrated by the way we reported it," Teachey says. "People thought we were both trying to get credit for a discovery but also kind of covering our rear because we're not fully claiming it. I understand people's frustration—is it there or not there? But there's a lot of unknown unknowns."

Immediately following their initial announcement, other astronomers jumped into the fray. René Heller, an astronomer at the Max Planck Institute for Solar System Research in Göttingen, Germany, replicated part of Teachey's findings but found insufficient evidence for a moon. Laura Kreidberg, who studies exoplanet atmospheres, was unable to confirm a key part of the results. Kreidberg, now director of the new Atmospheric Physics of Exoplanets Department at the Max Planck Institute for Astronomy in Heidelberg, Germany, recalled having a friendly but somewhat awkward conversation with Teachey a few months after his paper published. "Alex worked so hard on this, and I don't want to minimize what he did," she recounted. "I sort of swooped in there with a bunch of years of experience using this instrument. I'm rooting for Alex. Both of us want the moon to be there. I mean, How cool would that be?"

THE RACE

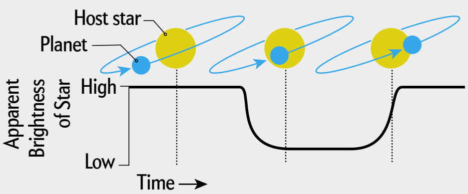
EXOMOON ATTENTION only grew in the months after Kipping and Teachey's announcement. Soon teams of researchers were poring over Kepler data on their own, trying to find transit variations that could indicate moons. Others turned to instruments such as the Very Large Telescope's Spectro-Polarimetric High-contrast Exoplanet REsearch tool (SPHERE). Cecilia Lazzoni, who recently completed her Ph.D. work at the University of Padova in Italy, claimed finding a giant exomoon using a SPHERE survey. In a paper published in *Astronomy & Astrophysics,* she described it as a companion to a very low-mass brown dwarf, a dim object between a planet and a star that does not fuse hydrogen but is many times the size of Jupiter. Lazzoni's world and its accompanying body may be more like binary giant planets than a world and a moon. If such objects are common, astronomers will have to grapple with how to define what constitutes a planet and a moon.

How to Detect an Exomoon

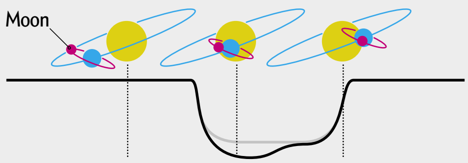
Astronomers are still getting a handle on discovering planets around other stars, but some scientists are already dreaming of detecting moons around those alien worlds. In the past few years several teams have claimed possible detections of exomoons, but none have been confirmed. There are two main ways researchers have looked for these distant satellites: by observing a star's dimming when the planet and moon both pass in front of it and by seeking signs that a moon has caused its planet to wobble.

The Transit Method

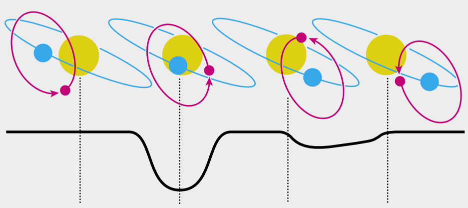
If a planet crosses between its host star and Earth, it will slightly dim the star's light that reaches our telescopes. This technique is responsible for most of the exoplanets known.



Moons could show up this way, too. If the planet and moon are oriented just so, a host star could dim more than usual during planet transits where the moon also blocks light.

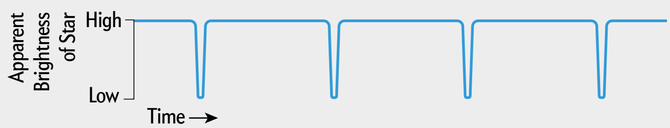


Or the host star could even dim twice if the moon's orbit was sufficiently distant from the planet.

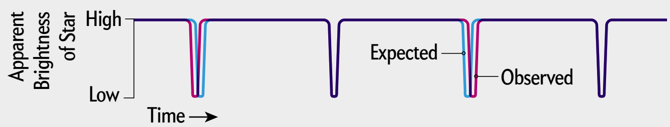


Transit Timing Variations

Even if an exomoon is not positioned in a way that dims a star's light, astronomers might still detect it by looking at how a planet's transit pattern appears to change over time. Often transits recur with metronomelike precision.



But sometimes a transit occurs just a bit earlier or later than expected. This pattern could indicate moons circling planets, causing both to wobble a bit around their mutual center of mass. The wobbling will alter the timing of the planet's transits and change the precision of the repeating light pattern.



In 2019 Phil Sutton of the University of Lincoln in England reanalyzed the super-Saturn, J1407b. The planet and its rings were first discovered by Eric Mamajek, now at NASA's Jet Propulsion Laboratory, and several colleagues. Sutton wanted to find evidence for moons that orbit outside the ring, as most of Saturn's do, so he set out to determine whether J1407b's 37 rings are sculpted in the same way. He could not find any evidence for external moons guiding the gaps in the rings and instead found that an external moon would likely shred the disk apart. "We all get excited that we might have actually found something," Sutton says, but reanalysis often dampens hopes. "It's just really tricky to confirm."

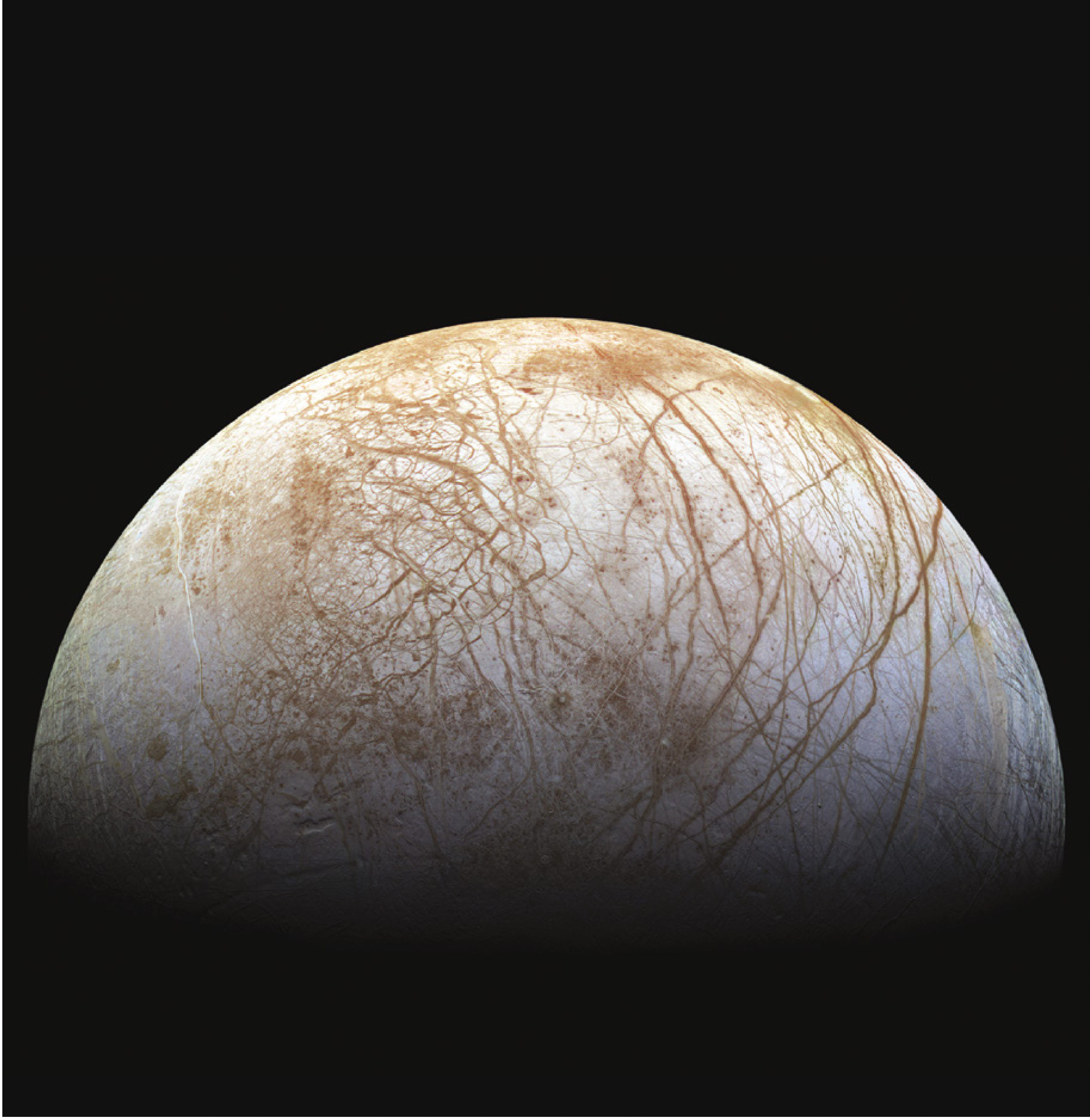
Then, last summer, Fox, the Western University grad student, peered through more Kepler data. He and his adviser, Paul Weigert, scrutinized 13 Kepler planets and found eight with transit timing variations that can be explained by exomoons. But, as Fox pointed out, the variations could be something else, too; the possibilities range from stellar activity such as flares to other planets. "In many cases, we were able to match the transit timing variation pattern with a moon, but in all the cases, we could explain them by the presence of a second planet," he says.

Teachey was critical of the work when Fox posted it to a preprint server during the summer and equally critical of coverage that claimed Fox was describing moons when he really described moon-or-planet scenarios. In a young and rapidly growing field, especially one with high stakes for career-making discoveries, some growing pains are inevitable, Teachey says. "We're not trying to stifle people working on moons, and we don't want to come across like we're being gatekeepers," he says. "But at the same time, this is part of the game. We're going to call into question conclusions that in our view are not supported by the evidence." Fox's paper was recently accepted to *Monthly Notices of the Royal Astronomical Society.*

Last November, Kipping hosted the first-ever exomoon meeting, an informal conference held over Zoom that brought together some 80 researchers from around the world. The scientists discussed new detection methods, theories for moon and exo-ring formation, new constraints on exomoon sizes and candidates, and related subjects. "I think we need to be a little more organized as a community to have a better shot," Kipping says.

A definitive detection remains elusive in part because the astronomers are all asking so much of their telescopes and their data. The wee blip in brightness that results from a planet transiting its star can be hard enough to see on its own. Comparing that with a shift in transit timing by just a few moments—remembering that

Illustration by Jen Christiansen



JUPITER'S MOON Europa harbors a buried ocean that might be hospitable to life.

NASA, JPL-CALTECH AND SETI INSTITUTE

the objects in question are hundreds of light-years away—is an excruciatingly exacting measurement.

Kreidberg says she is frustrated that she was unable to figure out why she and Teachey could not reach the same answer, using the same Hubble data. They shared each other's processing methods, and she tried to closely replicate his steps but could not reconcile the findings. "My only regret is that we weren't able to figure out what the difference was," she says. "The takeaway for me was, we are really pushing the limits of what Hubble can do. It was designed to look at faint distant galaxies, not nearby planets with moons. We're doing the best we can with data processing, but it's a fine art to pull the signal out."

Other challenges are geometric. Because of Kepler's laws (that is, Johannes Kepler, who discovered the rules governing planetary motion and for whom the planet-hunting telescope is named) and Newton's laws, moons' orbits are more stable within a certain distance from their planets, known as the Hill radius. The closer a planet orbits to its star, the likelier that the star's gravity will interrupt the moon's orbit, potentially sending it spiraling into the planet or out of the star system entirely. But the data from Kepler, Hubble and other observatories usually capture planets that orbit near their stars—often very near, closer than even Mercury is to the sun. Although these planets are relatively easier to find than planets farther away, they may be more likely to be moonless. "If we're looking at planets that are transiting their stars, we are looking at planets whose gravitational influence has been severely diminished and are less likely to host a moon," says Stephen Kane, a planetary astrophysicist at the University of California, Riverside. He published a paper in 2017 arguing that compact planetary systems, such as the TRAPPIST-1 system of seven terrestrial planets, are unlikely to host any moons at all.

Planets that wind up at greater distances from their stars, such as Jupiter and Saturn, are more likely to host moons, notes Alice Quillen, an astronomer at the University of Rochester, who has studied the super-Saturn J1407b. When a planet is more distant from the star, the star is less likely to fuss with the planet's gravity, allowing a moon to stay in place. If far-flung exoplanets resemble the solar system's own outer worlds in size and composition, they may also be likelier to grab planetary crumbs, errant asteroids and dwarf planets. Neptune's moon Triton is thought to be a captured dwarf planet from the distant Kuiper belt, a small world like Pluto, that was swept into Neptune's embrace after the solar system formed.

But large, distant planets are hard to find, partly because they take a long time to orbit their stars—one year on Jupiter, equaling one transit, takes almost 12 Earth years, meaning astronomers would have to watch such a planet for more than two decades before finding a definitive signal. And they are hard to spot because they can be confused with other objects. Periodic dims in a star's constant light are as likely to be caused by star pairs that occasionally move in front of each other as outer planets. "You can't find things in outer solar systems because it is too easy to confuse with eclipsing binaries," Quillen says. "You have to spend a lot of time trying to get rid of stuff that isn't what you want."

Stars themselves can also confuse the signals. The sun turns out to be a particularly quiescent star; other stars tend to be more active, churning out flares and radiation and developing spots that can also affect their apparent brightness. "The trouble with measuring the brightness of a star is that if you improve the precision too much further, you start to run into stellar activity," Kane says. "Stars will produce noise that is comparable or even greater than the signal expected from a moon. It essentially creates a ceiling you can't rise beyond, and that's a really big challenge."

Undaunted, some astronomers are turning to creative mathematical and observational methods. Apurva Oza, a lecturer at the University of Bern in Switzerland, is looking for an Io. The Jovian volcanic moon is visible with binoculars or a modest telescope; it is one of the four satellites Galileo Galilei observed in 1609. But viewed with sensitive instruments, Io is one of the most glaringly obvious objects in the sky. It positively emanates sodium and potassium, which it spews into space in vast quantities as Jupiter's gravity rends its innards and Io's volcanoes erupt. Io's exosphere can extend up to 500 times Jupiter's radius, Oza says. What is more, its signature would be visible no matter where the moon is located; an astronomer studying a transiting planet would not have to worry about the exomoon's phase. An exo-Io could be behind the planet, and its vast plasma cloud would still be detectable with the right instruments. "If you spray that gas everywhere, you just enshroud it, and you'll see it during transit," Oza says.

Spectrographs on several telescopes can already detect volatile gases within and around stars, he adds. Some have detected sodium, potassium and other signatures, which are often unexplained. "The missing factor could be a moon," Oza says. "It doesn't seem that outlandish when you think about it that way." He notes that an exo-Io would hardly be a place to look for any exobiology, however: "We're not looking for habitability here. We're looking for explosive environments, which is most of the universe."

THE WAY FORWARD

ASTRONOMERS hope the James Webb Space Telescope, currently scheduled to launch in October, will be able to hunt for exomoons with greater precision. Kepler was designed to find Earth-sized planets around sunlike stars, so objects smaller than Earth can be difficult to pick out. Researchers frequently used the Spitzer Space Telescope, but it was retired in January 2020. Not much else on Earth or in the heavens can find exomoons at the moment, so astronomers are relying on better data-processing methods—and getting ready to wait.

"Part of our job remains not just looking for these things but coming up with better ways to look for them," Teachey says. "People think a discovery is a eureka moment. And it's more like, 'Let's see if it fails this test. And this test.' Then you're like, 'Well, it's kind of holding up.'"

Ground-based observatories such as the Extremely Large Telescope, under construction in Chile's Atacama Desert, could also spot exomoons under the right circumstances. The European space telescope PLAnetary Transits and Oscillations of stars (PLATO), set to launch in 2026, could help the search, too. Further into the future, satellites such as the Large UV/Optical/IR Surveyor (LUVOIR)—which might launch sometime in the mid-2030s—could provide excellent exomoon-hunting capabilities. But all these projects are still years away.

"With exomoons, it's kind of Hubble or bust right now, until James Webb flies," Kipping says. In the meantime, he hopes the burgeoning exomoon community will continue figuring out new strategies for working with the data that exist so far. Kreidberg is also hopeful that James Webb will find exomoon signals but concedes that a definitive discovery may still be a while off.

"This is the cutting edge," Kreidberg says. "Figuring out what we know and how well we know it is an evolving process. You have to be an optimist to work on exoplanets." And, maybe, exomoons. SA

FROM OUR ARCHIVES

The Search for Life on Faraway Moons. Lee Billings; January 2014.

scientificamerican.com/magazine/sa

PSYCHOLOGY

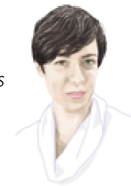
COPING WITH PANDEMIC STRESS

The yearlong COVID crisis has taken a terrible mental health toll. Coping methods based in disaster and trauma psychology can help

By Melinda Wenner Moyer

Illustrations by Cat O'Neil

Melinda Wenner Moyer, a contributing editor at *Scientific American,* is author of the forthcoming book *How to Raise Kids Who Aren't Assholes: Science-Based Strategies for Better Parenting—from Tots to Teens* (G. P. Putnam's Sons, 2021).



AMY NITZA HAS SPENT DECADES HELPING PEOPLE IN CRISIS. THE DIRECTOR of the Institute for Disaster Mental Health at the State University of New York at New Paltz has traveled to Puerto Rico in the wake of Hurricane Maria, to Botswana during an HIV crisis and to Haiti to help traumatized children forced into domestic servitude.

But the COVID-19 pandemic, Nitza says, is different. It keeps coming at people month after month as loved ones get sick or die, as jobs are lost, and as the actions taken to avoid infection—such as isolation from family—cause intense emotional pain and stress. Millions of people around the globe have died from the coronavirus, and the numbers keep climbing; grief, fear and economic hardship have hit every nation. The U.S. has the highest death toll on the planet—400,000 people perished by early 2021—and millions on millions have become seriously sick. Usually disasters have survivors and responders, Nitza says, but COVID is so widespread that people are both of those things at once. "We're training everybody [on] how to take care of themselves and how to support the people around them," she says.

This winter has been especially dark and hard. At the start, deaths climbed to exceed the losses of 9/11 every day. Sometimes outbreaks recede but then rise back up again like storm-tossed seas. Vaccines are months away for the vast majority of us. Many hospitals are overwhelmed with waves of new COVID patients. So no one knows when the pandemic will end or whether the future will look anything like the past. "We as a nation have never been in anything like this," says Charles Figley, who has worked in disaster psychology for 40 years and is director of the Traumatology Institute at Tulane University in New Orleans.

The stresses are taking a terrible toll on our country's mental health. In June 2020 researchers at the Centers for Disease Control and Prevention surveyed 5,412 U.S. adults and found that 25.5 percent had symptoms of anxiety and 24.3 percent had symptoms of depression—a threefold and fourfold increase, respectively, from 2019. It is "a staggering number," says Susan Borja, chief of the National Institute of Mental Health's Dimensional Traumatic Stress Research Program. In a study that has not yet been peer-reviewed, researchers at the City University of New York and the University of North Carolina at Chapel Hill surveyed 5,250 U.S. adults in April 2020 and found that 35 percent had moderate or severe anxiety symptoms. Those who had recently lost income were doing extremely poorly.

The pains of the pandemic and its consequences are sharpest among people of color, who are "more exposed and less protected," in the words of physician Camara Phyllis Jones, who studies health inequities. In November 2020 unemployment rates among Black and Hispanic workers were 75 and 42 percent higher, respectively, than that among white workers. Compared with white households, many more Black and Hispanic households are struggling with food insecurity, and nonwhite children are more likely to be learning remotely from home rather than in person at school. These hardships fall on top of the direct agonies inflicted by the disease: In a study published in July 2020, New York University researchers found that in urban U.S. counties where the population was substantially nonwhite, the COVID death rate was nearly 10 times higher than it was in predominantly white counties with the same median income. Among Native Americans, another less protected group, the death rate during the first half of 2020 was nearly twice that among white people.

We can now glimpse, with the advent of vaccines, a time in the future when the pandemic sputters out. But to get there, we have to keep going through months of trauma and strain. How do we do that? How do we endure more and more of the isolation, the deaths, the flare-ups, the economic wreckage, the fear and the uncertainty?

There are ways—not perfect solutions but methods that can help. Psychologists who specialize in trauma and disaster recovery, as well as those who work with patients who have chronic injuries or disabilities, say that although it feels impossible and although there will be losses, most of us will get through this disaster. And they point to strategies for coping born of experience and science. When people in devastating situations can spot warning signs of mental trouble, acknowledge and express their distress, focus on the present moment and the small things they can control, and find ways to connect with others, they can get through the darkest of moments and show resilience.

"The majority of people who have a major catastrophic life event are going to eventually either return to baseline or, in some cases, come out better on the other side than they were before," says Megan Hosey, a rehabilitation psychologist at Johns Hopkins Medicine, who works with chronically ill patients in intensive care units. Most of us, she says, "will be able to adapt and recover." To do so, however, we will need to be flexible, open and honest with ourselves and learn how to take things one day at a time.

LOOK FOR WARNING SIGNS

IT CAN BE HARD TO TELL the difference, in the midst of a crisis, between normal levels of angst and those that indicate we might be edging into serious psychological problems. Key signs of declining mental health include changes in appetite or sleep patterns that last more than a week. If you find yourself becoming more irritable—maybe you are lashing out more frequently at your family members—that can be another sign of depression or anxiety. Having more trouble concentrating than usual or being unable to enjoy things you used to enjoy may also indicate that your mental health is declining and that you need to try new coping strategies.

Keep track, too, of how much you rely on medications, as well as on recreational drugs or alcohol. "We are seeing an uptick in substance and alcohol use in the context of the pandemic," Hosey says. This does not mean that it is dangerous to have a beer or a glass of wine when you are feeling stressed. But "if a medication or a substance is one of your primary ways of coping and you're finding you need more and more of it to get through the day, that's a red flag," she says.

Other things to look out for are physical symptoms such as pain, dizziness or indigestion. When people struggle emotionally, their distress often manifests itself physically (of course, serious physical symptoms warrant a visit to a physician to rule out other causes). Psychologist Tracy A. Prout and her colleagues at Yeshiva University, along with researchers at the University of Haifa in Israel and the University of Pisa in Italy, surveyed 2,787 adults around the world about their mental health during the pandemic. They found that the people who were experiencing the most distress also had the most physical symptoms, as the group reported in its study, published in November 2020 in *Frontiers in Psychology*.

FEAR IS OKAY

BEHIND THESE SIGNALS are the loneliness, unpredictability, fear and deprivation of the pandemic, and those are experiences that hospital patients with long-term illnesses and injuries know all too well. Mana Ali, a rehabilitation psychologist at MedStar National Rehabilitation Hospital in Washington, D.C., treats people with spinal cord injuries and paralysis. She says that one of the first things she tells these individuals is to acknowledge such emotions and to not feel bad about having them. "I always tell my patients, 'It's totally normal that the anxiety is there—it's about managing it,'" she says. We tend to think that fear and worrying are bad and that strength is the absence of those things, but that is not the case, she adds: "You can feel scared and fearful and angry and resentful and simultaneously be a victor and be resilient. Reminding people that they are both, versus either/or, is extremely important."

> "You can feel scared and fearful and angry and resentful and simultaneously be a victor and resilient. Reminding people that they are both is extremely important."
> —Mana Ali, psychologist
> *MedStar National Rehabilitation Hospital*

Disaster and rehabilitation psychologists have done research showing that writing about negative feelings is very effective. "There's something about writing it down that's super important," Nitza says. In the early 1980s psychologist James W. Pennebaker, then at the University of Virginia, and his colleague conducted a study in which they told some college students to write about their stressful experiences and feelings for 15 minutes a day four days a week. They told others not to do anything unusual. The students who engaged in this "expressive writing," as Pennebaker called it, were only half as likely to visit the student health center over the next six months as those who did not. More recent analyses have supported these findings, confirming that writing about feelings is a powerful way to work through them.

These admissions about negative emotions are important because they "open the door for, 'What can I do next?'" Hosey explains. To be fair, this question can be hard to answer in the midst of a world-shaking pandemic. Nitza suggests trying to pinpoint what exactly worries you most at the moment and then identifying aspects of the situation that you can control or make progress on. If you have just lost your job and you are worried about paying your bills, brainstorm small things you can do to give yourself a sense of control. Maybe a goal for this week is to create a new household budget or to find out about financial relief programs you might be eligible for.

This kind of brainstorming requires open-mindedness about "things you're willing to learn and try," explains Deepa Ramanathan-Elion, a rehabilitation psychologist at the National Intrepid Center of Excellence at Fort Belvoir in Virginia, who works with military service members who have traumatic brain injuries. "If you continue in a sort of rigid way of thinking, it's going to be very difficult for you to adapt to a changing environment, no matter what the situation is—whether it's COVID or something else," she says. "You really need to be able to adapt and be flexible." That might mean considering jobs you would not have considered in the past or asking people you would not normally reach out to for help or support.

The idea is to think of problems as obstacles you can overcome (at least partially) rather than as insurmountable hurdles you can do nothing about. There are aspects of this pandemic we cannot control—but by focusing on the things we can tweak at least a bit and by thinking of ourselves as resilient and adaptable, we will do better, Ali says. Cognitive-behavioral therapy, which focuses on helping individuals identify, understand and change their thinking and behavior patterns in these ways, has consistently been shown to boost mental health. A 2020 study found that Internet-based cognitive-behavioral therapy improved symptoms in people suffering from either anxiety or depression.

If you are older and alone, connecting with others can be hard, especially if you are not tech-savvy. You can sign up for Caring Calls, which facilitates weekly phone conversations between older adults and volunteers.

Ali often thinks of her father and his family, who are from Somalia and have faced many hardships. "They have absolutely nothing, but they have this strong sense of resilience," she says. "If they feel like they can get through it, they can get through it. So trying to cultivate that in people, regardless of resources—having them see that 'you can do this'—I think is very, very, very important."

FIND NEW WAYS TO CONNECT

SEEKING OUT OTHERS can help, too. Researchers at the RAND Corporation found, based on interviews done after the 9/11 terrorist attacks, that the most common way adults dealt with their distress was by connecting with friends and family.

The trouble now is that staying safe during this pandemic strains those connections. It often requires physical distance from loved ones, which means people are forced to give up what they emotionally need the most. In a 2015 analysis of 70 studies, researchers at Brigham Young University found that people who reported feeling lonely were 26 percent more likely to die over the next seven years, on average, than those who were not lonely. "There is a consistent and growing—and highly replicated across context and across countries—literature on the detrimental effects of social isolation and loneliness and the mitigating or positive well-being effects of social support," says Courtney Welton-Mitchell, a psychologist at the Colorado School of Public Health and at the Natural Hazards Center at the University of Colorado Boulder. (If you are feeling extremely isolated or are having thoughts of suicide, please call the National Suicide Prevention Lifeline at 1-800-273-8255.)

If you are older and alone, connecting with others can be hard, especially if you are not tech-savvy enough to link up over a computer or a smartphone. Welton-Mitchell suggests reaching out to family members and friends regularly by phone, e-mail or snail mail and perhaps setting up regular phone calls or physically distanced visits. You can also sign up for Caring Calls, a service organized by the nonprofit organization DOROT, which facilitates once- or twice-weekly telephone conversations between older adults and volunteers. To sign up by phone, call 1-212-769-2850. If you are comfortable using the Internet, you can sign up for a service such as Big & Mini or Eldera, either of which connects older adults with younger people through video calls.

Working toward a meaningful cause—even from the safety of your home—can also improve emotional health. It helps to "feel like you're committing to something that's greater than yourself," says William Garmoe, a neuropsychologist who works with Ali at MedStar National Rehabilitation Hospital. In a 2007 paper, a group of 20 international disaster psychologists analyzed research on the most important psychological needs people have in the midst of a disaster. They reported the top five are to feel safe, calm, self-efficacious, socially connected and hopeful. When people engage in activities that benefit others, they may be able to check off three of those needs—feeling more useful, connected and hopeful about the future. If you are not sure where to start, search VolunteerMatch.org or Idealist.org for local or virtual opportunities.

Virtual therapy provides another means of connection. Since the pandemic began, federal and state legislation has loosened a number of restrictions on the use of telemedicine, so it is now easier for people to access mental health services online. Finding a therapist can be difficult if you do not have health insurance or the means to pay, but free or low-cost options do exist: Opencounseling.com, for instance, allows you to search for free or low-cost therapists in addition to those who accept insurance or who can be paid for out of pocket.

One key benefit of therapy is the close relationship between the patient and the provider, which fosters a strong sense of belonging. "You're meeting with somebody with whom you have a real relationship—this is a person who cares about you, seeks to understand you, is warm and accepting," says Bruce Wampold, a professor emeritus of counseling psychology at the University of Wisconsin–Madison. "And for many people, this is particularly healing."

Therapy can also help by nudging people toward constructive ways of coping with stress and anxiety. In their November 2020 study, Prout and her colleagues surveyed adults about what strategies they used to make themselves feel better during the pandemic. They found that people who connected with and

helped others felt less distressed than those who coped in less healthy ways, such as by repressing their feelings or expressing hostility indirectly.

PAY ATTENTION TO YOURSELF

ONE OF THE HARDEST THINGS about the coronavirus is that it creates so much uncertainty about the future. "We like to be able to plan and set goals," Ramanathan-Elion says. "We like to go through life in this very organized fashion." Yet many of us do not know when we will get access to a COVID vaccine or whether we can pay next month's rent or when social isolation will end. We do not know whether we will get sick with COVID or what will happen if we do.

Psychologists who work with people who have serious injuries or chronic illnesses note that such people always have to manage an unknown future, and they often do so best by focusing on the present—paying attention to their sensations and feelings in the moment rather than focusing on what cannot be known with any assurance. The goal is to "just look at this one day at a time. Because we really don't know what tomorrow is going to look like," Hosey says.

One evidence-based approach that helps people stay grounded in the present is "mindfulness," and there are various ways to do it, including through short meditations. A 2018 review and analysis of 18 studies concluded that regular mindfulness exercises—such as focused breathing and "body scans," in which you pay attention to how the parts of your body feel and try to relax them—reduce symptoms of anxiety and depression even in the absence of any other treatments. (If you want to try guided meditations, Ramanathan-Elion recommends the smartphone apps Breathe 2 Relax and Mindfulness Coach.)

If the idea of meditation makes you uncomfortable, it is possible to be mindful without it. One way is to focus on the sensations you experience while you do everyday things such as eating and brushing your teeth. Nitza says she recently bought several adult coloring books because she has found that coloring is what helps her "focus my attention on the immediate thing."

However we get to it, mindfulness makes us feel calmer because "it slows down our breathing, and it sends that message to the brain that we're okay and there's no trigger in the environment; there's no stressful issue that we need to be attending to," Ramanathan-Elion says.

There is no one-size-fits-all approach to keeping your mental health intact, and the approach that is best for you will depend on your situation, your access to resources and your preferences. Psychologists say to trust your instincts and to try the available strategies that you think might help the most. Be willing to try out new things if the approaches you first choose do not seem to be working.

And keep in mind that the more time we spend in this pandemic, the better we will get at muddling our way through—because humans adapt surprisingly well to challenging situations. It has been tough, and it could get tougher, no question. But people are "stronger than they think," Figley says. "I frequently find that people are unbelievably resilient." SA

FROM OUR ARCHIVES

The Biggest Psychological Experiment. Lydia Denworth; July 2020.

scientificamerican.com/magazine/sa

WISDOM, a Laysan albatross first banded in 1956, is the oldest known wild bird in the world.

100 YEARS OF BIRD BANDING

A rich archive of data illuminates the secret lives of birds

By Kate Wong (text), Jan Willem Tulp (graphics) and Liz Wahid (bird illustrations)

THE YEAR WAS 1902. PAUL BARTSCH, A MOLLUSK RESEARCHER AT THE SMITHSONIAN Institution, wondered whether the aquatic snails he was studying could be spread from one body of water to another by aquatic birds. To find out, he needed to track the movements of birds. Bartsch hatched a plan. He fastened lightweight aluminum rings inscribed with the year, a serial number and a Smithsonian return address around the legs of 23 nestling black-crowned night herons that he captured along the Anacostia River outside Washington, D.C. And then Bartsch waited for news of the banded birds—where they were sighted, what had become of them.

Only one of the 23 herons was reported to him. The bird was shot shortly after being banded, but its resighting revealed where the creature had been headed in the interim: the heron turned up in Abington, Md., 55 miles northeast of where Bartsch had banded it. Although that initial insight was modest, Bartsch's approach to obtaining it was revolutionary: he had just become the first person in North America to systematically band birds for scientific research.

Bartsch outfitted more herons with serially numbered bands the following year, and other researchers began banding other kinds of birds elsewhere in North America. In 1920 the federal bird banding office was established in the U.S. Known today as the U.S. Geological Survey Bird Banding Laboratory, it works with its Canadian counterpart to run the North American Bird Banding Program, which manages more than 77 million archived banding records and more than five million records of encounters with banded birds from the past 100 years. Every year the program sends about a million bands to banders in the U.S. and Canada and adds some 100,000 new encounter reports to its database. Birds may also be equipped with auxiliary markers such as color bands or satellite transmitters. Researchers around the world use the data to monitor resident and migratory birds.

Banding studies have illuminated the hidden lives of most of the more than 900 avian species that spend time in North America, from raptors to waterfowl, from seabirds to songbirds. A peregrine falcon monitoring project in coastal Washington State has found that in addition to hunting on the wing, this formidable predator—the fastest species on earth—actually scavenges food fairly often. On Midway Atoll, a female Laysan albatross named Wisdom, first banded in 1956 and sighted as recently as November 2020 incubating a new egg, has helped show that seabirds live and reproduce far longer than previously thought.

In many cases, banding data have identified imperiled species and populations—and informed the development of management strategies aimed at protecting the birds. The whooping crane, a spectacular five-foot-tall bird with snow-white plumage native to North America, is one of the shining success stories to come out of banding work, according to Antonio Celis-Murillo, head of the Bird

GREG JODER

Banding Laboratory. In the 1940s the species was on the brink of extinction. Its last remaining population had dwindled to just 16 individuals as a result of unregulated hunting for their meat and showy feathers, as well as loss of the wetlands where they live. Today, after five decades of captive breeding and careful monitoring of banded cranes, there are four populations of wild whooping cranes that together comprise more than 660 birds. The species is still endangered but trending in the right direction.

In recent years, Celis-Murillo says, the scientists who work with banding data have been shifting their focus toward saving not just birds but their habitats. For instance, banding studies have identified a major previously unknown wintering ground for the Atlantic subspecies of piping plover, a small sand-colored shorebird that skitters along the water's edge feeding on worms and other invertebrates. About a third of the subspecies, which breeds along the Atlantic coast, spends the winter months on a clutch of islands in the Bahamas called the Joulter Cays. The discovery helped lead to the designation of the area as a protected national park in 2015.

Bird banding has always relied on amateur scientists—from the volunteers who undergo rigorous training to catch and band birds to the people who report sightings of these birds. Traditionally most human encounters with banded birds have been between hunters and waterfowl, according to biologist Danny Bystrak of the Bird Banding Laboratory. Indeed, one of the major applications of banding data has been establishing regulations for hunters to help maintain sustainable populations of game birds.

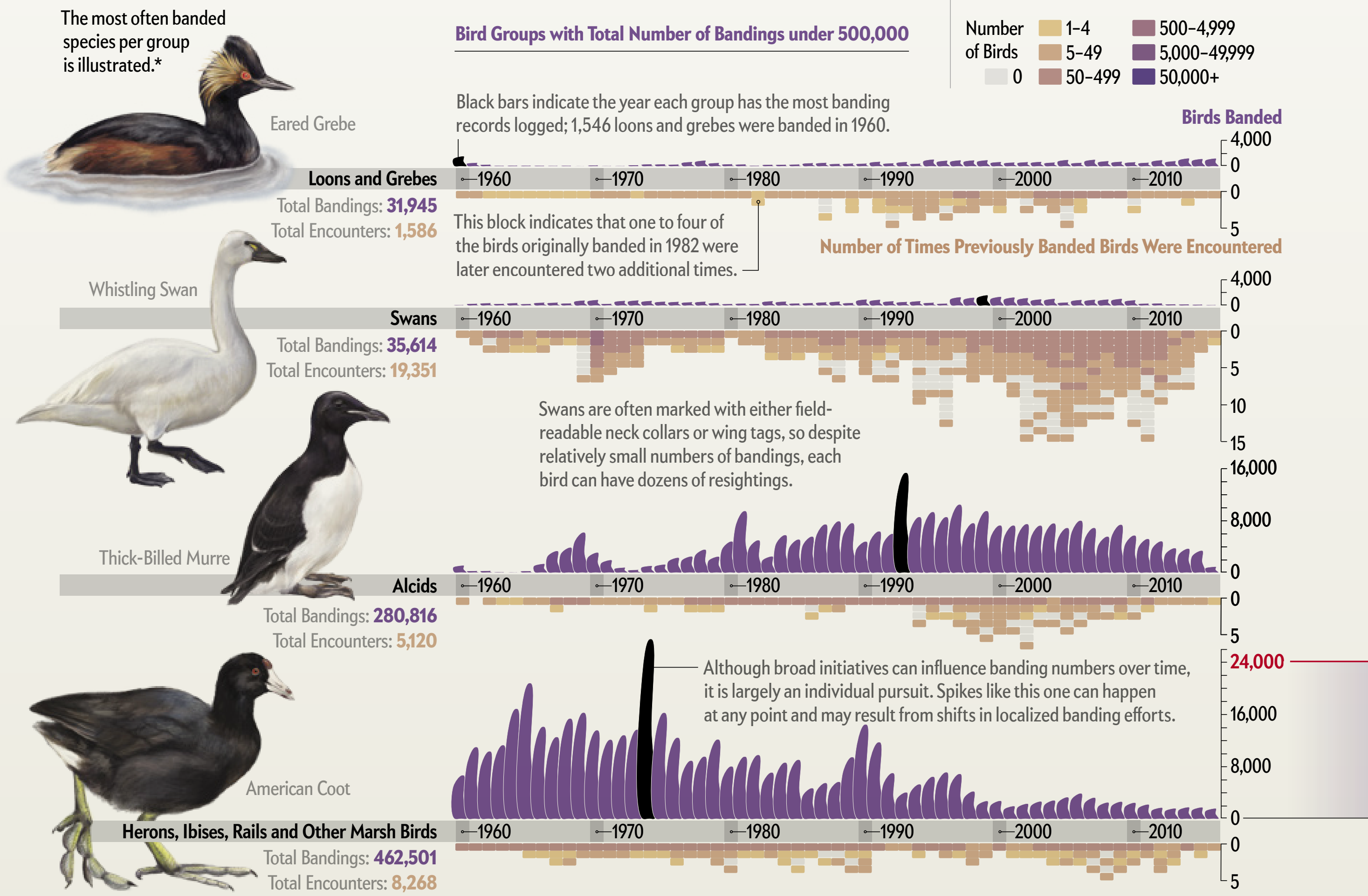
But that pattern is changing. Hunting is decreasing, and bird observation and photography are on the rise, Celis-Murillo says. The trend could offer a bright spot in the pandemic gloom. With so many of us taking up bird-watching in these lonely times, he predicts a bump in sightings of banded birds, which can be reported at www.reportband.com. The resulting data will help new studies of birds and their habitats take wing. SA

Over the Decades

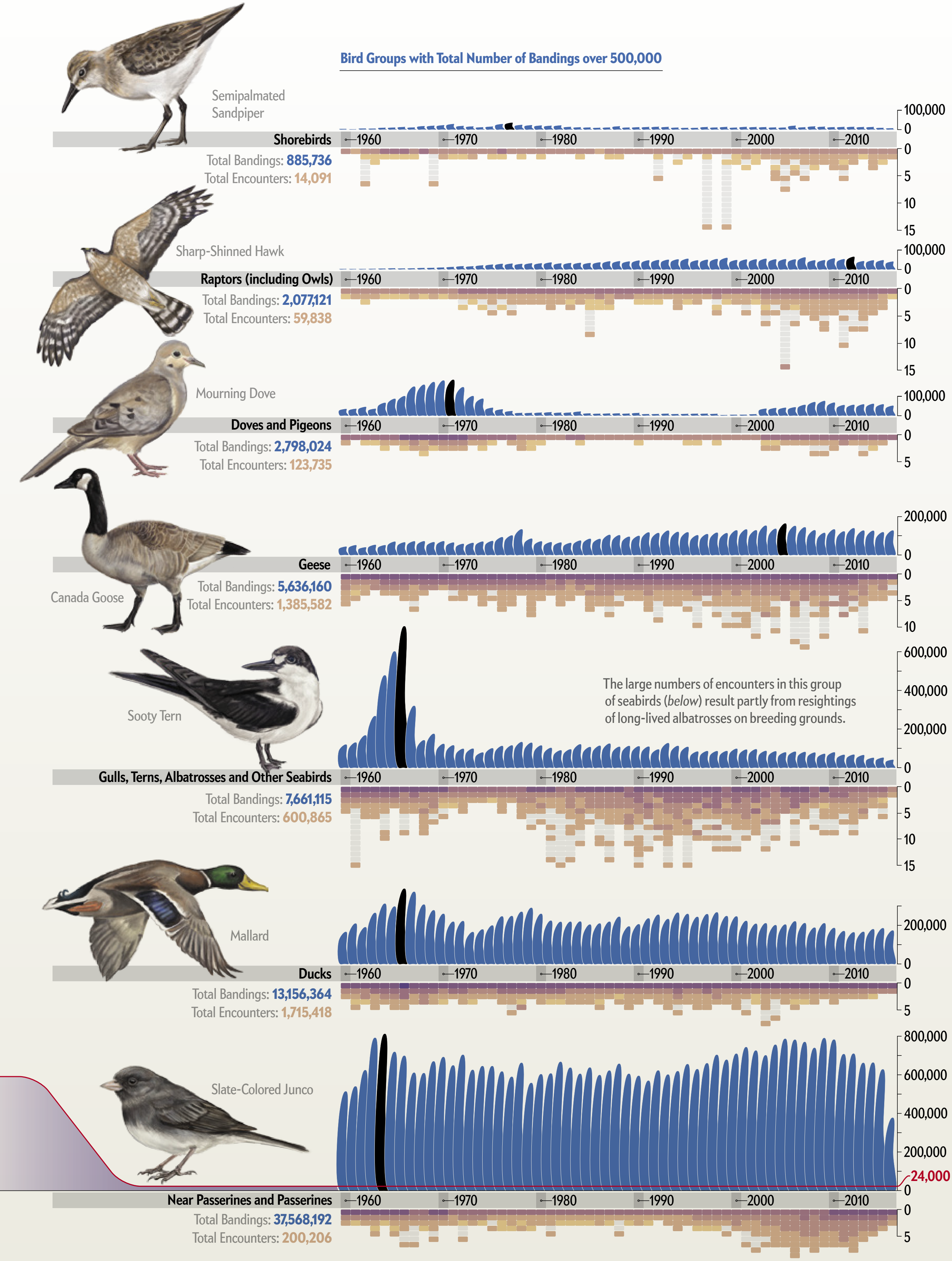
The Bird Banding Laboratory has been curating bird banding records since 1920. In 1959 a fire damaged many of the records, which helped to drive a shift toward electronic record keeping. For practical reasons, most research projects today deal with the digitized records, starting with birds first banded or reencountered after 1960. Here we show the birds that lie at the heart of the digitized data: 70,593,588 banding records and 4,134,060 reencounter records from 1960 through 2016.

Bandings: Bar length indicates the number of birds from each group banded each year.

Encounters: Vertical position of each block indicates the number of times birds originally banded on that date (*horizontal position*) were encountered again at some point later. The color of the square represents the number of birds that share that coordinate.



Bird classification systems have changed over time: some of the names used here are rooted in legacy categories.



Bird Groups with Total Number of Bandings over 500,000
Semipalmated Sandpiper
Shorebirds
Total Bandings: 885,736
Total Encounters: 14,091
Sharp-Shinned Hawk
Raptors (including Owls)
Total Bandings: 2,077,121
Total Encounters: 59,838
Mourning Dove
Doves and Pigeons
Total Bandings: 2,798,024
Total Encounters: 123,735
Canada Goose
Geese
Total Bandings: 5,636,160
Total Encounters: 1,385,582
Sooty Tern
The large numbers of encounters in this group of seabirds (below) result partly from resightings of long-lived albatrosses on breeding grounds.
Gulls, Terns, Albatrosses and Other Seabirds
Total Bandings: 7,661,115
Total Encounters: 600,865
Mallard
Ducks
Total Bandings: 13,156,364
Total Encounters: 1,715,418
Slate-Colored Junco
Near Passerines and Passerines
Total Bandings: 37,568,192
Total Encounters: 200,206
1960
1970
1980
1990
2000
2010
100,000
200,000
400,000
600,000
800,000
24,000
0
5
10
15

On the Move

Long-term banding records can show changes in bird populations, behaviors and environments over time. That information, in turn, can inform decisions about how to protect the animals and their habitats. Here we map the digitized banding data by location and season, revealing the relative number and diversity of birds banded at each point in space and time from 1960 through 2016.

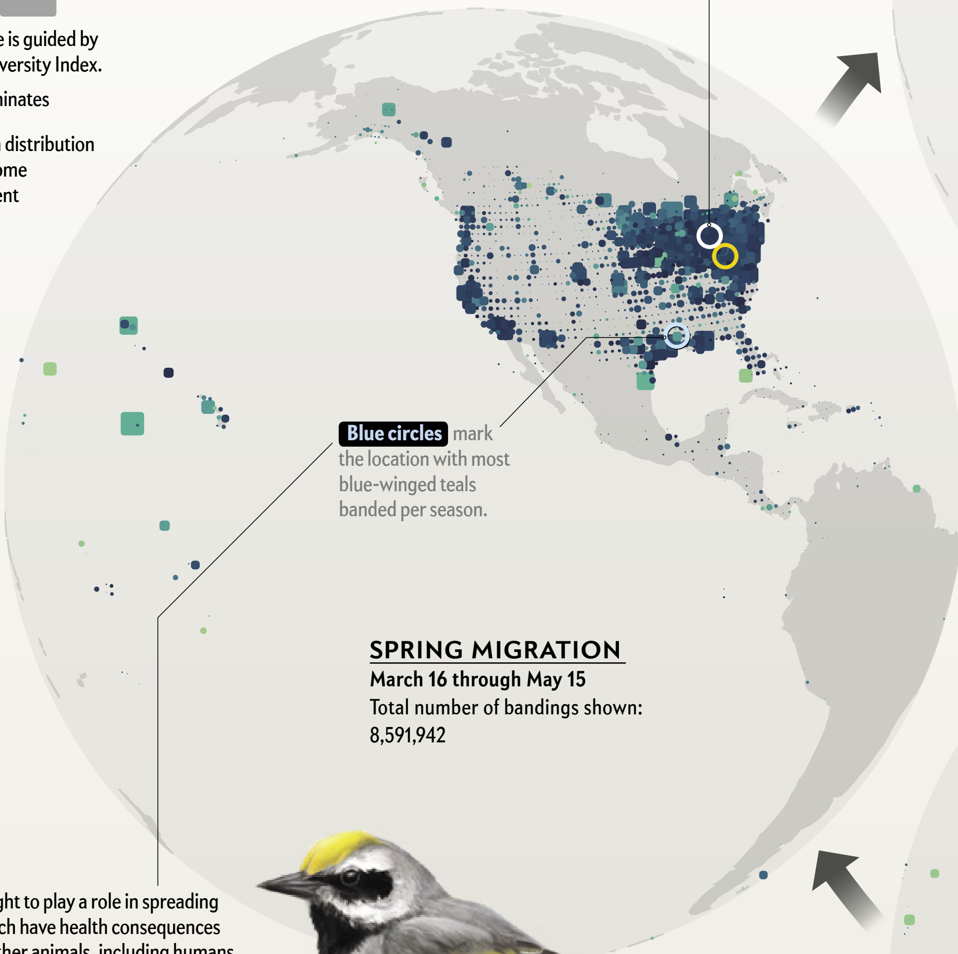
HOW TO READ THE MAPS

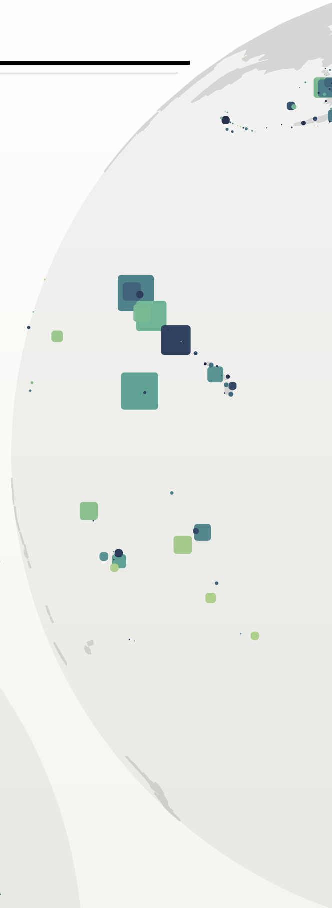
The size of each square represents the number of individual birds banded in the location of its center point. (Latitude and longitude coordinates were rounded to the nearest degree.)

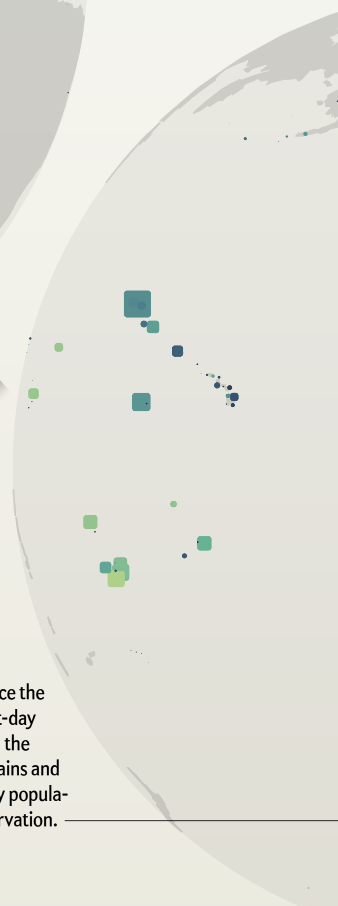
1,000 · 50,000 · 500,000

The color of each square is guided by the Shannon Wiener Diversity Index.

- One species dominates
- Reasonably even distribution of species, but some are more prevalent than others
- Relatively even distribution of species

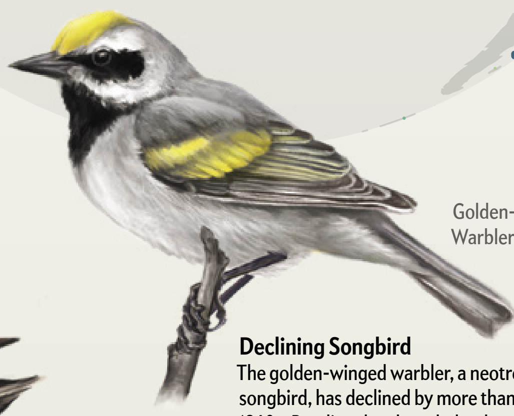






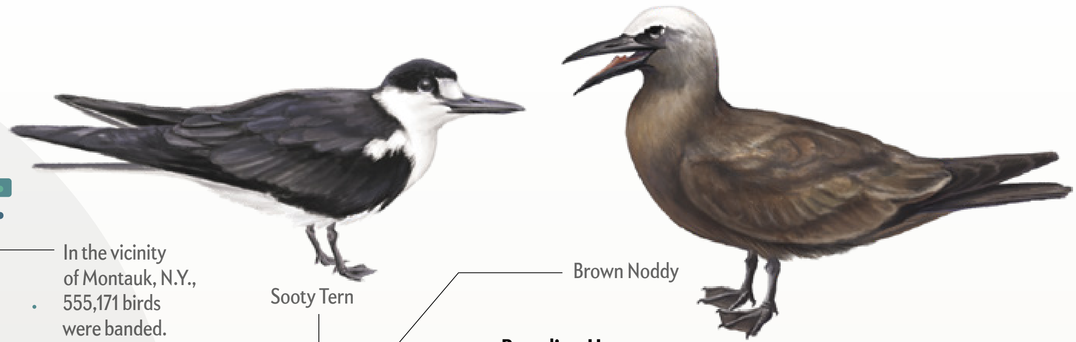
Tracking Disease

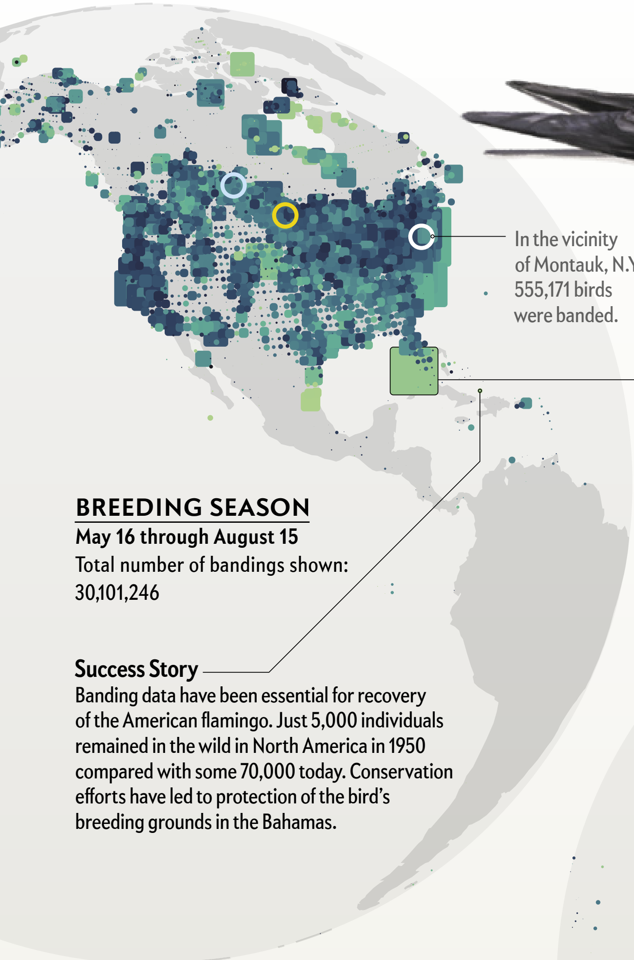
Blue-winged teals are thought to play a role in spreading avian influenza viruses, which have health consequences for not only birds but also other animals, including humans. Scientists are tracking the movements of teals to identify areas where they may be transmitting viruses to other wild birds as well as domestic poultry.

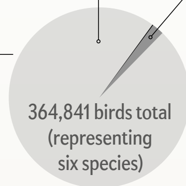


Declining Songbird

The golden-winged warbler, a neotropical migrant songbird, has declined by more than 70 percent since the 1960s. Banding data have helped reveal the present-day distribution of the species—which breeds mainly in the regions of the Great Lakes and Appalachian Mountains and winters in Central and South America—and identify population concentrations that could be targets for conservation.





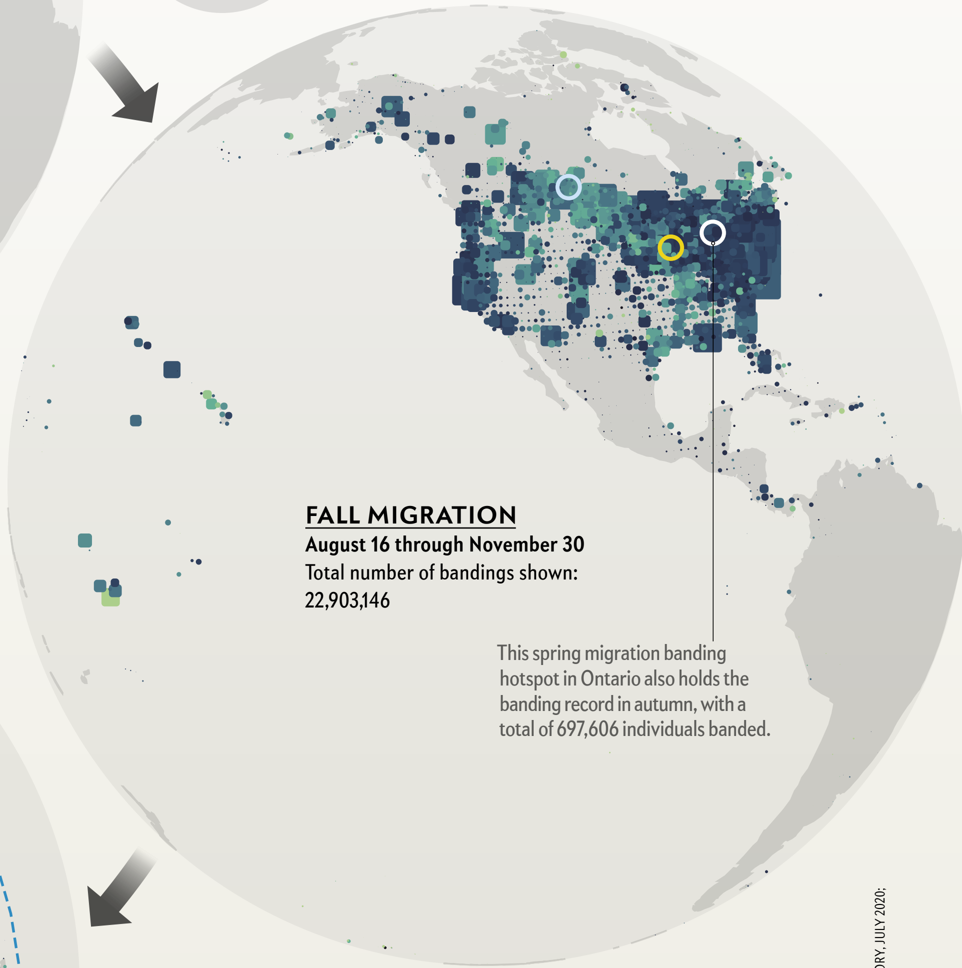


Breeding Hotspot
Since 1960, 364,841 birds have been banded in the vicinity of Dry Tortugas National Park at the end of the Florida Keys during the breeding season, between May 16 and August 15. The sooty tern and brown noddy dominate the species logged there, with 348,366 and 8,699 individuals banded, respectively.

BREEDING SEASON

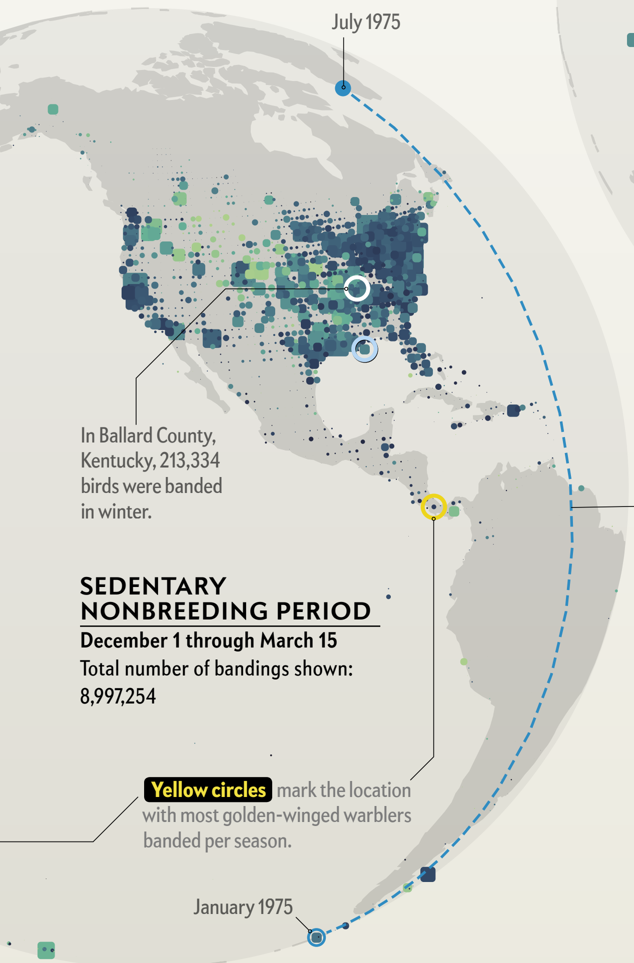
May 16 through August 15
Total number of bandings shown: 30,101,246

Success Story
Banding data have been essential for recovery of the American flamingo. Just 5,000 individuals remained in the wild in North America in 1950 compared with some 70,000 today. Conservation efforts have led to protection of the bird's breeding grounds in the Bahamas.



FALL MIGRATION

August 16 through November 30
Total number of bandings shown: 22,903,146



SEDENTARY NONBREEDING PERIOD

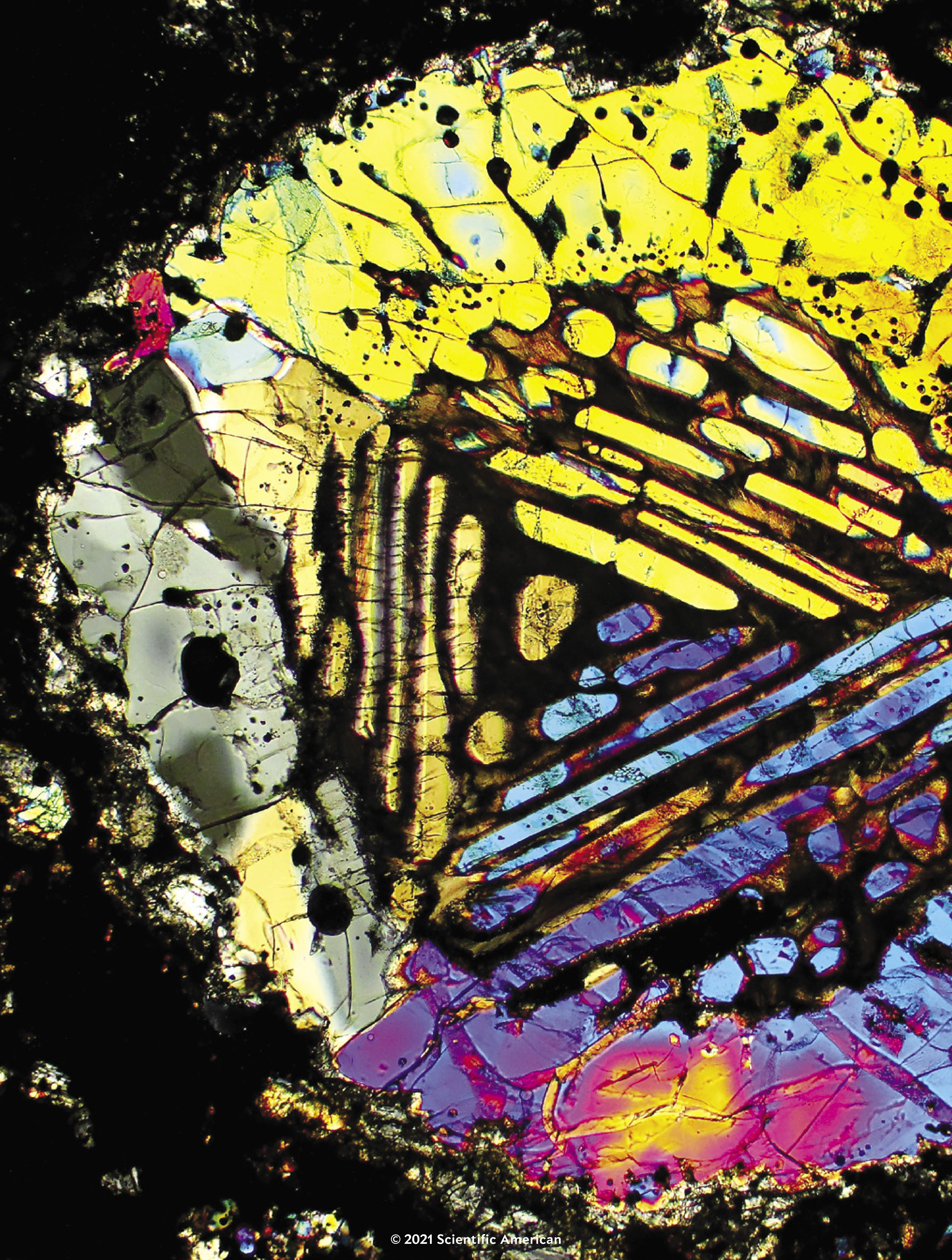
December 1 through March 15
Total number of bandings shown: 8,997,254

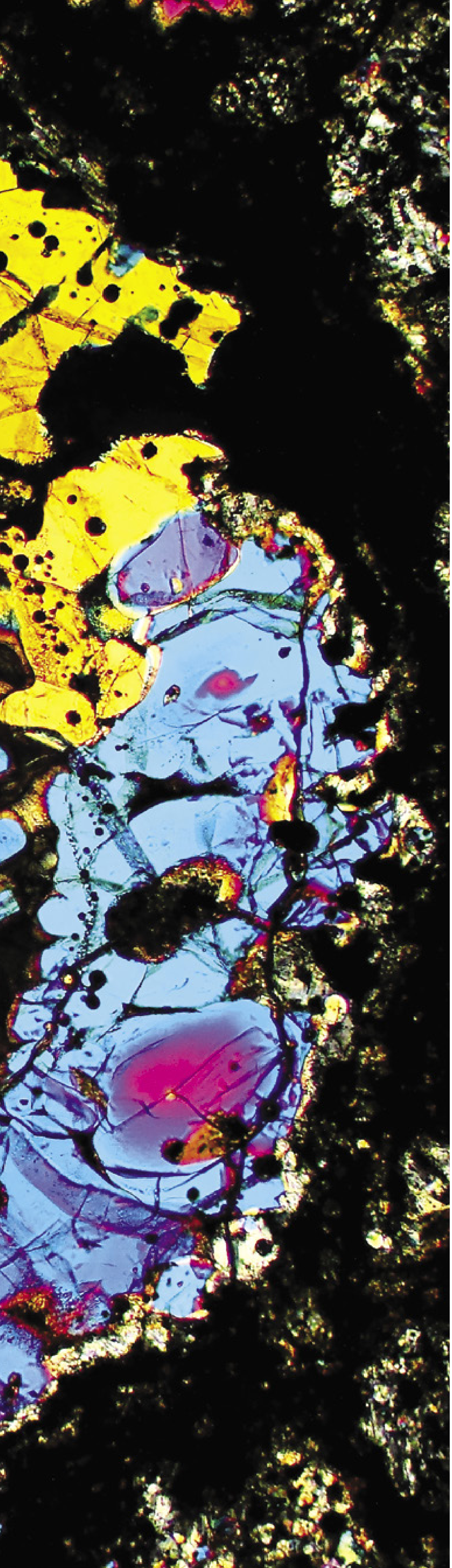
Yellow circles mark the location with most golden-winged warblers banded per season.

Long-Distance Traveler
A South Polar skua is the leading contender for greatest distance between banding location and reencounter location. Individual 877-34271 was banded on Shortcut Island, Antarctica, in January 1975 and shot six months later on the southwestern coast of Greenland, 8,929 miles away. (Dashed line shows shortest distance between the bird's banding and encounter locations, not necessarily its path.)

FROM OUR ARCHIVES
How Birds Branched Out. Kate Wong; November 2020.
scientificamerican.com/magazine/sa

SOURCE: ALLBIRDS CD, OBTAINED FROM USGS BIRD BANDING LABORATORY, JULY 2020; PATUXENT WILDLIFE RESEARCH CENTER, LAUREL, MD. (*data*)





The Curious Science of Chondrules

PLANETARY SCIENCE

With material from the asteroid Ryugu, scientists may finally discover the origin of these enigmatic objects—and what they tell us about the birth of the solar system

By Jonathan O'Callaghan

THE TOASTER-SIZED CAPSULE HIT OUR ATMOSPHERE AT 12 KILOMETERS per second, enduring temperatures of 3,000 degrees Celsius during its fiery descent before deploying a parachute to slow its velocity. It continued to fall until it finally reached terra firma in the Australian outback. Within hours teams of scientists located the capsule's landing site with radar and rushed via helicopter to retrieve it. Onboard were pieces of an asteroid, the biggest such haul in history, captured millions of kilometers from Earth and returned safely to our planet.

Jonathan O'Callaghan is a freelance journalist covering commercial spaceflight, space exploration and astrophysics. Follow him on Twitter at @Astro_Jonny

This event, the climax of the Japanese space agency JAXA's Hayabusa2 mission to the asteroid Ryugu, took place, in local time, on Sunday, December 6, 2020. It marked only the second time (the first being its predecessor, the Hayabusa mission, which launched in 2003) that a spacecraft has carried pieces of an asteroid back to Earth. With these samples, scientists hope to answer difficult questions about the history of our solar system and our own planet. How old are asteroids like Ryugu? How much water and organic material do they contain? And could they have first brought the raw ingredients for life to Earth billions of years ago?

While most groups of Ryugu researchers grapple with these outsized questions, a more rarefied cadre will be preoccupied with another, deceptively smaller matter: whether or not Hayabusa2's samples contain an intriguing ingredient of nearly all known meteorites. So far no one has been able to explain this ingredient's origins, yet the ramifications of doing so are tremendous. It may reveal to us not just some nebulous history of the solar system but also never before seen details of the process by which our sun's retinue of planets formed. In our understanding of how Earth—any planet in the cosmos, in fact—came to be, there may be nothing as important as the mystery of the chondrule.

Chondrules are small, seedlike rocks measuring up to just a few millimeters across and are thought to have formed some 4.5 billion years ago, shortly after the birth of our solar system. From there they became embedded in larger rocks, called chondrites, which make up the majority of the roughly 60,000 meteorites that humans have discovered throughout recorded history.

"Chondrules are everywhere," says Fred Ciesla, a planetary scientist at the University of Chicago. Even so, scientists have been unable to agree on how they formed for almost two centuries. Some think they were by-products of planet formation; others posit they were the seeds of planet formation itself. Either way, the menu of chondrule creation scenarios is vast, ranging from lightning-fused dust to colliding chunks of protoplanets to giant, gas-heating shock waves rippling through the primordial cloud of material that surrounded our newborn sun.

Understanding chondrule formation could, in other words, reveal our solar system's earliest moments. And now, with fresh or prospective results from missions such as Hayabusa2 as well as other avenues of research, chondrule-obsessed scientists are on the cusp of answering the long-standing question of where they—and perhaps we—came from. "They are stained-glass windows to the earliest time period of the solar system," says Harold Connolly, a cosmochemist and chondrule expert at Rowan University. "They are witnesses to processes that operated in the early solar system. The question is, What did they witness?"

DROPLETS OF FIRE

IN 1802 British chemist Edward Howard was one of the first scientists to recognize chondrules as "rounded globules" in meteorites. Their name, given later by German mineralogist Gustav Rose and Austrian mineralogist Gustav Tschermak, originates from the Greek *chóndros* ("grains") and the German *kleine kugeln* ("small balls"). In 1877 British scientist Henry Sorby would characterize them in greater detail, describing chondrules as "droplets of fiery rain," molten globules that condensed around the sun, although then, as now, no one knew exactly how they formed.

The broad outlines of our solar system's genesis are clearer. This creation story, which scientists have assembled through decades of observation and modeling, begins more than 4.5 billion years ago, when dust and gas from a giant molecular cloud gravitationally collapsed to create a protostar that would become our sun.

PRECEDING PAGES: JEFF HODGES

CHONDRULES make up most of the material in a slice of "Barratta," a 203-kilogram ordinary chondrite that fell in New South Wales, Australia.

MATTEO CHINELLATO *Alamy Stock Photo*

This protosun was surrounded by a spinning disk of gas and dust. Within this disk, a mix of gravity, aerodynamics and electrostatic force caused grains of dust to stick together, forming larger and larger agglomerations—such as planetesimals, the kilometer-scale building blocks of planets—and within a few million years the planetesimals coalesced into planets. These worlds gradually settled into the familiar forms and orbits we know today. But if the outlines of this story are clear, the details remain mysterious. Chondrules appear in the opening chapters, somewhere amid the leap from dust to planetesimals. How do you get from microscopic motes to entire worlds thousands of kilometers across?

Chondrules are essentially rocks within rocks. They appear as rounded flecks in chondritic meteorites. Some are visible to the naked eye, whereas others can be seen only under a microscope. It is difficult to overstate just how abundant chondrules are: Despite the fact that none are known to have survived the process of incorporation into planets, they are very common off-world, often constituting the bulk of material within chondrite meteorites. Some chondrites are so packed with chondrules they look almost like a conglomeration of beads.

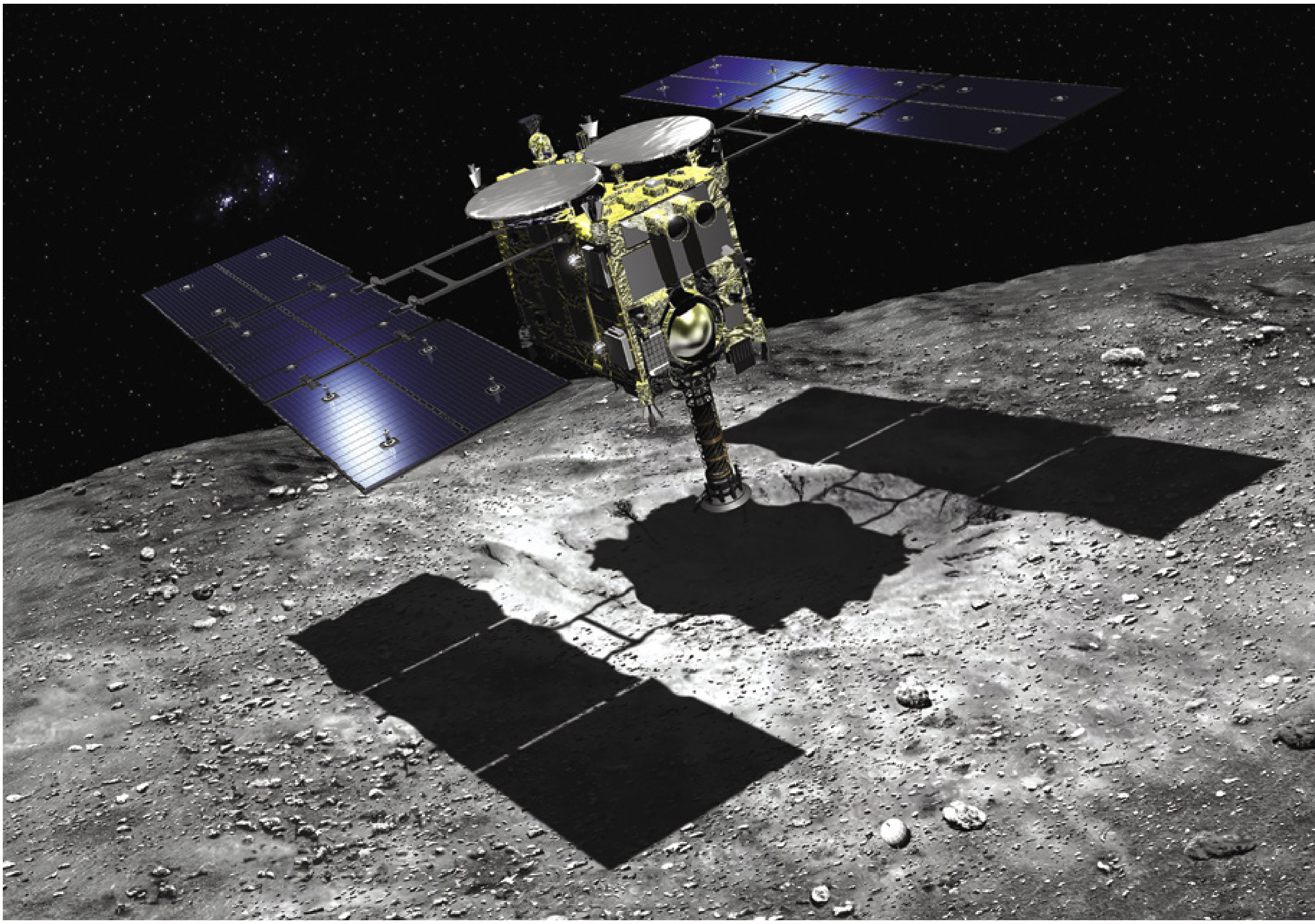
Made of minerals such as olivine and pyroxene and sometimes glass, chondrules themselves come in a variety of shapes, sizes and compositions. They often contain a glittering array of crystals. Scientists can date their formation to a window of a few million years, circa 4.567 billion years ago, by measuring the abundance of aluminum 26, a short-lived radioactive isotope they contain. That chronology makes chondrules the second-oldest recognizable objects in our solar system, after calcium-aluminum-rich inclusions (CAIs), specks of white in meteorites that are thought to have formed one million to three million years earlier by condensing out of the gas that surrounded our young sun.

There are many classes of chondrites. Ordinary chondrites, for example, are full of chondrules and account for more than nine out of every 10 chondrule-containing space rocks. Carbonaceous chondrites, which account for about 4 percent of all chondrites, typically have a high abundance of carbon; the most carbon-rich ones are thought to have formed in the outer solar system. A subgroup called CI chondrites possesses only microscopic chondrules because larger ones were weathered away by liquid water that once flowed through the parent body. And CB chondrites hold the distinction of being the only type of chondrite for which there is near-universal agreement on how they formed. "These are a group that we think formed during one giant impact," says Sara Russell, a planetary scientist at the Natural History Museum in London. That pinned-down provenance makes them "kind of magical."

As for the exact origins of all the other chondrite varieties? Those remain anyone's guess. "It's frustrating, but it's also kind of fun that we don't know," Russell says. "They're obviously telling us about some ubiquitous, super important process about how our solar system formed. We just have to work out what that is."

AN IMPOSSIBLE PROBLEM

IN 2000, at the Lunar and Planetary Science Conference in Houston, a stunned audience watched as John A.



HAYABUSA2, seen here in an artist's rendition, recovered potentially chondrule-rich material from the asteroid Ryugu in July 2019 for later return to Earth.

© AKIHIRO IKESHITA

Wood, then at Harvard University and one of the most revered scientists in meteoritics, appeared to admit defeat in understanding the origin of chondrules. Like many before him, Wood became fascinated by chondrules at first sight. "[These] little balls of stone were so charming and interesting and mysterious that I just got seduced by them," he says. But he was frustrated at the lack of progress that had been made. "We still don't understand what the meteorites are telling us, and sometimes I wonder if we ever will," he wrote in a summary of his speech. A few years later, facing a lack of funding, he opted to retire, turning his attentions to oil painting and spending time with his wife. "I quit science cold turkey," Wood says.

The speech was a shock to many. "He basically said he'd wasted his entire life working on chondrules because it was an impossible problem to solve," says Conel Alexander, a cosmochemist at the Carnegie Institution for Science in Washington, D.C. "That got a lot of people pretty upset." Larry Nittler, also a cosmochemist at Carnegie, who was in the audience, says he "actually stood up" to defend chondrule research. "I said, 'I'm still excited about these incredible rocks from space,'" he recalls. "I don't think I've gotten as much attention or praise for anything I've done in my career. The whole room erupted in applause."

Wood's pessimism is understandable. After all, space scientists have managed to definitively solve a wealth of seemingly intractable mysteries. They have teased apart the first moments of the universe's existence, discovered worlds around other stars, observed gravitational waves and captured images of a black hole. Against such achievements, the stubborn enigma of the lowly chondrule seems to shrink even smaller than its already niche status. Today there are, the joke goes, as many theories about chondrule formation as there are chondrule scientists themselves—and tomorrow there will inevitably be more.

The problem of chondrules has from the start been intergenerational, inspiring one cohort after another to try tackling the issue, with varying success. The main problem is finding a model that can explain all the different, diverse properties of chondrules. "There are no models that tick all the boxes," Alexander says. For chondrules to form, dust must have been heated to temperatures of up to 2,000 degrees C by some process in the early solar system, before rapidly cooling over just days or even hours. This process, whatever it was, most likely occurred throughout the solar system; that seems to be the only way to account for the large abundance of chondrules found in chondrites on Earth. The telltale rings of accumulated dust found in the centers of chondrules suggest that they must also have drifted for a time through the dusty environs around our newly coalescing sun.

Most chondrule scientists fall into one of two camps. The first believes chondrules were among the earliest solid objects to appear in the solar system, forming directly from the solar nebula—the cloud of dust and gas that surrounded our young sun. This would make chondrules a key stepping-stone from minuscule dust to larger kilometer-sized planetesimals. The second camp believes that chondrules were not among the first solids to form but actually arose after planetesimals—perhaps even after the planets themselves. They were, in this view, by-products of the planet formation process rather than an active part of it.

Within the first camp, one idea is that gravitational instabilities in the disk of dust and gas around our sun resulted in "shock fronts" that fused some of the dust into chondrules. "If you look at a picture of a galaxy, you see spiral arms spiraling round, and the same thing would have happened in the protoplanetary disk," says Rhian Jones, a cosmochemist at the University of Manchester in England. "And you can produce shock fronts associated with those density differences between the clumpy arms and the gas."

The more radical nebula-lightning model, meanwhile, proposes that friction between dust and gas particles around the sun sparked immense discharges of electricity that fused this dust into chondrules—although it is not clear how such lightning would be produced. Some models propose chondrule creation factories emerging from sheets of electric current trapped by huge magnetic fields within the spinning protoplanetary disk. Such "hotspots" could have been tens or hundreds of thousands of kilometers across and would have melted dust grains to churn out the primordial globules.

In the other camp, whose members argue that chondrules formed after the planetesimals, one of the more prominent models is called impact jetting. Here planetesimals would collide at high velocities, creating the necessary heat to produce chondrules. "It essentially squirts out some molten material that could break up into droplets," says Brandon Johnson, a planetary scientist at Purdue University. A variant of this, called splashing, would have involved collisions between molten objects at lower velocities, releasing droplets into space that solidified into chondrules.

The nebula-shock model, meanwhile, posits that Mars-sized planetary embryos moving through the nebula could act like boats sailing through water, fusing dust into chondrules. "As it's moving through the gas at supersonic speeds, it drives a bow shock," says Steven Desch, an astrophysicist at Arizona State University. "The chondrule precursors, this dust, are heated by entering this compressed hot gas and are processed by it."

Other ideas include radiative heating, a relatively new inclusion in some models that suggests planetesimals flying low over molten bodies could have been roasted and then cooled to produce chondrules. Rocks that underwent this natural "heat treatment" would be sturdier and more likely to survive the passage through Earth's atmosphere, which would explain why most of the meteorites we find are chondrites. "The meteorites got hardened, and Earth's atmosphere is a filter that is weighted toward really dense and hard stuff," says astronomer William Herbst of Wesleyan University, one of the researchers behind the idea.

Today there are as many theories about chondrule formation as there are chondrule scientists—and tomorrow there will inevitably be more.

Against this rising theoretical tide, some wilder notions have already been ruled out. Events from outside the solar system such as gamma-ray bursts—enormously energetic explosions from sources such as merging neutron stars or black holes—were once considered a possibility but now seem implausible because of the great distances involved. Even so, many models still remain, complicated by the fact that chondrules are not really predicted by planet formation at all. "We can build a story about how planets form without ever invoking chondrule formation," Ciesla says. "It's obvious that there's a piece of the story that we're missing."

Narrowing down which of the remaining theories is correct is hard, and arguments can get heated. "The best way to make friends and enemies in meteoritics is to publish another chondrule-forming model," Connolly says. At stake is what role chondrules played in our solar system. If they were among the first solids to form, then some inescapable process took place around our young sun that could explain how planet formation begins around most any star. But if not, are they less vital to the process than once thought?

"I'm putting my money on collisions right now," says planetary scientist Eugene Chiang of the University of California, Berkeley. "And to be totally up front about it, that makes [them] a little less interesting. Because if you're interested in planet formation, it means the chondrules are not the most primitive objects. They're secondary products."

COOKING UP CHONDRULES

MOST OF OUR IDEAS on chondrule formation come from modeling the early solar system and performing experiments on Earth to replicate different formation methods. Meteorite scientist Aimee Smith of the University of Manchester and her colleagues are one of several teams around the world that perform such experiments, mixing chemicals into a powder to resemble different types of known chondrule compositions. Then they place the powder in a furnace and heat it to extremely high temperatures for anywhere from hours to days, before cooling it to mimic different formation models. "If we get ones that look similar to the natural chondrules that we've studied, then we have a better idea of how they formed," Smith says.

Experiments such as these are designed to work in concert with solar system modeling. "The experiments are just defining the conditions for chondrules," says Jones, Smith's collaborator. "But models are trying to come up with scenarios in which those conditions are satisfied." And in our solar system, such modeling is starting to paint a new picture of its earliest moments.

Recent work on measurements of isotope ratios in meteorites indicates that two different reservoirs of chondrites formed early on—one in the inner solar system and one in the outer solar system, where chondrules may have been produced separately. These separate populations would have mixed together after Jupiter, having initially formed more than twice as close to the sun, migrated out to its present position, an idea called the grand tack hypothesis. If true, this would suggest that the story of our solar system's turbulent history is stored within chondrules themselves, offering yet another reason to lavish them with careful attention.

Elsewhere, observations of other solar systems—in particular, protoplanetary disks of dust and gas around young stars—are yielding information about possible scenarios for chondrule creation. In 2014 astrophysicist Huan Meng, then a graduate student at the University of Arizona, and his colleagues reported a flash of infrared light around a star called NGC-2547 ID8 over 1,000 light-years from Earth—evidence for a potential protoplanetary smash-up. Though not definitively linked to the formation of chondrules, the observation at least showed that suitably energetic collisions to make them do seem to occur in young systems. "Before [our] paper, we didn't have any direct hard evidence of any extrasolar planetary impacts," Meng says.

In the future, astronomers should also be able to probe the distribution of dust around young stars with higher-resolution images, which could make it possible to refine some models of chondrule formation. "With improvements in techniques and telescopes, now we can start to see the dust production around young stars," says Yves Marrocchi, a planetary scientist at the French National Center for Scientific Research. "Maybe in the near future we can see the formation [process] of chondrules." Such telescopes may include NASA's much delayed James Webb Space Telescope, scheduled to launch this October.

If chondrules are among the first solids to form around stars, they may be crucial catalysts for subsequent planet formation, in particular the jump from dust-sized to kilometer-sized objects. "There's a gap when you need multimeter- to kilometer-size objects to actually form the rocky parent bodies of planets," Connolly says. "What happens in that gap becomes really important." And perhaps chondrules are even more essential; one model of planet formation, pebble accretion, posits that larger bodies swept up pebblelike dust to grow into planets. Could those pebbles in fact be chondrules? "We don't know if they're the same," says André Izidoro, a planetary scientist at Rice University. Finding out would likely require "a big sample of an asteroid," he says. And as it happens, we just got one.

"NO SINGLE-SENTENCE ANSWER"

EARLY ASSESSMENTS revealed that Hayabusa2 managed to bring back more than five grams of material from asteroid Ryugu. According to Shogo Tachibana, who leads JAXA's sample-analysis team, that should be more than enough to see if chondrules are present. He and his team began studying the samples early this year, after they were transported from Australia back to Japan. Most of their results are still forthcoming. "We don't know if chondrules in Ryugu are different from other types of chondrules in other chondrites," Tachibana says. Ryugu appears to be similar to Earth's carbonaceous chondrites, so most experts expect chondrules to be present in the samples, but as of this writing, no one yet knows whether they will resemble those already in collections or will be like nothing ever seen before.

It is possible that Hayabusa2's samples do not contain chondrules at all. "I think that would be shocking to the chondrule community," Herbst says. "If there were no chondrules, and it looked like there had never been chondrules in them, then maybe chondrule formation is not such a ubiquitous process," Russell says.

Early results from a lander called MASCOT, deployed by Hayabusa2 onto Ryugu in October 2018, have already tantalized scientists. Images from the lander showed many white markings on the surface, which may have been CAIs but also could have been chondrules. "We were surprised that we really could see [the markings] and that there were so many of them," says Ralf Jaumann, head of MASCOT's science team at the German Aerospace Center, or DLR, Germany's space agency. Only chemical studies of the samples conducted back on Earth will reveal the nature of those markings.

If there are chondrules in the Hayabyusa2 samples and if they are similar to chondrules scientists have already studied, it will be possible to pinpoint the location, time and perhaps even conditions in which they formed. If the samples contain new types of chondrules, however, that could provide a fresh perspective on the larger problem of the origin of the solar system. Scientists such as Connolly would welcome such a scenario. "I certainly hope there are a few surprises and we find

JAXA VIA AP PHOTO

objects we didn't expect," he says. And even if chondrules are not present, that could simply suggest that water made liquid from the heat released by radioactive decay, impacts and other sources had long ago erased evidence of its chondrules, similar to the origins of CI chondrites found on Earth.

Hayabusa2 is not the only sample-return mission with extraterrestrial gifts in store for chondrule scientists. NASA's OSIRIS-REx spacecraft is scheduled to return to Earth in September 2023 with recently acquired samples of another asteroid, called Bennu, that are expected to be chondrule-rich. "It would be really disappointing if we didn't find chondrules in the material," says Connolly, who is also part of the OSIRIS-REx team. "I'm looking forward to finding chondrules that I know and chondrules that I don't know."

If researchers ever manage to definitively determine how chondrules formed, that could go a long way toward revealing whether or not they were crucial to the subsequent creation of Earth and our sun's other small worlds. Presuming, of course, that the creation story ultimately revealed is relatively straightforward. Some experts, however, suspect no simple solutions will be found, in part because more than one theory is correct. "I do not think it is a single-sentence answer," says planetary scientist Sarah Stewart of the University of California, Davis. "There were probably many droplets being made in different ways." Russell agrees: "My favorite theory is that everyone's right. All these processes happened somewhere in the solar system. There were shock waves, there were impacts, there were bow waves, there was lightning. I think these things all happened, and they all formed chondrulelike objects."

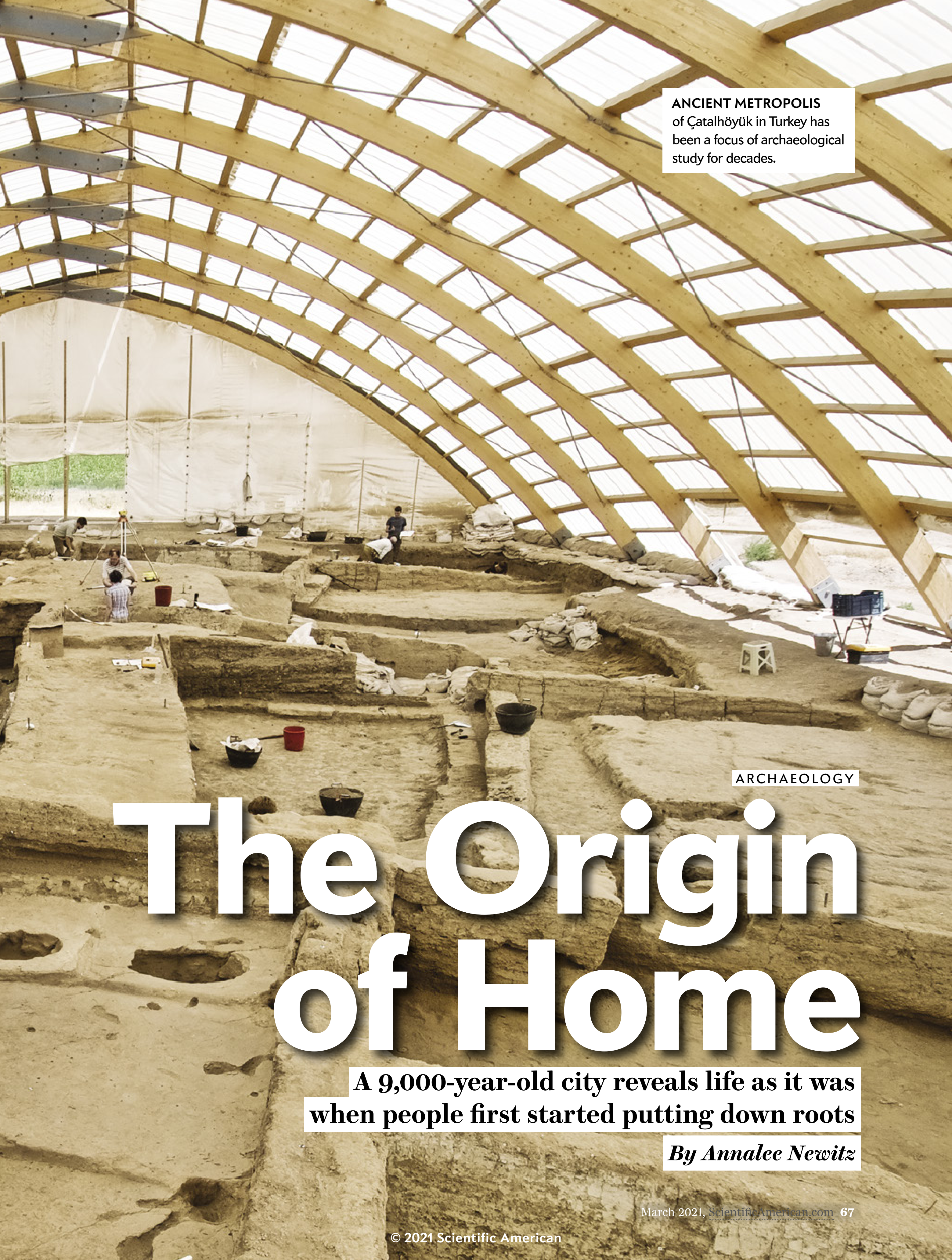
Which may mean Wood was on the right track all along when he made his infamous, career-capping declaration of futility: If nearly every idea for chondrule creation reflects a process that actually occurred in the solar system's ancient history, there may be no deeply meaningful distinctions among them. But that possibility won't keep new generations from trying, just as their predecessors did. "If I had to do it all over again, I would have made the same attempt," Wood says. And to anyone following in his footsteps? "I would wish them good luck." SA

TEAM MEMBER of the Hayabusa2 mission carries the spacecraft's sample-return capsule after its reentry and recovery near Woomera, Australia, in December 2020.

FROM OUR ARCHIVES

Chondrites and Chondrules. John A. Wood; October 1963.

scientificamerican.com/magazine/sa



ANCIENT METROPOLIS of Çatalhöyük in Turkey has been a focus of archaeological study for decades.

ARCHAEOLOGY

The Origin of Home

A 9,000-year-old city reveals life as it was when people first started putting down roots

By Annalee Newitz

Annalee Newitz is a science journalist and author based in Irvine, Calif. Their latest book is *Four Lost Cities: A Secret History of the Urban Age* (W. W. Norton, 2021).

THE KONYA PLAIN IN CENTRAL TURKEY IS A VAST, ELEVATED PLATEAU COVERED IN SMALL FARMS and dusty fields, edged by dramatic mountain ranges that cast purple shadows. At night, visitors can drive into the foothills and see distant city lights, shimmering like a mirage. The view here has not changed much over the past 9,000 years—even the illuminated metropolitan skyline would look familiar to a visitor from 7,000 B.C.E. That is because the Konya Plain is one of the cradles of urban life.

Millennia before the rise of Mesopotamian cities to the south, the proto-city Çatalhöyük (pronounced "Chah-tahl-hew-yook") thrived here. Sprawled over 34 acres and home to as many as 8,000 people, it was the metropolis of its day. People lived in this community continuously for almost 2,000 years, before slowly abandoning it in the 5,000s B.C.E. During its heyday, bonfires from the many parties held at Çatalhöyük would have been visible far across the flat grasslands.

Unlike later cities, Çatalhöyük had no great monuments nor any marketplaces. Think of it as a dozen agricultural villages that grew together, forming what some researchers call a "mega site." People entered its thousands of tightly packed, mud-brick homes through ceiling doors, and they navigated sidewalks that wound around the city's rooftops. They planted tiny farm plots around the city. Whether they were fixing up their houses or making clothes, tools, food and art, Çatalhöyük residents spent most of their days between four walls, right next to their bed platforms—or, in warmer months, on their roofs.

This was not exactly what archaeologists expected to find when they first began excavating at Çatalhöyük in the early 1960s. Based on what they knew of other ancient cities, these investigators were primed to discover shrines, markets and priceless loot. Instead they found the remains of home decor, cookware and ritual items associated with domesticity rather than formal churches. The mismatch between expectation and reality flummoxed Çatalhöyük researchers for decades. It took a new kind of archaeologist to figure out what it all meant, piecing together what life was really like when humans were transitioning from a nomadic existence to a settled one as farmers and urbanites with a strong sense of home.

DIDO'S HOUSE

IN 2000 archaeologist Ruth Tringham of the University of California, Berkeley, traveled to Çatalhöyük to visit a house that had not seen the light for thousands of years. Inside the structure she discovered the remains of a woman buried under a bed platform. Tringham nicknamed her Dido and returned every summer for the next several years with a team of researchers to excavate Dido's house. The group analyzed everything from the animal figurines and bones found inside to the many layers of plaster paint on its walls.

What they found was a household where everything was made from scratch—including the scratch itself, as it were. It is hard for modern people to imagine the intensity of the labor required to maintain a settled life back in Dido's day. If you wanted to cook dinner, you grew or hunted the food, built your own oven, made cooking tools such as obsidian knives, molded clay pots, then started cooking. People made their own bricks, built their own houses, wove mats for the floors out of reeds and sewed their own clothes (and made the needles, thread and textiles).

Even spirituality seems to have been handcrafted. People buried their loved ones underneath the floors, perhaps as a way to keep them close, and reverently decorated their skulls with plaster and paint. Archaeologists have found similar skulls at other sites dating to the Neolithic—the time spanning 12,000 to 6,500 B.C.E. in the Fertile Crescent—such as Jericho in the West Bank. It appears to have been relatively common at this

Map by Mapping Specialists

PRECEDING PAGES: JASON QUINLAN

time to honor the dead by recreating their faces using plaster applied to their skulls. At Çatalhöyük, people sometimes traded these skulls with other families and reburied them at a later time. Researchers often find several skulls buried alongside one body, suggesting that these rituals linked kin to their homes over several generations.

Archaeologists have found elaborate paintings on the interior house walls that were refreshed every year in the same patterns—as if generations of inhabitants wanted to keep the original paintings intact. Some of these patterns are abstract designs of swirls or zigzags, like the ancient equivalent of wallpaper. Others invoke scenes of wild animals and hunters. There are even some wall paintings that appear to shed light on the spiritual underpinnings of the skull ritual: in one house, researchers found a wall painting of headless bodies surrounded by vultures, giving the impression that the birds are bearing people's spirits away.

Animal bones, too, adorn the homes. Nearly every household had its own wall-mounted "bucranium," a plastered bull's skull painted deep red, its sharp horns pointing into the room. People also hid claws and teeth from dangerous animals in the mud brick of their walls in the way people today sometimes put a lucky penny into the foundation of a house.

In the 1960s archaeologists were confounded by finding these obviously symbolic, quasi-religious items mixed in with regular household garbage. One early researcher, James Melaart, thought the entire city must be a giant, mysterious shrine. But "it's only a mystery if you expect it to be something else, something bigger and more complex," Tringham says. Melaart and his colleagues expected to find spiritual objects in grand temples, not in people's kitchens. Tringham always preferred to let the evidence speak for itself, without preconceptions.

Stanford University archaeologist Ian Hodder, who led excavations at Çatalhöyük until 2018, supported Tringham's methods. Traditionally archaeologists had studied artifacts by stealing them from dig sites and bringing them back to museums. Hodder popularized the idea of "contextual archaeology," which suggests that we should understand artifacts not in isolation but by thinking about how they fit into the place where they were discovered. In the case of Çatalhöyük, contextual archaeology gave researchers such as Tringham a framework for interpreting why there were sacred objects in the middle of living rooms. It was because people were fashioning ritual spaces in their own homes.

In contrast to later cities, where separate spaces were built for worship, work and domestic life, Çatalhöyük residents merged them all together under one roof. That is why every house looked like a combination of temple, workshop and bedroom. Hodder believes that these multipurpose houses represent a key stage in the process of human domestication, when many people stopped leading nomadic lives and settled down to farm. At first, houses were just places to sleep and work. But over time, as Hodder puts it, people became "entangled" psychologically with their land—you might say they went from being a bunch of farmers living on Konya Plain to being Çatalites. The city was part of their identities, and they attributed a spiritual meaning to the places where they lived. In the process, houses became homes. In cities built later, there were separate spaces for worship, work and domestic life—but the idea that the city was a home, and not just a resting place, continued to endure.

INSTANT SOUP IN THE NEOLITHIC

ÇATALHÖYÜK SHOWS what everyday life was like at a time when "home" was a radical new idea. Inhabitants had to do many jobs to keep their houses and families intact, but they spent the most time acquiring and making food. We know that they were agriculturalists, tending family farms and flocks of animals on the fertile Konya Plain, which would have afforded them the stable food supply they needed to live year-round in permanent homes. They made a variety of cooking implements, from butcher's

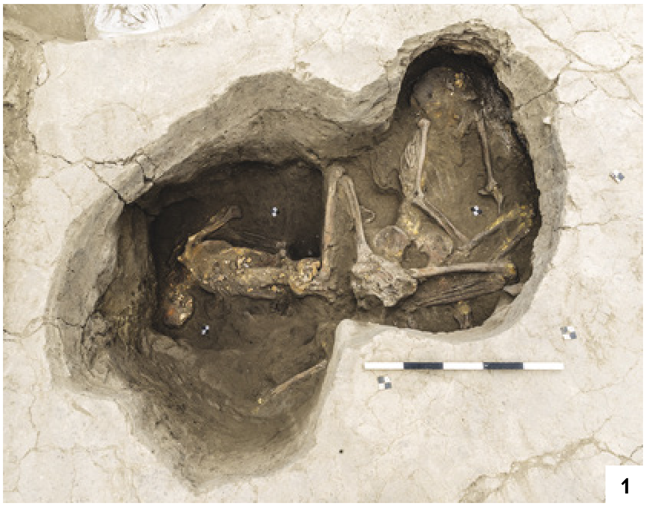

1


2


3

MOST HOUSES at Çatalhöyük were decorated with animal bones such as bull skulls (*1*). And elaborate paintings adorned the walls (*2*). A recreated home shows how symbolic and domestic items merged under one roof (*3*).

JASON QUINLAN (*1, 2*); LAURA DI BIASE *Alamy Stock Photo* (*3*)



1

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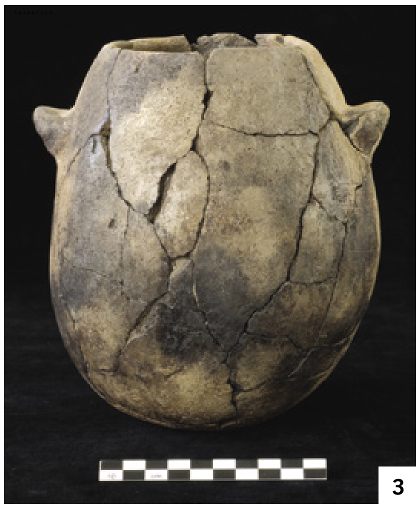
knives to soup bowls. And now, thanks to a high-tech analysis of their stew pots, we know what they ate.



3

4

HOME was not only where people slept but also where they worshipped and worked. Skeletons found buried under the floors attest to the spiritual aspect of home (*1*). Clay balls (*2*) may have helped heat food or keep people warm. Clay pots (*3*) and obsidian knives (*4*) evince food preparation.

JASON QUINLAN (*1, 3, 4*); MICHAEL ASHLEY (*2*)

"It was like a crime story," says archaeologist Eva Rosenstock with a laugh, as she describes how she and her colleague Jessica Hendy used forensics methods to extract telltale molecules from ancient food stuck to the inside of cooking vessels. Rosenstock is a research associate at the Einstein Center Chronoi in Berlin, and she has been studying foods and health during the Neolithic for most of her career. She met Hendy a few years ago at a conference, where Hendy was explaining how she had figured out what people ate in the Middle Ages by examining calcium deposits on their tooth enamel. Trapped inside that calcium were traces of lipids and proteins, chemicals found in all living things—including the ones we eat. Hendy could identify medieval foods by cross-referencing the molecular structures of the lipids and proteins on people's dirty teeth with those from known animals and plants.

It was a moment of inspiration for Rosenstock. She had examined a few clay bowl fragments from Çatalhöyük that had a thin calcite layer on the inside, "kind of like limescale in teapots," she explained. She convinced Hendy to examine those ancient dishes for molecules that would reveal Neolithic menu items.

There was a nail-biting period when Hendy started the analysis and her first matches were with exotic aquarium fish and lotus flowers—the result of contamination of the sample with modern molecules. Luckily, further analysis showed that there were much closer molecular matches to other edibles—and these were the real deal. Rosenstock, Hendy and their colleagues discovered traces of peas, wheat, barley, goat, sheep, cattle and even some deer. But the most interesting discovery by far was that all the bowls had held milk at a time before most humans evolved the genetic mutation that allows us to metabolize milk products as adults. Indeed, the dairy remains at Çatalhöyük are among the oldest ever recovered. This does not mean Çatalhöyük diners were getting sick in the way lactose-intolerant people do now. Recent research shows that our gut microbiome—all the microorganisms that live in our intestines—can help us digest milk. The researchers had simply gotten a rare glimpse of the moment when adults began to cook with milk. Over the next several thousand years the mutation that helps people digest dairy into adulthood spread throughout Europe and the Middle East.

Rosenstock believes these milk residues also reveal an ancient laborsaving strategy. Back in the Neolithic, dairy would have been seasonal. Animals gave birth in the spring, and their milk would have dried up by winter. To enjoy milk year-round, communities all across the world invented cheese and other fermented dairy foods that could keep for a long time. In Turkey and nearby regions, people prepare a dried sour milk dish known variously as *qurut* or *kashk*. Sometimes it is molded into balls and sometimes powdered; for added flavor, the milk can be fermented with ground grains, too. People at Çatalhöyük might have been making a similar dish. "You get this super storable thing that won't go rancid for years," Rosenstock says. "You put it in hot water, and it's like instant soup!" Perfect for a hot meal at home on a cold winter day, when nobody wants to go outside to farm or hunt.

THE CLAY BALL MYSTERY

CRAFTERS AT ÇATALHÖYÜK had other laborsaving tricks as well. Roughly 8,500 years ago, centuries after the city's founding, fired pottery was invented—and it was as revolutionary for Neolithic cooks as microwaves were for impatient, hungry people in the 1970s. Before the rise of ceramics, cooking was a labor-intensive process. University of Massachusetts Amherst anthropologist Sonya Atalay found evidence that stews were made in watertight woven baskets. You put your water and ingredients into the basket and heated it with large stones or clay balls heated in the fire. When the balls cooled, you took them out and replaced them with hot ones. It was no doubt a tiresome process, especially after a long day of gathering food and water.

Atalay's portrait of preceramic kitchen life came from two sources of evidence. First, there are a few modern people who still cook with heated stones because it is part of their cultural traditions. And second, the settlement of Çatalhöyük is simply bursting with piles of large clay balls, about the size of grapefruits, that are covered in scorch marks from fires. Some houses have hundreds of them, scattered in and around hearths. To Atalay, it seemed obvious that these clay balls were cooking stones.

After the rise of ceramics at Çatalhöyük, people mostly stopped making large clay balls and woven cooking baskets. Because ceramic pots are heat-resistant, they could be put on stands over the fire to simmer stews all day. It must have felt incredibly luxurious to cook without constantly juggling hot clay balls.

There is just one problem with this story. When scientists analyzed these clay balls for lipids and proteins akin to the ones found on Rosenstock's bowls, they found nothing. It would appear the balls were heated and clearly used in the kitchen, but they were not ever submerged in food. So what were they for?

Lucy Bennison-Chapman, an archaeology researcher at Leiden University in the Netherlands, spent years analyzing the balls and made some surprising discoveries. Although she does not completely rule out their use in stews, she thinks that is extremely unlikely—they were simply too big and would have shed bits of clay and dirt into the food. She also dismisses the possibility that they were weapons. "They're different from sling missiles," she says. "They're smaller and generally a different shape."

Instead she thinks the large balls were heaters. In some cases, they were used to line the bottoms of ovens to hold warmth. They could also have been the Stone Age equivalent of heating trays—people might have pulled the balls from the fire, covered them in reed mats and placed food on top. There is yet another possibility, which will be familiar to anyone who has read a Charles Dickens novel where someone puts heated bricks in their bed at night. "On the Konya Plain, it gets really cold in winter. You could heat them and use them as a body warmer. Or you could wrap them in linen and put them in your bedding," Bennison-Chapman explains. "People worked on rooftops and in the fields, so you could place heated balls in your pockets while you were outside. This would explain why they were reheated and reused so often."

Making these multifunctional balls was incredibly time-consuming. "They would have spent a long time going over them with their hands, smoothing them," Bennison-Chapman says. "They're covered in fingerprints." Perhaps because it took so long to make them, the balls were used over and over, reheated in the fire until they were cracked. Most balls found at Çatalhöyük have been reduced to fragments. Some were recycled and turned into packing material in mud bricks or were placed between walls, perhaps for insulation.

Clay balls also figure importantly at Çatalhöyük for another reason. In addition to the big heaters, residents made miniature clay balls, which were occasionally decorated with dots and other patterns. These mini balls, or tokens, are the earliest examples at Çatalhöyük of "counting pieces," named by archaeologists who believed they were for simple record keeping or tallying up resources. Bennison-Chapman cautions, however, that tokens were not purpose-built for counting—they probably served as gaming pieces, weights, ritual objects and even just decoration. Still, the tokens show that domestic life was not simply focused on cooking and staying cozy. Crafting objects at Çatalhöyük would eventually lead to counting and written language.

NO PLACE LIKE HOME

THE NEOLITHIC was a period of rapid change for humanity, especially when it came to defining what it meant to be at home. Before about 12,000 years ago, very few people lived in agricultural settlements year-round—most were nomadic or seminomadic, living in small groups as hunter-gatherers who moved from site to site according to seasonal changes in food availability. So when people finally did begin to build permanent houses and form larger settlements, they had to figure out new ways of living in one place, cheek by jowl with their neighbors.

Mostly they did it by building those homes together—sharing the backbreaking labor but also the joys of community. John S. Allen, an anthropology researcher at Indiana University Bloomington, is author of the 2015 book *Home: How Habitat Made Us Human*. "A home is a space you have an emotional attachment to, through habitual use," he says. Humans create homes by forming an association between their community and a specific place, he adds. This might be one reason graves at Çatalhöyük lay just below the floors of homes. "A burial signifies a special place for family and friends," Allen suggests, underscoring the idea of a home as an emotional space as well as a practical one.

When Rosenstock described all the foods that people ate at Çatalhöyük, one topic came up again and again: her intense conviction that sooner or later she and her colleagues will find evidence for beer. Partly that is because archaeologists have found evidence of beer production in other Neolithic cultures around the world. But it is also because there is so much evidence for merrymaking at Çatalhöyük. "They have massive amounts of pottery—they're creating and discarding it like crazy. You can't help but think they were eating and smashing the pots," she says. They also threw away bones that still had meat on them, as if they were feasting and drinking.

Building a city is not all about work. It's about parties, too. Perhaps, at the dawn of city life, working and partying were two sides of the same coin: they were the tissues that knit us together in a single place we came to know as home. SA

FROM OUR ARCHIVES

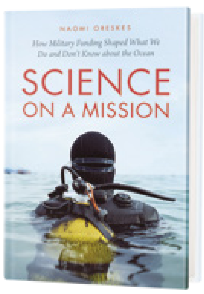
Women and Men at Çatalhöyük. Ian Hodder; January 2004.

scientificamerican.com/magazine/sa

By Andrea Gawrylewski

Science on a Mission: How Military Funding Shaped What We Do and Don't Know about the Ocean

by Naomi Oreskes. University of Chicago Press, 2020 ($40)



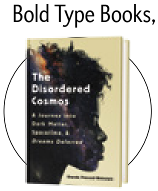
RESEARCH VESSEL *Roger Revelle* in the Arctic Ocean in 2007 on a mission to collect data on ocean circulation, chemistry, physics and biology.

COURTESY OF SCRIPPS INSTITUTION OF OCEANOGRAPHY

How much does funding affect the course of scientific discovery? In this insightful book, science historian (and *Scientific American* columnist) Oreskes examines the military backing that poured into oceanography programs during World War II and the cold war. The expansion of naval warfare created a sudden need to better understand the deep sea. Oreskes shows that in some cases, that largesse enriched our knowledge—for example, the need to study the effect of water density on sonar transmission led to a breakthrough in understanding deep ocean circulation. But military secrecy also prevented discussions and publication of crucial ocean research; bathymetric data about undersea topography that would have been useful for the development of plate tectonic theory were kept classified, for example. Overall, the book reminds us that science does not happen in a vacuum. *—Andrea Thompson*

The Disordered Cosmos: A Journey into Dark Matter, Spacetime, and Dreams Deferred

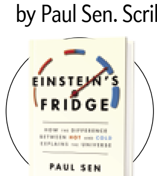
by Chanda Prescod-Weinstein. Bold Type Books, 2021 ($28)



"I used to think physics was just physics, separate from people," writes theoretical physicist Prescod-Weinstein. "I was wrong." In this eye-opening book Prescod-Weinstein describes her work studying particle physics, dark matter and cosmology, as well as how that work is affected by being a "queer agender Black woman" in physics. She has faced abuse most of her colleagues have not—told by advisers she was not smart enough to be a physicist and subjected to racism and even physical assault from fellow researchers. Somehow her awe at the cosmos remained intact, and it illuminates this fascinating tour of the universe, from cosmic inflation to the physics of melanin. *—Clara Moskowitz*

Einstein's Fridge: How the Difference between Hot and Cold Explains the Universe

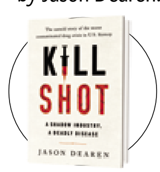
by Paul Sen. Scribner, 2021 ($28)



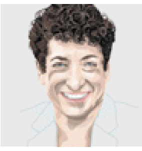
Although thermodynamics has been studied for hundreds of years, filmmaker Sen writes, few nonscientists appreciate how its principles have shaped the modern world. "From sewage pumps to jet engines ... to the biochemistry of lifesaving drugs, all the technology that we take for granted needs an understanding of energy, temperature, and entropy," he writes. To elucidate this field—including Einstein's lesser-known contributions—Sen sums up the history of thermodynamics, blending the biographies of key scientists with explanations of how their work led to specific innovations. These figures include pioneer Sadi Carnot, the first to describe an ideal heat-driven engine, and mathematician Emmy Noether, whose theorems on the conservation of energy vindicated Einstein. *—Sophie Bushwick*

Kill Shot: A Shadow Industry, a Deadly Disease

by Jason Dearen. Avery, 2021 ($27)



Pharmaceutical-industry regulation is not often featured in the plot of murder mysteries—but that is exactly how Dearen's *Kill Shot* reads. In it, the Associated Press investigative journalist traces the disturbing story of a contaminated batch of pain-relieving steroid injections that sickened nearly 800 people around the U.S. in 2012 and killed more than 100. As a growing number of patients who received the injections started to show signs of fungal meningitis, the Centers for Disease Control and Prevention began to investigate. The source of the botched drugs was a family-owned pharmacy that grew into a lucrative business by exploiting a loophole in U.S. drug regulations. The company's pharmacists were put on trial for murder and fraud, but no verdict will bring back the lives of those killed by deadly negligence. *—Tanya Lewis*



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).

When Experts Get It Wrong

Accurate assessments are hard to come by if you consult the wrong people

By Naomi Oreskes

"Experts are always getting it wrong" is now a familiar trope. As a historian of science, I disagree: I think history shows that scientific experts mostly get things right. But examples where experts have gone wrong offer the opportunity to better understand the limits of expertise. A case in point is the Global Health Security Index (GHSI), the result of a project led by the Nuclear Threat Initiative and the Johns Hopkins Center for Health Security. It was published in October 2019, just weeks before the novel coronavirus made its appearance.

GHSI researchers evaluated global pandemic preparedness in 195 countries, and the U.S. was judged to be the most prepared country in the world. The U.K. was rated second overall. New Zealand clocked in at 35th. Vietnam was 50th. Well, those experts certainly got that wrong. Vietnam and New Zealand had among the best responses to the COVID-19 pandemic; the U.K. and the U.S. were among the worst.

In fairness, the study did not conclude that overall global preparedness was good or even adequate. It warned that global health security was "fundamentally weak" and that no country was fully prepared for either an epidemic or a pandemic. The COVID pandemic was equivalent to a giant fire before which almost no one had done a fire drill. But while these experts got the coarse-grained analysis right, they were grossly wrong in their nation-by-nation assessment. As we now know, both the U.S. and the U.K. have suffered death rates much higher than many countries that the GHSI rated as far less prepared. The study results were so wrong in this regard that one post-hoc analysis concluded that it was "not predictive"; another dryly observed that it was predictive but in " the opposite direction." So what happened?

The GHSI framework was based heavily on "expert elicitation"—the querying of experts to elicit their views. (This method contrasts with consensus reports such as those produced by the U.S. National Academy of Sciences or the Intergovernmental Panel on Climate Change, which are primarily based on a review of existing, peer-reviewed publications.) Expert elicitation is often used to predict risks or otherwise evaluate things that are hard to measure. Many consider it to be a valid scientific methodology, particularly to establish the range of uncertainty around a complex issue or, where published science is insufficient, to answer a time-sensitive question. But it relies on a key presumption: that we've got the right experts.

The GHSI panel was understandably heavy with directors of national and international health programs, health departments and health commissions. But the experts included no professional political scientist, psychologist, geographer or historian; there was little expertise on the political and cultural dimensions of the problem. In hindsight, it is clear that in many countries, political and cultural factors turned out to be determinative.

Consider the U.S., a country with some of the most advanced scientific infrastructure in the world and a prodigious manufacturing and telecommunications capacity. The U.S. failed to mobilize this capacity for reasons that were largely political. Initially the president did not take the pandemic seriously enough to organize a forceful federal response, and then, by his own admission, he played it down. More than a few politicians and celebrities flouted public health advice, appearing in public without masks well after the evidence of their benefits had been communicated. Our layered and decentralized system of government led to varied policies, in some cases putting state governments in conflict with their own cities. And many refused to practice social distancing, interpreting it as an unacceptable infringement on their freedom.

To evaluate American preparedness accurately, the GHSI group needed input from anthropologists, psychologists and historians who understood American politics and culture. In fact, it would have had to grant social scientific expertise primacy because social factors, such as racial inequality, most strongly shaped the American outcome. Around the globe, whether countries were able to mount an effective pandemic response depended crucially on governance and the response of their citizens to that governance. The GHSI team got it wrong because the wrong experts were chosen.

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Illustration by Jay Bendt

Compiled by Dan Schlenoff

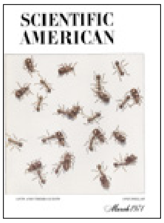
MARCH

1971 In-Patient Therapy

"The treatment of mental illness in the U.S. has changed profoundly over the past 20 years. One change, which is not widely known outside the mental health profession, has been the development of a method of treatment that is called the therapeutic community. The term describes a way of operating a small psychiatric unit in a hospital. Ideally a unit will have between 20 and 40 patients; a large hospital may have more than one therapeutic community. A key constituent of the method is a close relationship between the staff and the patients, who share the work and activities of the unit and participate in the making of decisions affecting it."

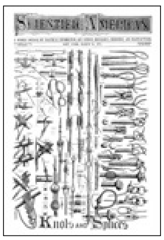
Politics of Holiday Cards

"'The patterns in which people send and receive Christmas cards can ... be explained in terms of certain social characteristics, especially their social status and mobility aspirations.' This hypothesis, developed by Sheila K. Johnson, has now been modestly field-tested by her and published in *Trans-action*. Mrs. Johnson divides all Christmas cards into three groups: (1) reciprocals, (2) sent but not received and (3) received but not sent. Reciprocals are exchanged with relatives or with friends of similar social status. People also send cards, however, to those who never send them cards but whom they want to cultivate, and they receive cards from those to whom they never send cards but who want to cultivate them. A graduate student reported that 70 percent of his cards were reciprocals, 30 percent were sent upward and none were received from below."



1971

1921



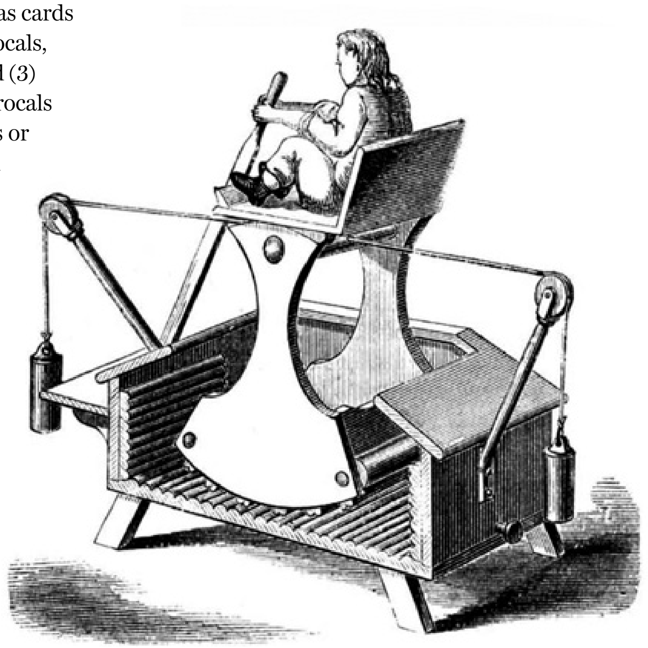
1871

1921 War on Crime

"Three bank robbers were routed by mustard gas in a Michigan bank. Tubes of the gas had been placed in the bank vault a few days before as a precaution against bandits. When the yeggmen blew in the doors the tubes burst and the thieves fled, leaving 85 cents of their own money and an expensive kit of burglars' tools behind them. It was several hours before the building could be entered with safety. Only the first door of the big vault had been blown away, the escaping gas defeating the purpose of the yeggmen."

Age of the Earth

"The Abbe Theodore Moreaux, Director of the Observatory at Bourges, has recently given some estimates of the age of the earth and when the phenomenon of life appeared on it. He considers 500,000,000 years about right for the age of the earth and he thinks that the temperature dropped to a point where life could exist about 250,000,000 years ago. Man was a comparative newcomer and the Abbe gives only some tens of thousands of years, thus refuting an estimate of a German scientist, who recently gave 400,000 years as the probable period for the advent of man."



1871: Patented washing machine, powered by an energetic child.

SCIENTIFIC AMERICAN, VOL. XXIV, NO. 10; MARCH 4, 1871

1871 Breeding Leeches for Medicine

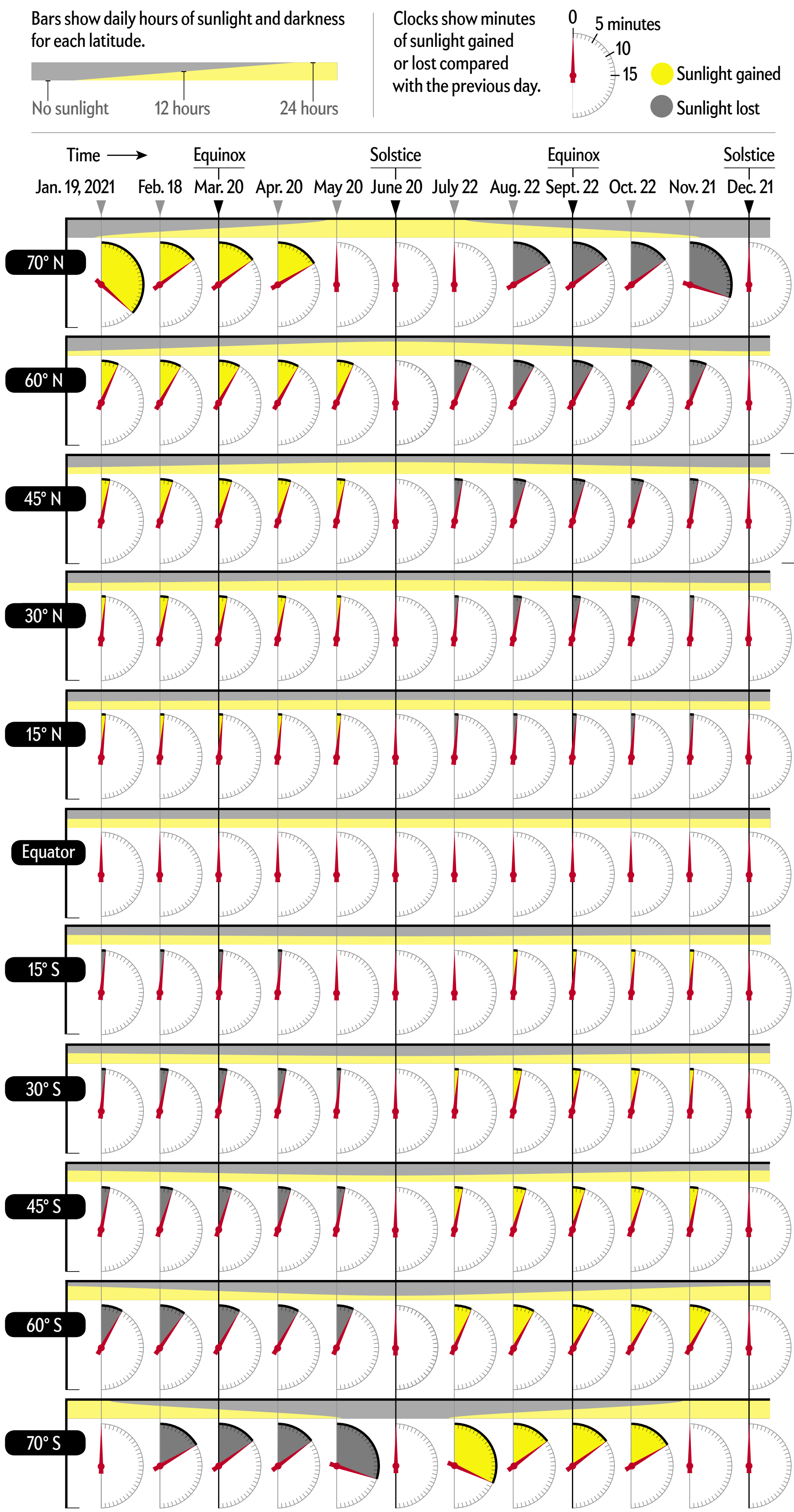
"The universal use of leeches in surgery gives a great importance to their propagation, in the few places where they are raised. In France they are made an object of cultivation. On the Landes, near Bordeaux, they are bred by the hundreds of thousands, the wasted forms of moribund cattle being put into the marshes to supply them with nourishment. A cow is used by preference for this purpose, as, when the poor wretch is drained of her blood, she can be driven to a meadow where there is good feed, and will rapidly recover to furnish a fresh supply, whereas horses and asses sink under the attacks of the leeches. The inhabitants of the country around the beautiful bay of Arcachon follow this trade largely, and send as many as 1,500,000 leeches to Bordeaux in a year."

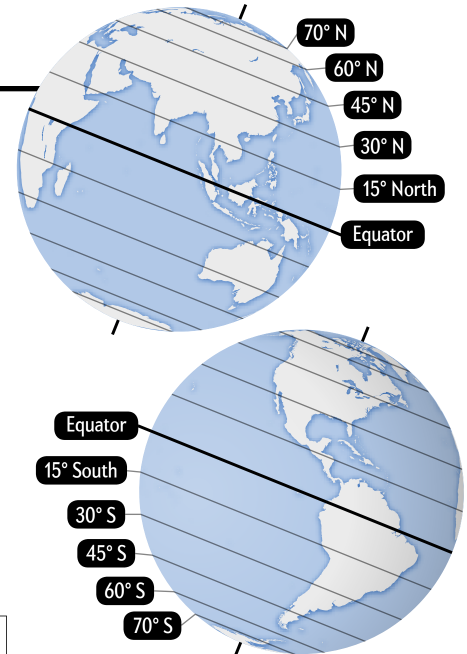
Baby Power

"The credit of this invention—the application of baby power to washing machines—in the unique manner illustrated in the annexed engraving, belongs to John Highbarger, of Sharpsburg, Md., who not long ago secured the patent. A tank with ribbed sides is intended to hold the clothing, the water and the soap. The clothes are washed by the oscillation of a rocking chair, the rocking being effected by the hands of the operator, which grasp a hand bar, as shown. This plan of utilizing baby power is certainly novel, and would be, no doubt, amusing to the operator."

There were almost 2,000 patents for hand-cranked washing machines in the U.S. by 1875.

Text by Mark Fischetti | Graphic by Jen Christiansen and Mapping Specialists





At 45 degrees north latitude—Bangor, Maine; Bordeaux, France; Toyotomi, Japan—the daily rate of sunlight change is almost exactly two minutes in January, May, July and November and more than three minutes in March and September.

Daylight's Uneven March

Sunlight changes unequally all year long

People who live in the midlatitudes enjoy maximum daylight on the summer solstice and put up with maximum darkness on the winter solstice. Between the two extremes, sunlight increases or decreases each day, but the rate of change is not steady. It is least in midsummer and midwinter and greatest around the spring and fall equinoxes. The biggest shifts occur at very high latitude: Just before the period of total darkness (or just after total darkness), the sun is barely above the horizon around solar noon, when the solar elevation changes very slowly, resulting in a large daily difference in daylight minutes lost (or gained). People who live along the equator see no change; they experience a steady 12 hours of day and night throughout the year.

SOURCE: NOAA SOLAR CALCULATOR