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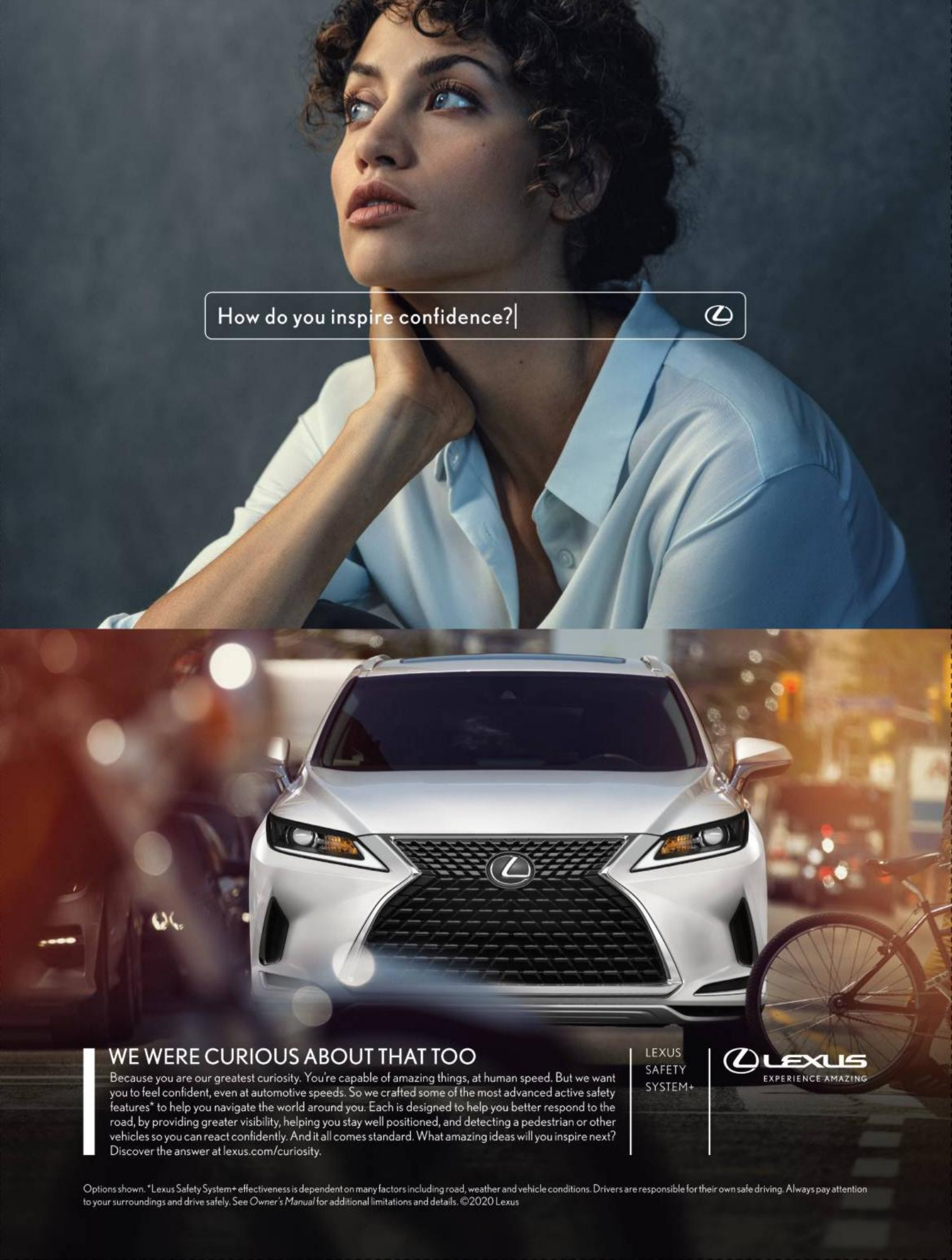
COVID DREAMS

How the pandemic is changing the world's sleep



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OCTOBER 2020

VOLUME 323, NUMBER 4

SCIENTIFIC AMERICAN

ON THE COVER

Dreams can be strange, but the COVID-19 pandemic has made them more bizarre. Many people report dreams about being threatened or being unable to cope. Lockdowns and social distancing, so alien to our normal lives, may also be overwhelming useful functions that dreams provide, such as helping us regulate our emotions. **Illustration by Goñi Montes.**

Photograph by Christian Rodriguez

SCIENTIFIC AMERICAN


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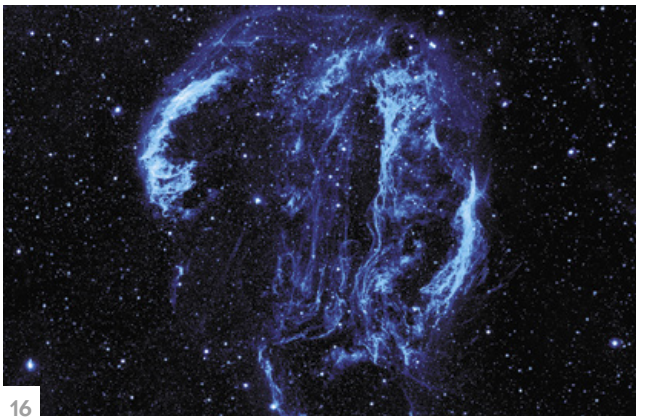
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BIG QUESTIONS FROM... DAVID JULIUS

Best known for untangling the neuroscience of pain, David Julius describes shape-changing receptors, the quest to develop objective methods for diagnosing pain, and the hunt for analgesics that target an arthritic knee, an annoying itch, or a migraine.

Anyone who's ever tucked into a plate of extra-spicy chicken wings is familiar with capsaicin, the fiery chemical that lets chili peppers bring the heat. But how exactly does capsaicin elicit that burning sensation? That's something that David Julius of the University of California, San Francisco, pondered long and hard, even at the supermarket.

"I was in the aisle where all these spices are lined up, all these different types of chili extracts," recalls Julius. "And my wife, who's also a scientist, finds me just standing there, staring. She says, 'What are you doing?' And I say, 'This damn receptor, it's got to exist!' And she says, 'Why don't you just focus on it and get it done?'"

That shot of straight talk spurred the discovery of TRPV1, the cellular receptor that responds to capsaicin—and senses temperature as well. It also led to a series of findings that uncovered the molecular roots of pain.

These findings earned Julius the 2020 Kavli Prize in Neuroscience, which he shared with Ardem Patapoutian of the Scripps Research Institute, who uncovered the receptors we use to sense pressure.

For decades, biologists have known how chemical signals are transmitted—including our senses of smell and taste, Patapoutian says. "But we knew much less about how we sense physical forces, including temperature and pressure—which define our sense of touch."

"When you touch a hot stove, something must be detecting temperature," Julius says. "But was there a discrete molecule that does that?" Since spicy food is hot, it stood to reason that it might be the capsaicin receptor. And when Julius's team poured increasingly warmer solutions over pain-sensing neurons, "Lo and behold, the capsaicin receptor was activated."

Then his lab and Patapoutian's, working independently, discovered a receptor that responds to menthol and cold temperatures. And they realized that when these receptors are activated, they all act as channels that allow calcium to flood into sensory neurons and trigger neural impulses. "That was an amazing, eureka moment," Julius says. It also led to the discovery of an entire family of channels that detect chemicals that the body produces in response to injury, inflammation, or disease.

Here, Julius describes the next big questions for pain researchers: how these channels shape-shift in response to heat or cold, how new pain-killing drugs could target them, and how better understanding of pain pathways could lead to precision diagnosis and treatment for specific types of pain.

How can a protein receptor help us sense heat?

That's a very important question. We have a pretty good idea of how capsaicin works. We know where it binds, and we have some idea of how that induces conformational movements in the channel to open it up. But for heat, we don't

know. We think that by using cryo-electron microscopy, which allows you to capture proteins at different stages in their life cycle better than x-ray crystallography, we might be able to see temperature-dependent changes in the structure of the channel as it opens. Are specific regions of the channel more temperature-sensitive than others, or is the response integrated over the whole protein? And how does that play into its role in pain sensation physiologically? These are things that we definitely want to understand.

Can we find a drug that eases pain but does not disrupt our ability to sense heat?

The challenge is to develop an analgesic that can diminish hypersensitivity to pain without losing this protective function. Some early TRPV1 antagonists scored well in models of osteoarthritic knee pain, but they also blocked the channel's ability to detect heat, so drug companies worried about people drinking hot coffee and burning themselves. There are new drugs that diminish heat sensation less. If someone has osteoarthritic knee pain and they can't even walk, you could counsel them and say, "Look, this drug will really help you, but you have to be careful when you encounter things that are hot." We could allow patients to make the decision about whether it's worth the trade-off.

Will there ever be a single pill that can cure all pain?

There won't be a magic bullet for all types of pain. Acute and chronic pain are distinct processes—and there are multiple types of chronic pain. Migraines differ from bladder pain, which differs from cutaneous pain. And, tissues sense different types of pain using different subsets of sensory neurons and different molecules. But if you can develop a drug that's great for dealing with one type of pain—say, a persistent itch due to one type of clinical syndrome—that would be a major development for many patients. We have to give chemists a chance to make the right compounds, and then test these drugs in clinical trials to see where they'll be most effective.

Can we develop better methods to measure and treat long-term chronic pain?

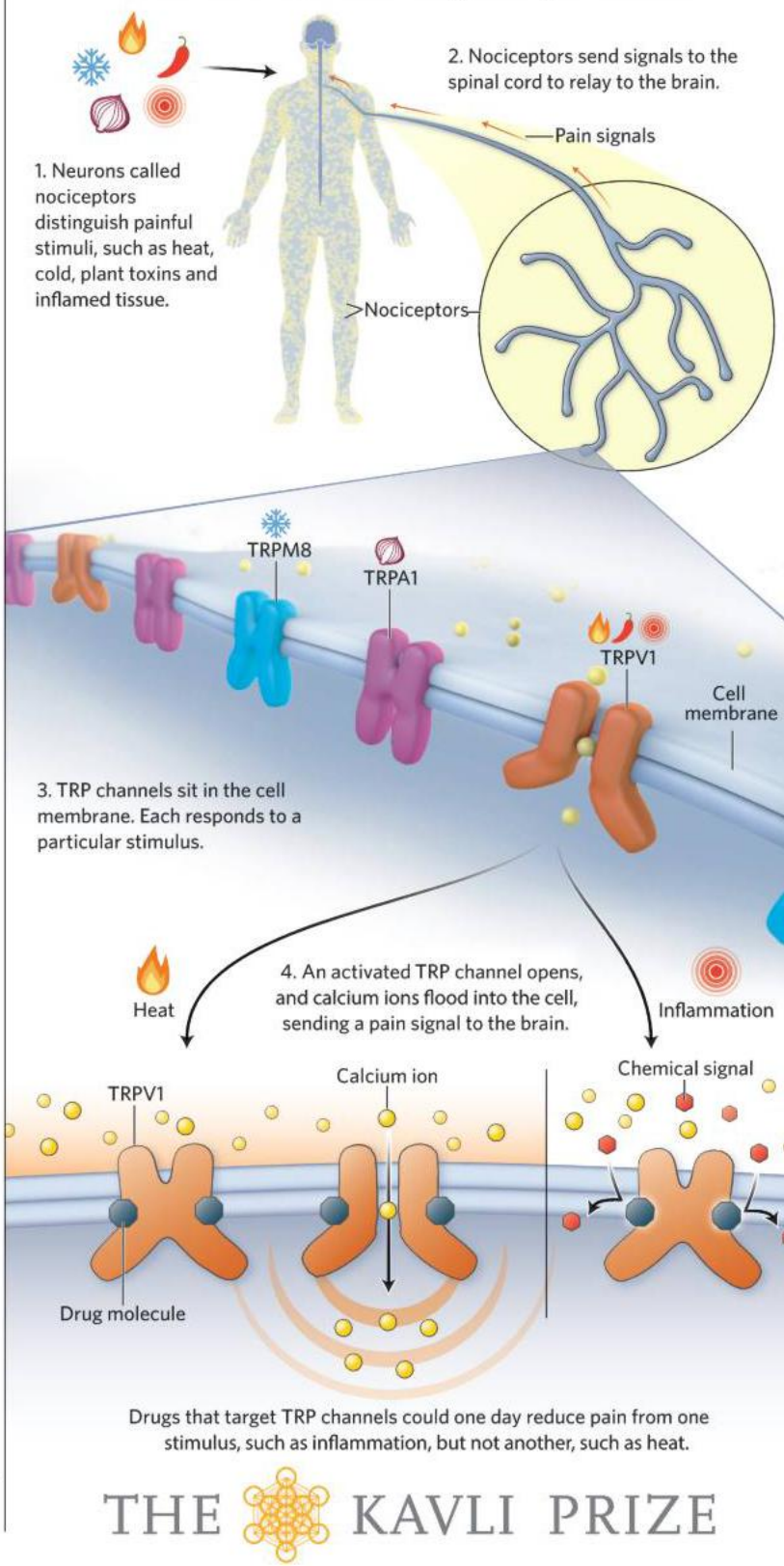
When people come into the clinic, say they're in pain but don't have a physical manifestation of an injury, they're up against a hard place. Pain has a very subjective component to it, and a lot of times people will say, "It's all in your head." Having more objective measures would enable them to be more accurately assessed as patients. These people need help. We're just beginning to understand how different sensory neurons talk to the nervous system, including the circuitry and the molecular players that regulate these circuits. That will be critically important for understanding how neurons in the central nervous system end up hypersensitized in persistent pain syndromes.

For long-term pain management, we really need to come up with alternatives to opiates, as the whole opioid epidemic has clearly brought home. There's been a lot of progress in the pain field over the last 20 years. I think we need to keep going on this path, identifying and understanding mechanisms, then targeting them and staying with it. Like I always tell people in my lab, persistence pays off.

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

PERCEIVING PAIN

Pain tells our brains to act decisively to protect our body, but first we must identify the threat. To do so, pain-sensing neurons employ proteins called TRP channels. Detailed knowledge of TRP channel function could help scientists design better pain medicines.



Drugs that target TRP channels could one day reduce pain from one stimulus, such as inflammation, but not another, such as heat.

THE KAVLI PRIZE

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

Synchronicity

Have you been sleeping well this year? If not, you're not alone. Nightmares about COVID-19—fears of being in crowded spaces, touching germy surfaces, feeling exposed without a mask—have been disturbing the sleep of people around the world. The pandemic seems to have introduced a new shared unreality, with dreams that are as alarming as that one about being late for a final exam you haven't studied for. Our cover story this month is from psychiatrist and dream researcher Tore Nielsen, who is busy studying the largest inadvertent sleep-disruption experiment in history. Please turn to page 30.

COVID-19 is the worst pandemic in a century, in part because the coronavirus behaves in unexpected ways. At first, we thought the disease spread primarily through sneezes and coughs and from people touching surfaces where respiratory droplets had landed. Now we know the virus spreads through the air, often from people who don't have symptoms and don't realize they're infected. Asymptomatic transmission is one of the ways the new pandemic resembles the HIV/AIDS pandemic, and longtime researcher William A. Haseltine shares lessons for COVID-19 from the early days of AIDS, starting on page 36. One of his more touching observations is that there is a social element to both diseases. People go to bars and parties when they are seeking companionship, which is natural and human.

When a bizarre object zipped through our solar system in late 2017, astronomers quickly realized it was from out of this world. 'Oumuamua is the first object from another solar system to be detected in ours. We call it an object because nobody really knows what it is—it's kind of comet-ey, kind of asteroid-ey, and according to a few theorists, it's not entirely unlike an alien ship. (In general, whenever somebody says, "Maybe it's aliens," it's never aliens.) A second extrasolar interloper soon followed, and astronomers David Jewitt and Amaya Moro-Martín (*page 42*), among others, are eagerly anticipating the next ones.

The COVID-19 pandemic is exacerbating the health effects of racism, with disproportionate illness and deaths among people of color. Janet Currie, an expert on social and environmental impacts on health, explains how infants can be unequal at birth. One hopeful side of her article (*page 50*) is that access to health care and nutritional support, as well as other interventions and policies, can and do improve the health of babies born at a disadvantage, leading to dramatic improvements in lifelong health and economic security.

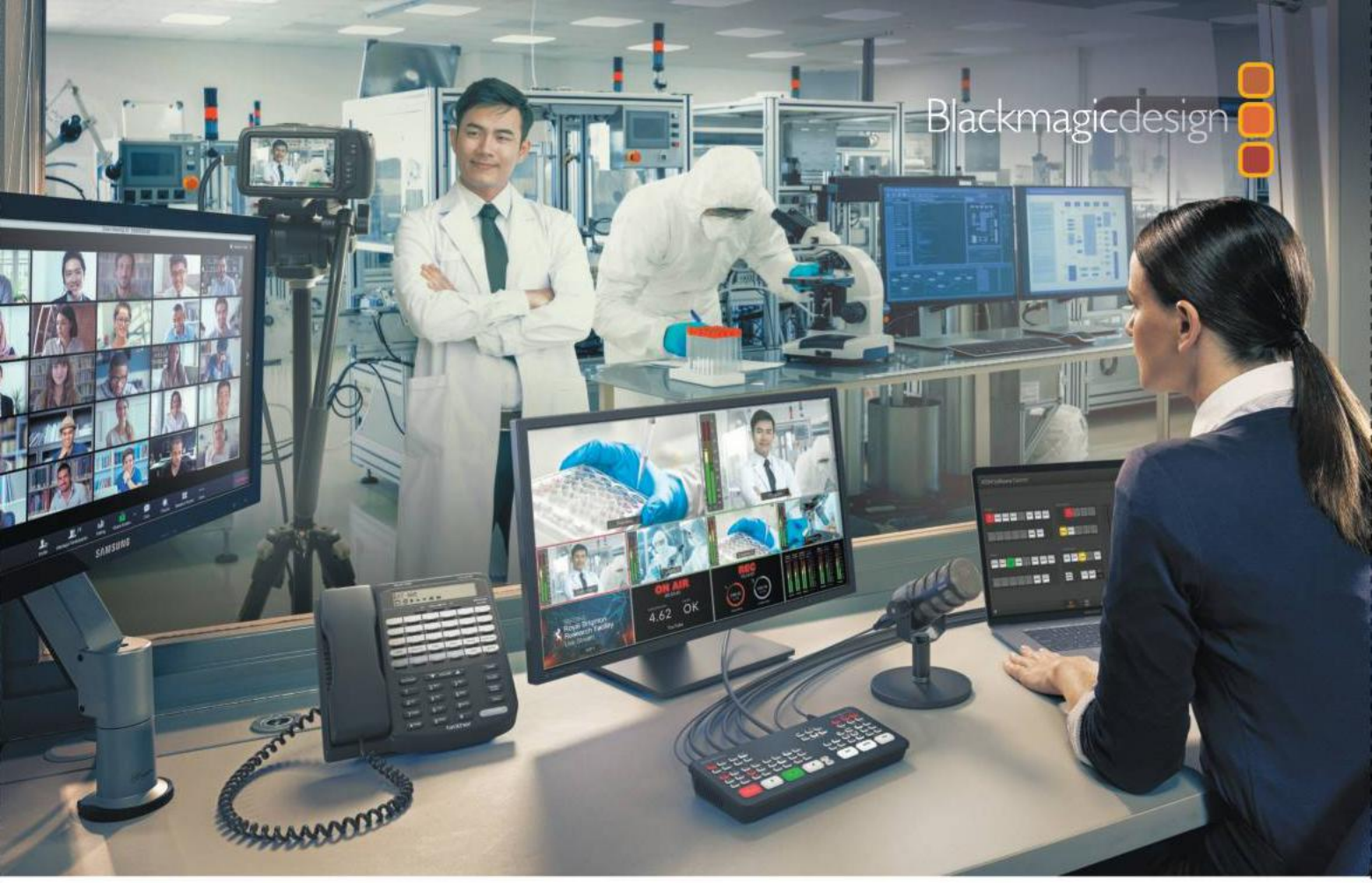
The story on unlearning racism (*page 58*) shows one person's struggle, using science and scholarship, to understand and confront the bias we're pickled in. A lot of people are newly recognizing systemic inequalities in the U.S. and other parts of the world, and we hope writer Abigail Libers's story and the books she recommends will help.

People who live in the forests around Lake Mensabak in the southern Mexican state of Chiapas are descendants of the Lacandon Maya, a group that left the large cities of the Maya empire when drought, war, slavery and disease devastated the civilization. Now modern Lacandon Maya are collaborating with archaeologists to study their history and understand how their ancestors adapted to a new life. Freelance writer Zach Zorich takes us there, beginning on page 70.

When people move, dance, sing or swing together, they often experience a distinct form of joy and fellowship. Writer Marta Zaraska (*page 64*) shares the social science and brain science of synchrony, which some researchers claim has a social-bonding function that helped early humans form cohesive groups (and make beautiful music together).

Thank you for reading *Scientific American*. All of us here wish you good health and pleasant (or as pleasant as possible) dreams. SA

Illustration by Nick Higgins



Introducing ATEM Mini

The compact television studio that lets you create training videos and live streams!

Blackmagic Design is a leader in video for the medical industry, and now you can create your own streaming videos with ATEM Mini. Simply connect up to 4 HDMI cameras, computers or even technical equipment. Then push the buttons on the panel to switch video sources just like a professional broadcaster! You can even add titles, picture in picture overlays and mix audio! Then live stream to Zoom, Skype or YouTube!

Create Training and Educational Videos

ATEM Mini's includes everything you need. All the buttons are positioned on the front panel so it's very easy to learn. There are 4 HDMI video inputs for connecting cameras and computers, plus a USB output that looks like a webcam so you can connect to Zoom or Skype. ATEM Software Control for Mac and PC is also included, which allows access to more advanced "broadcast" features!

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ATEM Mini is really a professional broadcast switcher used by television stations. This means it has professional effects such as a DVE for picture in picture effects commonly used for commentating over a computer slide show. There are titles for presenter names, wipe effects for transitioning between sources and a green screen keyer for replacing backgrounds with graphics!

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The ATEM Mini Pro model has a built in hardware streaming engine for live streaming via its ethernet connection. This means you can live stream to YouTube, Facebook and Twitch in much better quality and with perfectly smooth motion. You can even connect a hard disk or flash storage to the USB connection and record your stream for upload later!

Monitor all Video Inputs!

With so many cameras, computers and effects, things can get busy fast! The ATEM Mini Pro model features a "multiview" that lets you see all cameras, titles and program, plus streaming and recording status all on a single TV or monitor. There are even tally indicators to show when a camera is on air! Only ATEM Mini is a true professional television studio in a small compact design!

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June 2020

CALCULATING CATASTROPHE

"What Should Carbon Cost?" by Gilbert E. Metcalf, is unsuccessful in answering the question of how to calculate the most appropriate carbon tax rate. The uncertainties are too great. And probable impacts of climate change are beyond the scale of usual economic analyses. The use of integrated assessment models (IAMs) to calculate climate damage is like employing Newtonian physics to analyze phenomena far outside its range of applicability.

Metcalf states that "the richer future generations are compared to us, the less we should feel compelled to incur costs now to make them better off. That leans toward a high discount rate." But it is quite possible that future generations will be poorer than us as a result of the climate change that is already baked into current atmospheric carbon dioxide—and because perpetual economic growth is not sustainable. If so, ethical and economic considerations suggest a negative discount rate.

Further, Metcalf mentions "low-probability, high-damage" catastrophes such as runaway heating caused by thawing permafrost. There is much uncertainty about such events. But "uncertainty" is different from "low probability." Their probability may be high with the surprising six-degree-Celsius increase in economist William D. Nordhaus's cited analysis—three times the limit recommended by climate scientists.

Dick Walton *Billings, Mont.*

"History is rife with moments in which disasters would have been lessened or stopped if leaders had listened to their subordinates."

Ralph Kundtz, Jr. *Akron, Ohio*

METCALF REPLIES: Economist Frank Ramsey's rule states that the richer future generations are, the higher the discount rate. Walton is correct that the poorer they are, the lower that rate should be. But 2,000 years of history suggest our best estimate is of rising economic well-being going forward. As for permafrost melting, the probability may be high if we fail to reduce emissions, but the ultimate damages after accounting for unforeseen feedbacks still involve considerable uncertainty. The larger point, however, is that the possibility of catastrophes complicates measuring the social cost of carbon.

DEATH ON THE BRAIN

In "Tales of the Dying Brain," Christof Koch describes near-death and out-of-body experiences in humans. He does not mention nonhuman animals, however.

Many animal species, vertebrate and invertebrate, exhibit a temporary deathlike state called thanatosis, or tonic immobility, when confronted or physically touched by predators. Physically, vertebrates exhibit reduced respiratory rate, bradycardia and hypotension. Recovery takes at least minutes after the threat is removed.

Does tonic immobility relate to human near-death experiences?

Bernd Esche *via e-mail*

Koch's article reminded me of a comment by a Baptist minister who had attended many bedside deaths. He related the story of one individual who, on his deathbed, saw glimpses of heaven and called out, "They are all there," naming deceased members of his family. When the minister was asked about this near-death experience, his response surprised and pleased me. He said he believed that such an experience of heaven was whatever the dying person believed heaven would be.

Jean Howard *via e-mail*

KOCH REPLIES: In response to Esche: the possibility of animals having near-death experiences (albeit shorn of their cultural context) during thanatosis is fascinating. Death feigning may indeed trigger such a state. The methodological challenge would be to train animals to subsequently report something about their internal condition—say, by pressing levers or some other simple motor behavior—in a way accessible to an external, trained observer.

Howard reports a wise comment by a Baptist minister. To me, this astute observation—that people from different faiths and cultures experience their own idiosyncratic heaven and hell—argues against the hypothesis that near-death experiences reveal a single, universal truth about the hereafter. Instead everyone seems to be granted a very different vision of an afterlife that is formed by their own expectations and upbringing.

UNHEEDED WARNING

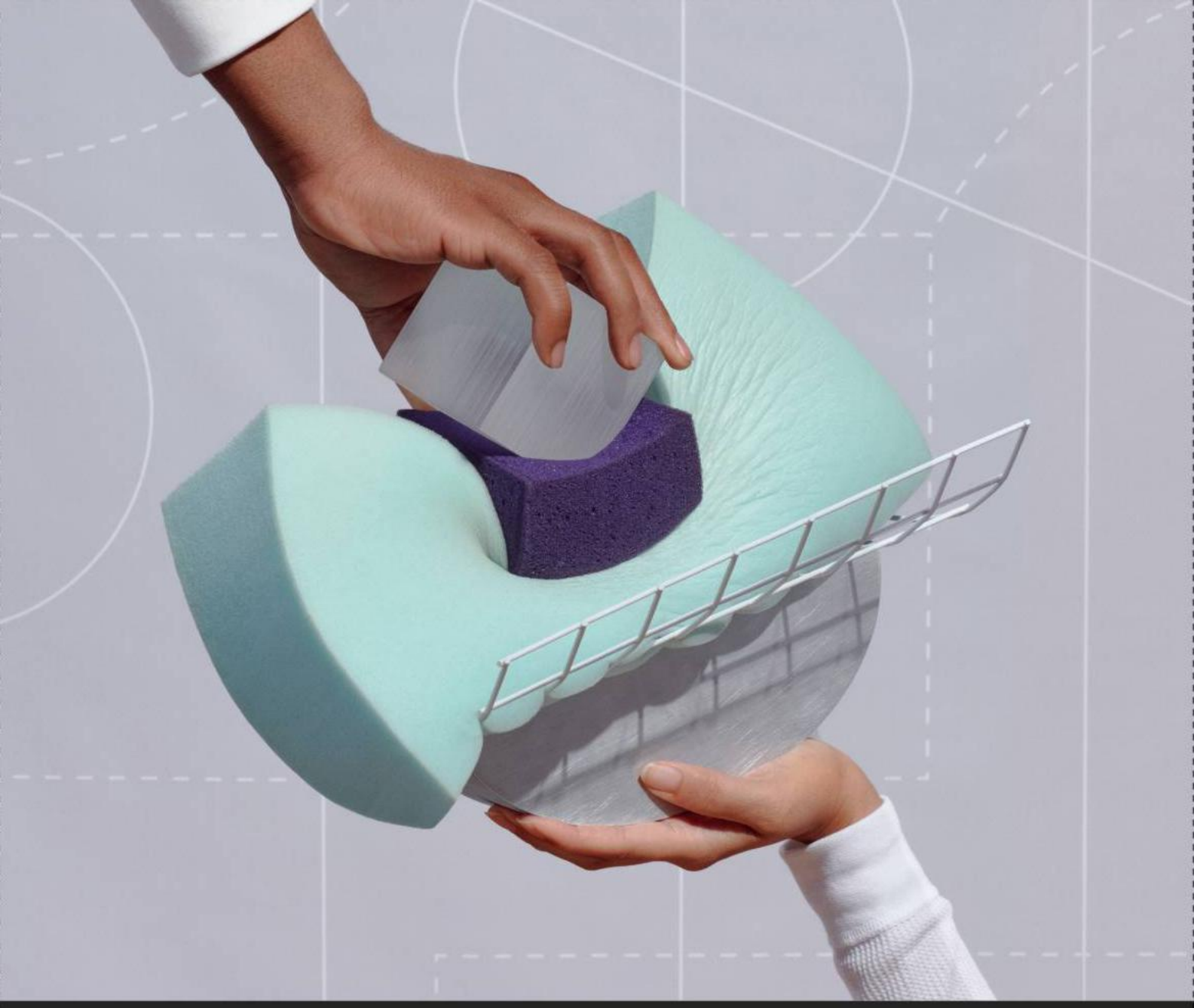
Ben Santer does a very good overview of our nation's current president in "Failure to Lead" [Forum]. He does leave out one very important occurrence, however: Donald Trump's trade adviser circulated a memo, dated January 29, 2020, that warned the West Wing that the coronavirus was coming and would be a pandemic. Of course, history is rife with moments in which disasters would have been lessened or stopped if leaders had listened to their subordinates.

Ralph Kundtz, Jr. *Akron, Ohio*

COVID-19 ANTIBODIES

In "The Vaccine Quest," Charles Schmidt describes the new DNA and RNA techniques being pursued for a speedy vaccine for the novel coronavirus SARS-CoV-2. The article left me with a nagging question about possible side effects: With these methods, once your cells make virus antigens, do they not display them on their surface—akin to waving a red cape at a bull? Could a vaccine thus cause your antibodies to savage your own cells?

I cannot help but think of the 1966 sci-



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fi movie *Fantastic Voyage,* in which a group is shrunk and placed into a scientist's body. In the film, a miniaturized Raquel Welch injures some of the scientist's cells, causing multiple antibodies to attack her.

ROBERT A. LEE *Brewster, N.Y.*

SCHMIDT REPLIES: The answer to Lee's perceptive question is that the number of human cells expressing SARS-CoV-2's spike protein is very small, and their location is limited to sites close to where a given vaccine is administered. Those cells could potentially be killed by the immune reaction to the spike protein. But they are so few in number that there would be no adverse effects if they were eliminated.

PLANE ERROR

"Landing on the Right Foot," by Leslie Nemo [Advances], discusses problems caused by two different types of "feet" used in measurements: the international foot and the U.S. survey foot. It cites an engineer's account of a building that was constructed near a landing strip and had to lose its top floor at the last minute to avoid obscuring planes' glide path because of that discrepancy.

But the article says the ratio between the two types is only 0.999998. With that calculation, the difference would only come to a small fraction of an inch for a mile-high building.

ALBERT D. MASON *via e-mail*

THE EDITORS REPLY: A handful of letters requested more information about how such a small difference in the length of the foot could lead to a building needing to be a floor shorter. A structure's location is designated in coordinates, which are typically rendered in meters and then converted to feet—and these values can be in the millions. At such high numbers, the otherwise minuscule differences between U.S. survey and international feet add up. In this case, surveyors and designers from different companies used different versions of the foot, resulting in the building being built two feet farther south than intended. This result meant the top of the building intersected with planes' east-west flight paths to a nearby airport. Had everything gone to plan, the flight path would have sat just south of the building.

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Halfway into our ambitious trek through the rain forest I had to remind myself that "Nothing good comes easy." These days it seems that every business trip to Brazil includes a sweltering hike through overgrown jungles, around cascading waterfalls and down steep rock cliffs. But our gem broker insisted it was worth the trouble. To tell you the truth, for the dazzling emeralds he delivered, I'd gladly go back to stomping through jaguar country.

Now our good fortune is your great reward. Don't miss this rare opportunity to own an impressive 50 total carat strand of genuine South American emeralds for **under $100**.

Faced with this embarrassment of riches, our designer transformed this spectacular cache of large stones (each is over 8 carats average weight) into a stunning 50 total carat necklace of faceted enhanced emeralds set into .925 sterling silver. Each emerald is surrounded by delicate sterling silver rope work and filigree in the Bali-style. The 18" necklace dangles from a sterling silver chain that fastens with a secure double-sided shepherd's hook clasp.

What is the source of our emerald's timeless appeal? The enchanting color of the Stauer ***Carnaval Faceted Emerald Necklace*** comes from nature's chemistry. Our polished and faceted, well-formed natural emeralds are immediately recognized as something special.

★★★★★

"Love it! Can't say enough about this piece. It is beautiful."

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From Fear to Hope

Joe Biden should be the next U.S. president

By the Editors

Scientific American has never endorsed a presidential candidate in its 175-year history. This year we are compelled to do so. We do not do this lightly.

The evidence and the science show that Donald Trump has badly damaged the U.S. and its people—because he rejects evidence and science. The most devastating example is his willfully ignorant and inept response to the COVID-19 pandemic, which cost more than 170,000 Americans their lives by the middle of August. He has also attacked environmental protections, medical care, and the researchers and public science agencies that help this country prepare for its greatest challenges. That is why we urge you to vote for Joe Biden, who is offering fact-based plans to protect our health, our economy and the environment. These and other proposals he has put forth can set the country back on course for a safer, more prosperous and more equitable future.

The pandemic would strain any nation and system, but Trump's rejection of evidence and public health measures have been catastrophic in the U.S. He was warned many times in January and February about the onrushing disease, yet he did not develop a national strategy to provide protective equipment, coronavirus testing or clear health guidelines. Testing people for the virus, and tracing those they may have infected, is how countries in Europe and Asia have gained control over their outbreaks, saved lives, and successfully reopened businesses and schools. But in the U.S., Trump claimed, falsely, that "anybody that wants a test can get a test." That was untrue in March and remained untrue through the summer. Trump opposed $25 billion for increased testing and tracing that was in a pandemic relief bill as late as July. These lapses accelerated the spread of disease through the country—particularly in highly vulnerable communities that include people of color, where deaths climbed disproportionately to those in the rest of the population.

It wasn't just a testing problem: if almost everyone in the U.S. wore masks in public, it could save about 66,000 lives by the beginning of December, according to projections from the University of Washington School of Medicine. Such a strategy would hurt no one. It would close no business. It would cost next to nothing. But Trump and his vice president flouted local mask rules, making it a point not to wear masks themselves in public appearances. Trump has openly supported people who ignored governors in Michigan and California and elsewhere as they tried to impose social distancing and restrict public activities to control the virus. He encouraged governors in Florida, Arizona and Texas who resisted these public health measures, saying in April—again, falsely—that "the worst days of the pandemic are behind us" and ignoring infectious disease experts who warned at the time of a dangerous rebound if safety measures were loosened.

And of course, the rebound came, with cases across the nation rising by 46 percent and deaths increasing by 21 percent in June. The states that followed Trump's misguidance posted new daily highs and higher percentages of positive tests than those that did not. By early July several hospitals in Texas were full of COVID-19 patients. States had to close up again, at tremendous economic cost. About 31 percent of workers were laid off a second time, following the giant wave of unemployment—more than 30 million people and countless shuttered businesses—that had already decimated the country. At every stage, Trump has rejected the unmistakable lesson that controlling the disease, not downplaying it, is the path to economic reopening and recovery.

Trump repeatedly undercut clear public health messages, falsely saying the virus was "under control" and no worse than the flu. This encouraged people to engage in risky behavior, spreading the virus further, and has driven wedges between Americans who take the threat seriously and those who believe Trump's falsehoods. The White House even produced a memo attacking the expertise of the nation's chief infectious disease physician, Anthony Fauci, in a despicable attempt to sow further distrust.

Trump's reaction to America's worst public health crisis in a century has been to say "I don't take responsibility at all." Instead he blamed other countries and his White House predecessor, who left office three years before the pandemic began.

But Trump's refusal to look at the evidence and act accordingly extends beyond the virus. He has repeatedly tried to get rid of the Affordable Care Act while offering no alternative; comprehensive medical insurance is essential to reduce illness. Trump has proposed billion-dollar cuts to the National Institutes of Health, the National Science Foundation, and the Centers for Disease Control and Prevention, agencies that increase our scientific knowledge and strengthen us for future challenges. Congress has countermanded his reductions. Yet he keeps trying, slashing programs that would ready us for future pandemics and withdrawing from the World Health Organization. These and other actions increase the risk that new diseases will surprise and devastate us again.

Trump also keeps pushing to eliminate health rules from the Environmental Protection Agency, putting people at more risk for heart and lung disease caused by pollution. He has replaced scientists on agency advisory boards with industry representatives. In his ongoing denial of reality, Trump has hobbled U.S. preparations for climate change, falsely claiming that it does not exist and pulling out of international agreements to mitigate it. The changing climate is already causing a rise in heat-related deaths and an increase in severe storms, wildfires and extreme flooding.

Joe Biden, in contrast, comes prepared with plans to control COVID-19, improve health care, reduce carbon emissions and restore the role of legitimate science in policy making. He

solicits expertise and has turned that knowledge into solid policy proposals.

On COVID-19, he states correctly that "it is wrong to talk about 'choosing' between our public health and our economy.... If we don't beat the virus, we will never get back to full economic strength." Biden plans to ramp up a national testing board, a body that would have the authority to command both public and private resources to supply more tests and get them to all communities. He also wants to establish a Public Health Job Corps of 100,000 people, many of whom have been laid off during the pandemic crisis, to serve as contact tracers and in other health jobs. He will direct the Occupational Health and Safety Administration to enforce workplace safety standards to avoid the kind of deadly outbreaks that have occurred at meat-processing plants and nursing homes. While Trump threatened to withhold money from school districts that did not reopen, regardless of the danger from the virus, Biden wants to spend $34 billion to help schools conduct safe in-person instruction as well as remote learning.

Biden is getting advice on these public health issues from a group that includes David Kessler, epidemiologist, pediatrician and former U.S. Food and Drug Administration chief; Rebecca Katz, immunologist and global health security specialist at Georgetown University; and Ezekiel Emanuel, bioethicist at the University of Pennsylvania. It does not include physicians who believe in aliens and debunked virus therapies, one of whom Trump has called "very respected" and "spectacular."

Biden has a family and caregiving initiative, recognizing this as key to a sustained public health and economic recovery. His plans include increased salaries for child care workers and construction of new facilities for children because the inability to afford quality care keeps workers out of the economy and places enormous strains on families.

On the environment and climate change, Biden wants to spend $2 trillion on an emissions-free power sector by 2035, build energy-efficient structures and vehicles, push solar and wind power, establish research agencies to develop safe nuclear power and carbon capture technologies, and more. The investment will produce two million jobs for U.S. workers, his campaign claims, and the climate plan will be partly paid by eliminating Trump's corporate tax cuts. Historically disadvantaged communities in the U.S. will receive 40 percent of these energy and infrastructure benefits.

It is not certain how many of these and his other ambitions Biden will be able to accomplish; much depends on laws to be written and passed by Congress. But he is acutely aware that we must heed the abundant research showing ways to recover from our present crises and successfully cope with future challenges.

Although Trump and his allies have tried to create obstacles that prevent people from casting ballots safely in November, either by mail or in person, it is crucial that we surmount them and vote. It's time to move Trump out and elect Biden, who has a record of following the data and being guided by science. SA

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Illustration by Ross MacDonald

Siri Is a Biased Listener

Most popular speech-recognition software has trouble with minority voices

By Claudia Lopez-Lloreda

"Clow-dia," I say once. Twice. A third time. Defeated, I say the Americanized version of my name: "Claw-dee-ah." Finally, Siri recognizes it. Having to adapt our way of speaking to interact with speech-recognition technologies is a familiar experience for people whose first language is not English or who do not have conventionally American-sounding names. I have now stopped using Siri, Apple's voice-based virtual assistant, because of it.

The growth of this tech in the past decade—not just Siri but Alexa and Cortana and others—has unveiled a problem in it: racial bias. One recent study, published in the *Proceedings of the National Academy of Sciences USA,* showed that speech-recognition programs are biased against Black speakers. On average, the authors found, all five programs from leading technology companies, including Apple and Microsoft, showed significant race disparities; they were roughly twice as likely to incorrectly transcribe audio from Black speakers compared with white speakers.

This effectively censors voices that are not part of the "standard" languages or accents used to create these technologies. "I don't get to negotiate with these devices unless I adapt my language patterns," says Halcyon Lawrence, an assistant professor of technical communication and information design at Towson University, who was not part of the study. "That is problematic." For Lawrence, who has a Trinidad and Tobagonian accent, or for me as a Puerto Rican, part of our identity comes from speaking a particular language, having an accent or using a set of speech forms such as African American Vernacular English (AAVE). Having to change such an integral part of an identity to be able to be recognized is inherently cruel.

Claudia Lopez-Lloreda is a freelance science writer and neuroscience graduate student at the University of Pennsylvania.

The inability to be understood impacts other marginalized communities, such as people with visual or movement disabilities who rely on voice recognition and speech-to-text tools, says Allison Koenecke, a computational graduate student and first author of the *PNAS* study. For someone with a disability who is dependent on these technologies, being misunderstood could have serious consequences. There are probably many culprits for these disparities, but Koenecke points to the most likely: the data used for training, which are predominantly from white, native speakers of American English. By using databases that are narrow both in the words that are used and how they are said, training systems exclude accents and other ways of speaking that have unique linguistic features. Humans, presumably including those who create these technologies, have accent and language biases. For example, research shows that the presence of an accent affects whether jurors find people guilty and whether patients find their doctors competent.

Recognizing these biases would be an important way to avoid implementing them in technologies. But developing more inclusive technology takes time, effort and money, and often the decision to invest these are market-driven. (In response to several queries, only a Google spokesperson responded in time for publication, saying, in part, "We've been working on the challenge of accurately recognizing variations of speech for several years and will continue to do so.")

Safiya Noble, an associate professor of information studies at the University of California, Los Angeles, admits that it's a tricky challenge. "Language is contextual," says Noble, who was not involved in the study. "But that doesn't mean that companies shouldn't strive to decrease bias and disparities." To do this, they need the input of humanists and social scientists who understand how language actually works.

From the tech side, feeding more diverse training data into the programs could close this gap, Koenecke says. Noble adds that tech companies should also test their products more widely and have more diverse workforces so people from different backgrounds and perspectives can directly influence the design of speech technologies. Koenecke suggests that automated speech-recognition companies use the *PNAS* study as a preliminary benchmark and keep using it to assess their systems over time.

In the meantime, many of us will continue to struggle between identity and being understood when interacting with Alexa, Cortana or Siri. But Lawrence chooses identity every time: "I'm not switching," she says. "I'm not doing it." SA

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Illustration by Martin Gee

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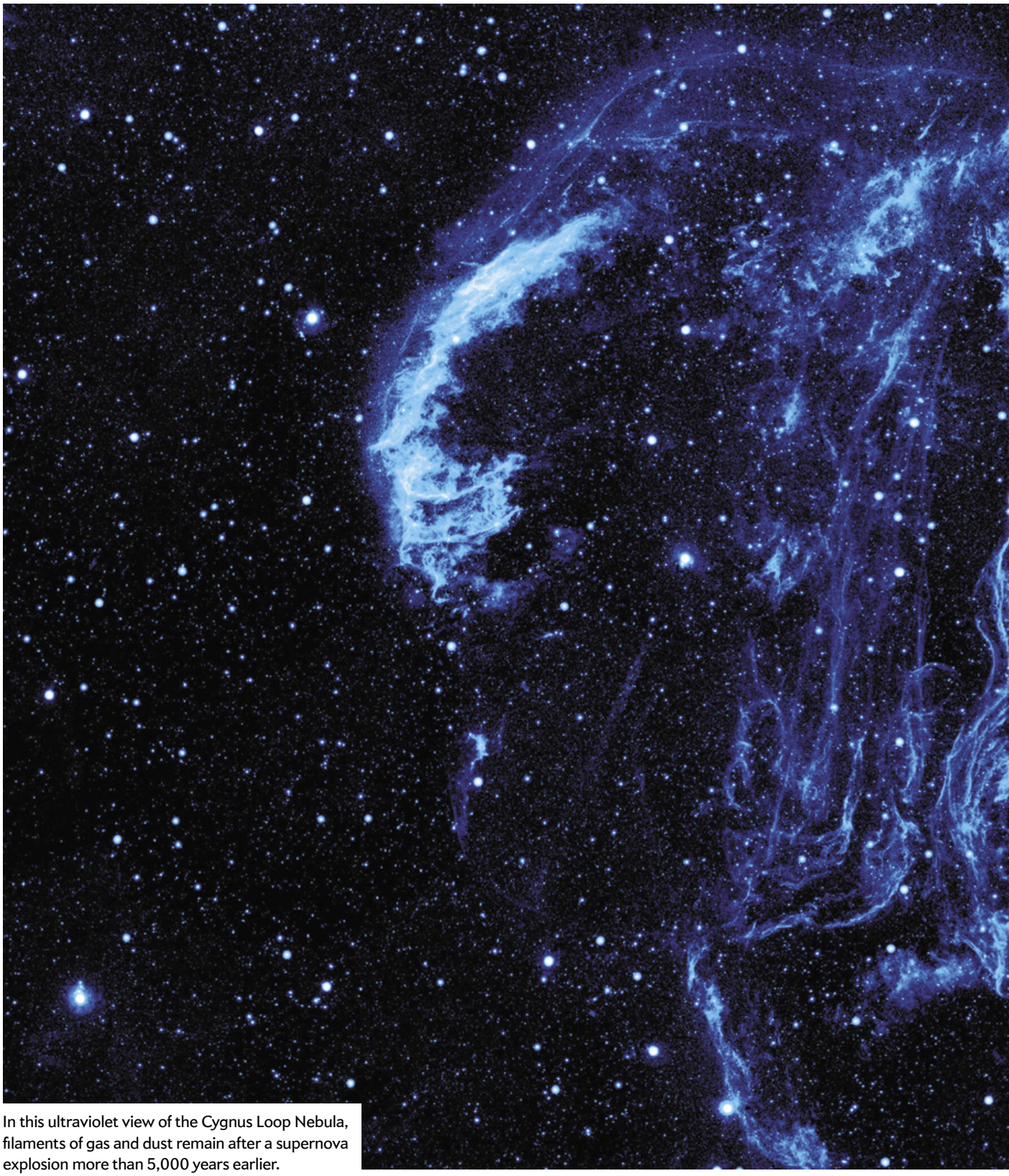
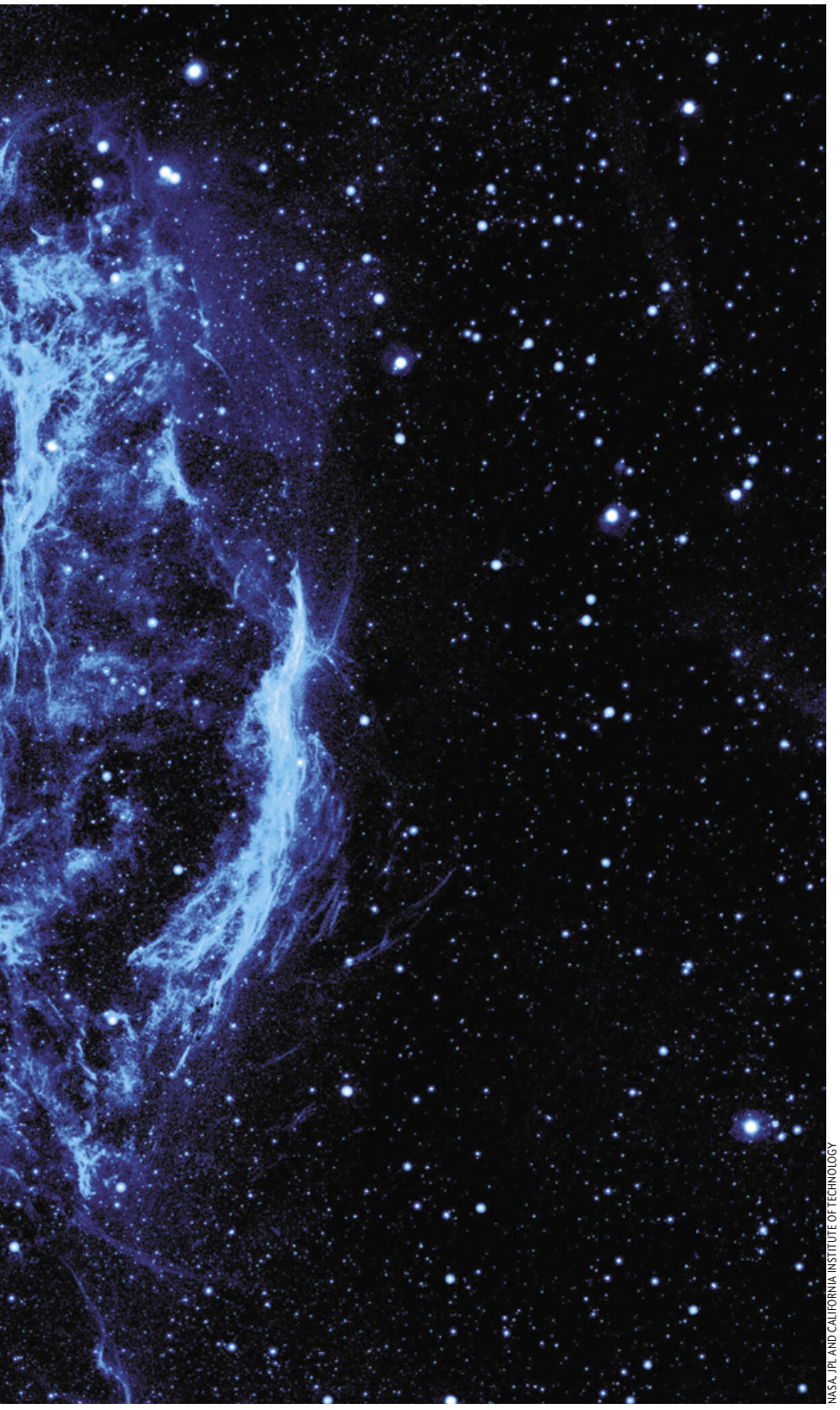


In this ultraviolet view of the Cygnus Loop Nebula, filaments of gas and dust remain after a supernova explosion more than 5,000 years earlier.



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INSIDE

ASTRONOMY

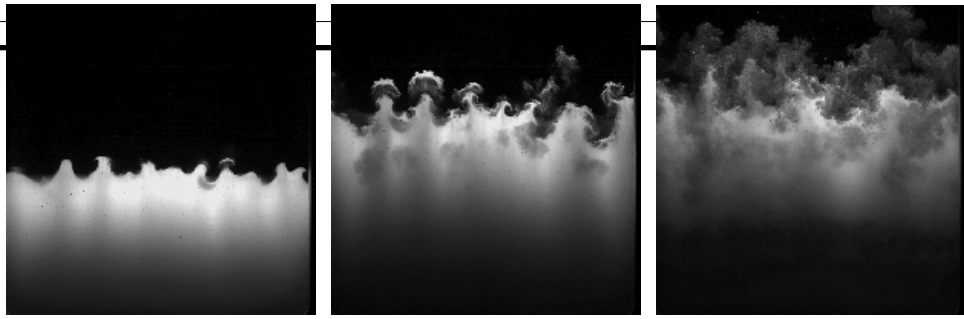
Supernova Slice

A door-sized experiment models massive stellar blasts

When a star explodes at the end of its lifetime, it smears the elements forged in its heart across vast stretches of space. The results, dramatic designs of gas and dust known as supernova remnants, contain structures that have long puzzled researchers. But supernovae occur in the Milky Way only once or twice a century, often without warning, making it difficult to study their initial moments. Researchers have modeled these events through simulations, but computing limitations require them to make assumptions about the finer details.

Researchers at the Georgia Institute of Technology hope to change that with a new experiment to look at how gases in a supernova might mix, confirming and helping to refine previous simulations. Their wedge-shaped apparatus—which they sometimes call "supernova pizza"—is about four feet wide at the top and roughly the thickness of a double door, enclosing two separated, inert gases. Its shape lets it re-create physical dynamics as they would occur within a slice of a cylinder or sphere in space. The team sets off commercial detonators at the point of the wedge, which mimics the center of a supernova, and the blast waves mix the two gases. A high-speed camera snaps images of the process every 0.1 millisecond, revealing the equivalent of roughly the first hour after a supernova explosion. The researchers described the experiment in June in the *Astrophysical Journal*.

The team observed how small pertur-



Gases expand outward in the milliseconds after a simulated supernova blast.

DEVESH RANJAN, STAM LAB AND GEORGIA INSTITUTE OF TECHNOLOGY

bations along the line where the two gases meet are amplified by the push-and-pull nature of the blast waves, forming mushroom-shaped disturbances that quickly grow larger. These curls of gas create turbulence, eventually forming low-density bubbles and long, high-density spikes. If a spike travels fast enough, it can break off and accelerate like a bullet to pierce several layers of gas.

Researchers have puzzled over outflows of heavy elements that come from deep within supernova explosions and behave similarly to those spikes. "It isn't clear if we're seeing something due to the intrinsic, asymmetric nature of the explosion or if it's actually due to the turbulence happening," says Anthony Piro, a supernova theorist at Carnegie Observatories in Pasadena, Calif., who was not involved in the research. The new study illustrates how strong an effect turbulence might have, Piro says, although further checks are necessary to understand the model's limitations.

Most supernova models incorporate basic assumptions about what happens at the smaller scales to avoid weeks of extra computational time, Piro says. The new research helps to evaluate such assumptions. Scientists now "can see different, smaller-scale structures evolve," says Carolyn Kuranz, a physicist at University of Michigan, who was also not involved in the work. The structures created by the experiment resemble what she has seen while investigating how plasmas mix: "Theory predicted that they should be similar, and [the researchers] found them to be."

According to Piro, the experiment provides "an amazing confirmation of a lot of the physics" involved in supernovae. He says it will help calibrate the models he works with while giving scientists a better understanding of supernova and remnant observations.

Building a supernova-in-a-box came with its own challenges. Earth's gravity is much weaker than a dying star's, and tiny commercial blasters produce far less energy. But "even though the explosive pop is smaller, the other things we are dealing with are also smaller, so the ratios match," says Benjamin Musci, a Georgia Tech graduate student and the study's lead author.

Preventing gases from bouncing off the experiment's sidewalls, which obviously do not exist in space, "was a long and arduous battle," Musci says. It took him nearly a year to figure out a surprisingly simple solution: lining the walls with packing foam from a new computer's box. The material absorbs the gases, stopping them from reflecting. "This foam gets blown to bits every so often by the explosive, so it slows down our run time," he adds. "But without it the physics would be completely different."

Another concern is dimensionality. Piro notes that gases expanding in two dimensions tend to act differently than they would in three, creating larger eddies and taking longer to break apart. This is something the researchers may work on in the future.

Previous supernova experiments have been performed at larger scales, says the study's principal investigator, Georgia Tech astrophysicist Devesh Ranjan. Sites such as

GEOPHYSICS

Metal Detecting

New research reveals geology behind ore deposit hotspots

Copper, lead and zinc are essential for modern technology's electronics and batteries. Demand has skyrocketed, and mining companies are depleting known deposits faster than prospectors can find more. Now an international team of scientists has discovered a relationship between deposits of these metals and the thickness of the lithosphere (the earth's crust and upper mantle), providing a reliable way to locate these crucial resources.

The project began by chance, says Mark Hoggard, first author of the new study and a geologist at Harvard University and Columbia University's Lamont-Doherty Earth Observatory. His coauthor Karol Czarnota, a researcher at Geoscience Australia, was visiting Harvard and mentioned noticing—and wondering why—metal deposits in northern Australia seemed to align with areas where the lithosphere's thickness varies. The research team found that this connection applies globally, hinting at more places to search for the hidden ores. The study, published in July in *Nature Geoscience,* comprehensively maps the correlation between known metal deposits and lithosphere thickness and proposes a potential mechanism for that correlation.

The lithosphere can reach up to 300 kilometers below the surface, making its thickness "actually really hard for geophysicists to measure," says Maureen Long, a Yale University geophysicist, who was not involved in the study. To calculate the lithosphere's thickness, seismometer readings are typically used to record how fast earthquake vibrations travel through the planet.

Salt Lake City copper mine

PAVISHA *Getty Images*

Long notes, however, that the world's limited number of earthquakes and seismometers means "our ability to resolve the earth's structure is not perfect."

To create a high-resolution world map of lithosphere thickness, Hoggard and his colleagues combined and calibrated existing regional and global models, adding temperature and pressure data from lithospheric rocks carried to the surface in volcanic eruptions. They found that metal deposits tend to appear where the litho-

Lawrence Livermore National Laboratory train dozens of lasers on material the size of a pencil eraser, evaporating it to trigger an impressive blast. The trade-off comes in the amount of detail, Ranjan says: the bigger experiments generate few images, with only fleeting glimpses of the structures produced. But the supernova pizza manages 200 shots in a few seconds as the gases mix. "What our experiment provides is a dynamic view of the whole process," Ranjan says. By combining insights from both kinds of experiments, "we should be able to say something jointly about what's going on in a real-life supernova."

Piro is not surprised that the team's experiment is the first of its kind. "You have to be an expert in all different types of experimental techniques to put this all together," he says. "The creativity of this group in trying to address these problems in a laboratory setting is really inspiring to see."

Combining this study with others that probe different aspects of supernovae, along with evolving models, will help researchers eventually tease out details they cannot observe when a real star explodes. "If a universal model that describes what is occurring on different scales is the overall goal," Kuranz says, "using these experiments—especially at different scales and under different conditions—can help push toward that." *—Nola Taylor Redd*

sphere is around 170 kilometers thick. Theorizing about why, they note that metal's building blocks are commonly found near the earth's surface, where they accumulate in basins. If these basins sit above a part of the lithosphere with the right thickness, the amount of heat that rises from the deeper mantle could set the perfect temperature for the constituents to concentrate into metal deposits.

Finding these metals has traditionally involved "boots on the ground," Hoggard says, with people widely sampling mineral content in soil or measuring the earth's magnetic field to find anomalies. The team's discovery provides an opportunity to find promising sites remotely; in fact, mining companies have already begun using this information to inform their searches, Hoggard says.

"What these authors have done that's really novel is ... connecting these deeper structures in the upper mantle to something that we can see [near] the surface, which is the distribution of these metal deposits," Long says. "It's a really exciting piece of work." *—Karen Kwon*

GEOLOGY

Magma Far Afield

One third of volcanoes may have molten reservoirs kilometers away

Magma—the molten rock that nourishes volcanoes—can lurk in underground pockets surprisingly far from where it emerges, new research shows. This means the instruments placed on a volcano's flanks might fail to pick up signs of moving magma that can signal an impending eruption.

University of Oregon volcanologist Allan Lerner and his colleagues focused on 56 volcanoes in subduction zones (geologically active areas where one tectonic plate is diving under another) on five continents for a new paper, published in July in *Geophysical Research Letters.* Compiling volcano data from other studies, the team estimated the center of each volcano's magma reservoir and compared it with the estimated center of the volcano's aboveground portion. The reservoirs had been found through processes such as measuring the earth's surface moving up or down and tracing how the planet's crust conducts electricity.

The researchers calculated that roughly one third of volcanoes were more than four kilometers away from their magma reservoirs. Five volcanoes, including two in Japan, two in Indonesia and one in Mexico, had offsets of more than 10 kilometers. "It was a surprise," Lerner says, because a long-standing tenet of volcanology is that magma reservoirs are located directly underneath volcanoes.

Offset magma reservoirs have been reported before, but the researchers say their investigation is the first to focus on an ensemble of volcanoes. Thanks to their large sample size, Lerner and his collaborators were also able to demonstrate correlations. They showed that smaller volcanoes tended to be farther from their magma reservoirs than larger volcanoes. This makes sense, the team suggests, because geologic structures such as fault lines essentially create an underground obstacle course for magma. The large quantities of magma that feed big volcanoes carry enough heat to blow straight through such natural boundaries, but the smaller reservoirs associated with smaller volcanoes must forge convoluted paths to the surface. "In small volcanoes, the magma that ascends is kind of at the mercy of preexisting crustal structures," Lerner says.

These results have implications for how volcanoes are monitored. Researchers usually aim to place ground-based instruments on or near a volcano, says Diana Roman, a volcanologist at the Carnegie Institution for Science, who was not involved in the research. But this new study indicates that such a strategy might not be best. "This tells us we should be looking farther afield, especially for volcanoes with relatively small edifices," Roman says.

Studying more volcanoes, including those not in subduction zones, would be valuable to see if these same trends persist, Lerner says: "A very clear next direction would be to expand this study to look at volcanoes in other tectonic settings."

—*Katherine Kornei*

South Sister volcano in Oregon has an offset magma reservoir.

ALAMY

San Francisco's Bay Bridge obscured by smoke from the Camp Fire

ENVIRONMENT

Deadly Air

Strongest evidence yet shows that air pollution kills

As California's Camp Fire raged in 2018, soot and other pollution filled the skies. Particulate matter concentrations widely surged above 12 micrograms per cubic meter ($\mu g/m^3$), pushing them into the Environmental Protection Agency's "unhealthy" range. And in some places, they jumped to hundreds of $\mu g/m^3$.

This miasma included particles 2.5 microns in diameter or smaller, known as PM2.5, which also spew from tailpipes and smokestacks as cars burn gas and power plants combust coal. These particles' minuscule size lets them travel deep into the lungs, causing short-term breathing problems. Thousands of previous studies show such particles can also exacerbate asthma in the long term and contribute to cardiovascular concerns, low birth weight and other issues. This association has widespread medical consensus, but some members of an EPA committee overhauled by a Trump administration appointee, along with oil and gas industry consultants, claim that the studies did not show direct causality. Harvard University biostatistician Francesca Dominici and her colleagues address such assertions in a study published in July in *Science Advances*. They say their investigation shows the most comprehensive link yet between air pollution and premature deaths.

Typical air-pollution studies use only regression analysis, a statistical method designed to sort out the likelihood that a particular factor, such as air pollution, influences an outcome—in this case, mortality. But it is not always clear whether such models adequately account for other possible factors. In the new paper, Dominici's team instead used five separate statistical approaches (including regression analysis) with a data set of 570 million observations collected over 16 years from 68.5 million Medicare enrollees. Their technique helped to isolate particulate-pollution effects from other influences. It effectively mimicked a randomized experiment—the gold-standard test for teasing out cause and effect—which would be unethical to conduct for this kind of investigation. "This area of statistics has never been applied to air pollution and mortality," Dominici says.

The results show that tightening allowable PM2.5 levels from 12 to 10 $\mu g/m^3$ could lower mortality risk in the elderly by up to 7 percent—saving more than 143,000 lives in a decade.

The study impressed others in the field, including C. Arden Pope III, an air-pollution expert at Brigham Young University, and John Bachmann, a former associate director at the EPA's air-quality office. "In terms of size, in terms of statistical power and in terms of analytic sophistication, this is as good as it gets," Pope says.

The findings come as the Trump administration has been rolling back air-pollution regulations. In April the EPA proposed keeping PM2.5 rules unchanged, after what the agency says was a careful review and consultation with its science advisers. Before the review was completed, however, EPA administrator Andrew Wheeler dismissed an auxiliary panel of advisers that typically provides scientific expertise on such matters. The whole collection of air-pollution studies is powerful, Bachmann says, and "this [new] one as a topper is a pretty potent response" to the EPA's proposal. —*Susan Cosier*

MICHAEL SHORT *Getty Images*

BIOLOGY

Seaweed Sleuths

Decades-old specimens solve a long-standing mystery

The 1930s and early 1940s were a good time to fish for sardines off California. Catches soared in a boom that was centered on Monterey Bay and supported the state's flourishing economy. But the tides began to turn in 1946, and sardine catches eventually fell from an average of 234,000 tons to just 24,000 tons. The industry went belly-up.

Scientists have speculated for decades about what factors drove this infamous boom and bust, but they lacked data to test their theories. Now researchers have finally found one apparent culprit: cycles of ocean upwelling, a defining feature of the West Coast marine environment in which deep, nutrient-rich water rises to the nutrient-poor surface and replenishes the food supply there. The key that unlocked this mystery turned out to be old seaweed specimens gathered from herbaria around the U.S.

Historic sardine canneries

CRAIG LOVELL *Alamy*

"Plants are just sitting there, recording data about the state of the ocean," says Kyle Van Houtan, chief scientist at the Monterey Bay Aquarium and senior author of the new study, published in June in the *Proceedings of the Royal Society B*. "If we can access physical specimens from museums and natural history repositories, we can get information about historical ecosystems embedded in those tissues."

Van Houtan and others had suspected upwelling played a role in sardine population trends, but scientists only started measuring the process in Monterey Bay in 1946. Historic seaweed specimens, Van Houtan realized, might fill in the blanks for earlier years—similar to the way ice cores can help reconstruct carbon dioxide levels from times before researchers started collecting real-time measurements.

For the new study, the scientists relied on the fact that deeper water near Monterey typically hosts more of a particular nitrogen isotope, a rarer version of nitrogen with an extra neutron that makes each atom heavier. Looking at modern upwelling data and recently collected seaweed, they found that higher levels of this nitrogen in the plants' cells corresponded with periods of more upwelling. Next they measured the isotope levels in 70 historic specimens of the red seaweed *Gelidium,* gathered from Monterey as far back as 1878. The results suggested a gradual increase in upwelling and then a dramatic decrease, which lined up with the sardine population's growth and decline.

"This paper is an excellent example of the creative detective work of historical ecology," says Loren McClenachan, a marine ecologist at Colby College, who was not involved in the research. "There are thousands and thousands of similar specimens in collections around the world, and applying similar methods could teach us a great deal about long-term ocean change." —*Rachel Nuwer*

URBAN PLANNING

Freeze-Proof Concrete

A bio-inspired additive lets the material resist temperature shifts

Daily temperature swings can make water freeze and expand, then thaw and contract. Because concrete is porous and absorbs liquid, these changes often make its surface flake and peel. But researchers say a new process can help prevent such deterioration.

"The primary way in which we have resisted this freeze-thaw damage in the past was by using a technology that was developed in the 1930s, which was to put in tiny little air bubbles all throughout the concrete," says Wil Srubar, a materials scientist and architectural engineer at the University of Colorado Boulder. These flexible bubbles absorb some pressure but also reduce concrete's strength, make it soak up more water and require a finicky distribution process.

Srubar's laboratory looked to the natural world, specifically "antifreeze" proteins that let some fish and bacteria endure frigid temperatures. In cells, these molecules cling to ice crystals' surfaces and prevent them from growing too large—but they do not function in highly alkaline cement paste, a key concrete ingredient. So the researchers tried a tougher substance with similar properties: a polymer called PEG-PVA, which is currently used in time-released pharmaceutical pills.

To test it, the team mixed several batches of concrete, including one control, one with air bubbles and a few with different concentrations of the PEG-PVA additive. After 300 consecutive freeze-thaw cycles, the quality of the control sample plummeted while others maintained their integrity. The research was published in June in *Cell Reports Physical Science.*

Vikki Edmondson, a civil engineer at Northumbria University in England, who was not involved in the study, says the new work is important but will need investigation beyond the lab. "For instance, if we look at the design life of a bridge," she says, "how is this going to help protect critical infrastructure?" Edmondson wonders how this additive would function in the real world, where concrete must withstand vibrations, for instance, and endure exposure to contaminants.

"Anything that makes cement more durable … is obviously progress," says Roland Pellenq, a director of research at the French National Center for Scientific Research, who was also not involved in the new study. Because freeze-thaw damage presents such a threat to infrastructure, other researchers are also exploring solutions—Pellenq says his own team has experimented with a water-repelling black carbon additive for this purpose.

Srubar has filed a provisional patent and hopes to bring the PEG-PVA process to market within five years. Meanwhile he continues the hunt for molecules that mimic antifreeze proteins' behavior. "Everybody in my lab is convinced that nature has solved all of our problems for us," he says. "We just have to know where to look." —*Sophie Bushwick*

IN THE NEWS

Quick Hits

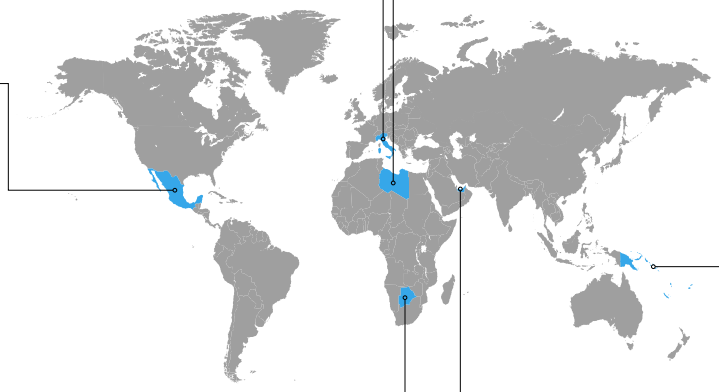
By Scott Hershberger

ITALY

A massive bloom of pink algae, triggered by low snowfall and high spring and summer temperatures, could accelerate the melting of the Presena glacier by causing the ice to absorb more sunlight.

LIBYA

A seven-million-year-old crocodile skull suggests the prehistoric animals may have traveled from Africa to the Americas. Computerized tomography of the fossil, found in Libya, revealed a slight bump in the middle of the snout—a feature of modern American crocodiles but not their African counterparts.



MEXICO

In now flooded caves, researchers discovered the oldest known ochre mines in the Americas. Around 12,000 years ago inhabitants of the Yucatán Peninsula extracted the red pigment, possibly for use as an antiseptic and sunscreen or for symbolic purposes such as body painting.

POLYNESIA

Through a genetic analysis of modern-day Polynesians and Indigenous people from South America's Pacific coast, scientists concluded the two groups came into contact between A.D. 1150 and 1230. Where the transoceanic encounter occurred remains unknown, but the team suspects eastern Polynesia.

BOTSWANA

At least 350 elephants have dropped dead in the Okavango Panhandle since March, and live elephants have acted disoriented or seemed partially paralyzed. With poaching and anthrax ruled out as potential causes, investigators suspect an unknown disease.

UNITED ARAB EMIRATES

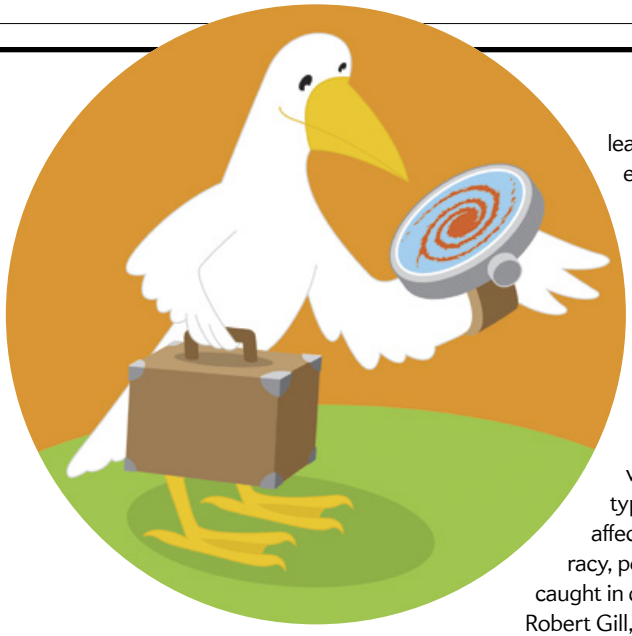
The successful launch of a Mars orbiter called Hope marked the first interplanetary mission conducted by an Arab nation. Carrying instruments to study the Red Planet's daily and seasonal weather, the spacecraft is set to enter Martian orbit in February 2021.

For more details, visit www.ScientificAmerican.com/oct2020/advances

ANIMAL BEHAVIOR

Migration Meteorologist

Seabirds anticipate typhoons to help their journey



Migrating terns may alter their flight plans based on a keen sense of approaching typhoons, escaping the brunt of the storms but still benefiting from feeding opportunities in their wakes.

Researchers at the Yamashina Institute for Ornithology examined data recorded by tracking devices on six black-naped terns from Okinawa, Japan, to learn more about the birds' migrations over multiple years. The terns flew across part of the Philippine Sea's "typhoon highway" to get to the islands of Borneo and Sulawesi and varied their departure times—often apparently waiting to leave until a large typhoon was about to cross their projected path.

"They seem to be able to predict it," says Jean-Baptiste Thiebot, a postdoctoral fellow at the National Institute of Polar Research in Japan and lead author of the new study, which was published in June in *Marine Biology*. The study offers few clues about how terns might do this, but other research suggests some migrating birds detect infrasonic weather signals or observe changing clouds.

The terns Thiebot studied typically avoided the typhoons themselves. But these storms can churn food to the ocean surface, so their immediate aftermath may help the hungry travelers. "They might actually use the typhoon to know when to leave" for their migrations each year, Thiebot says. In the unusually quiet 2017 season, without a strong typhoon cue, the birds started their journeys later and flew without pit stops. Thiebot would like to see this pattern confirmed in a larger study. He also worries that increasing typhoon frequency could affect birds' prediction accuracy, potentially getting them caught in dangerous weather.

Robert Gill, an emeritus research wildlife biologist with the U.S. Geological Survey, who was not involved in the work, says that although the study's sample size is small, it adds to scientists' overall understanding of migration. He has studied shorebirds that time their migrations based partly on incoming storms, but little research has delved into this behavior. "They are able to predict better than the best weather forecasters we have," Gill says, "but they've also had tens of thousands, if not millions, of years to hone that skill." —*Joshua Rapp Learn*

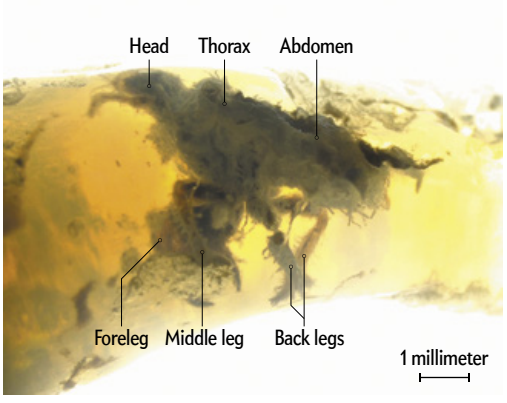
PALEONTOLOGY

Entombed in Opal

A rare fossil hints at records of early life

A bug trapped in a precious gem could offer new clues in the hunt for ancient life on Earth and Mars. The opal, pulled from rock in Indonesia and nicknamed "Beverly," contains the shell of a tiny cicada nymph. In June in *Scientific Reports*, researchers explained how it likely formed.

Other opal fossils have been found among silica-containing rocks that form near geysers, says Boris Chauviré, a geologist at Grenoble Alpes University in France. Hot water dissolves these rocks; when the resulting silica-rich fluid cools, it can harden to form the shimmery gem—sometimes filling in spaces left by decayed organisms or trapping creatures' bodies. But this fossil comes from soil made by volcanic rocks eroding, and it is the first animal found entombed in opal that formed this way. Knowing this can happen, Chauviré says, suggests new places to look for ancient life.



FROM "ARTHROPOD ENTOMBMENT IN WEATHERING-FORMED OPAL: NEW HORIZONS FOR RECORDING LIFE IN ROCKS," BY BORIS CHAUVIRÉ ET AL., IN *SCIENTIFIC REPORTS*, VOL. 10, ARTICLE NO. 10575; 2020. HTTPS://DOI.ORG/10.1038/S41598-020-67412-9

This kind of opal formation is in fact more common than the hydrothermal process, but it is slower and thus considered less likely to preserve traces of life. But the team found a layer of zeolite, a silica-rich mineral, coating the exoskeleton; the researchers' analysis suggests that the substance crystallized on the shell while it was buried in soil and exposed to silica-carrying water, preserving its structure before the surrounding liquid eventually formed opal.

"This is the first time I've seen this type of preservation," says Frances Westall, a geologist and astrobiologist at CNRS in Orléans, France, who was not involved in the study. She says the viability of this process—somewhat analogous to more common cases of insects preserved in amber, a fossilized tree resin—opens up more possibilities for finding evidence of ancient life. "The early Earth was a volcanic environment like Indonesia," she says. "And so was early Mars."

"Now we know that all kinds of silica can contain this kind of fossil or biomolecules," Chauviré says. Opal fossils that formed in volcanic settings such as early Earth or early Mars could reveal ancient underground critters that are not typically preserved in sedimentary rock or amber, he adds: "The future Jurassic Park can be with opal, maybe." —*Carolyn Wilke*

Illustration by Thomas Fuchs

Red Sea corals

REINHARD DIRSCHERL *Getty Images*

ECOLOGY

Coral Stress Test

Short-term heat tolerance can help identify resilient reefs

As rising ocean temperatures threaten coral reefs worldwide, identifying the most heat-resilient coral colonies is crucial for conservation efforts. Typical methods require flying samples to distant laboratories and subjecting them to high temperatures for weeks. Now a new heat-stress test brings the lab to the reef, yielding results within a single day.

The Coral Bleaching Automated Stress System (CBASS), made from materials commonly available at hardware stores, consists of four 10-liter tanks that can be set up on the same boats researchers use to reach the reefs. "You just jump into the water, get the corals, and put them into the tanks and get everything started," says Carol Buitrago López, a graduate student at King Abdullah University of Science and Technology (KAUST) in Saudi Arabia. She and her colleagues described CBASS in August in *Global Change Biology*.

The team placed finger-sized coral samples from two Red Sea sites into CBASS tanks at a baseline temperature of 30 degrees Celsius (86 degrees Fahrenheit). Over three hours the system increased each tank's temperature to a different value—39 degrees C was the maximum—then held there it for another three hours, dropping it back to 30 over the next hour. Finally, the scientists gave the corals 11 more hours to recover. They used a flashlightlike device to measure how efficiently the microalgae in the corals used light when photosynthesizing (a well-established indicator of a plant's stress level). This short-term measurement aligned with the results from a traditional long-term heat-stress experiment, showing the method's potential to rapidly identify resilient corals.

"I would love to adopt [CBASS] in my research," says Mikhail Matz, who researches coral genetics at the University of Texas at Austin and was not involved with the study. "The whole simplicity of this approach is very appealing." Although coral reefs are too vast to test in their entirety, researchers can harness CBASS's speed to measure targeted coral samples at a scale not previously possible. In a follow-up experiment, "we measured 500 corals in two weeks," says Christian Voolstra, a researcher at KAUST and the University of Konstanz in Germany and lead author of the new paper. "Traditionally this would be your lifetime as a professor."

Whether the corals that perform best in CBASS experiments will indeed withstand climate change remains an open question, Matz cautions. Still, he says, CBASS's standardized procedure will let researchers directly compare the heat tolerances of coral colonies around the world, a key step in restoration efforts. Conservation scientists commonly grow coral fragments in a nursery and then transfer them to degraded reef systems. So far such "outplanting" projects have met with limited success. But outplanting the most heat-tolerant corals, Voolstra says, could help buy time until climate change can be brought under control. —*Scott Hershberger*

Astrophysicist **Kip Thorne** began collaborating with artist **Lia Halloran** five years before winning the Nobel Prize for his part in discovering gravitational waves from colliding black holes, a finding memorialized in their upcoming book of paintings and verse, excerpted here.

The Warped Side of Our Universe

A billion years ago
—while here on Earth
multicelled life was arising and spreading—
in a galaxy far far away
two spinning black holes danced 'round one another,
rippling the fabric of space and time.

The ripples, called *gravity waves*
sucked energy from the holes' orbit, so
The holes spiraled inward,
eclipsing each other,
toward a climactic collision:

The holes,
at half of light speed,
collided catastrophically
and merged
in a brief, cataclysmic storm
of writhing and twisting spacetime
that brought the waves to crescendo.

The climaxing gravity waves
surged into interstellar space.
Spreading across our universe,
they stretched and they squeezed
all that they met
(stars and planets and nebulae...)
in patterns that encoded
a portrait of their birth:
colliding holes and spacetime storm.

The gravity waves were hugely strong,
with fifty times more total power
—more luminosity—
than all of the light from all of the stars in all of our universe, combined.

Fifty universe luminosities
from two black holes colliding.
But not any light. Not any x-rays. Not any gamma rays or radio.
No electromagnetic waves at all,
None of any type.

Fifty universe luminosities
carried wholly and solely by gravity waves,
by tendices and vortices, entwined,
by structures made from warped spacetime.

Fifty thousand years ago,
when humans shared Earth with Neandertals,
the waves plunged into our galaxy:
The Milky Way. Our home.

On September fourteen of twenty fifteen
they dove into Earth in Antarctica.
Whispering up through Earth's bowels unscathed,
and emerging near New Orleans,
the waves encountered *LIGO*
—a complex and huge, L-shaped device
designed and built to perceive them.

In LIGO the gravity waves stretched and squeezed
two long beams of light,
which extracted the portraits the waves encoded:
colliding holes and spacetime storm.

A momentous Eureka Event, it was
humans' first moment of contact
with the *Warped Side of Our Universe.*

Illustration by Lia Halloran

New Player in Cancer's Spread

A commonplace mouth bacterium now is tied to metastasis of some tumors

By Claudia Wallis

When people hear that they might have cancer, perhaps the only thing more frightening than the C word is the M word. Metastatic disease—in which the malignancy has traveled beyond its primary site to other spots in the body—is responsible for nine out of every 10 cancer deaths.

Recently an unexpected player in this process has emerged: a common bacterium. *Fusobacterium nucleatum,* which normally lives harmlessly in the gums, appears to have a role in the spread of some cancers of the colon, esophagus, pancreas and—possibly—breast. Laboratory studies and evidence in patients indicate that the microbe can travel through the blood and infect tumor cells by attaching to a sugar molecule on their surface. There it provokes a range of signals and immune responses known to cause tumor cells to migrate. If further confirmed, the work with *F. nucleatum* could add to a growing understanding of how the microbiome influences cancer progression and may even point the way to fresh approaches to treatment.

In a healthy human mouth, *F. nucleatum* is a law-abiding member of the microbial community. With poor dental hygiene, uncontrolled diabetes and other conditions, however, it can go rogue and cause periodontitis, tonsillitis, appendicitis and even preterm labor. A connection to colorectal cancer was first hinted at about nine years ago, when two research groups discovered that the bacterium's DNA was overrepresented in colon tumor tissue compared with normal tissue. Dozens of studies have since found that the infection in tumor cells is a sign of trouble: it is linked to a poorer prognosis in patients with pancreatic, esophageal or colorectal cancer; resistance to chemotherapy in the latter two groups; and metastasis in colorectal cancer, which is the world's third most common and second most deadly malignancy.

Still, the question remained: Is this bug merely a warning sign, or is it an active participant in cancer progression? This year at least three studies of colon cancer, by separate teams, pointed to an active role. "We reached the same conclusion through different pathways," says biochemist Daniel Slade of Virginia Tech. Slade and his colleagues found that when cultured human colon tumor cells were invaded by the bacterium, they produced two inflammatory proteins called cytokines—specifically, interleukin-8 and CXCL1—that have been shown to promote the migration of malignant cells, a step in metastasis. A second paper reported that the bacterium induces changes in gene regulation that boost metastasis to the lungs in mice. A third study determined that the abundance of *F. nucleatum* in human colon cancer tissue correlates with the amount of metastases and, in mice, identified additional signals by which the microbe may "orchestrate" metastasis. Slade and others have also demonstrated that the bacterium incites a kind of cytokine storm that is aimed at controlling the infection but that ultimately exacerbates the cancer. "It's like throwing gas on an already lit fire," Slade says.

Something similar may be going on in some breast tumors. In June a team led by microbiologist Gilad Bachrach of Hebrew University reported finding *F. nucleatum* DNA in 30 percent of the human breast cancer tissue examined; the bacterium was most common in cancer cells that expressed a lot of the surface sugar molecule Gal/GalNAc. Researchers also showed that the infection promotes growth of both primary tumors and metastases in mouse models of breast cancer. "The data imply that fusobacterium is not a cause of cancer, but it can accelerate progression," Bachrach says.

How much this is happening in humans is, of course, a critical question. "The findings are intriguing, and it makes sense," says Joan Massagué of Memorial Sloan Kettering Cancer Center, who is a leading investigator of metastasis. Inflammation is invariably part of the metastatic process, he says, so an infection that incites a dramatic inflammatory reaction in a tumor will have a consequence: "it helps cancer cells engage in mobile, invasive behavior."

The discoveries about fusobacterium are part of a fast-moving field that is illuminating the way the microbiome both promotes and battles cancer. Many modern immunotherapy drugs, for instance, work best in the presence of beneficent microbes—as do some older chemotherapies. Some scientists envision that fusobacterium eventually could be turned into a cancer fighter. Given the microbe's attraction to a sugar on tumor cells, they suggest, perhaps it could be deployed as a Trojan horse, bound to cancer drugs and carrying them straight to a malignant target. SA

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.*

Illustration by Fatinha Ramos

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The Ecolab Science Certified™ program promotes four key elements that help ensure rigor and give consumers confidence.

1. Create Clean:
Our team of more than 1,200 scientists, engineers and technical specialists have been studying germs for decades, and developing innovative solutions to help reduce exposure to germs.

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The Ecolab Science Certified program helps deliver a high level of cleanliness through on-demand training and periodic auditing to verify procedures are being followed.

3. See Clean:
When you visit our partner locations you'll also notice their commitment to a high level of cleanliness with visible signage, hygiene practices and sanitizing stations throughout.

4. Believe Clean:
You can be sure that when you spot the Ecolab Science Certified seal at a hotel, restaurant, retail store or other location, they are committed to science-backed products and protocols to achieve a high level of cleanliness.

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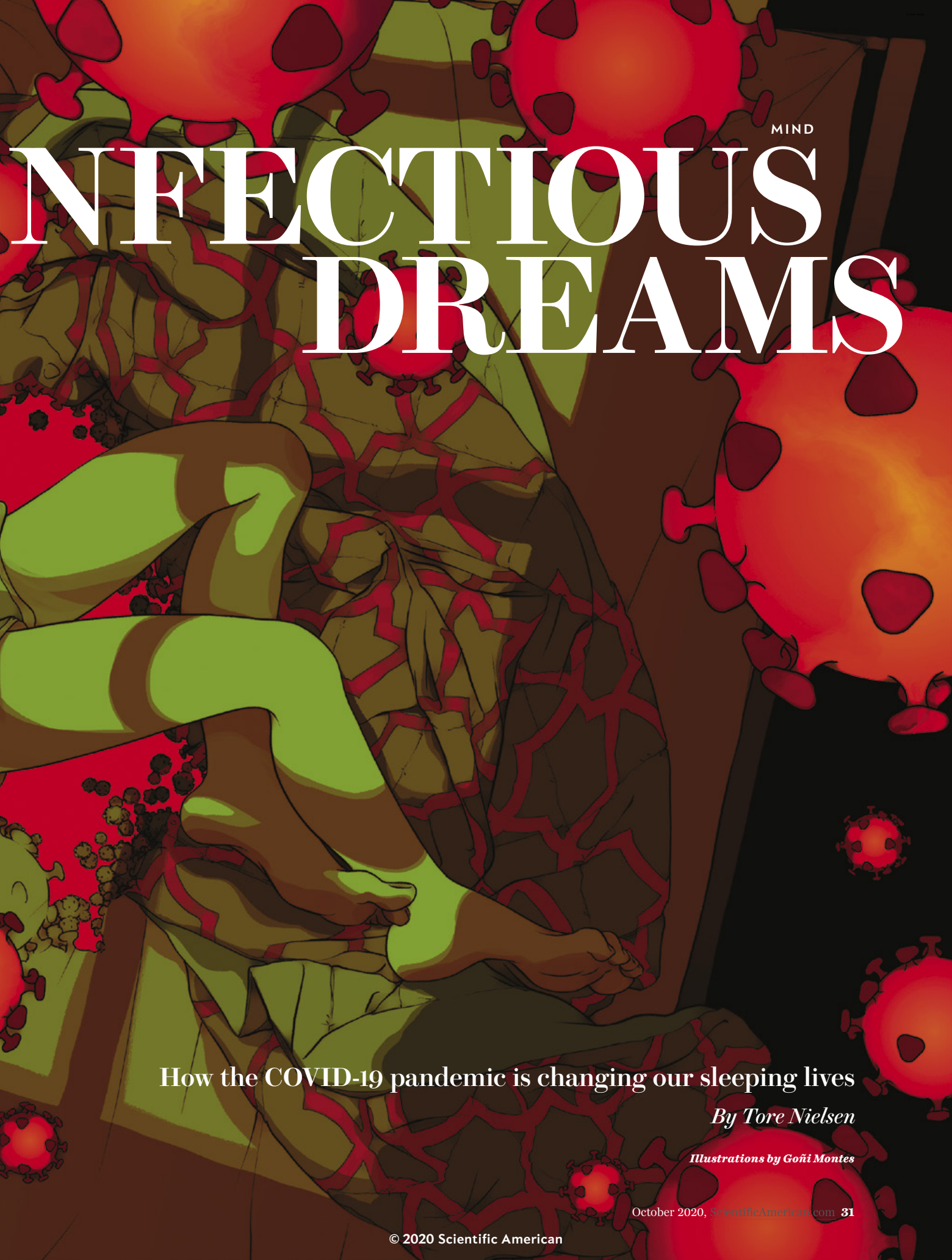
NFECTIOUS DREAMS



How the COVID-19 pandemic is changing our sleeping lives

By Tore Nielsen

Illustrations by Goñi Montes

Tore Nielsen is a professor of psychiatry at the Université de Montréal and director of the Dream and Nightmare Laboratory there.

微博@英文杂志全球首发

FOR MANY OF US, LIVING IN A COVID-19 WORLD FEELS AS IF WE HAVE BEEN THROWN into an alternative reality. We live day and night inside the same walls. We fear touching groceries that arrive at our doorstep. If we venture into town we wear masks, and we get anxious if we pass someone who is not. We have trouble discerning faces. It's like living in a dream.

COVID-19 has altered our dream worlds, too: how much we dream, how many of our dreams we remember and the nature of our dreams themselves. Early this year, when stay-at-home directives were put in place widely, society quite unexpectedly experienced what I am calling a dream surge: a global increase in the reporting of vivid, bizarre dreams, many of which are concerned with coronavirus and social distancing. Terms such as coronavirus dreams, lockdown dreams and COVID nightmares emerged on social media. By early April, social and mainstream media outlets had begun broadcasting the message: the world is dreaming about COVID-19.

Although widespread changes in dreaming had been reported in the U.S. following extraordinary events such as the 9/11 attacks in 2001 and the 1989 San Francisco earthquake, a surge of this magnitude had never been documented. This upwelling of dreams is the first to occur globally and the first to happen in the era of social media, which makes dreams readily accessible for immediate study. As a dream "event," the pandemic is unprecedented.

But what kind of phenomenon is this, exactly? Why was it happening with such vigor? To find out, Deirdre Barrett, an assistant professor at Harvard University and editor in chief of the journal *Dreaming,* initiated a COVID-19 dreams survey online in the week of March 22. Erin and Grace Gravley, San Francisco Bay Area artists, launched IDreamofCovid.com, a site archiving and illustrating pandemic dreams. The Twitter account @CovidDreams began operation. Kelly Bulkeley, a psychologist of religion and director of the Sleep and Dream Database, followed with a YouGov survey of 2,477 American adults. And my former doctoral student Elizaveta Solomonova, now a postdoctoral fellow at McGill University, along with Rebecca Robillard of the Royal's Institute of Mental Health Research in Ottawa and others, launched a survey to which 968 people aged 12 and older responded, almost all in North America. Results of these inquiries, not yet published in journals but available in preliminary form online, document the precipitous surge, the striking variety of dreams and many related mental health effects.

Bulkeley's three-day poll revealed that in March, 29 percent of Americans recalled more dreams than usual. Solomonova and Robillard found that 37 percent of people had pandemic dreams, many marked by themes of insufficiently completing tasks (such as losing control of a vehicle) and being threatened by others. Many online posts reflect these findings. One person, whose Twitter handle is @monicaluhar, reported, "*Had a dream about returning as a sub teacher in the fall, unprepared. Students were having a difficult time practicing social distancing, and teachers couldn't stagger classes or have one-on-one meetings.*" And @therealbeecarey said, "*My phone had a virus and was posting so many random pictures from my camera roll to instagram and my anxiety was at an all time high.*"

More recent studies found qualitative changes in dream emotions and concerns about health. Dream reports from Brazilian adults in social isolation had high proportions of words related to anger, sadness, contamination and cleanliness. Text mining of accounts of 810 Finnish dreams showed that most word clusters were laden with anxiousness; 55 percent were about

the pandemic directly (lack of regard for social distancing, elderly people in trouble), and these emotions were more prevalent among people who felt increased stress during the day. A study of 100 nurses conscripted to treat COVID-19 patients in Wuhan, China, revealed that 45 percent experienced nightmares—twice the lifetime rate among Chinese psychiatric outpatients and many times higher than that among the 5 percent of the general population who have nightmare disorder.

It seems clear that some basic biological and social dynamics may have played a role in this unprecedented opening of the oneiric floodgates. At least three factors may have triggered or sustained the dream surge: disrupted sleep schedules augmenting the amount of REM sleep and therefore dreaming; threats of contagion and social distancing taxing dreaming's capacity to regulate emotions; and social and mainstream media amplifying the public's reaction to the surge.

MORE REM SLEEP, MORE DREAMS

ONE OBVIOUS EXPLANATION for the surge is that sleep patterns changed abruptly when lockdowns took effect. Early publications demonstrate elevated levels of insomnia in the Chinese population, especially among front-line workers. In contrast, stay-at-home orders, which removed long commutes to work, improved sleep for many people. Chinese respondents reported an average increase of 46 minutes in bed and an extra 34 minutes in total sleep time. Some 54 percent of people in Finland said they slept more after lockdown. Overall, from March 13 to 27, time asleep in the U.S. increased almost 20 percent nationwide, and states with the longest commute times, such as Maryland and New Jersey, showed the largest increases.

Longer slumber leads to more dreams; people in sleep laboratories who are allowed to snooze more than 9.5 hours recall more dreams than when sleeping a typical eight hours. Sleeping longer also proportionally increases rapid eye movement (REM) sleep, which is when the most vivid and emotional dreams occur.

Relaxed schedules may also have caused dreaming to occur later than usual in the morning, when REM sleep is more prevalent and intense and, thus, dreams are more bizarre. Dreamtweets reflect these qualities: "*I was taking care of a newborn girl that had COVID … it was so vivid and real.*" Increased dreaming during late-morning REM intervals results from the convergence of several processes. Sleep itself cycles through deep and light stages about every 90 minutes, but pressure for REM sleep gradually increases as the need for deep, recuperative sleep is progressively satisfied. Meanwhile a circadian process that is tightly linked to our 24-hour core body temperature rhythm gives an abrupt boost to REM sleep propensity late in the sleep period and stays elevated through the morning.

After the pandemic began, many people did sleep longer and later. In China, average weekly bedtime was delayed by 26 minutes but wake-up time by 72 minutes. These values were 41 and 73 minutes in Italy and 30 and 42 minutes among U.S. university students. And without commutes, many people were freer to linger in bed, remembering their dreams. Some early birds may have turned into night owls, who typically have more REM sleep and more frequent nightmares. And as people eliminated whatever sleep debts they may have accrued over days or even weeks of insufficient rest, they were more likely to wake up at night and remember more dreams.

DREAM FUNCTIONS OVERWHELMED

THE SUBJECT MATTER of many COVID-19 dreams directly or metaphorically reflects fears about contagion and the challenges of social distancing. Even in normal times, we dream more about novel experiences. For example, people enrolled in programs to rapidly learn French dream more about French. Replaying fragments of experiences is one example of a functional role that researchers widely ascribe to REM sleep and dreaming: it helps us solve problems. Other roles include consolidating the prior day's events into longer-lasting memories, fitting those events into an ongoing narrative of our lives and helping us regulate emotions.

Researchers have documented countless cases of dreams assisting in creative achievement. Empirical studies also show that REM sleep aids in problem-solving that requires access to wide-ranging memory associations, which may explain why so many dreams in the 2020 surge involve creative or strange attempts to deal with a COVID-19 problem. One survey respondent said, "*I was looking for a kind of cream that would either prevent or cure Covid-19. I got my hands on the last bottle.*"

Two other widely claimed dream functions are extinguishing fearful memories and simulating social situations. They are related to emotion regulation and help to explain why pandemic threats and social distancing challenges appear so often in surge dreams. Many dreams reported in the media include fearful reactions to infection, finances and social distancing. "*I tested positive for pregnancy and covid … now I'm stressed.*" Threats may take the form of metaphoric imagery such as tsunamis or aliens; zombies are common. Images of insects, spiders and other small creatures are also widely represented: "*My foot was covered in ants and 5-6 black widows were imbedded in the bottom of my foot.*"

One way to understand direct and metaphoric imagery is to consider that dreams express an individual's core concerns, drawing on memories that are similar in emotional tone but different in subject matter. This contextualization is clear in posttraumatic nightmares, in which a person's reaction to a trauma, such as terror during an assault, is depicted as terror in the face of a natural disaster such as a tsunami. The late Ernest Hartmann, a Boston-area dream and nightmare research pioneer who studied dreams after the 9/11 attacks, stipulated that such contextualization best helps people adapt when it weaves together old and new experiences. Successful integration produces a more stable memory system that is resilient to future traumas.

Metaphoric images can be part of a constructive effort to make sense of disruptive events. A related process is the extinguishing of fear by the creation of new "safety memories." These possibilities, which I and others have investigated, reflect the fact that memories of fearful events are almost never replayed in their entirety during dreaming. Instead elements of a memory appear piecemeal, as if the original memory has been reduced to basic units. These elements recombine with newer memories and cognitions to create contexts in which metaphors and other unusual juxtapositions of imagery seem incongruous or incompatible with waking life—and, more important, are incompatible with feelings of fear. This creative dreaming produces safety imagery that supersedes and inhibits the original fear memory, helping to assuage distress over time.

This mechanism can break down after severe trauma, however. When this happens, nightmares arise in which the fearful memory is replayed realistically; the creative recombining of

memory elements is thwarted. The pandemic's ultimate impact on a person's dreams will vary with whether or how severely they are traumatized and how resilient they are.

A second class of theories—also still speculative—may explain social distancing themes, which permeated IDreamofCovid.com reports. Emotions in these dreams range from surprise to discomfort to stress to nightmarish horror. Tweets located by the @CovidDreams account illustrate how incompatible dream scenarios are with social distancing—so incompatible that they often trigger a rare moment of self-awareness and awakening: "*We were celebrating something by having a party. And I woke myself up because something wasn't right because we're social distancing and not supposed to be having parties.*"

These theories focus on dreaming's social simulation function. The view that dreaming is a neural simulation of reality, analogous to virtual reality, is now widely accepted, and the notion that the simulation of social life is an essential biological function is emerging. In 2000 Anne Germain, now CEO of sleep medicine start-up Noctem, and I proposed that images of characters interacting with the self in dreams could be basic to how dreaming evolved, reflecting attachment relationships essential to the survival of prehistoric groups. The strong interpersonal bonds reiterated during dreaming contribute to stronger group structures that help to organize defenses against predators and cooperation in problem-solving. Such dreams would still have adaptive value today because family and group cohesion remain essential to health and survival. It may be the case that an individual's concerns about other people are fine-tuned while they are in the simulated presence of those people. Important social relationships and conflicts are portrayed realistically during dreaming.

Other investigators, such as cognitive neuroscientist Antti Revonsuo of the University of Turku in Finland, have since proposed additional social functions for dreaming: facilitating social perception (who is around me?), social mind reading (what are they thinking?) and the practice of social bonding skills. Another theory advanced by psychology professor Mark Blagrove of Swansea University in Wales further postulates that by sharing dreams, people enhance empathy toward others. The range of dream functions is likely to keep expanding as we learn more about the brain circuits underlying social cognition and the roles REM sleep plays in memory for emotional stimuli, human faces and reactions to social exclusion. Because social distancing is, in effect, an experiment in social isolation at a level never before seen—and is likely antagonistic to human evolution—a clash with deep-rooted dream mechanisms should be evident on a massive scale. And because social distancing disrupts normal relationships so profoundly—causing many of us to spend excessive time with some people and no time with others—social simulations in dreams may play a crucial role in helping families, groups, even societies deal with sudden, widespread social adaptation.

THE ECHO CHAMBER OF SOCIAL MEDIA

THERE IS ONE BASIC QUESTION about pandemic dreams that we would like to nail down: whether the dream surge was amplified by the media. It is quite possible that early posts of a few dreams were circulated widely online, feeding a pandemic-dreams narrative that went viral, influencing people to recall their dreams, notice COVID themes and share them. This narrative may have even induced people to dream more about the pandemic.

Evidence suggests that mainstream media reporting probably did not trigger the surge but may have amplified its scope, at least temporarily. The Bulkeley and Solomonova-Robillard polls corroborated a clear groundswell in dream tweeting during March, before the first media stories about such dreams appeared; indeed, the earliest stories cited various tweet threads as sources of their reporting.

Once stories emerged, additional surges in dream reporting through early April were detected by @CovidDreams and IDreamofCovid.com. The format of most early stories almost guaranteed amplification: they typically described some salient dream themes observed in a survey and provided a link directing readers to participate in the same survey. In addition, 56 percent of articles during the first week of stories featured interviews with the same Harvard dream scientist, which may have influenced readers to dream about the themes repeated by her in various interviews.

The surge began to decline steadily in late April, as did the number of mainstream media articles, suggesting that any echo-chamber effect had run its course. The final nature of the surge remains to be seen. Until COVID-19 vaccines or treatments are distributed and with waves of future infections possible, threats of disease and social distancing are likely to persist. Might the pandemic have produced a lasting increase in humanity's recall of dreams? Could pandemic concerns become permanently woven into dream content? And if so, will such alterations help or hinder people's long-term adjustments to our postpandemic futures?

Therapists may need to step in to help certain people. The survey information considered in this article does not delve into nightmares in detail. But some health care workers who saw relentless suffering are now themselves suffering with recurrent nightmares. And some patients who endured the ICU for days or weeks suffered from horrific nightmares during that time, which may in part have been the result of medications and sleep deprivation induced by around-the-clock hospital procedures and interminable monitor noises and alarms. These survivors will need expert help to regain normal sleep. Thankfully, specialized techniques are highly effective.

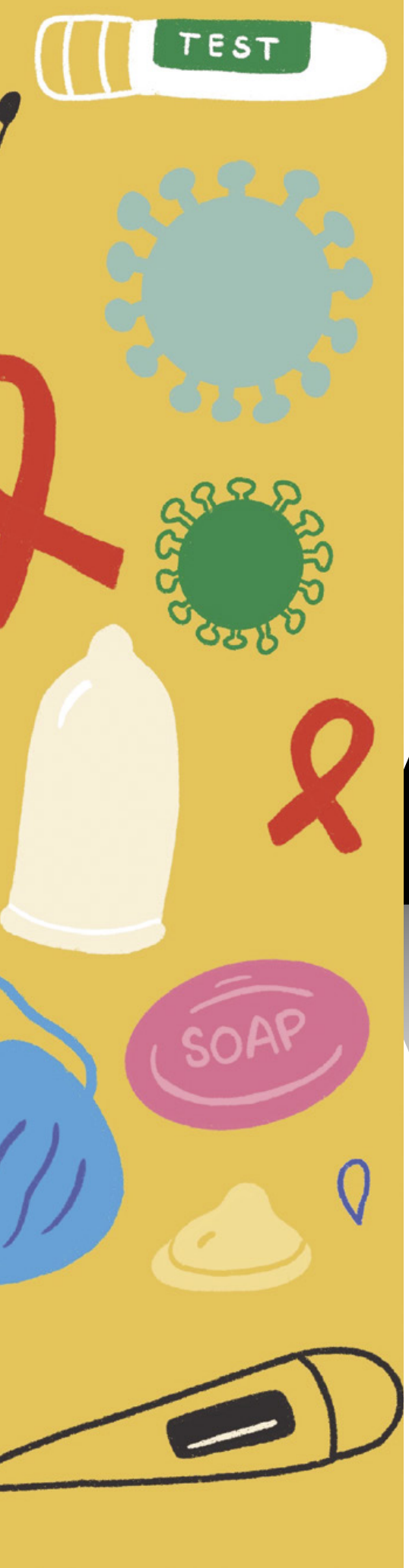
People who are not traumatized but still a little freaked out about their COVID dreams also have options. New technologies such as targeted memory reactivation are providing individuals with more control over their dream narratives. For example, learning how to practice lucid dreaming—becoming aware that you are now dreaming—aided by targeted memory reactivation or other methods could help transform worrisome pandemic dreams into more pleasant, maybe even useful, dreams. Simply observing and reporting pandemic dreams seems to positively impact mental health, as Natália Mota of the Federal University of Rio Grande do Norte in Natal, Brazil, found in her studies.

Short of therapy, we can give ourselves permission to ease up and to enjoy banking those surplus hours of sleep. Dreams can be vexing, but they are also impressionable, malleable and at times inspirational. SA

FROM OUR ARCHIVES

The Significance of Dreams. Eugenio Rignano; May 24, 1919.

scientificamerican.com/magazine/sa



VIROLOGY

WHAT WE LEARNED FROM AIDS

Lessons from another pandemic for fighting COVID-19

By William A. Haseltine

Illustration by Sol Cotti

William A. Haseltine is a former Harvard Medical School professor and founder of the university's cancer and HIV/AIDS research departments. He also serves as chair and president of the global health think tank ACCESS Health International. He has founded more than a dozen biotechnology companies and is the author, most recently, of *A COVID Back to School Guide: Questions and Answers for Parents and Students* and *A Family Guide to COVID-19: Questions and Answers for Parents, Grandparents and Children.*

"WE ARE NOW ENGAGED IN ANOTHER DEADLY EPISODE IN THE HISTORIC battle of man versus microbe. These battles have shaped the course of human evolution and of history. We have seen the face of our adversary, in this case a tiny virus." I spoke these words in testimony before a U.S. Senate subcommittee on September 26, 1985. I was talking about HIV, but I could say the same thing today about the coronavirus we are facing.

Like all viruses, coronaviruses are expert code crackers. SARS-CoV-2 has certainly cracked ours. Think of this virus as an intelligent biological machine continuously running DNA experiments to adapt to the ecological niche it inhabits. This virus has caused a pandemic in large part because it acted on three of our most human vulnerabilities: our biological defenses, our clustering patterns of social behavior and our simmering political divides.

How will the confrontation unfold in the next years and decades? What will be the human toll in deaths, ongoing disease, injuries and other impairments? How effective will new vaccines and treatments be in containing or even eradicating the virus?

No one can say. But several lessons from the long battle with HIV, the human immunodeficiency virus that causes AIDS, suggest what may lie ahead. HIV/AIDS is one of the worst scourges humans have encountered. As a code cracker, HIV is an expert. By the end of 2019 the global death toll from this virus was roughly 33 million people. In all, 76 million people have been infected, and scientists estimate another 1.7 million people acquire the virus every year.

Yet we must appreciate what our scientific defenses have accomplished. Of the nearly 38 million people currently living with HIV/AIDS, 25 million are receiving full antiretroviral treatments that prevent disease and suppress the virus so well they are unlikely to pass it along. I would wager that another 25 million or more infections never happened, primarily in sub-Saharan Africa, because these treatments became available in most countries.

From fighting this epic war against AIDS, doctors, virologists, epidemiologists and public health experts have learned crucial lessons that we can apply to the battle we are currently waging. For instance, we saw that vaccines are never a guarantee but that treatments can be our most important weapon. We discovered that human behavior plays a vital role in any disease-fighting effort and that we cannot overlook human nature. We have also seen how critical it is to build on knowledge and tools gained fighting earlier outbreaks—a strategy only possible if we continue funding research in between pandemics.

VACCINE CHALLENGES

EARLY OBSERVATIONS of how HIV behaves in our bodies showed the road to a vaccine would be long and challenging. As the outbreak unfolded, we began tracking antibody levels and T cells (the white blood cells that wage war against invaders) in those infected. The high levels of both showed that patients were mounting incredibly active immune responses, more forceful than anything we had seen for any other disease. But even working at its highest capacity, the body's immune system was never strong enough to clear out the virus completely.

Unlike the hit-and-run polio virus, which evokes long-term immunity after an infection, HIV is a "catch it and keep it" virus—if you are infected, the pathogen stays in your body until it destroys the immune system, leaving you undefended against even mild infections. Moreover, HIV continually evolves—a shrewd opponent seeking ways to elude our immune responses. Although this does not mean a vaccine is impossible, it certainly meant developing one, especially when the virus hit in the 1980s, would not be easy. "Unfortunately, no one can predict with certainty that an AIDS vaccine can ever be made," I testified in 1988 to the Presidential Commis-

sion on the HIV Epidemic. "That is not to say it is impossible to make such a vaccine, only that we are not certain of success." More than 30 years later there still is no effective vaccine to prevent HIV infection.

From what we have seen of SARS-CoV-2, it interacts with our immune system in complex ways, resembling polio in some of its behavior and HIV in others. We know from nearly 60 years of observing coronaviruses that a body's immune system can clear them. That seems to be generally the case for SARS-CoV-2 as well. But the cold-causing coronaviruses, just like HIV, also have their tricks. Infection from one of them never seems to confer immunity to reinfection or symptoms by the same strain of virus—that is why the same cold viruses return each season. These coronaviruses are not a hit-and-run virus like polio or a catch-it-and-keep-it virus like HIV. I call them "get it and forget it" viruses—once cleared, your body tends to forget it ever fought this foe. Early studies with SARS-CoV-2 suggest it might behave much like its cousins, raising transient immune protection.

The path to a SARS-CoV-2 vaccine may be filled with obstacles. Whereas some people with COVID-19 make neutralizing antibodies that can clear the virus, not everybody does. Whether a vaccine will stimulate such antibodies in everyone is still unknown. Moreover, we do not know how long those antibodies can protect someone from infection. It may be two or three years before we will have the data to tell us and any confidence in the outcome.

Another challenge is how this virus enters the body: through the nasal mucosal membranes. No COVID-19 vaccine currently in development has shown an ability to prevent infection through the nose. In nonhuman primates, some vaccines can prevent the disease from spreading efficiently to the lungs. But those studies do not tell us much about how the same drug will work in humans; the disease in our species is very different from what it is in monkeys, which do not become noticeably ill.

We learned with HIV that attempts to prevent virus entry altogether do not work well—not for HIV and not for many other viruses, including influenza and even polio. Vaccines act more like fire alarms: rather than preventing fires from breaking out, they call the immune system for help once a fire has ignited.

The hopes of the world rest on a COVID-19 vaccine. It seems likely that scientists will announce a "success" sometime this year, but success is not as simple as it sounds. As I write, officials in Russia have reported approving a COVID-19 vaccine. Will it work? Will it be safe? Will it be long lasting? No one will be able to provide convincing answers to these questions for *any* forthcoming vaccine soon, perhaps not for at least several years.

We have made remarkable improvements in our molecular biology tools since the 1980s, yet the slowest part of drug development remains human testing. That said, the infrastructure created for HIV/AIDS research is accelerating the testing process now. Thirty thousand volunteers around the world participate in networks built by the National Institutes of Health for studies of new HIV vaccine candidates, and these networks are being tapped for initial testing of COVID-19 vaccines, too.

KAREN BLEIER *Getty Images*

AIDS MEMORIAL QUILT, made up of 48,000 panels, commemorates those who have died of AIDS-related causes.

When doctors treat a patient who is likely to die, they are willing to risk that a drug might sicken the patient but still save their life. But doctors are less willing to do that to *prevent* disease; the chances of causing greater harm to the patient are too high. This is why for decades the quest for a vaccine to prevent HIV infection has lagged so far behind development of therapeutic drugs for HIV.

FOCUS ON TREATMENTS

THESE DRUGS now stand as an incredible success story.

The first set of HIV drugs were nucleic acid inhibitors, known as chain terminator drugs. They inserted an additional "chain terminating" nucleotide as the virus copied its viral RNA into DNA, preventing the HIV chain of DNA from elongating.

By the 1990s we had gotten better at using combinations of drugs to control HIV infections soon after patients were exposed. The first drug, AZT, found immediate application for health care workers who accidentally had a needlestick injury that infected them with contaminated blood. It was also used to reduce mother-to-child transmission. For example, prenatal treatments for mothers with AIDS at that time reduced the number of babies born infected by as much as two thirds. Today combination chemotherapy reduces mother-to-child transmission to undetectable levels.

The next set of drugs was protease inhibitors, one of which I helped to develop. The first was introduced in 1995 and was combined with other drugs in treating patients. These drugs inhibited the viral protease enzyme responsible for longer precursor proteins in the short active components of the virus. But there is a fundamental problem with these drugs, as well as those that inhibit viral polymerases, which help to create virus DNA. Our bodies also use proteases for normal functioning, and we need polymerases to replicate our own nucleic acids. The same drugs that inhibit the viral

proteins also inhibit our own cells. The difference between a concentration in which the drug inhibits the virus target and a concentration in which it hurts the human proteins is called the therapeutic index. The therapeutic index gives you the window in which the drug will be effective against the virus without causing undue side effects. That window is rather narrow for all polymerase and protease inhibitors.

The gold standard for AIDS treatment now is called antiretroviral therapy—essentially patients take a cocktail of at least three different drugs that attack the HIV virus in different ways. The strategy is based on earlier success we had in fighting cancer. In the late 1970s I established a laboratory at Harvard University's Dana-Farber Cancer Institute to develop new drugs to treat cancer patients. Cancers developed resistance over time to single drugs, but combinations of drugs were effective in slowing, stopping or killing the cancers. We took that same lesson of combination chemotherapy to HIV. By the early 1990s the first combination AIDS treatments were saving the lives of people infected with HIV. Today an infection is far from the death sentence it used to be—patients can now live almost unaffected by HIV, with a relatively minimal impact on life expectancy.

Just as with AIDS and cancer, we will need a combination of medicines to treat this disease.

We already know resistance to single drugs will bedevil COVID-19 treatments. We have seen resistance to single, anti-SARS-CoV-2 drugs develop rapidly in early lab studies. Just as with AIDS and cancer, we need a combination of medicines to treat this disease. The goal of the biotechnology and pharmaceutical industries now is to develop an array of highly potent and specific drugs, each of which targets a different function of the virus. Decades of research on HIV has shown the way and gives us confidence in our eventual success.

HUMAN BEHAVIOR

IN TRYING TO UNDERSTAND and counter the AIDS epidemic, physician and virologist Robert Redfield (who is now head of the Centers for Disease Control and Prevention) and I became good friends in the early 1980s. We quickly learned that while many politicians across the globe refused to recognize HIV as a threat to their populations, militaries were an exception. Nearly all countries considered AIDS a serious danger to troops and military readiness and a potentially huge drain on future military funds. Their view was, "Let's not blind ourselves and pretend soldiers are saints. They are not. They are humans." Redfield, then at Walter Reed Army Medical Center, helped to design and manage a program to test the entire U.S. uniformed forces for HIV infection (although the consequences of this test were controversial, and recruits who tested positive were barred from service).

At the time there were no effective drugs; the disease killed more than 90 percent of those infected. When married couples were tested and one partner was infected and one not, doctors advised them in the strongest possible terms to use condoms. I was stunned to learn that fewer than a third complied with the advice. "If people don't respond to the lethal danger of unprotected sex with their husband or wife, we are in real trouble," I thought. Over the next five years more than three quarters of the uninfected partners contracted HIV.

I have always used this experience as a guide to pit hope against reality. Human sexuality—the drive for sex and physical connection—is deeply embedded in our nature. I knew in the 1980s it was very unlikely people would change their sexual behavior in a major way. In the 19th century everyone knew how syphilis was contracted and that it was serious disease. Yet syphilis still infected at least 10 to 15 percent of American citizens at the beginning of the 20th century. It was not that people were ignorant of how to catch it; it is that they did not change their lifestyle accordingly.

There is likewise a sexual dynamic to COVID-19 that often goes unmentioned. It is part of what is driving people out of their homes and into bars and parties. Anyone with a craving for a beer can quench their thirst in the safety of their own home, but gratification comes less easily for other desires, especially when one is young, single and living alone. Our public health strategies should not ignore this fact.

The same lessons we learned in the midst of the HIV epidemic to help young people change their behaviors apply today to COVID-19: know your risk, know your partners and take necessary precautions. Many young people operate under the false assumption that even if they become infected, they will not become severely ill. Not only is this belief untrue, but even people with asymptomatic infections can suffer serious, lasting damage. But the more people understand the risk—younger people especially—the greater likelihood they will take the steps necessary to protect themselves and others. We saw this happen with AIDS.

FUNDING

WHEN I ASK WORLD EXPERTS what they know about the detailed molecular biology of SARS-CoV-2 or, for that matter, any other coronavirus, they do not have the kind of answers they should. Why? Because governments and industry pulled the plug on coronavirus research funding in 2006 after the first SARS (severe acute respiratory syndrome) pandemic faded away and again in the years immediately following the MERS (Middle East respiratory syndrome, also caused by a coronavirus) outbreak when it seemed to be controllable. Funding agencies everywhere, not just in the U.S. but in China, Japan, Singapore, Hong Kong and the Middle East—countries affected by SARS and MERS—underestimated the threat of coronaviruses. Despite clear, persistent, highly vocal warnings from many

of those who battled SARS and MERS up close, funding dried up. The development of promising anti-SARS and MERS drugs, which might have been active against SARS-CoV-2 as well, was left unfinished for lack of money.

With 776,000 dead and 22 million infected globally as of mid-August, we have every motive to accelerate funding. The U.S. quickly opened the funding spigots last spring for research to hasten discoveries of vaccines and drugs. But will it be enough?

We learned from the HIV crisis that it was important to have research pipelines already established. Cancer research in the 1950s, 1960s and 1970s built a foundation for HIV/AIDS studies. The government responded to public concerns, sharply increasing federal funding of cancer research during those decades. These efforts culminated in Congress's approval of President Richard Nixon's National Cancer Act in 1971. This $1.6-billion commitment for cancer research, equal to $10 billion in today's money, built the science we needed to identify and understand HIV in the 1980s, although of course no one knew that payoff was coming.

In the 1980s the Reagan administration did not want to talk about AIDS or commit much public funding to HIV research. The first time President Ronald Reagan gave a major speech on AIDS was in 1987. In his first administration, funding for HIV research was scarce; few scientists were willing to stake their careers on deciphering the molecular biology. Yet once the news broke that actor Rock Hudson was seriously ill with AIDS, Ted Stevens, the Senate Republican Whip, joined with Democratic Senator Ted Kennedy, actor Elizabeth Taylor, me and a few others in campaigning effectively to add $320 million in the fiscal 1986 budget for AIDS research. Barry Goldwater, Jesse Helms and John Warner, Republican leaders in the Senate, supported us. The money flowed, and outstanding scientists signed on. I helped to design this first congressionally funded AIDS research program with Anthony Fauci, the doctor now leading our nation's fight against COVID-19. (And if there is one person in the world who has made the greatest contribution to the prevention and treatment of AIDS, that person is Fauci.)

One difference between the 1980s and now is that Republican members of Congress were more willing to stand up to the president and White House staff when they failed to take the necessary steps to fight a global disease. For example, Stevens decided it was his job to protect the U.S. Army and other arms of the military and Secret Service as much as possible from HIV infection. He helped to move $55 million within the defense budget, designating it for screening recruits for HIV/AIDS.

Our tool set for virus and pharmaceutical research has improved enormously in the past 36 years since HIV was discovered. This is one reason I am confident we will have effective antiviral drugs for treating COVID-19 infections by next year, if not sooner. What used to take us five or 10 years in the 1980s and 1990s in many cases now can be done in five or 10 months. We can rapidly identify and synthesize chemicals to predict which drugs will be effective. We can do cryoelectron microscopy to probe virus structures and simulate molecule-by-molecule interactions in a matter of weeks—something that used to take years. The lesson is to never let down our guard when it comes to funding antivirus research. We would have no hope of beating COVID-19 if it were not for the molecular biology gains we made during earlier virus battles. What we learn this time around will help us out during the next pandemic, but we must keep the money coming.

A LEAP INTO DARKNESS

IN NOVEMBER 2019 I spent several days in Wuhan, China, chairing a meeting of the U.S.-China Health Summit. Our group's major concern, looming amid the U.S.-China trade war, was the threat of restrictions on sharing research discoveries. Otherwise, it was a delightful time in a beautiful city.

Weeks later, back home in New York City, I could not shake a lingering cold virus infection I picked up on the Wuhan trip. (I later tested negative for COVID-19 antibodies, but that result is not definitive.) The head of my foundation in China called me one day with awful news. Three of his grandparents had died from some strange virus. "Everyone who gets this is really sick," my colleague, in his mid-30s, said. "Everything is closed down. I can't even go to my grandparents' funerals."

A few weeks later I received a vivid firsthand account of how aggressively China was confronting the outbreak from another colleague who had just emerged from 14 days of isolation in a quarantine hotel. He explained that when one person in the back of his flight from Frankfurt, Germany, to Shanghai tested positive for the coronavirus, contact tracers called my friend days later and ordered him into isolation. His only human contact then was with hazmat-clad inspectors who came daily to disinfect his room and drop off meals.

We are just beginning to glimpse what the long-term toll of COVID-19 might be. This is a new virus, so we will not have a clearer idea until after a few years, but we know it will be very high. We have *barely* scratched the surface of coronavirus molecular biology. What story will our children and grandchildren recount about our successes as scientists and as a society, and our failures, to contain this pandemic—the worst we have faced in 100 years?

Science leaps into the darkness, the very edge of human knowledge. That is where we begin, as if deep in a cave, chipping away at a wall of hard stone. You do not know what you will find on the other side. Some people chip away for a lifetime, only to accumulate a pile of flakes. We may be in for a protracted pandemic, or we may get lucky with effective treatments and vaccines soon. But we have been here before, facing an unknown viral enemy, and we can lean on lessons we have learned. This is not the first and will not be the last global epidemic. SA

FROM OUR ARCHIVES

The Molecular Biology of the AIDS Virus. Flossie Wong-Staal and William A. Haseltine; October 1988.

scientificamerican.com/magazine/sa

ASTRONOMY

Interstellar

Two recently sighted space rocks that came from beyond the solar

1I/'OUMUAMUA, the first interstellar object ever observed in the solar system, passed close to Earth in 2017.

elope Interlopers

system have puzzled astronomers

By David Jewitt and Amaya Moro-Martín

Illustrations by Ron Miller

David Jewitt is an astronomer at the University of California, Los Angeles, where he studies the primitive bodies of the solar system and beyond.

Amaya Moro-Martín is an astronomer at the Space Telescope Science Institute in Baltimore. She investigates planetary systems and extrasolar comets.

LATE IN THE EVENING OF OCTOBER 24, 2017, AN E-MAIL ARRIVED CONTAINING tantalizing news of the heavens. Astronomer Davide Farnocchia of NASA's Jet Propulsion Laboratory was writing to one of us (Jewitt) about a new object in the sky with a very strange trajectory. Discovered six days earlier by University of Hawaii astronomer Robert Weryk, the object, initially dubbed P10Ee5V, was traveling so fast that the sun could not keep it in orbit. Instead of its predicted path being a closed ellipse, its orbit was open, indicating that it would never return. "We still need more data," Farnocchia wrote, "but the orbit appears to be hyperbolic." Within a few hours, Jewitt wrote to Jane Luu, a long-time collaborator with Norwegian connections, about observing the new object with the Nordic Optical Telescope in Spain. Many other observatories around the world were simultaneously scrambling to spot it.

So began a new era in astronomy. Renamed C/2017 U1 (the "C" standing for "comet"), then A/2017 U1 (for "asteroid") and, finally, 1I/'Oumuamua, the object turned out to be the first body astronomers have ever seen in the solar system that originated outside it. The "1I" in its designation indicates its official status as the first known interstellar object, and the name 'Oumuamua—"a messenger from afar arriving first" in Hawaiian—was proposed by Weryk and his colleagues, who had used the Pan-STARRS telescope on the Hawaiian island of Maui to make the discovery.

What first caught the observers' attention was the object's extreme speed relative to the sun. After accounting for the pull of the sun's gravity, 'Oumuamua had an excess speed of 26 kilometers a second (58,000 miles an hour). No interaction with a solar system body could generate such a kick, and the sun's gravity cannot capture something moving so quickly; 'Oumuamua had to have come from outside.

What kind of journey must this object have taken? From what we can tell, it could have been wandering the galaxy for hundreds of millions of years. Observations suggest that it came from the direction of the bright star Vega, in the constellation Lyra, although Vega would not have been in the same spot when 'Oumuamua was there roughly 300,000 years ago.

Although astronomers have long believed that interstellar bodies pass through the solar system, actually finding one was a big surprise. Only the year before, an exhaustive analysis by Toni Engelhardt, then at the University of Hawaii, and his colleagues concluded that prospects for identifying such an interstellar interloper "appear to be bleak"—they were thought to be just too small and faint for us to have much hope of finding them. But as we discovered more about 'Oumuamua, our surprise turned into utter bewilderment. Everything from its shape and size to its lack of cometlike properties ran counter to our expectations. If this was a typical visitor from the greater universe, we had a lot to learn.

ALIEN ARTIFACT OR COSMIC DUST BUNNY?

OBSERVATIONS FROM THE NORDIC OPTICAL and other telescopes soon showed that 'Oumuamua lacked a tail and a surrounding coma of sublimated dust and ice transitioning directly from solid to gas—the hallmarks of a comet. Rather, except for its unique orbit, 'Oumuamua looked like a rocky asteroid. Still, given that it had come from interstellar space, where the average temperature is only a few degrees above absolute zero, the absence of evidence for sublimating ice was startling. Water, the most abundant molecule in the universe after molecular hydrogen, should have been present.

And then there was the object's shape. Astronomers use the brightness of an asteroid as a measure of its size because bigger objects reflect more sunlight to Earth. 'Oumuamua's average brightness suggested a diameter of about 100 meters—quite small compared with most known asteroids. Indeed, if 'Oumuamua had been as far

2I/BORISOV, the second known interstellar visitor, was first spotted in 2019.

away as the asteroid belt, where most of the asteroids in our solar system reside, we never would have seen it. Instead we got lucky: it passed very close to us—about 60 million kilometers, which is only 40 percent of the average distance between the sun and Earth. The brightness of most asteroids, shaped like lumpy potatoes rotating in space, varies cyclically as they present alternately smaller and larger sides of themselves to Earth. Observing this rotation produces a "light curve," a plot of how the light changes that tells us the rotation period and gives us an estimate of the asteroid's proportions. In December 2017 scientists reported 'Oumuamua's light curve. At about eight hours its period was unremarkable compared with those of solar system asteroids. But whereas most asteroids vary in brightness by 10 to 20 percent as they spin, 'Oumuamua changed by an unprecedented factor of 10, suggesting an extraordinary needlelike shape that sometimes presented a large and bright surface and sometimes showed only a very narrow edge.

The object's resemblance in size and proportions to a large rocket—for example, the Saturn V, which measures about 110 meters by 10 meters—was hard to ignore. Indeed, discarded rockets orbiting the sun are occasionally rediscovered by astronomers surveying the sky for asteroids and comets, as was the case for 2000 SG344, a likely Apollo-program relic discovered in 2000. But the orbit of 'Oumuamua was too extreme for it to be a rocket from the 1960s. Could it be a rocket from another civilization? Incredible as it sounds, scientists could not immediately reject the possibility based on the available data.

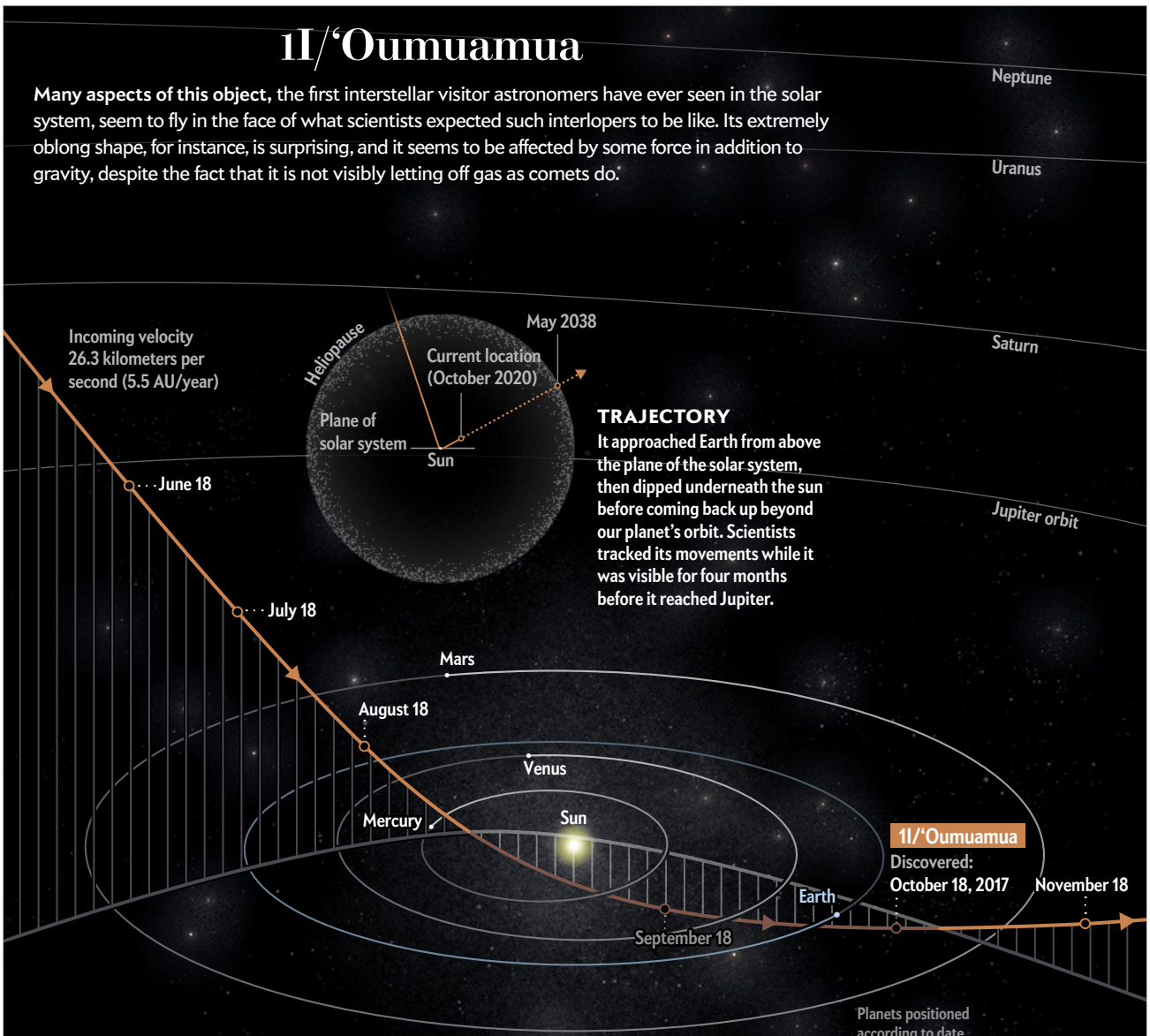
While astronomers were pondering this conundrum, they got another surprise. In June 2018 Italian astronomer Marco Micheli of the European Space Agency and his colleagues reported measurements of the shape of 'Oumuamua's orbit, which revealed the action of a weak, rocketlike force pushing on the body in addition to the gravitational forces of the sun and planets.

So-called nongravitational forces are well known to exist in comets, arising from the asymmetric push of ices sublimating from the dayside of the comet's core. But 'Oumuamua is not a comet. And it showed no evidence that it was losing mass at all, which could have explained the force. Could it be that 'Oumuamua emitted only gas, which is harder to detect than comet dust? Possibly, but it would make 'Oumuamua unique: astronomers know of no other cosmic object that lets off gas but no dust or ice. Micheli suggested that 'Oumuamua might eject very large dust particles that were invisible to our telescopes.

In November 2018 Shmuel Bialy and Avi Loeb of the Center for Astrophysics | Harvard & Smithsonian proposed that the nongravitational force could be caused by sunlight, which exerts a weak pressure on any object placed in its path. To experience enough radiation pressure that we could measure it, however, 'Oumuamua would have to be either extraordinarily thin like a sheet of Mylar (the aluminized plastic used to make birthday balloons) or of very low density. Bialy and Loeb suggested that the object could be a "light sail," a flat, sail-shaped vehicle sent from another civilization and designed to be pushed through space by starlight.

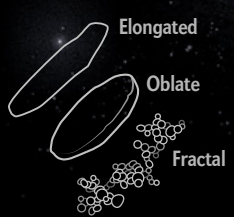
1I/'Oumuamua

Many aspects of this object, the first interstellar visitor astronomers have ever seen in the solar system, seem to fly in the face of what scientists expected such interlopers to be like. Its extremely oblong shape, for instance, is surprising, and it seems to be affected by some force in addition to gravity, despite the fact that it is not visibly letting off gas as comets do.



TRAJECTORY
It approached Earth from above the plane of the solar system, then dipped underneath the sun before coming back up beyond our planet's orbit. Scientists tracked its movements while it was visible for four months before it reached Jupiter.

DISCOVERY
First spotted by Robert Weryk using the Pan-STARRS 1.6-meter telescope on the Hawaiian island of Maui.



APPEARANCE
Its exact dimensions are unknown, but its highly elongated shape is unlike any of the thousands of solar system bodies that have been measured.

LIGHT CURVE
What astronomers do know of 'Oumuamua's shape comes from its light curve—the variation in light bouncing off it. The extreme changes here show that it must be highly elongated, sometimes presenting a small reflective face and other times a large surface.

ORIGIN
The object is most likely a relic from the formation of a distant planetary system that got ejected long ago.

SOURCE: SMALL-BODY DATABASE BROWSER, JET PROPULSION LABORATORY/NASA (*trajectory*)

Illustration by Matthew Twombly

As intriguing as that idea may be, most astronomers favor a natural origin for ‘Oumuamua. In February 2019 one of us (Moro-Martín) calculated that for ‘Oumuamua to be propelled by sunlight, it would have to be 100 times less dense than air. Such a cosmic dust bunny—an “icy fractal aggregate”—might have grown in the outer parts of the protoplanetary disk of another star, where baby planets congeal out of ice and dust rubble. This past summer Luu, Eirik Flekkøy and Renaud Toussaint, all at the University of Oslo, proposed that ‘Oumuamua grew from a collection of dust particles in the coma of an active comet, then escaped. This type of material is unknown on Earth but could conceivably survive in the ultimate vacuum of interstellar space.

Given how odd ‘Oumuamua is, what might be most incredible of all is that objects like it must be common. We know that this relatively tiny body was detected only because it passed close to Earth and that humans have had the capability to see such an object for only a few years (the Pan-STARRS facility began operating in 2010 but reached full efficiency only recently). Based on statistics alone, these two facts allowed scientists to estimate that the number of similar interstellar interlopers per unit volume of space is about one per 10 cubic AU (one AU, or astronomical unit, is the distance between Earth and the sun). Thus, in the planetary region of our solar system, defined as a sphere with the radius of Neptune’s orbit, there must be about 10,000 similar objects, of which ‘Oumuamua is only the first one close enough to be detected in the operational lifetime of Pan-STARRS. If these objects take about a decade to cross the planetary region, the average rate of interloper arrivals must be about three a day!

What, then, does this frequency suggest about the origin of ‘Oumuamua? Aliens might be capable of sending a Saturn V–size rocket or a large piece of Mylar-like material across the galaxy and through our solar system, but why would they send so many? Even more astonishing, if we extrapolate our analysis from the solar system to the whole of the Milky Way, we find that there must be 1×10^{24} to 1×10^{25} (a trillion trillion to 10 trillion trillion) similar objects in our galaxy. It is hard to believe that an extraterrestrial civilization would have the capacity to flood the galaxy with so much space junk, and it is even more difficult to see why it would do so. Thus, given the maxim that extraordinary claims require extraordinary evidence, most astronomers think ‘Oumuamua is just a weirdly shaped, but natural, piece of debris from elsewhere in the galaxy.

A SECOND DISCOVERY

THE SHEER STRANGENESS of ‘Oumuamua left astronomers eagerly awaiting the discovery of the second interstellar interloper. Would the next one be as peculiar, or would it look like a regular solar system comet or an asteroid without nongravitational motion?

Without knowing the answers to these questions, we predicted that the second object would arrive within a year or two, based on the estimate that there must be about one body like ‘Oumuamua per 10 cubic AU. To our delight, two years after ‘Oumuamua, Ukrainian amateur astronomer Gennadiy Borisov discovered C/2019 Q4 using a homemade telescope; it was soon renamed 2I/Borisov—the second interstellar object. It has an orbit even more extreme than that of ‘Oumuamua, but it appears to be a rather ordinary comet. Measurements from the Hubble Space Telescope showed that its nucleus is larger than ‘Oumuamua, with a radius between 0.2 and 0.5 kilometer. In contrast to ‘Oumuamua, 2I/Borisov displays no extreme light curve, and its nongravitational motion is simply a consequence of asymmetric outgassing as ice comes off its surface, just as in solar system comets. This past March it briefly flared in brightness and then took on a doubled appearance as a small piece of the nucleus detached, something commonly observed with solar system comets. In other words, this body is pretty much exactly what we would have expected an interstellar object to be like.

Our expectations are based on theories of planet formation, which suggest a ready mechanism for kicking some objects out of their home planetary systems and into the galaxy, where they may eventually make their way to our little corner of the cosmos. Studies suggest that planet formation begins in an orderly way but ends in a chaotic mess. The sun, for instance, was born 4.6 billion years ago in a flattened, rotating disk that grew as a giant molecular cloud contracted under its own gravity. This disk of gas, ice and dust feeding the nascent star in its center was very dense, which allowed tiny grains to collide and stick to one another. At first pebbles formed, then larger bodies known as planetesimals and, eventually, the planets. Some of the planetesimals escaped further growth and heating when they were scattered to the outer solar system shortly after they formed. There, in deep freeze, they have remained mostly unaltered ever since.

The object’s resemblance in size and proportions to a large rocket was hard to ignore.

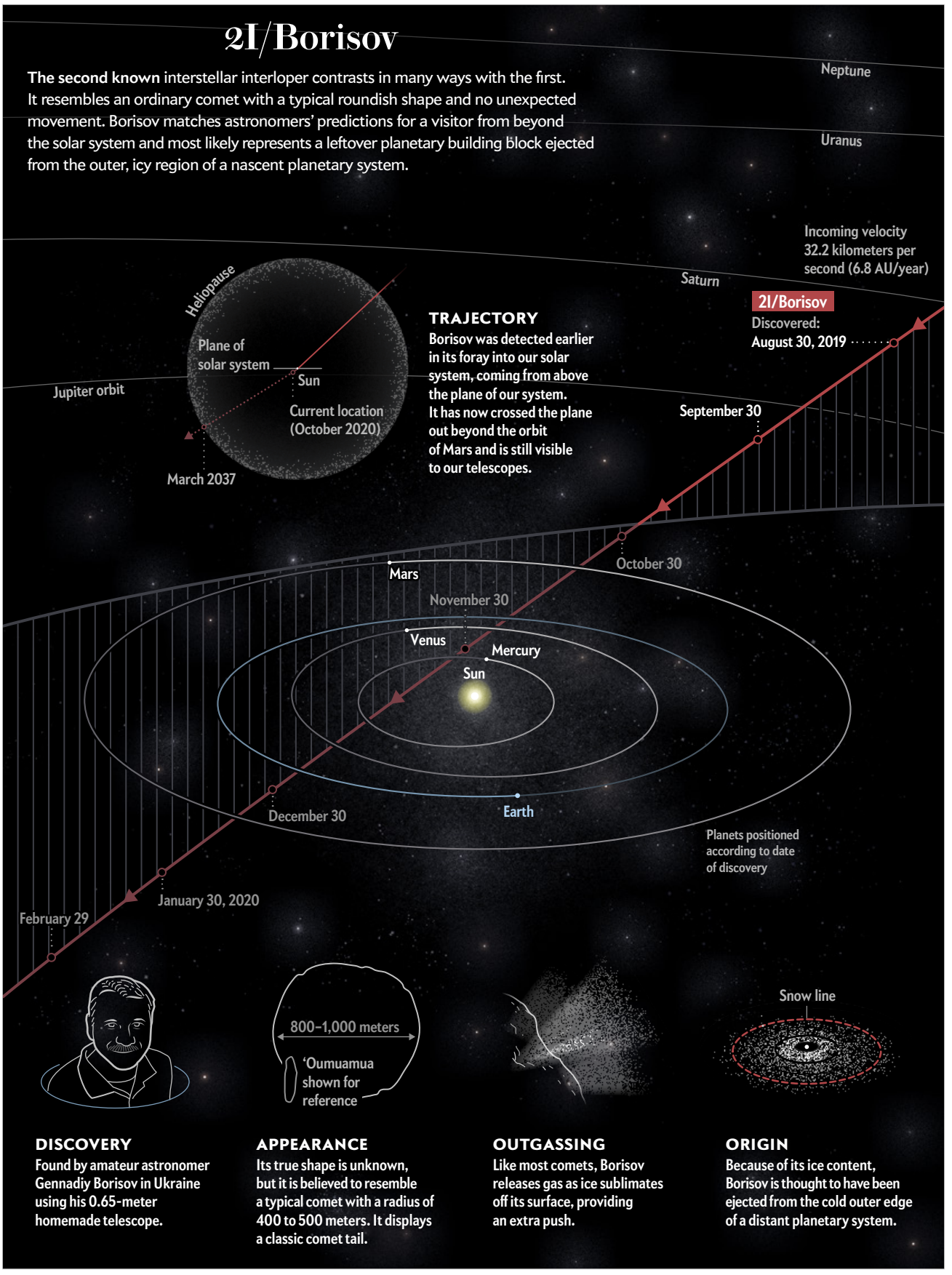
Sometimes, though, these bodies get scattered back into the inner system, where the sun’s heat causes their ice to sublimate; they develop tails of ejected material, and we call them comets. Other planetesimals are expelled from the system entirely, destined to spend eternity drifting among the stars. Once lost in the vastness of the Milky Way, such an object has a negligible chance of reentering the planetary system it came from, but it could certainly be deflected by the gravity of an alien star. Given the chaos of this process and the numerous encounters ‘Oumuamua and Borisov must have had before they reached us, we will likely never know precisely how long these objects have been adrift or determine with confidence where they came from.

Nevertheless, we can feel confident that Borisov is an ice-rich planetesimal from the outer regions of the planet-forming disk of an unknown star. In fact, everything we have learned about Borisov—and the proof it offers that some interstellar objects look much like we expected—puts the strangeness of ‘Oumuamua in stark relief. Given the extraordinary differences between the two, there is no reason to assume that they share a common origin.

Astronomers are still trying to puzzle out what ‘Oumuamua is, and new ideas come up often. One recent suggestion, proposed this past May by Darryl Seligman of the University of Chicago and Gregory Laughlin of Yale University, is that ‘Oumuamua is a novel type of body made of molecular hydrogen ice—a cosmic iceberg that originated in the coldest regions of a molecular cloud. In June, however, Loeb and Thiem Hoang of the Korea Astronomy and Space Science Institute argued that molecular hydrogen is so volatile that such a body could neither have formed in a molecular

2I/Borisov

The second known interstellar interloper contrasts in many ways with the first. It resembles an ordinary comet with a typical roundish shape and no unexpected movement. Borisov matches astronomers' predictions for a visitor from beyond the solar system and most likely represents a leftover planetary building block ejected from the outer, icy region of a nascent planetary system.



TRAJECTORY
Borisov was detected earlier in its foray into our solar system, coming from above the plane of our system. It has now crossed the plane out beyond the orbit of Mars and is still visible to our telescopes.

DISCOVERY
Found by amateur astronomer Gennadiy Borisov in Ukraine using his 0.65-meter homemade telescope.

APPEARANCE
Its true shape is unknown, but it is believed to resemble a typical comet with a radius of 400 to 500 meters. It displays a classic comet tail.

OUTGASSING
Like most comets, Borisov releases gas as ice sublimates off its surface, providing an extra push.

ORIGIN
Because of its ice content, Borisov is thought to have been ejected from the cold outer edge of a distant planetary system.

SOURCE: SMALL-BODY DATABASE BROWSER, JET PROPULSION LABORATORY/NASA (*trajectory*)

Illustration by Matthew Twombly

cloud nor have survived interstellar travel. Another option, put forward in April by Yun Zhang of the National Astronomical Observatories of the Chinese Academy of Sciences and Douglas N. C. Lin of the University of California, Santa Cruz, is that 'Oumuamua might instead be shrapnel produced by gravitational shredding of a planet or other body passing too near its parent star.

'Oumuamua's strange properties aside, the fact that the object was detected at all runs counter to the conventional wisdom about planetary system formation, which suggests that interstellar visitors should be very rare. We can estimate the number of interstellar planetesimals we expect to exist per unit volume of space based on the observed number of stars and on our knowledge of star and planet formation, stellar evolution and dynamics. The calculation involves many uncertainties, but a generous upper limit is at least a tenth to a hundredth the size of the previously mentioned statistical frequency estimate of 10,000 such objects in the planetary region. Put simply, we cannot account for that much litter in the galaxy. Perhaps as we detect more interlopers and understand them better, the inferred and estimated values of their space density will start to converge. But it is also possible that we are missing an important source of interstellar objects—maybe some process in space other than the planetesimal scattering we have described creates bodies that find their way to us.

LIFEBOATS FROM BEYOND

BESIDES TEACHING US about how planetary systems form, the discovery of interstellar visitors may have a bearing on one of the most fundamental mysteries in science: How did life on Earth begin? One idea, called panspermia, is that the seeds of ancient organisms hitched a ride on asteroids hailing from other systems.

Just as we expect interstellar bodies to enter our solar system occasionally, we must also assume that they sometimes hit our planet. Based on the value of one object per 10 cubic AU that we inferred from the detection of 'Oumuamua and 2I/Borisov, we can estimate that similar objects strike about once every 100 million to 200 million years, thousands of times less frequently than asteroids of comparable size. Most would probably detonate and disperse in the atmosphere, but a few would actually reach the ground. Scientists estimate that over the eons several billion tons of interstellar material must have crashed into Earth.

Could these impacts have delivered life to our planet? The modern scientific notion of panspermia dates back to the 19th century. Surprisingly, asteroids and comets might be good protectors of fragile cellular life. Damaging cosmic rays, capable of breaking DNA, penetrate only a few meters into solid material, so living cells buried inside rocks might survive interstellar journeys lasting millions or even hundreds of millions of years. At near-zero interstellar temperatures, any cells would be in suspended animation. They would need to withstand the shock of planetary impact, but this might not be as problematic as it sounds. Experiments have already shown that earthly bacteria can survive impacts at cosmic speed. Although there is no evidence that life spreads through the galaxy while riding in the bellies of asteroids and comets, given our present state of ignorance, we must acknowledge that this possibility remains.

To improve our understanding of interstellar objects, we need to find more examples. Currently, with only two to go on, our grasp is limited. Fortunately, new developments in astronomy make it very likely that we will soon observe dozens of similar objects, and those discoveries will allow us to better pin down the statistics and to understand their physical properties. Most professional telescopes have very small fields of view, often only a few thousandths of the area of the full moon. But optics and large detectors are now capable of capturing the whole moon and more in a single shot and the entire sky in a night or two of continuous scanning. Powerful computers make it possible to compare successive all-sky scans to find moving objects, including interstellar interlopers.

Having a larger sample of interstellar objects will help us answer many questions about the objects themselves. How many interlopers are strangely iceless and oblong like 'Oumuamua versus akin to a comet like 2I/Borisov? Are there bigger examples? Are there smaller ones? What are they made of? Are some really porous enough to be pushed around by the pressure of light? New data from the Rubin Observatory, now under construction on a Chilean mountaintop, should provide fresh insights. The Rubin telescope has a collecting mirror 8.4 meters in diameter and a three-billion-pixel detector that would have been unthinkable just a decade ago. Each image from this gigantic camera will cover an area 40 times that of the moon, an enormous advance. It will also systematically survey the sky more deeply than has ever been attempted and on a repeated basis. This new facility is expected to reveal interstellar interlopers in abundance, along with vast numbers of asteroids, comets and Kuiper belt objects from our own solar system.

To truly understand the nature of any given interloper, we would like to send a spacecraft to visit it or even land on it. One practical problem is that there is not much time to make plans because these objects move so fast. 'Oumuamua faded to invisibility for even the largest telescopes within a few months of its discovery. 2I/Borisov will be too faint to detect within a year or two. For comparison, space missions often take a decade or more, including their design, approval, construction and launch, making it impossible to plan for any particular interstellar target. A solution might be to send the spacecraft into a storage orbit before even knowing where the mission will go. This is the idea behind the European Space Agency's Comet Interceptor, due to be launched in 2028. The Interceptor will park at Earth's L2 Lagrangian point 1.5 million kilometers away, where it can easily maintain a stable orbit as it awaits the flyby of an interesting object. The Interceptor lacks the power to rendezvous with an interloper unless one happens by chance to pass very close to L2, however.

More capable rockets are intrinsically heavy and expensive to launch; even if a flyby is possible, accelerating to hyperbolic orbit speed to grab a sample will not be easy. Spacecraft powered by novel propulsion methods, such as light sails accelerated by a laser beam from Earth or by solar radiation pressure, are another option, but they involve difficulties of their own. Still, the prospect of being able to closely examine an object that unequivocally originated beyond our solar system is extraordinary, and scientists have not been shy in proposing ways to do so. One way or another, we will pry the secrets from our interstellar visitors. SA

FROM OUR ARCHIVES

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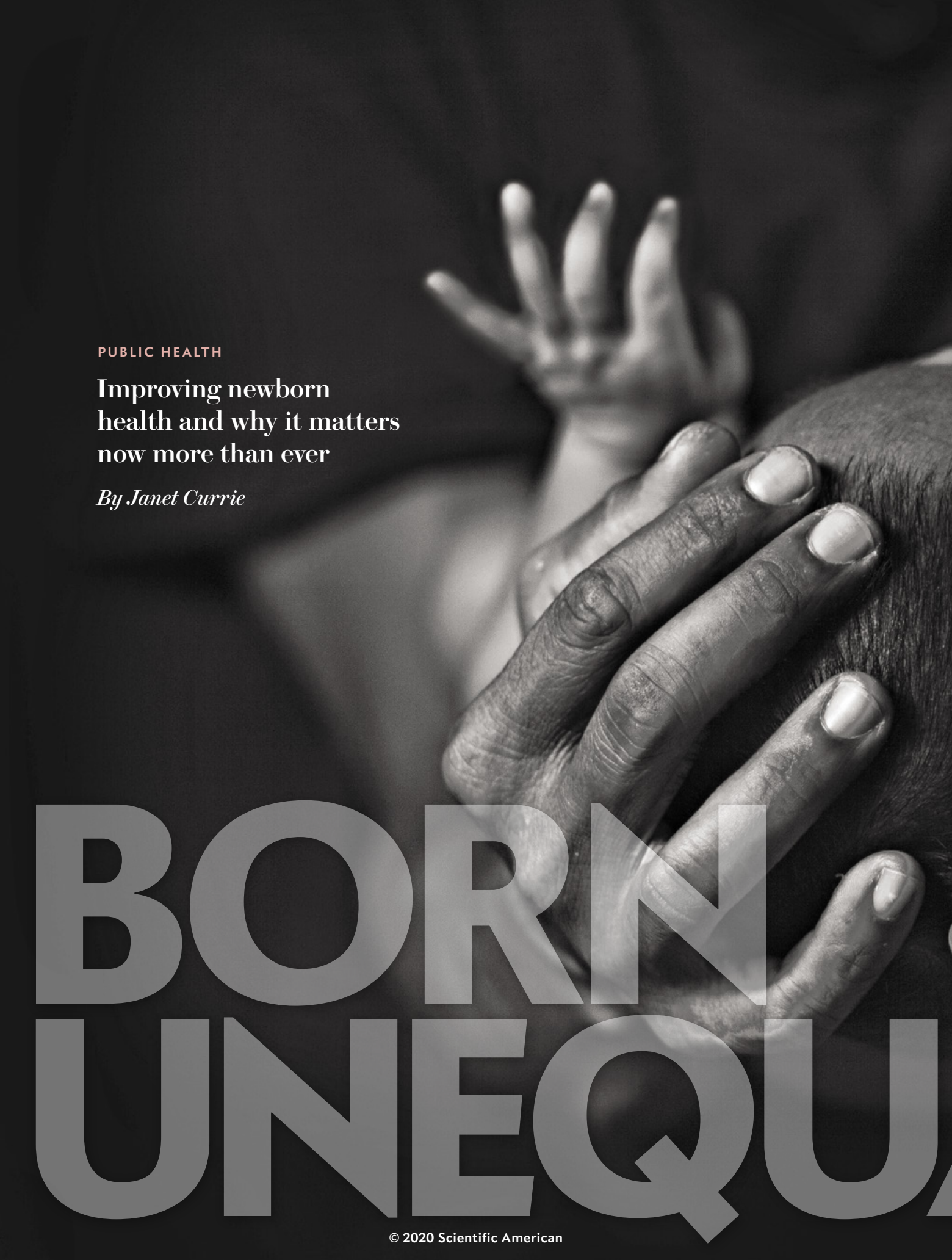


PUBLIC HEALTH

Improving newborn health and why it matters now more than ever

By Janet Currie

BORN UNEQU

AL

Janet Currie is Henry Putnam Professor of Economics and Public Affairs and co-director of the Center for Health and Wellbeing at Princeton University. She studies socioeconomic differences in health and access to health care, as well as environmental threats to health.

THE COVID-19 PANDEMIC HAS DISPROPORTIONATELY HURT MEMBERS OF MINORITY COMMUNITIES IN THE U.S. As of late July, 73.7 Black people out of every 100,000 had died of the coronavirus—compared with 32.4 of every 100,000 white people. Structural racism accounts for much of this disparity. African-Americans are more likely to have jobs that require them to leave their homes and to commute by public transport, for example, both of which increase the chances of getting infected. They are also more likely to get grievously ill when the virus strikes. As of early June, the hospitalization rate for those who tested positive for SARS-CoV-2 infection was more than four times higher for Black people than for non-Hispanic white people.

One reason for this alarming ratio is that African-Americans have higher rates of diabetes, hypertension and asthma—ailments linked to worse outcomes after infection with the coronavirus. Decades of research show that these health conditions, usually diagnosed in adulthood, can reflect hardships experienced while in the womb. Children do not start on a level playing field at birth. Risk factors linked to maternal poverty—such as malnutrition, smoking, exposure to pollution, stress or lack of health care during pregnancy—can predispose babies to future disease. And mothers from minority communities were and are more likely to be subjected to these risks.

Today's older African-Americans—those most endangered by COVID-19—are more likely than not to have been born into poverty. In 1959, 55 percent of Black people in the U.S. had incomes below the poverty level, compared with fewer than 10 percent of white people. Nowadays 20 percent of Black Americans live below the poverty line, whereas the poverty rate for white Americans remains roughly the same. Despite the reduction in income inequality between these groups, ongoing racism works through circuitous routes to worsen the odds for minority infants. For example, partly because of a history of redlining (practices through which financial and other institutions made it difficult for Black families to buy homes in predominantly white areas), even better-off African-Americans are more likely to live in polluted areas than are poorer whites—with a corresponding impact on fetal health. Worryingly, people disadvantaged in utero are more likely to have lower earnings and educational attainments, so that the effects of poverty and discrimination can span generations.

Researchers now have hard evidence that targeted programs can improve health and reduce inequality. Expansions of public health insurance offered to women, infants and children under Medicaid and the Children's Health Insurance Program have already had a tremendous effect, improving the health and well-being of a generation—with the largest impacts on African-American children. And interventions after birth can often reverse much of the damage suffered prenatally. Along with other researchers, I have shown that nutrition programs for pregnant women, infants and children; home visits by nurses during pregnancy and after childbirth; high-quality child care; and income support can improve the outcomes for disadvantaged children. Such interventions came too late to help those born in the 1950s or earlier, but they have narrowed the health gaps between poor and rich children, as well as between white and Black children, in the subsequent decades.

Enormous disparities in health and vulnerability remain, however, and raise disturbing questions about how children born to poorer mothers during the current pandemic, with all its social and economic dislocations, will fare. Alarmingly, just before the pandemic hit, many of the most essential programs were being cut back. Since the beginning of 2018, more than a million children have lost Medicaid coverage because of new work requirements and other regulations, and many have become uninsured. Now that the COVID-19 death toll has exposed stark inequalities in health status and their attendant risks, Americans must act urgently to reverse these setbacks and to strengthen public health systems and the social safety net, with special attention to the care of mothers, infants and children.

PRECEDING PAGES: MOHD FAUZIE *Getty Images*

THE HUNGER WINTER

DECADES OF CAREFUL OBSERVATION and analysis have gone into uncovering the manifold ways in which the fetal environment affects the future health and prospects of a child, and much remains mysterious. It would be unethical to run experiments to measure the toll on a fetus of, say, malnutrition or pollution. But we can look for so-called natural experiments—the (sometimes horrific) events that cause variations in these factors in ways that mimic an actual experiment. The late epidemiologist David Barker argued in the 1980s that poor nutrition during pregnancy could "program" babies in the womb to develop future ailments such as obesity, heart disease and diabetes. Initial evidence for such ideas came from studies of the Dutch "Hunger Winter." In October 1944 Nazi occupiers cut off food supplies to the Netherlands, and by April 1945 mass starvation had set in. Decades later military, medical and employment records showed that adult men whose mothers were exposed to the famine while pregnant with them were twice as likely to be obese as other men and were more likely to have schizophrenia, diabetes or heart disease.

Anyone born in the Netherlands during the famine is part of a cohort that can be followed over time through a variety of records. Nowadays many researchers, including me, look for natural experiments to delineate such cohorts and thereby tease out the long-term impacts of various harms experienced in utero. We also rely heavily on the most widely available measure of newborn health: birth weight. A baby may have "low" birth weight, defined as less than 2,500 grams (about 5.5 pounds), or "very low" birth weight of less than 1,500 grams (3.3 pounds). The lower the birth weight, the higher the risk of infant death. We have made enormous progress in saving premature babies, but low-birth-weight children are still at much higher risk for complications such as brain bleeds and respiratory problems that can lead to long-term disability.

In recent years computer analysis of large-scale electronic records has made it possible to connect infant health, as measured by birth weight, to long-term outcomes not just for cohorts but also for individuals. Studies of twins or siblings, who have similar genetic and social inheritance, show that those with lower birth weight are more likely to have asthma or attention deficit hyperactivity disorder (ADHD) when they get older. Several studies also show that lower-birth-weight twins or siblings have worse scores on standardized tests. As adults, they are more likely to have lower wages, to reside in lower-income areas or to be on disability-assistance programs. In combination, cohort and sibling studies demonstrate that low birth weight is predictive of several adverse health outcomes later in life, including increased probabilities of asthma, heart disease, diabetes, obesity and some mental health conditions.

Birth weight does not capture all aspects of a child's health: a fetus gains most of its weight in the third trimester, for example, but many studies find that shocks in the first trimester are particularly harmful. I nonetheless use the measure in my studies because it is important and commonly available, having been recorded for tens of millions of babies for decades.

Significantly, low birth weight is much more common among infants born to poor and minority mothers. In 2016 13.5 percent of African-American mothers had low-birth-weight babies, compared with 7.0 percent of non-Hispanic whites and 7.3 percent of Hispanic mothers. Among those with college educations, 9.6 percent of Black mothers had low-birth-weight babies, compared with 3.7 percent of non-Hispanic white mothers. These inequalities in health at birth reflect large differences in exposure to several factors that affect fetal health.

Poor nutrition during pregnancy can "program" babies in the womb to develop future ailments.

THE POVERTY CONNECTION

AS ALREADY NOTED, the quality of a mother's nutrition substantially influences the health of her babies. In 1962 geneticist James V. Neel hypothesized that a so-called thrifty gene had programmed humankind's hunter-gatherer ancestors to hold on to every calorie they could get and that in modern times, that tendency, combined with an abundance of high-calorie foods, led to obesity and diabetes. Recent studies on laboratory animals indicate, however, that the link between starvation and disease is not genetic in origin but epigenetic, altering how certain genes are "expressed" as proteins. Prolonged calorie deprivation in a pregnant mouse, for example, prompts changes in gene expression in her offspring that predispose them to diabetes. What is more, the effect may be transmitted through generations.

Outright starvation is now rare in developed countries, but poorer mothers in the U.S. often lack a diet rich in fruits and vegetables, which contain essential micronutrients. Deficiencies in folate intake during pregnancy are linked to neural tube defects in children, for example.

At present, one of the leading causes of low birth weight in the U.S. is smoking during pregnancy. In the 1950s pregnant women were told that smoking was safe for their babies. Roughly half of all new mothers in 1960 reported smoking while pregnant. Today, thanks to public education campaigns, indoor-smoking bans and higher cigarette taxes, only 7.2 percent of pregnant women say that they smoke. And 55 percent of women who smoked in the three months before they got pregnant quit for at least the duration of their pregnancy.

Possibly because going to college places women in a milieu where smoking is strongly discouraged, moth-

ers with higher education levels are less likely to smoke. Among mothers with less than a high school education, 11.7 percent smoke, compared with 1 percent of mothers with a bachelor's degree.

Among the many harmful chemicals in cigarette smoke is carbon monoxide (CO), which restricts the amount of oxygen carried by the blood to the fetus. In addition, nicotine affects the development of blood vessels in the uterus and disrupts developing neurotransmitter systems, leading to poorer psychological outcomes. Maternal cigarette smoking during pregnancy has also been associated with epigenetic changes in the fetus, although how these alterations affect an individual in later years remains mysterious. The recent surge in vaping, which delivers high doses of nicotine and which surveys show has been tried by almost 40 percent of high school seniors, is an extremely worrying development that could have long-term implications for fetal and infant health.

Yet another significant source of harm for fetuses is pollution. Pregnant women may be exposed to thousands of toxic chemicals in the air, water, soil and sundry products at home and at work. Complicating matters, each pollutant acts in a different way. Particulates in the atmosphere are thought to cause inflammation throughout the body, which has been linked to preterm labor and, consequently, to low birth weight. Lead, ingested through water or air, crosses the placenta to accumulate in the fetus and harm brain development. In 2005 Jessica Wolpaw Reyes of Amherst College showed that the phase-out of leaded gasoline in the U.S. led to a decrease of up to 4 percent in infant mortality and low birth weight.

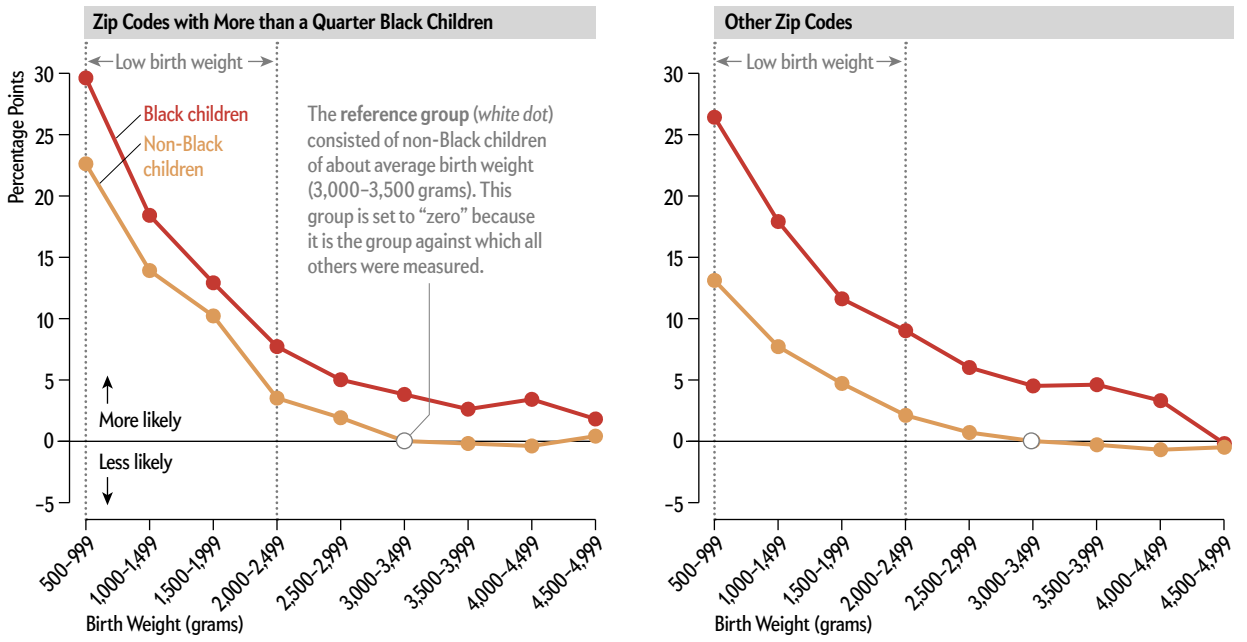
A fetus may also receive less oxygen if its mother inhales CO from vehicle exhaust. In a 2009 study of mothers who lived near pollution monitors, my co-workers and I found that high levels of ambient CO were correlated with reduced birth weight. Worryingly, the effects of CO from air pollution are five times greater for smokers than for nonsmokers.

Reducing pollution can have immediate benefits for pregnant women and newborns. In a 2011 study of babies born in New Jersey and Pennsylvania, Reed Walker of the University of California, Berkeley, and I focused on mothers who lived near E-ZPass electronic toll plazas before and after they began operating. We compared them with mothers who lived a little farther

Asthma, Pollution and Residential Segregation

Asthma rates were twice as high for Black people as for other people in the U.S. in 2010. Part of this disparity comes from low birth weight, which is linked to asthma and is more common in Black infants. These graphs illustrate the impact of pollution and residential segregation on asthma rates. They compare New Jersey children in neighborhoods where more than a quarter of children are Black versus children in all other neighborhoods. Comparing the left and right panels shows that low birth weight has a larger effect on asthma rates among children of *all* races in the neighborhoods where most Black children live. Hence, residential segregation, which results in Black children being more likely to live in more polluted places, compounds the negative effects of low birth weight.

Likelihood of Developing Asthma Compared with Non-Black Children of Average Birth Weight



SOURCE: "IS IT WHO YOU ARE OR WHERE YOU LIVE? RESIDENTIAL SEGREGATION AND RACIAL GAPS IN CHILDHOOD ASTHMA," BY DIANE ALEXANDER AND JANET CURRIE. IN *JOURNAL OF HEALTH ECONOMICS*, VOL. 55; JULY 25, 2017

Graphic by Amanda Montañez

from the toll plazas but along the same busy roads. Both groups of mothers were exposed to traffic, but before E-ZPass, the mothers near the toll plazas were exposed to more pollution because cars idled while waiting to pay the tolls. E-ZPass greatly reduced pollution right around the toll plazas by allowing cars to drive straight through. Startlingly, the introduction of E-ZPass reduced the incidence of low birth weight by more than 10 percent in the neighborhoods nearest the toll plazas.

In another study, my collaborators and I examined birth records for 11 million newborns in five states. We found that a shocking 45 percent of mothers lived within about a mile of a site that emitted toxic chemicals such as heavy metals or organic carcinogens—a number that rose to 61 percent among African-American mothers. Focusing on babies born to mothers who lived within a mile of a plant, we compared birth weights when the facility was operating with birth weights when it was closed. For additional context, we also compared babies born within a mile of a plant with babies born in a one-to-two-mile band around the plants. Both groups of mothers were likely to be similarly affected by the economics of factory openings and closings, but mothers who lived closer were more likely to have been exposed to pollution during pregnancy. We found that an operating plant increased the probability of low birth weight by 3 percent among babies whose mothers lived less than a mile from the plant.

The racial divide in pollution exposure is profound, in part because of continuing segregation in housing that makes it difficult for Black families to move out of historically Black neighborhoods. Disadvantaged communities may also lack the political power to fend off harmful development, such as a chemical plant, in their vicinity. In the E-ZPass study, roughly half of the mothers who lived next to toll plazas were Hispanic or African-American, compared with only about a tenth of mothers who lived more than six miles away from a toll plaza. And in a paper published this year, John Voorheis of the U.S. Census Bureau, Walker and I show that across the entire U.S., neighborhoods with higher numbers of African-American residents have systematically worse air quality than other neighborhoods. African-Americans are also twice as likely as others to live near a Superfund hazardous waste site. For these reasons, pollution-control measures such as the Clean Air Act have greatly benefited African-Americans.

FIGHT OR FLIGHT

STRESS DISPROPORTIONATELY impacts the poor—who have chronic worries about paying bills, for example—and also harms fetuses. A stressful situation triggers the release of hormones that orchestrate a range of physical changes associated with the fight-or-flight response. Some of these hormones, including cortisol, have been linked to preterm labor, which in turn leads to low birth weight. High circulating levels of cortisol in the mother during pregnancy may damage the fetus's cortisol-regulation system, making it more vulnerable to stress. And stress can trigger behavioral responses in a mother such as increased smoking or drinking, which are also harmful to the fetus.

One revealing study indicates that fetal exposure to maternal stress can have greater negative long-term effects on mental health than stress directly experienced by a child. Petra Persson and Maya Rossin-Slater, both at Stanford University, looked at the impact of the death of a close relative. Death can bring many unwelcome changes to a family, such as reduced income, which may also influence child development. To account for such complications, the researchers used administrative data from Sweden to compare children whose mothers were affected by a death during the prenatal period with those whose mothers were affected by a death during the child's early years. They found that children affected by a death prenatally were 23 percent more likely to use medication for ADHD at ages nine to 11 and 9 percent more likely to use antidepressants in adulthood than were children whose families experienced a death a few years after their birth.

Reducing pollution can have immediate benefits for pregnant women and newborns.

Another pathbreaking study measured levels of cortisol, an indicator of stress, during pregnancy. By age seven, children whose mothers had higher cortisol levels during pregnancy had received up to one year less schooling than their own siblings, indicating that they had been delayed in starting school. Moreover, for any given level of cortisol in the mother's blood, the negative effects were more pronounced for children born to less educated mothers. This finding suggests that although being stressed during pregnancy is damaging to the fetus, mothers with more education are better able to buffer the effects on their children—an important finding in view of the severe stress imposed by COVID-19 on families today.

It is no surprise that disease can also harm a fetus. Douglas V. Almond of Columbia University looked at people born in the U.S. at the peak of the influenza epidemic of 1918 and found that they were 1.5 times more likely to be poor as adults than were those born just before them. In work I did with Almond and Mariesa Herrmann of Mathematica looking at mothers born between 1960 and 1990 in the U.S., we found that women who were born in areas where an infectious disease was raging were more likely to have diabetes when they gave birth to their own children decades later—and the effects were twice as large for African-Americans. More recently, Hannes Schwandt of Northwestern University examined Danish data and found that maternal infection with ordinary seasonal influenza in the third trimester doubles the rate of premature birth and low birth weight, and

infection in the second trimester leads to a 9 percent reduction in earnings and a 35 percent increase in welfare dependence once the child reaches adulthood.

PREVENTING HARM

HEALTH AT BIRTH and beyond can nonetheless be improved through thoughtful interventions targeting pregnant women, babies and children and through reductions in pollution. The food safety net in the U.S. has already had tremendous success in preventing low birth weight in the babies of disadvantaged women. The rollout of the food stamp program (now called the Supplemental Nutrition Assistance Program, or SNAP) across the U.S. in the mid-1970s reduced the incidence of low birth weight by between 5 and 11 percent. In addition, children who benefited from the rollout grew up to be less likely to have metabolic syndrome—a cluster of conditions that include obesity and diabetes. Notably, women who had benefited as fetuses or young children were more likely to be economically self-sufficient.

The U.S. food safety net has already had immense success in improving children's future prospects.

The 1970s also saw the introduction of the Special Supplemental Nutrition Program for Women, Infants and Children, popularly known as WIC. Approximately half of pregnant women in the U.S. receive nutritious food from WIC, along with nutrition counseling and improved access to medical care. Dozens of studies have shown that when women participate in WIC during pregnancy, their babies are less likely to have low birth weight. In recent work looking at mothers in South Carolina, Anna Chorniy of Northwestern University, Lyudmyla Sonchak of the State University of New York at Oswego and I were able to show that children whose mothers got WIC during pregnancy were also less likely to have ADHD and other mental health conditions that are commonly diagnosed in early childhood.

In the late 1980s and early 1990s, state and federal governments worked together to greatly expand public health insurance for pregnant women under the Medicaid program. In work with Jonathan Gruber of the Massachusetts Institute of Technology, I showed that public health insurance lowered infant mortality and improved birth weight. Today the children whose mothers became eligible for health insurance coverage of their pregnancies in that period have higher levels of college attendance, employment and earnings than the children of mothers who did not. They also have lower rates of chronic conditions and are less likely to have been hospitalized. The estimated effects are strongest for African-Americans, who, having lower average incomes, benefited the most from the expansions. The fact that these babies are more likely to eventually get a college education also increases the life chances of *their* children. In the U.S., an additional year of college education for the mother reduces the incidence of low birth weight in her children by 10 percent.

Even so, too many children are still born with low birth weight, especially if their mothers are Black. Significantly, targeted interventions after birth can improve their outcomes. Programs such as the Nurse-Family Partnership provide home visits by nurses to low-income women who are pregnant for the first time, many of whom are young and unmarried. The nurse visits every month during the pregnancy and for the first two years of the child's life to provide guidance about healthy behavior. The assistance reduces child abuse and adolescent crime and enhances children's academic achievement.

Providing cash payments to poor families with young children also improves both maternal health and child outcomes, suggesting that COVID-19 relief payments will have important protective effects. In the U.S., the largest preexisting program of this type is the Earned Income Tax Credit (EITC). Studies of beneficiaries of the EITC show that children in families that received increased amounts had higher test scores in school. With financial stress being somewhat relieved, the mental health of mothers in these families also improved. In addition, quality early-childhood education programs augment future health, education and earnings and reduce crime. Head Start, the federally funded preschool program that was rolled out beginning in the 1960s, has also had substantial positive effects on health and education outcomes, especially in places with less access to alternative child care centers.

A recent study, especially noteworthy in light of the tragic lead poisoning in Flint, Mich., shows that even some of the negative effects of lead can be reversed. In Charlotte, N.C., lead-poisoned children who received lead remediation, nutritional and medical assessments, WIC and special training for their caregivers saw reductions in problem behaviors and advanced school performance.

LOOKING AHEAD

INVESTMENTS IN PREGNANT WOMEN and infants have been paying off, their success reflected in dramatically falling infant mortality rates in the U.S.—despite rising inequality in income and wealth. Alarmingly, however, many successful programs, such as the Clean Air Act, SNAP and Medicaid, are under attack. The Coronavirus Aid, Relief and Economic Security (CARES) Act passed in March provided some relief, at least with respect to Medicaid. CARES temporarily suspended disenrollment from the program, giving additional flexibility to state Medicaid programs in terms of time lines and eligibility procedures. Still, states may be hard-pressed to enroll the many who will become newly eligible for Medicaid because of job loss. Moreover, states that have not expanded the Medicaid program to cover otherwise ineligible low-income adults, as allowed by the Affordable Care Act, may see many more uninsured.

BRETT CARLSEN Getty Images

SKYLINE of Flint, Mich., in 2016, after declaration of a federal emergency because of lead contamination in the water supply.

A National Academies of Sciences, Engineering and Medicine report published last year laid out a road map for reducing child poverty by half within 10 years. One of the most stunning findings of the report is that it is feasible to meet that target by expanding programs that already exist. Following these directions would have a profound impact on health and health disparities. Targeted approaches, such as more thorough investigation of maternal deaths occurring up to one year after a birth, are also necessary. Even simple preventive measures such as giving pregnant women flu shots can have a tremendously positive effect on infant health and child development. Diagnosis and treatment of conditions such as preeclampsia (high blood pressure associated with pregnancy) are key to both protecting babies and lowering maternal mortality rates. It is important to help pregnant women quit smoking and to develop new approaches relevant to a new generation addicted to vaping. Also needed are stronger protections for women at risk of domestic violence, which leads directly to chronic stress, premature deliveries and low birth weight.

One salient open question is what effect the pandemic will have on the generation of children affected by it in utero and in early life. COVID-19 itself may have negative effects on the developing fetus, although the best information available to date suggests that pregnant women are not especially likely to become critically ill (as they are with influenza or SARS) and that affected babies are not being born with obvious birth defects (as they are with the Zika virus). Still, given the fact that COVID-19 affects many body systems, it may prove to have subtler negative effects on the developing fetus. The pandemic is also an extremely stressful event compounded by the sharpest economic downturn since the Great Depression. There are reports of increases in domestic violence, alcohol consumption and drug overdoses, all of which are known to be harmful to the developing fetus. In consequence, the generation now in utero is likely to be at increased risk going forward and will require intensive social investments to overcome its poorer start in life.

In a recent sermon on the late civil-rights leader John Robert Lewis, Reverend James Lawson recounted the significant gains for Americans of all colors that had resulted from that movement. He went on to ask that America's political leaders "work unfalteringly on behalf of every boy and every girl, so that every baby born on these shores will have access to the tree of life … let all the people of the U.S.A. determine that we will not be quiet as long as any child dies in the first year of life in the United States. We will not be quiet as long as the largest poverty group in our nation are women and children." As we rebuild our shattered safety nets and public health systems in the aftermath of COVID-19, we need to seize the moment and use the knowledge we have gained about how to protect mothers and babies—to give every child the opportunity to flourish. SA

FROM OUR ARCHIVES

The Health-Wealth Gap. Robert M. Sapolsky; November 2018.

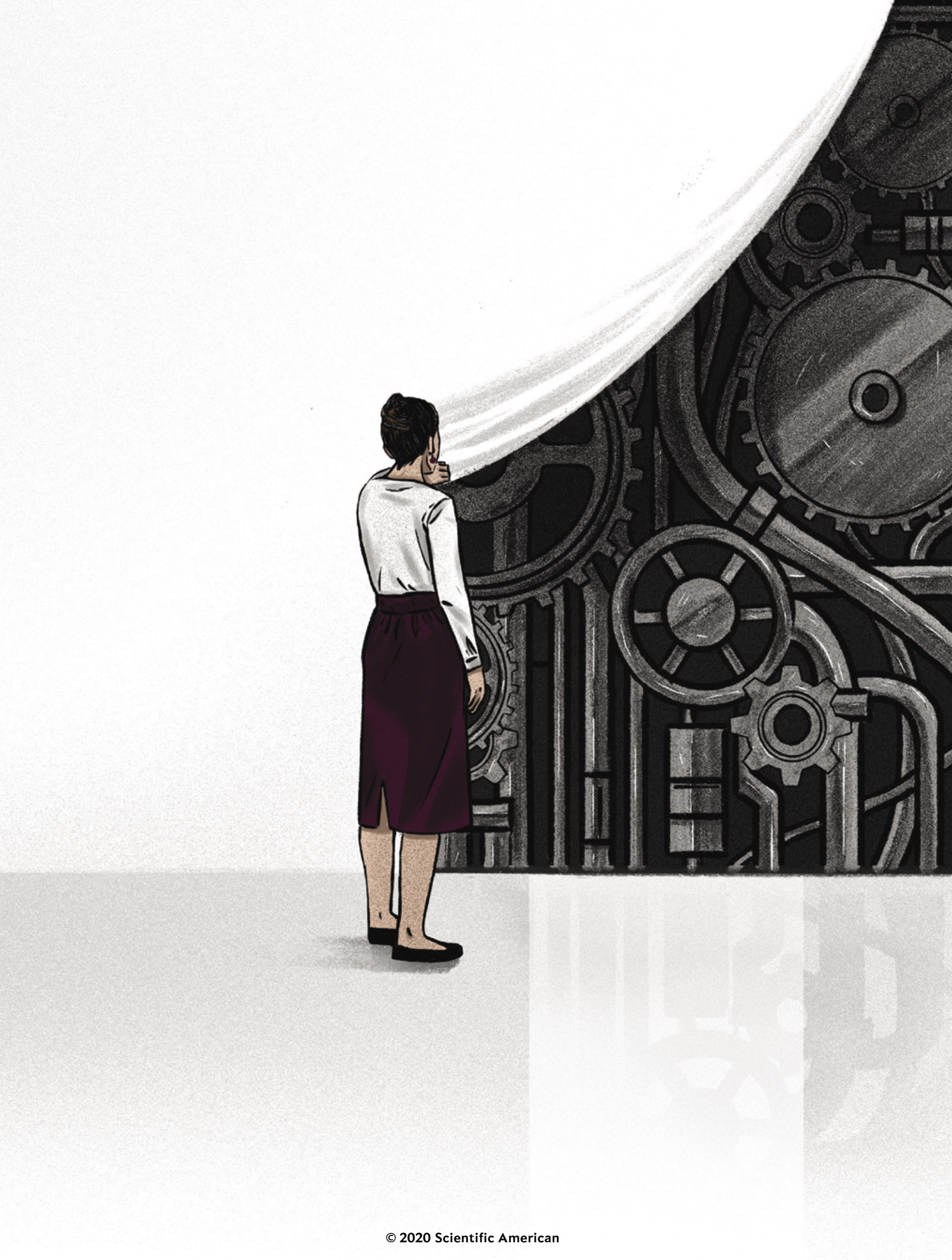
scientificamerican.com/magazine/sa

HOW TO UNLEARN RACISM

Implicit bias training isn't enough. What actually works?

By Abigail Libers

Illustration by Benjamin Currie



Abigail Libers is a freelance journalist and editor based in New York.

IN FEBRUARY 2016 I SAT IN A CONFERENCE ROOM ON THE UPPER EAST SIDE OF MANHATTAN with about 35 other people attempting to answer what seemed like a straightforward question: *What is racism?*

I—a white, able-bodied, cis-gendered woman in my 30s—thought that racism was prejudice against an individual because of race or ethnicity. That's why I had signed up for the Undoing Racism Workshop, a two-and-a-half-day antiracist training that analyzes race and power structures in the U.S.: I wanted to gain a better understanding of why some people have so much contempt toward those who are different from them. My yearning for answers came from personal experience with discrimination as a Jewish woman and the daughter of immigrants; my parents fled to the U.S. from the former Soviet Union in 1979. Growing up in a small town in upstate New York followed by an even smaller, more rural town in Georgia, I was picked on and often felt "othered."

The workshop was hosted by the People's Institute for Survival and Beyond (PISAB), an organization that was founded 40 years ago by community organizers who wanted to create a more equitable society by addressing the root causes of racism. Our leaders—a Black man, a white woman and a Latina woman—called on each of us to share our definitions of racism. People's responses were all over the map, from "a mean-spirited, close-minded way of thinking" to "discrimination based on someone's skin color or ethnic background." The trainers validated each of our responses before pointing out how varied they were and explaining that few of us had identified racism as a web of institutional power and oppression based on skin color. Not having a simple or agreed-on definition of racism makes it easier to keep racism in place. To undo racism, they said, we need a common language that ties together individual and systemic factors. Hearing racism described as a power hierarchy was eye-opening for me. Having been marginalized myself, I thought I was sensitive toward other groups who faced discrimination. I thought I got it.

Over the past several months, America has been reckoning with racism on a scale that has not been seen since the civil-rights movement. The recent killings of George Floyd, Ahmaud Arbery, Breonna Taylor and others sparked protests against systemic racism and police violence that have drawn multiracial participation. Some white Americans attended Black Lives Matter protests for the first time—the movement has been active since 2013—and saw up close the police brutality they previously only read about or witnessed through short video clips on phone screens. These experiences were a tiny window into the reality of violence and oppression that Black people endure. The pandemic further emphasizes the racial disparities that people are protesting, with Black, Latinx and Indigenous communities disproportionately affected by COVID-19. It has become widely discussed that police violence and virus deaths are not disparate issues—they are both embedded in a pervasive system of racism.

PISAB's definition of racism (which is similar to that of other antiracism organizations such as the Racial Equity Institute) is race prejudice plus power. It describes how individual and systemic racism are tied together. All of us have individual race prejudice: anyone can prejudge a person based on race alone. But what makes racism different from individual prejudice is who has institutional power. White people control

our government systems and institutions in every sector, from law enforcement and education to health care and the media, leading to laws and policies that can advantage white people while disadvantaging everyone else.

White people's dominance in our systems is why you may have heard people refer to the U.S. as a white supremacist society in recent months. In this context, white supremacy does not refer to hate groups such as neo-Nazis and the Ku Klux Klan but rather an entire *system* where one group has all the advantages. "Racism *is* white supremacy," says Joseph Barndt, an organizer and core trainer with PISAB and author of *Understanding and Dismantling Racism: The Twenty-First Century Challenge to White America*. "It's empowering one alleged racial group over another and creating systems to reinforce that."

As more white people seek to confront and undo racism in their own lives, they are figuring out how to "do the work." In recent years implicit bias trainings, which aim to expose people to the negative associations and stereotypes they hold and express unconsciously, have been widely used to raise people's awareness of racism in workplaces. But addressing bias is not sufficient for confronting the racist systems, ideas and legacies that are present in our day-to-day lives. There is no one-size-fits-all solution, but research shows that undoing racism often starts with understanding what race and racism actually are. It is also crucial to develop a positive racial identity; to feel—not just intellectualize—how racism harms *all* of us and, finally, to learn how to break prejudice habits and become an active antiracist. Doing so, however, is not accomplished in a weekend. For me, one of the first steps was unlearning false ideas about the basis of racial categories.

Although biology has shown that there are no genetically distinct races, racial *identity* is very real. In a white-dominant society, white people tend to be unaware of their identity and may think of themselves as neutral, as nonracial.

SEEING WHITENESS IN THE ORIGINS OF RACE

RACE IS DEEPLY EMBEDDED in our society, yet it is persistently misunderstood to be a biological construct rather than a cultural one. The concept of racial categories is actually quite modern, explains Crystal Fleming, a professor of sociology at Stony Brook University and author of *How to Be Less Stupid about Race:* "If we think about our species existing for at least a few hundred thousand years, it's only in the last several centuries that we see the historical emergence of the idea of race." This is a history that most Americans are not taught in school.

False classifications of humans that would later be called "races" began in the 16th and 17th centuries with Christian clergy questioning whether "Blacks" and "Indians" were human. As colonial expansion and slavery increased, religion was used to justify classifying Black people and other people of color as "pagan and soulless." But as many of them were converted to Christianity and the Age of Enlightenment took off in the 1700s, religion lost its legitimizing power.

Instead "science" was used to justify the enslavement of Africans and the genocide of Indigenous peoples, which had already been occurring in British colonies for more than a century. Johann Friedrich Blumenbach, a German anthropologist and comparative anatomist, is known for proposing one of the earliest classifications of the human race, which he wrote about in the late 1700s.

His measurement of skulls from around the world led him to divide humans into five groups, which were later simplified by anthropologists into three categories: Caucasoids, Mongoloids and Negroids. It did not seem to matter that some prominent scientists, including Charles Darwin, dismissed a biological basis for race over the next century. Many scientists dedicated themselves to proving a false racial hierarchy in which "Caucasians" were superior to other races.

In the U.S., political and intellectual leaders reinforced the false ideology that Africans were biologically inferior to other races and therefore best suited for slavery. After Bacon's Rebellion in 1676, which had united white and Black indentured servants, Virginia lawmakers began to make legal distinctions between "white" and "Black" people. Poor white indentured servants who served their term could go free and own land; Black servants were committed to lifelong servitude. With the Naturalization Act of 1790, Congress codified white racial advantage into law by limiting citizenship by naturalization to "free white persons," namely white men. Women, people of color and indentured servants were excluded.

With white superiority cemented firmly into law, the social and political power of *whiteness* was born. As a category, it was increasingly associated with resources and power: explicit laws and practices that created whiteness as a requirement for being able to live in certain neighborhoods, to be able to vote, to own land, to testify in court before a jury. The legacy of "scientific" racism persists to this day.

Although biology has shown that there are no genetically distinct races, racial *identity*—how you and others perceive your race—is very real, as are its ramifications. In a white-dominant society like America, white people tend to be unaware of their identity and may think of themselves as neutral, as nonracial. According to the work of psychologist Janet Helms, who published six stages of white racial identity development in 1999, the first stage is defined by a lack of awareness of cultural and institutional racism. This stage is also characterized by being "color-blind"—imagining one does not see people's differences and viewing that as a positive trait others should aspire to.

As scholar and activist Peggy McIntosh notes in a 1989 article, this lack of awareness is common. She describes white privilege as an "invisible package of unearned assets that I can count on cashing in each day, but about which I was 'meant' to remain oblivious. White privilege is like an invisible weightless knapsack of special provisions, maps, passports, codebooks, visas, clothes, tools, and blank checks."

To unlearn racism then, white people must first examine their racial identity. Black scholars and writers of color have known this for more than a century; their survival depended on it. Frederick

Douglass, W.E.B. Du Bois, James Baldwin, Audre Lorde, Angela Davis, Ta-Nehisi Coates and many others have observed, analyzed and written about whiteness for generations. Du Bois made observations about whiteness in 1899 with his sociological study *The Philadelphia Negro* and in 1935 with his book, *Black Reconstruction in America*. Recently Ijeoma Oluo, author of *So You Want to Talk about Race,* wrote in a popular Medium article: "I know white culture better than most white people know white culture."

It has only been in the past few decades that white scholars have turned the lens on themselves with the emergence of Critical Whiteness Studies (CWS), a growing academic field that aims to examine the structures of white supremacy and privilege and to investigate the meaning of white privilege and how it is connected to complicity in racism. According to Barbara Applebaum, a professor of philosophy and education at Syracuse University, CWS shifts the focus, and thus the blame, from the victims of racism to the perpetrators. As she explains, "it names the elephant in the room—the construction and maintenance of whiteness."

This awakening may lead people to work on creating a positive racial identity away from white supremacism. Shame isn't an effective motivator and can inhibit the stamina needed to push for systemic change.

WORKSHOPS AREN'T ENOUGH

OVER THE PAST 20 YEARS OR SO initiatives to address racism have focused heavily on implicit bias trainings. A growing body of cognitive research demonstrates how these hidden biases impact our attitudes and actions, which result in real-world consequences such as racial profiling.

The trainings, which are often sponsored by human resources departments but delivered to employees by outside consulting firms, may consist of modules that walk people through what implicit bias is and where it comes from, how it shows up in the workplace, how it is measured (typically through the Implicit Association Test) and how to reduce it. Over the past decade these trainings have been widely used in the law-enforcement industry as well as in the tech industry, with companies such as Facebook and Google putting thousands of employees through trainings. More recently, antibias trainings have been implemented in schools for teachers.

While these sessions may be useful in exposing people's hidden biases, those revelations have not been shown to result in long-term behavioral change on an individual or systemic level. In a 2018 paper published in *Anthropology Now,* Harvard University sociologist Frank Dobbin writes: "Hundreds of studies dating back to the 1930s suggest that antibias training does not reduce bias, alter behavior or change the workplace."

A recent meta-analysis of 492 studies (with a total of 87,418 participants) on the effectiveness of implicit bias training found weak effects on unconscious bias. The authors note that "most studies focused on producing short-term changes with brief, single-session manipulations" and that most trainings "produced trivial changes in behavior." The authors conclude that changes in implicit bias are possible, but they do not necessarily translate into changes in explicit bias or behavior, and there is a significant lack of research on the long-term effects.

"Implicit bias trainings raise awareness, but they also tell people, 'This is just how the brain works,'" says Rachel Godsil, cofounder and co-director of the Perception Institute, an organization that works with social scientists to identify the efficacy of interventions to address implicit bias, racial anxiety and the effects of stereotypes. "It kind of leaves people feeling like they are let off the hook." It's not that your brain is hard-wired to be racist, but it *is* programmed to put people into categories. And the categories that have been constructed in the U.S., Godsil explains, have meanings that tend to be negative for people from marginalized groups. She emphasizes that part of what it means to unlearn racism is to delink stereotypes from identities and absolute truths: "You're not trying to be color-blind or pretend that these categories don't exist, but you don't presume you know anything about a person based on their identity."

Antiracism trainings, such as the Undoing Racism Workshop, differ significantly from implicit bias trainings in that they are more intense on both an intellectual and emotional level. Because they are not done in a corporate setting, the discussions tend to be more honest and raw. In the PISAB training I attended, we took a hard look at white supremacy and our role in upholding it. After reviewing a history of racism in the U.S., the trainers discussed individual and institutional racial attitudes, oppression and privilege, and how institutions implicitly or explicitly perpetuate racism. We were empowered to be "gatekeepers"—leaders who can affect change in our workplaces and communities.

PISAB's methodology is rooted in community organizing principles that the group's founders honed for decades. Their approach is based on philosopher Paulo Freire's pedagogy, which focuses on linking knowledge to action so people can make real change in their communities. Other antiracist trainings, such as the one offered by Crossroads Antiracism Organizing & Training, provide a similar approach. In contrast, Robin DiAngelo, author of *White Fragility: Why It's So Hard for White People to Talk about Racism,* who has received much attention in recent months, gives "keynote presentations" that are more focused on individual prejudice and white privilege.

Whereas these trainings can be powerful in many ways, it is unclear to what degree they are effective—and if they are, how and why they work. A 2015 study published in *Race and Social Problems* aimed to measure the impact of PISAB's training and found that approximately 60 percent of participants engaged in racial equity work after completing the Undoing Racism Workshop. "These trainings are well intentioned, but we don't know if they work, because there aren't randomized controlled experiments to prove that they do," says Patricia Devine, a professor of psychology who studies prejudice at the University of Wisconsin–Madison.

Trainings on implicit bias, diversity and antiracism may be limited in their efficacy in part because they tend to be brief one-

off events. Promising research by Devine in 2013 showed that prejudices and biases can be more successfully unlearned through longer-term intervention. The 12-week longitudinal study was based on the premise that implicit bias is like a habit that can be broken through the following steps: becoming aware of implicit bias, developing concern about the effects of that bias and using strategies to reduce bias—specifically, ones that replace biased reactions with responses that reflect one's nonprejudiced goals.

The researchers argue that the motivation to "break the prejudice habit" comes from two sources: First, you have to be aware of your biases, and second, you have to be *concerned* about the consequences of your biases to be motivated to make the effort needed to eliminate them. Recent research has shown that interacting with a wide variety of racial groups can help people care more about racial justice. For instance, a 2018 review suggested that increased contact among racial groups deepens psychological investment in equality by making people more empathetic.

For Fleming, who has educated thousands of university students, teaching implicit bias within the context of a comprehensive, three-month course "is far more effective than being dragged into a diversity training for an afternoon," she says. "People have to feel inspired. They have to feel a desire to critically reflect on not just their biases but on their socialization and conditioning and to be part of a positive social transformation. You can't force that on anyone."

FEELING THE HARMS OF RACISM

THE INSPIRATION that Fleming speaks to is what motivates me to unlearn racism, to reeducate myself on swaths of American history, and to open my eyes to whiteness and white supremacy. But the process of unlearning is only the first step, and it needs to translate into a commitment to practices such as breaking white silence and bringing an antiracist lens to my work. That is only possible, and sustainable, by building empathy and *feeling* the ways in which racism is not just harmful for people of color—it hurts white people, too.

This realization didn't hit me until I took PISAB's workshop for a second time in 2019. I had signed up at the urging of Stoop Nilsson, a social worker and racial reeducation coach who shows white people how to become antiracist leaders in their communities. During the workshop, Barndt, one of the trainers, pointed out how easy it can be for white people to think racism does not harm them. But "the truth is, with racism we lose, too," he said. "All of humanity loses. With the end of racism, we get our lives back."

H. Shellae Versey, a critical health researcher and professor of psychology at Fordham University, studies how white supremacy culture impacts the mental health of both white and nonwhite populations. In a 2019 paper, she and her co-authors explain how white people are harmed by the myth of meritocracy—the idea that working hard and pulling yourself up by your bootstraps leads to success. When this does not happen (for example, if you do not land a promotion you worked hard for), it threatens your worldview and leads to significant stress, research shows.

Versey notes that many white people oppose social health programs such as the Affordable Care Act that would actually benefit them, in part because they believe these programs are designed to benefit people of color. In his recent book *Dying of Whiteness,* physician Jonathan Metzl writes about how some white Americans support politicians who promote policies that increase their risk of sickness and death.

Another way we are all harmed on a day-to-day basis is through white supremacy culture. As Kenneth Jones and Tema Okun write in the book *Dismantling Racism: A Workbook for Social Change Groups,* the characteristics of white supremacy culture include perfectionism, a sense of urgency, defensiveness, quantity over quality, paternalism, either/or thinking, power hoarding, individualism, and more.

Understanding and *feeling* how racism hurts me—even though it is a mere fraction of the pain people of color experience—is part of what helps me internalize the motivation I need to consistently work to undo it. I wonder if white supremacy culture contributes to my elevated anxiety levels, which manifest as migraine headaches and torn-up cuticles. I am more clearly connecting white supremacy culture with climate change denial as well as the paternalism and overly rigid thinking I have experienced in various jobs.

Working with Nilsson is helping me create a positive racial identity of my own—as both a white person and a Russian Jew. Our country prides itself on being a melting pot, but much gets lost in the assimilation to whiteness and white supremacy culture. Markers of ethnic identity such as language, food, culture and music are discouraged; those from a non–Western European heritage are often vilified. In my family, my parents were so committed to learning English that they hardly ever spoke Russian around the house. I never learned it. It saddens me that I can't speak to my own parents in their native language and that I still know so little about our heritage. Recently my mom became frustrated trying to remember a word in English to describe how she was feeling; I worry that her last words will be in Russian, and I'll have no idea what they mean.

In the midst of COVID-19, a high-stakes election season and racial protest movements that illuminate issues affecting everyone, many Americans are reevaluating what matters most. White people may be waking up to areas of their lives that were previously inaccessible to them and to histories and literature and legacies that have long been excluded from school curriculums. This awakening may lead people to work on creating a positive racial identity away from white supremacism, one based on fully acknowledging the power of whiteness in our society and using that knowledge to pursue equality and justice for everyone. Skipping that step risks giving up or doing even more harm; shame and self-loathing are not effective motivators and can inhibit the strength and stamina needed to push for systemic change.

Having been in this process myself for several years, I am certain of only one thing: that antiracism is a lifelong practice. In her book *Why Are All the Black Kids Sitting Together in the Cafeteria?,* psychologist Beverly Daniel Tatum compares racism to smog, writing that it is something we all breathe in; no one is immune to it. Attempting to unlearn racism has meant becoming aware of each inhalation—and doing my best to exhale less of it. SA

FROM OUR ARCHIVES

Automating Bias. Virginia Eubanks; November 2018.

scientificamerican.com/magazine/sa

PSYCHOLOGY

ALL TOGETH NOW

Synchronized activities such as group dancing and exercise promote surprisingly strong social bonds, probably through changes in brain chemistry

By Marta Zaraska

STUDENTS PRACTICE their moves in unison at a large martial arts school in China.

ER

Marta Zaraska, a freelance writer based in France, is author of *Growing Young: How Friendship, Optimism and Kindness Can Help You Live to 100* (Penguin Random House, 2020). She wrote "Shrinking Animals" in the June 2018 issue.

TO SAVE ANY OF HIS MARCHING BANDMATES, STEVE MARX SAYS, HE WOULD RUN INTO ONRUSHING traffic with no hesitation. It's the kind of language often heard from former army buddies, not musicians, but Marx brings up the scenario to show the strength of his feelings about this group. The marching band director at Gettysburg College in Pennsylvania has been participating in musical ensembles for more than 20 years, since he was in high school, and says that "the sort of bonding that you form is extremely strong. It's like a family." Everyone is in matching uniforms, musical instruments in hands, marching forward in perfect harmony, left leg, right leg, movements and sounds so synchronized that individuals blur into the greater group. The allure is not even that much about music, he admits. Marching, for him, is mostly about the sense of kinship.

Many group activities boost our sense of belonging, but research shows that doing things synchronously can build even stronger social ties and create a greater sense of well-being. Crew rowing, line dancing, choir singing or simply tapping fingers in sync increases generosity, trust and tolerance toward others, often beyond effects seen in more disorderly doings. It can even increase people's threshold for pain. Why simultaneous, coordinated movement delivers this extra dose of affinity is just now becoming understood, according to Laura Cirelli, a psychologist and synchrony researcher at the University of Toronto. The phenomenon's powerful effects on us result from a combination of neurohormonal, cognitive and perceptual factors. "It's a complicated interplay," she says. There is also evidence that we have a propensity for synchrony that may have been selected during the course of human evolution, in part because it allows us to bond with large numbers of people at once, offering a survival advantage.

People are not unique in their capability to synchronize activities—certain animals do it as well. Bottlenose dolphins arc through the water in unison, for instance, and males of some firefly species harmonize their flashes. Animal behaviorists theorize that, as with humans, these coordinated behaviors promote various positive social benefits, like attracting a mate. What sets us apart is that our synchrony happens across such a wide variety of behaviors. Some are organized—think of group prayers, chorale singing, military parades and flash mobs. Some are spontaneous—think of concertgoers clapping in time to a song or of a couple strolling through a park, their feet hitting the path at the exact same time. If two people sit in rocking chairs beside each other, studies have shown, they will impulsively start moving back and forth in parallel.

Marx credits synchrony for his devotion to his bandmates, and psychological experiments have shown this kind of coordination does improve group feelings. In one study, researchers at the University of Oxford split young schoolchildren into two groups. One wore orange vests and the other green vests. Such costuming can incite divisions among kids. The experimenters, however, asked the children to spend time dancing together synchronously. Afterward the greens and the oranges bonded more and played closer to each other than similarly divided children who danced in an uncoordinated way.

IMPROVED AFFINITY

IT'S NOT JUST CHILD'S PLAY. A series of experiments in Hungary, published in 2019, suggests that walking in sync with a person from an ethnic minority can reduce prejudice. Negative stereotyping of Roma people is prevalent in Hungary. When researchers asked non-Roma to assign positive or negative words to pictures of traditionally dressed Roma people, they used more negative words. When the same group looked at pictures of traditionally dressed Hungarian people, they used more positive words. Then the investigators asked the non-Roma to walk laps around a large room either in sync or out of sync with someone who was introduced as Roma. When later the researchers asked about the volunteers' feelings toward the Roma, those who engaged

PRECEDING PAGES: GETTY IMAGES

PERFORMERS move as a group for *ingoma,* a traditional Zulu dance in South Africa.

RAJESH JANTILAL *Getty Images*

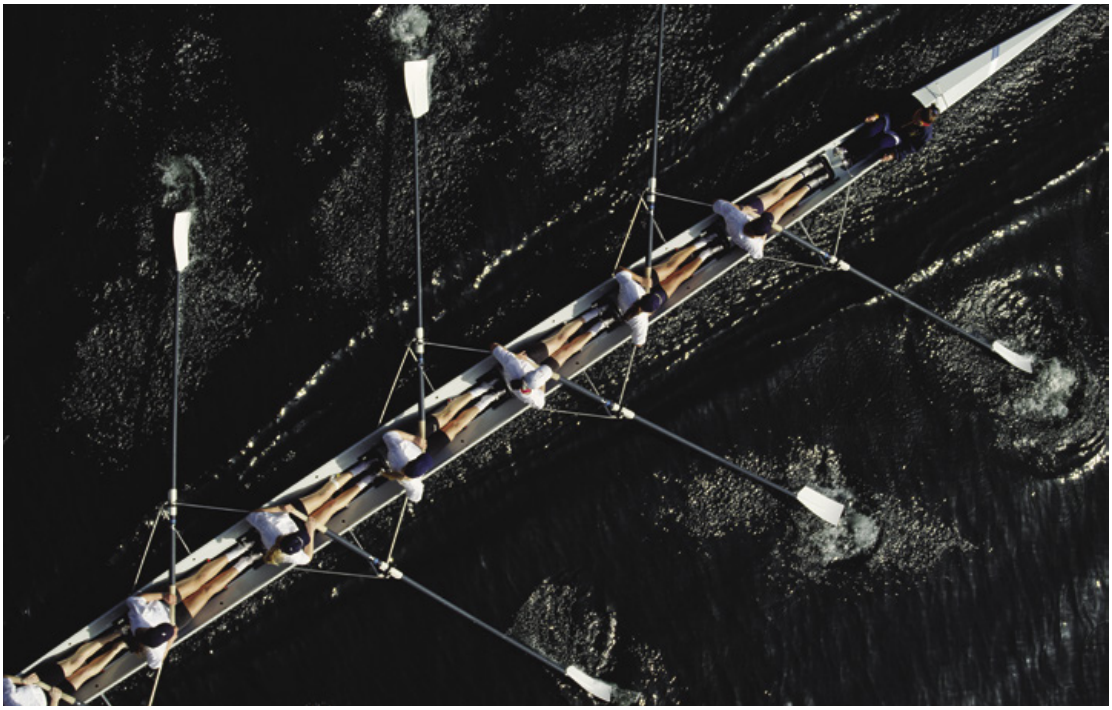
in synchrony expressed a greater sense of closeness and indicated more desire to see their partners again.

The scientists do not know how long such effects might last, so coordination may not be a permanent remedy for antagonism. Still, it does appear to minimize bias in some situations, and one possible reason may be because it simply makes us like one another more. In a study published in 2009 in *Social Cognition,* participants tapped their fingers in rhythm with a metronome and in some instances were joined by an experimenter who drummed either to the same beat or to a different one. Results showed that volunteers who were coordinated with the experimenter were later more inclined to say that they found him likable.

These feelings of affinity translate into more positive behavior toward others. Synchronous finger tapping, for example, can prompt people to be more generous when donating money. In a series of experiments published in 2017 in *Basic and Applied Social Psychology,* researchers divided volunteers into groups of six, which were then further split into subgroups of three. After members briefly worked together on a group activity, they were given various scenarios for splitting money among themselves and asked to whom they would give. If they then spent time tapping fingers in synchrony with their little trio only, they were more willing to donate money to those people. But if two of these trios tapped in sync—forming a group of six for a few minutes—the members were more likely to donate to all six. Asynchronous tapping, meanwhile, did nothing to boost generosity. A 2017 meta-analysis of 42 studies confirmed that synchronous activities, from running in sync to rocking in chairs at the same pace, prompt people to behave prosocially.

Psychologists and neuroscientists explain the way synchrony draws people together with a dry term: self-other blurring. "It's a weakening of boundaries between self and other. As we become attuned to other people's actions, whether we do it consciously or not, we integrate them with our own," says Ivana Konvalinka, a cognitive neuroscientist at the Technical University of Denmark.

Even very small children tend to be more helpful after engaging in synchrony. Babies cannot be told to act in sync, of course, so researchers have come up with creative ways to examine the effect. In one experiment published in 2017 in *Music Perception,* a person had a 14-month-old infant strapped to his or her chest in a baby carrier and another person standing in front of them. Both adults began to bounce, sometimes in perfect synchrony, sometimes not. This made the babies bounce, too. Psychologists conducted a series of experiments using this design. After the in-unison bouncing session, if the second adult dropped a ball or other object, the babies were quite eager to pick it up and hand it back. But those infants who were not bounced in sync were not as helpful. The fact that the effects of synchrony are apparent in such small children suggests this behavior is important to the species, says cognitive



ROWERS who train in synchrony have higher levels of endorphins, brain chemicals that blunt pain.

HARALD SUND *Getty Images*

anthropologist Emma Cohen of the University of Oxford. "If something is emerging really early in life, then it's likely fairly automatic and really salient for us as humans," she says. It may even have played an important role in our evolution.

EVOLVING IN UNISON

PSYCHOLOGIST ROBIN DUNBAR of Oxford believes that by facilitating prosocial behaviors and cooperation, synchrony could have encouraged bonding in groups of early humans as their populations grew. He has been researching synchrony for years, a fascination that started at a conference on the archaeology of music. One of the evening sessions was unusual. A musician from South Africa invited Dunbar and other attendants to participate in something resembling a traditional Zulu dance. He told them to stand in a circle, handed them plastic pipes cut to different lengths and instructed them to blow across the top of the pipes, making random noise, and to start walking around the circle. At first, Dunbar says, the noise was horrible, but after a few minutes the sounds and movements changed without particular effort, the scientists became synchronized, playing music in a consistent tune with one another. "Everybody felt this sense of belonging, being part of the group. I realized this was an amazing effect," he says.

Dunbar now theorizes that in human evolution synchrony might have enhanced grooming as an important bonding mechanism. Nonhuman primates groom one another to remove fleas and other parasites, and the time spent doing this promotes group cohesion. The activity does take a lot of time and effort as the number of groomed individuals increases, and Dunbar argues that sets an upper limit on the size of a close-knit group. When he plotted the time that various primate species spend grooming one another against their typical group size, it appeared that the two were directly correlated. The upper limit corresponded to a group size of 50 primates. No monkey or ape species forms groups that are, on average, larger, but humans do. Dunbar calculated that a natural community for us stands at about 150 people. He worked out this number based on the size of the human neocortex compared with those of other primates, as well as the populations of villages in small-scale societies and the number of friends and family that people in larger-scale societies tend to have. That figure is borne out in early historical records, too: it was the average village size in England in A.D. 1086 when William the Conqueror surveyed his new kingdom. (Not everyone agrees 150 is a solid number; some scientists have argued it is based on overly selective data.)

One reason early humans may have been able to sustain a group size that is triple that of the average ape, Dunbar suggests, is they came up with a way to "groom" several people at once—using voices or body movements instead of picking parasites with fingers. The larger size offered groups protection against raids by other humans, increasing their ability to survive and reproduce, which in turn allowed for the natural selection of a propensity for synchrony in future generations, Dunbar contends.

The adoption of such behavior often has biological underpinnings. In nonhuman primates grooming triggers the release of neurochemicals called endorphins, which seems to enhance good feelings, Dunbar says. And research suggests that endorphins, which the body produces to reinforce pleasure and relieve pain, might be among the mechanisms that allowed singing and danc-

ing to replace classic grooming in human bonding. Some researchers have called them the "neurochemical glue" of human relationships.

BRAINS AND MOVEMENT

AN ENDORPHIN-INFUSED SENSE of bonding and commitment has been apparent in several experiments, some of them coming from Dunbar's laboratory. One of the early studies showed not only that synchronous behaviors likely trigger the endorphin systems but also that they do so beyond the effects produced by the physical activity itself (the famed "runner's high"). In one of Dunbar's studies, male athletes from the University of Oxford Boat Club were invited to train on rowing machines independently and then work out in synchrony. After the exercise, researchers measured how much pain each of the rowers could take by inflating blood pressure cuffs on their arms until they could no longer take the discomfort. (Measuring endorphin levels directly is difficult, so brief pain perception is commonly used as a proxy.) Dunbar and his colleagues learned that athletes who exercised in sync with others were much more resistant to pain afterwards, and the scientists calculated their endorphin output basically doubled.

A similar series of experiments showed that when it comes to dancing, synchrony boosts endorphin effects far more than do dissonant moves around the floor. Volunteers were first taught some basic dance moves such as "driving" (one hand is extended as if resting on top of a steering wheel, crossing from left to right and back, while the other hand hangs relaxed along the body) or "swimming" (knees bending rhythmically, arms alternating from side to side as if doing the front crawl). Afterward, the participants were divided into groups of four and went onto the dance floor, where everyone was handed headphones through which music would flow. The trick, though, was that in some groups all four volunteers heard exactly the same music and were instructed to do the same movement routine, causing synchrony. But in other foursomes, the members heard different tunes or were instructed to do different routines—causing a weird, discordant silent disco. After the dancing was over, the blood pressure cuffs came out, and the measurements began. Once again, those who engaged in synchrony proved more resistant to pain, confirming that the effects are not merely caused by dancing with others but by dancing with others in synchrony. The scientists behind the experiments, which were published in 2016 in *Evolution and Human Behavior,* also checked how well the participants bonded. As in other studies of emotional reactions, those who boogied in sync said they felt closer to the other participants than did those who danced separately.

Although endorphins offer a neurochemical explanation for synchrony's powerful effects, other biological mechanisms may be at play, too. When it comes to activity patterns within the brain, synchrony seems to prompt different effects than does humming or shimmying without harmony. A 2020 study using functional near-infrared spectroscopy—a noninvasive technique that measures how much oxygen a particular brain region is using, which indicates how hard it is working—showed that while nonsynchronous movements mostly activate just the left hemisphere of the brain, synchrony involves activation of both the left and right hemispheres. This suggests that synchrony is a far more complex behavior than simpler movements.

COORDINATED REWARDS

OTHER RESEARCH SUGGESTS that the brain's reward system, including the neural structures involved in desire and motivation, also plays a role in the power of synchrony by creating a positive feedback loop. Using functional magnetic resonance imaging—another way to gauge brain activity—a series of experiments revealed that for those who find drumming easy, doing it in sync hikes activity in the right caudate, a reward-related area, which in turn makes people more likely to help the person they drummed with. "We believe that during synchronized drumming, the caudate activity reflects the rewarding nature of the experience," says Christian Keysers, a neuroscientist at the Netherlands Institute for Neuroscience and the study's lead author. "Participants will then be more likely to engage in joint actions with that person in the future." People synchronize, our reward areas of the brain activate, and that pushes us to do more to help our partners.

Early humans may have been able to sustain a group size that is triple that of the average ape because they came up with a way to "groom" several people at once—using voices or body movements.

Although not everyone experiences the effects of synchrony with equal force, the experience of moving in rhythm with others or of harmonizing voices appears to play an important role in human societies. That is likely why we see synchrony all over, in large symphony concerts, in dance parties and in village ceremonial performances. When we are in sync, our hormones and our brain activity help to smooth societal wrinkles, keeping us together. Joining a marching band may not be the path to world peace, but behavior like it may help make us more tolerant and better able to see the greater good in wider communities. SA

FROM OUR ARCHIVES

The Evolution of Dance. Thea Singer; June 2017.

scientificamerican.com/magazine/sa

ARCHAEOLOGY

Fate of the Unconquered Maya

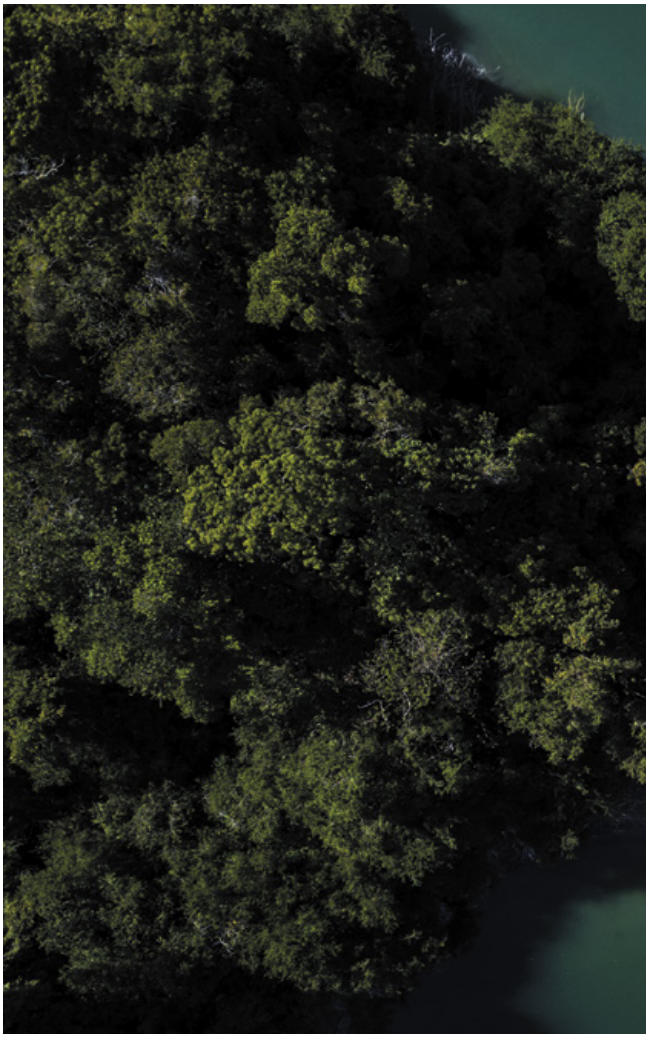
The Lacandon Maya eluded the Spanish conquistadors and survived in the jungle for hundreds of years. Archaeological discoveries are revealing their past

By Zach Zorich

Photographs by Christian Rodriguez

LAKE MENSABAK in southern Mexico is home to the Lacandon Maya.

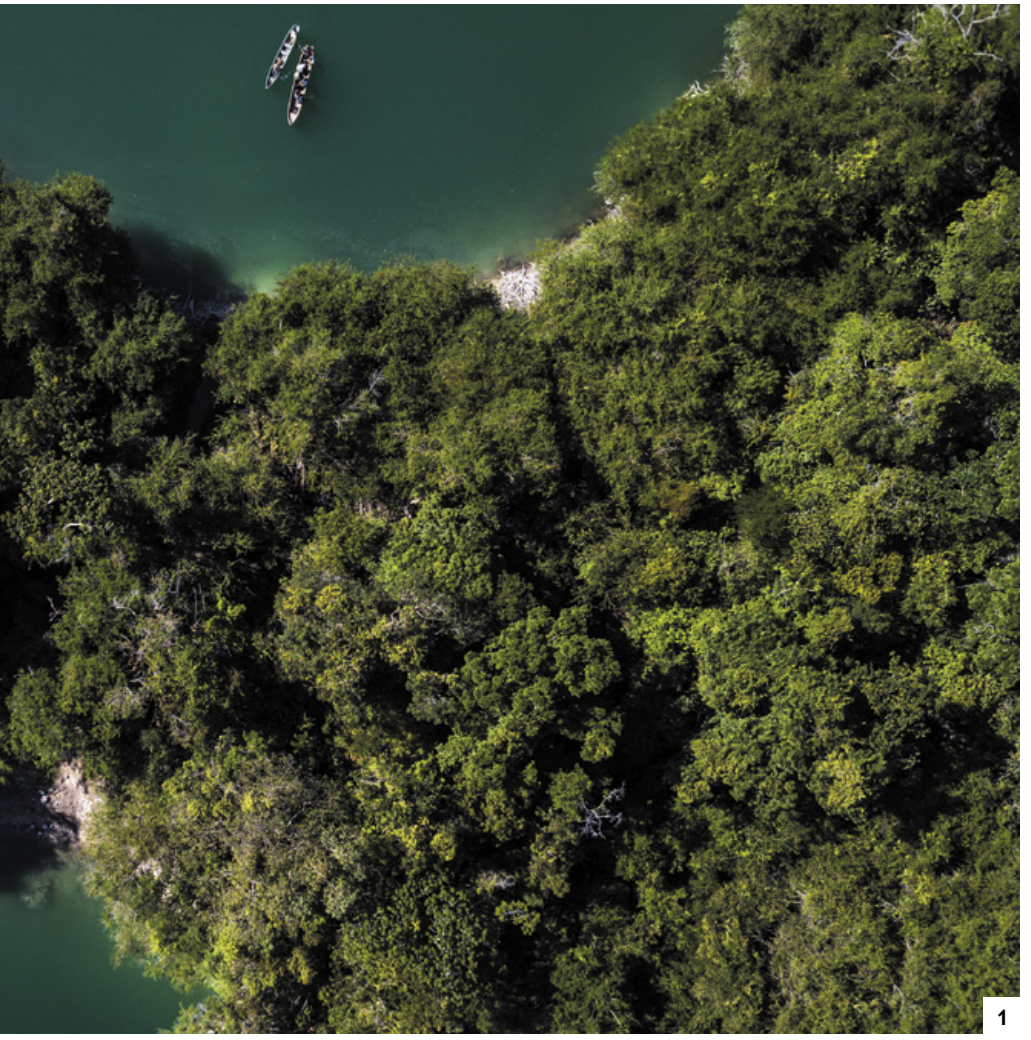
Zach Zorich is a Colorado-based freelance writer. His last feature article for *Scientific American* examined the reasons for the decline of the Greenland Vikings.



SOME 550 YEARS AGO THE LAST OF the great city-states of the Maya civilization that had flourished in the Americas for centuries met their demise. As drought and warfare tore apart the social and political fabric and the Spanish conquistadors began claiming Maya land for plantations and subjugating Maya people to work on them, many residents of storied stone cities such as Yaxchilan and Palenque fled to the countryside in search of a better life. Ultimately they founded a host of new Maya cultures. Some people, known as the Lacandon Maya, established themselves in the forests around Lake Mensabak in the southern Mexican state of Chiapas. Their descendants still live in this region today. They are the *Hach Winik,* "the true people" in Yucatec Mayan.

For decades anthropologists thought these modern-day Lacandon were a time capsule of sorts, a Maya group that had survived the collapse and subsequent Spanish conquest intact, unchanged for hundreds of years. Starting in the 1980s, however, as researchers learned more about the Lacandon, it became clear that this was not the case. Although it incorporated elements of classic Maya culture, the Lacandon way of life was distinctive.

For the past 17 years archaeologists Joel Palka of Arizona State University and Fabiola Sanchez Balderas, president of Xanvil, a Mexican organization that studies and supports Maya culture, have been collaborating with the modern Lacandon Maya to learn what they can about the birth of their culture and to understand how their ancestors adapted to a world that was being radically reshaped by forces outside their control. The team's excavations at various sites around Lake Mensabak are the first to explore the Lacandon past. The research is yielding a detailed picture of the lives of Maya people who survived colonialism to carry on the traditions of their ancestors while developing customs, beliefs and survival strategies of their own.



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SACRED LANDSCAPE of Lake Mensabak (*1*) contains dozens of spiritually important sites. One of the most significant is a limestone cliff that is believed to be both the home of Mensabak—the god of agriculture and rain—and the gateway to the heaven of Mensabak, where the Lacandon people go when they die. At the base of the cliff lies a bone shrine containing the remains of people who may have been some of the first Lacandon. The skulls have flattened foreheads and craniums that were shaped into two separate lobes during early childhood when the bone was pliable (*2*). Clay pots bearing the faces of gods accompany the bones (*3*). Each god pot overflows with a tarry substance that is left over when resin from the seed pods of copal trees is burned and prayers are chanted over the fragrant smoke. Archaeologists draw a direct connection between these god pots and the elaborate ceramic *incensarios* that Maya people used to make offerings to their gods for 3,000 years. It is one of many examples of cultural continuity between the Lacandon and the ancient Maya.

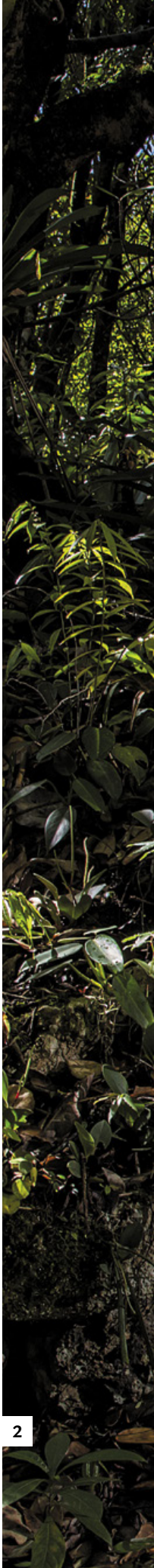
THE LACANDON were not isolated in this area of southern Mexico—and they appear to have fought extensively with neighboring Maya groups. Excavations at a site called Tzibana on the eastern side of the lake are revealing how the Lacandon defended their territory. There, among the village ruins, the archaeologists have found the remains of a defensive wall that was built between two pyramids, which form a choke point in the landscape. Constructed from uncut chunks of limestone, the wall stands a few feet high. Team member Josuhé Lozada Toledo of Mexico's National Institute of Anthropology and History thinks that warriors stood on the wall behind a taller wood palisade, which would have given them cover as they fought with spears and javelins. The hillside below the wall was planted with piñuela, a species of agave that has sharp spines along the edges of its leaves, forming a kind of natural barbed wire. Tzibana may have been the first line of defense against attackers coming from the east.

1

2

CITY DWELLERS moved to the countryside in search of not only farmland and water for irrigation but also places that held spiritual forces they believed could protect them from a world that offered enemies in every direction. "It wasn't just natural resources but supernatural resources" that drew the Maya to Lake Mensabak, Joel Palka says. Evidence of religion as a driving force in Lacandon society is everywhere here. Ancient paintings of gods and spiritually significant animals adorn the limestone cliffs at Tzibana and other sites around the lake (*1*). A carved serpent at the base of the Tzibana cliffs resembles the Aztec feathered serpent god Quetzalcoatl, according to Palka, and may reflect the influence of the Aztecs on the Lacandon (*2*).

1



2

EL MIRADOR mountain bridges the underworld (represented by the lake), the world of the living (represented by the land) and the heavens (represented by the sky), according to the Lacandon (*1*). They believe that the god Chak Aktun lives here. Palka observes that this mountain rising from the waters of a lake is a natural version of the altepetl ("water mountain"), a concept that formed the basis for Maya and Aztec communities. The temple pyramids that dominated their stone cities were human-made altepetls. Roughly 2,000 years ago the ancient Maya leveled the top of Mirador and built a massive temple platform there (*2*). The team has also found remnants of terraces that form what may have been a pilgrimage route up the side of the mountain to the temple, where visitors would make offerings to Chak Aktun for good health and bountiful crops.

2

AS A CHILD, Rafael Tarano (*1*) learned the stories of the Lacandon gods—from Mensabak and Chak Aktun to Hachakyum, the supreme creator, to Akyantho, god of foreigners and technology. He also learned how to make the traditional Lacandon offerings at the sacred sites around the lake. But times have changed—and the Lacandon have changed with them. No one makes the offerings anymore, Tarano says. Everyone in the community—about 19 families in all—has either converted to evangelical Christianity or does not practice a religion at all, Fabiola Sanchez Balderas explains.

The families live in a village at the southern end of the lake with two churches, an administrative building where a small police force is headquartered, four tiendas that sell essential goods and snacks, and a new tourist center. People grow food for their personal consumption in nearby fields called milpas. A gravel road connects the village to the world outside the rain forest (*2*).

The Mexican government designated the territory around the lake as the Metzabok Floral and Faunal Protection Area, which offers the land some legal protections that help the Lacandon people to maintain their way of life. They also receive some income from the Mexican government for taking care of the protected area. Tarano, like his ancestors who settled this area in the aftermath of the Spanish conquest, views religion as essential to meeting whatever challenges the future holds. "I don't know who the true god is, Hesuklisto [Jesus Christ] or Hachakyum," he says, "but in bad times it is believe or die."

FROM OUR ARCHIVES

The Storm God's Tale. Zach Zorich; December 2014.

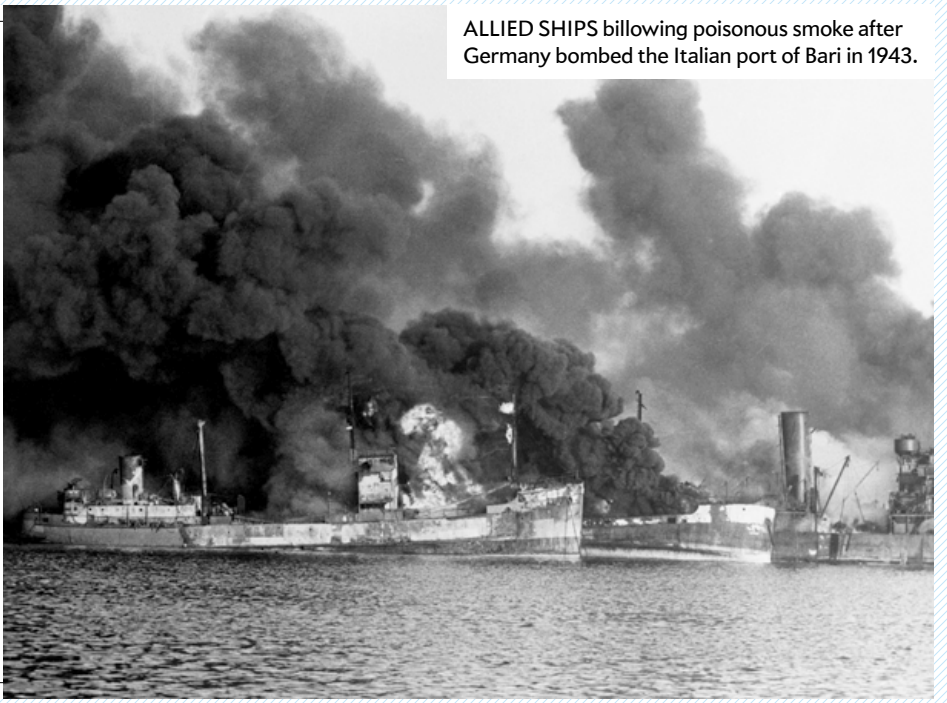
scientificamerican.com/magazine/sa

RECOMMENDED

By Andrea Gawrylewski

The Great Secret: The Classified World War II Disaster That Launched the War on Cancer

by Jennet Conant. W. W. Norton, 2020 ($27.95).

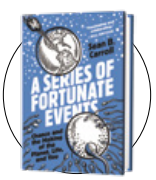


ALLIED SHIPS billowing poisonous smoke after Germany bombed the Italian port of Bari in 1943.

On December 2, 1943, a German air raid bombed a port in the Italian city of Bari. Among the 40 ships that were damaged, destroyed or sunk was the U.S. Liberty ship *John Harvey,* which carried a secret cargo of 2,000 mustard gas bombs. With the ship's destruction, mustard gas leaked into the harbor and dispersed into the clouds of smoke and flame from the bombing. In 24 hours more than 600 people in the area reported symptoms of mustard gas poisoning. Writer Conant gives a riveting account of the surprising twist that evolved out of this devastating military disaster. Observing the cell-killing effects of mustard gas on victims' tissue samples, diligent doctors Lieutenant Colonel Stewart F. Alexander and Colonel Cornelius P. Rhoads, among others, carried out research that led to several cancer therapies, including methotrexate, which is still in use today. The nascent field of chemotherapy that resulted suffered innumerable obstacles and setbacks—some treatments proved too toxic, and others offered only temporary inhibition of tumor growth. Although more than 75 years have passed since this work began, Conant shows how the challenges facing modern oncologists—and their determination to keep trying new treatments—bear a remarkable resemblance to those early efforts.

A Series of Fortunate Events: Chance and the Making of the Planet, Life, and You

by Sean B. Carroll. Princeton University Press, 2020 ($22.95).



The idea that chance rules our lives "vaporizes the comforts of anthropocentrism," biologist Carroll writes. But for the author, this notion is also a freeing revelation. With conversational wit, Carroll encourages us to embrace the randomness of the world. If the asteroid that wiped out the dinosaurs had arrived 30 minutes earlier or later, for instance, the impact would not have produced enough soot and aerosols to precipitate a mass extinction. And in the microscopic realm, spontaneous quantum fibrillations lasting one one-thousandth of a second cause mutations in our DNA, enabling both evolution and cancer. Drawing philosophical inspiration from Nobel Prize–winning biologist Jacques Monod's 1970 *Chance and Necessity,* Carroll explores these and other cosmological, geological and biological accidents that have shaped the course of the world—and that continue to shape our individual lives.

—Scott Hershberger

Beyond Earth's Edge: The Poetry of Spaceflight

edited by Julie Swarstad Johnson and Christopher Cokinos. University of Arizona Press, 2020 ($19.95).

The heavens are fertile ground for poetry. They are, after all, the original tapestries on which our ancestors wove their myths and legends, making sense of life on Earth by projecting the deeds of deities and heroes onto stellar constellations and planetary conjunctions. With the dawn of the Space Age, a new era of myth-making was also ushered in, one in which the outsize actions of astronauts, robots and satellites could profoundly influence the hearts and minds of everyone dwelling down below—including some of our world's greatest poets. Offering selections from Ray Bradbury, Nikki Giovanni, Robert Hayden, Pablo Neruda, May Swenson, and many other luminaries alongside their own works, editors Johnson and Cokinos have created a profoundly stirring evocation of the glory and tragedy of spaceflight that lets us better see not only worlds beyond but also ourselves.

—Lee Billings

GETTY IMAGES

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).

Sexism and Racism Persist in Science

We kid ourselves if we insist that the system will magically correct itself

By Naomi Oreskes

Tempers are running hot in science (as they are in the U.S. at large) as the field embarks on a long-overdue conversation about its treatment of women and people of color. In June, for example, thousands of researchers and academics across the globe—as well as the preeminent journals *Science* and *Nature*—stopped work for a day to protest racism in their ranks. The American Physical Society endorsed the effort to "shut down STEM," declaring its commitment to "eradicating systemic racism and discrimination" in science.

Physics exemplifies the problem. African-Americans make up about 14 percent of the college-age population in the U.S., commensurate with their numbers in the overall population, but in physics they receive 3 to 4 percent of undergraduate degrees and less than 3 percent of Ph.D.s, and as of 2012 they composed only 2 percent of faculty. No doubt there are many reasons for this underrepresentation, but one troubling factor is the refusal of some scientists to acknowledge that a problem could even exist. Science, they argue, is inherently rational and self-correcting.

Would that were true. The history of science is rife with well-documented cases of misogyny, prejudice and bias. For centuries biologists promoted false theories of female inferiority, and scientific institutions typically barred women's participation. Historian of science and MacArthur fellow Margaret Rossiter has documented how, in the mid-19th century, female scientists created their own scientific societies to compensate for their male colleagues' refusal to acknowledge their work. Sharon Bertsch McGrayne filled an entire volume with the stories of women who should have been awarded the Nobel Prize for work that they did in collaboration with male colleagues—or, worse, that they had stolen by them. (Rosalind Franklin is a well-documented example of the latter: her photographs of the crystal structure of DNA were shared without her permission by one of the men who then won the Nobel Prize for elucidating the double-helix structure.) Racial bias has been at least as pernicious as gender bias; it was scientists, after all, who codified the concept of race as a biological category that was not simply descriptive but also hierarchical.

Good scientists are open to competing ideas; they attend to challenging data, and they listen to opposing views. But scientists are also humans, and cognitive science shows that humans are prone to bias, misperception, motivated reasoning and other intellectual pitfalls. Because reasoning is slow and difficult, we rely on heuristics—intellectual shortcuts that often work but sometimes fail spectacularly. (Believing that men are, in general, better than women in math is one tiring example.) It is not credible to claim that scientists are somehow immune to the biases that afflict everyone else.

Fortunately, the objectivity of scientific knowledge does not depend on the objectivity of individual scientists. Rather it depends on strategies for identifying, acknowledging and correcting bias and error. As I point out in my 2019 book, *Why Trust Science*, scientific knowledge begins as claims advanced by individual scientists, teams or laboratories that are then closely scrutinized by others, who may bring forward additional proof to sustain them—or to modify or reject them. What emerges as a scientific fact or established theory is rarely if ever the same as the starting claim; it has been adjusted in light of evidence and argumentation. Science is a collective effort, and it works best when scientific communities are diverse. The reason is simple: heterogeneous communities are more likely than homogeneous ones to be able to identify blind spots and correct them. Science does not correct itself; scientists correct one another through critical interrogation. And that means being willing to interrogate not just claims about the external world but claims about our own practices and processes as well.

Science has an admirable record of producing reliable knowledge about the natural and social world, but not when it comes to acknowledging its own weaknesses. And we cannot correct those weaknesses if we insist the system will magically correct itself. It is not ideological to acknowledge and confront bias in science; it is ideological to insist science cannot be biased despite empirical validation to the contrary. Given that our failings of inclusion have been known for a long time, it is high time we finally fix them. SA

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Illustration by Jay Bendt

Steve Mirsky has been writing the Anti Gravity column since a typical tectonic plate was about 36 inches from its current location. He also hosts the *Scientific American* podcast Science Talk.

Hellscapes

Salary exposés, unethical ethicists and frog butts

By Steve Mirsky

Now is the summer of our really, really big discontent. As I write in early August, our offices are still closed as the pandemic rages on. And some people who stop their vehicles at red lights chaff, figuratively, at wearing masks in public, because freedom. It is under these conditions I want to share some recent items I chanced on.

As the saying goes, "A man may work from sun to sun, but a woman's work will probably not be compensated to the same extent as a man's, and her salary as a percentage of the average in her field will likely go down should her field undergo a transition to majority female." Hey, if it wasn't catchy, it wouldn't have become an axiom.

For examples of this phenowomenon, see an article entitled "When a Specialty Becomes 'Women's Work': Trends in and Implications of Specialty Gender Segregation in Medicine," published in *Academic Medicine*. The authors are Elaine Pelley and Molly Carnes of the School of Medicine and Public Health of the University of Wisconsin–Madison. Such an elite affiliation is instant grounds for nonpayment of attention among many of my fellow Americans these days, as it speaks to a certain level of knowledge and experience that they increasingly find, ya know, annoying.

Despite their credentials, let's hear these authors out. They note that "pediatrics earned 93% of the average physician salary in 1975 when it was 22% female, but earned only 71% of the median physician salary in 2017 when it was 63% female."

Another case: "The salaries in obstetrics and gynecology were 20%–25% higher than the mean physician salary in the mid-1970s and 1980s when the female share was 8% and 18%, respectively. However, by 2017 with a female share of 57%, an obstetrician/gynecologist became an average physician earner." (An extreme version of this trend can be easily found with a Google search using the terms "women doctors Russia status." The results could make you seek out a gastroenterologist of any sex.)

While wondering about the ethical implications of these financial disparities, I stumbled onto a 2016 paper by philosophers Eric Schwitzgebel and Joshua Rust entitled "The Behavior of Ethicists." They basically attempt to determine if professional ethicists behave more ethically in their personal lives than other people (for ease of access to study subjects, the other people were nonethicist philosophers and professors in other disciplines). And they found that the ethicists don't bring work home: "On average, professional ethicists' behavior is indistinguishable from the behavior of comparison groups of professors in other fields."

That finding makes sense to me. Because a while back, I attended a medical ethics symposium and had an insight—a jumping jack flash, if you will: Satan would make a terrific ethicist. To establish the most evil course of action in a given situation, he'd have to perform a comprehensive evaluation that would also reveal the best policy choice. Knowing right from wrong is thus a necessary but insufficient condition for goodness, and Old Nick could write excellent ethical white papers before setting them on fire.

Speaking of hell, a study in the August 3 issue of the journal *Current Biology* revealed that the vast majority of members of a species of beetle, *Regimbartia attenuata,* perform a literally death-defying feat after being swallowed by various species of frogs. The beetle apparently swims its little heart out till it pops out of the frog's derriere. Because, as another axiom has it, "If you're going through hell, keep going."

To find out whether the insect's passage was active or passive, researchers immobilized some beetles by coating them with wax before going into the mouth of hell, or rather, frog. None of these beetles survived. To paraphrase science-fiction legend Harlan Ellison (who definitely would have come up with this experimental protocol if he'd lived long enough): they really don't want to open their mouths, and they must scream. SA

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Illustration by Matt Collins

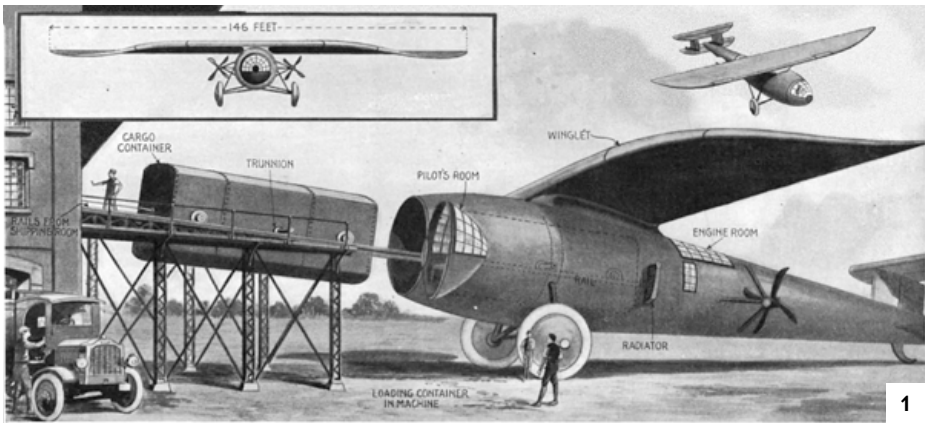
OCTOBER

1970 Sweet Suburbia

"Massive movement from central cities to their suburbs, a population boom in the West and Southwest, and a lower rate of population growth in the 1960's than in the 1950's are the findings that stand out in the preliminary results of the 1970 Census as issued by the U.S. Bureau of the Census. The movement to the suburbs was pervasive. Its extent is indicated by the fact that 13 of the 25 largest cities lost population, whereas 24 of the 25 largest metropolitan areas gained. Washington, D.C., was characteristic: the population of the city changed little between 1960 and 1970, but the metropolitan area grew by 800,000, or more than 38 percent."

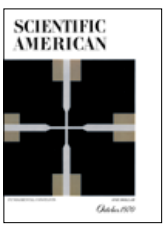
1920 Air Cargo

"The proposed machine, known as the 'Pelican Four-Ton Lorry,' is a colossal cantilever monoplane designed for two 460-horse-power Napier engines. Its cruising speed is 72 miles per hour. Its total weight is to be 24,100 pounds. The useful load is four tons, with sufficient fuel for the London-Paris journey. Most interesting of all, however, is the novel system of quick loading and unloading which has been planned. This permits handling of shipments with the utmost speed, and is based on a similar practice in the motor truck field. Idle airplanes mean a large idle capital, hence the designers plan to keep the airplane in the air for the greater part of the time."



1

1920: An idea for air transport: it's not just the airplane that is advanced; it's the cargo container that could be quickly loaded and unloaded.



1970

1920

1870

Don't Try This Anywhere

"Dr. Charles Baskerville points out that while the data thus far obtained on chlorine and influenza do not warrant drawing conclusions, such facts as have been established would indicate to the medical man the advisability of trying experimentally dilute chlorinated air as a prophylactic in such epidemics as so-called influenza. Dr. Baskerville determined to what extent workers in plants where small amounts of chlorine were to be found in the atmosphere were affected seriously by influenza. Many of those from whom information was requested expressed the opinion that chlorine workers are noticeably free from colds and other pneumatic diseases."

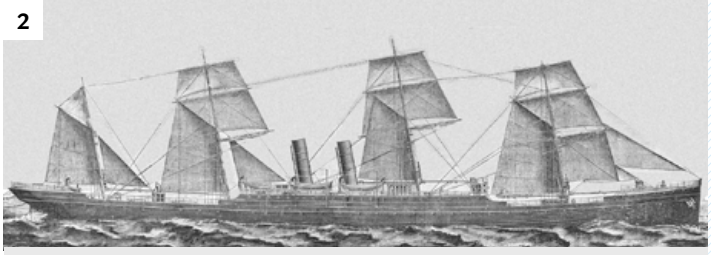
1870 The Rise of Telegraphy

"The rapid progress of the telegraph during the last twenty-five years has changed the whole social and commercial systems of the world. Its advantages and capabilities were so evident that immediately on its introduction, and demonstration of its true character, the most active efforts were made to secure them for every community which desired to keep pace with the advances of modern times. The Morse or signal system seemed for a time to be the perfection of achievement, until Professor Royal E. House astonished the world with his letter printing telegraph. Now, almost every considerable expanse of water is traversed, or soon will be, by the slender cords which bind continents and islands together and practically bring the human race into one great family."

SCIENTIFIC AMERICAN, VOL. CXXIII 1, NO. 15; OCTOBER 9, 1920 (1); *SCIENTIFIC AMERICAN SUPPLEMENT*, VOL. XXIII, NO. 574; JANUARY 1, 1887 (2)

EPIC TALES

2



1887: Cargo ship launched as *Golconda* had room for 6,000 tons of cargo, loaded and unloaded by crane and cargo nets, and 108 passengers.

The Transport of Goods

CELEBRATING 175 YEARS

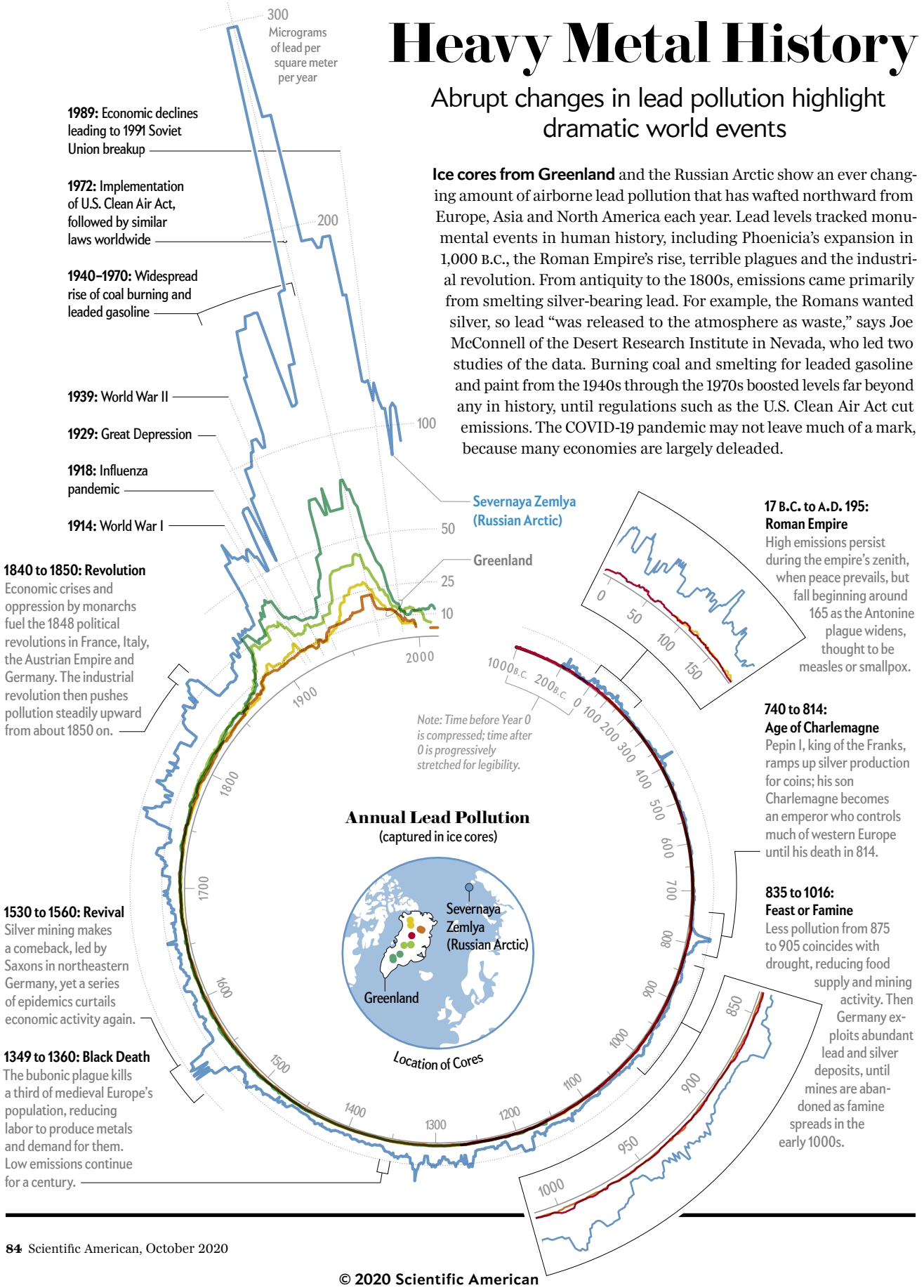
Oxcarts, railroad cars and freight ships can be loaded and unloaded one item at a time, but it is more efficient to handle cargo packed into "intermodal shipping containers" that are a standardized size and shape. Our October 1968 issue noted that a "break-bulk" freighter took three days to unload, a container ship less than one (including loading new cargo). Air transport became a link in this complex system, but the concept in the 1920 illustration shown is a little ahead of its time. These days air cargo (and luggage) makes abundant use of "unit load devices," cargo bins shaped to fit the fuselage of specific aircraft models. —*D.S.*

Text by Mark Fischetti | Graphic by Nadieh Bremer

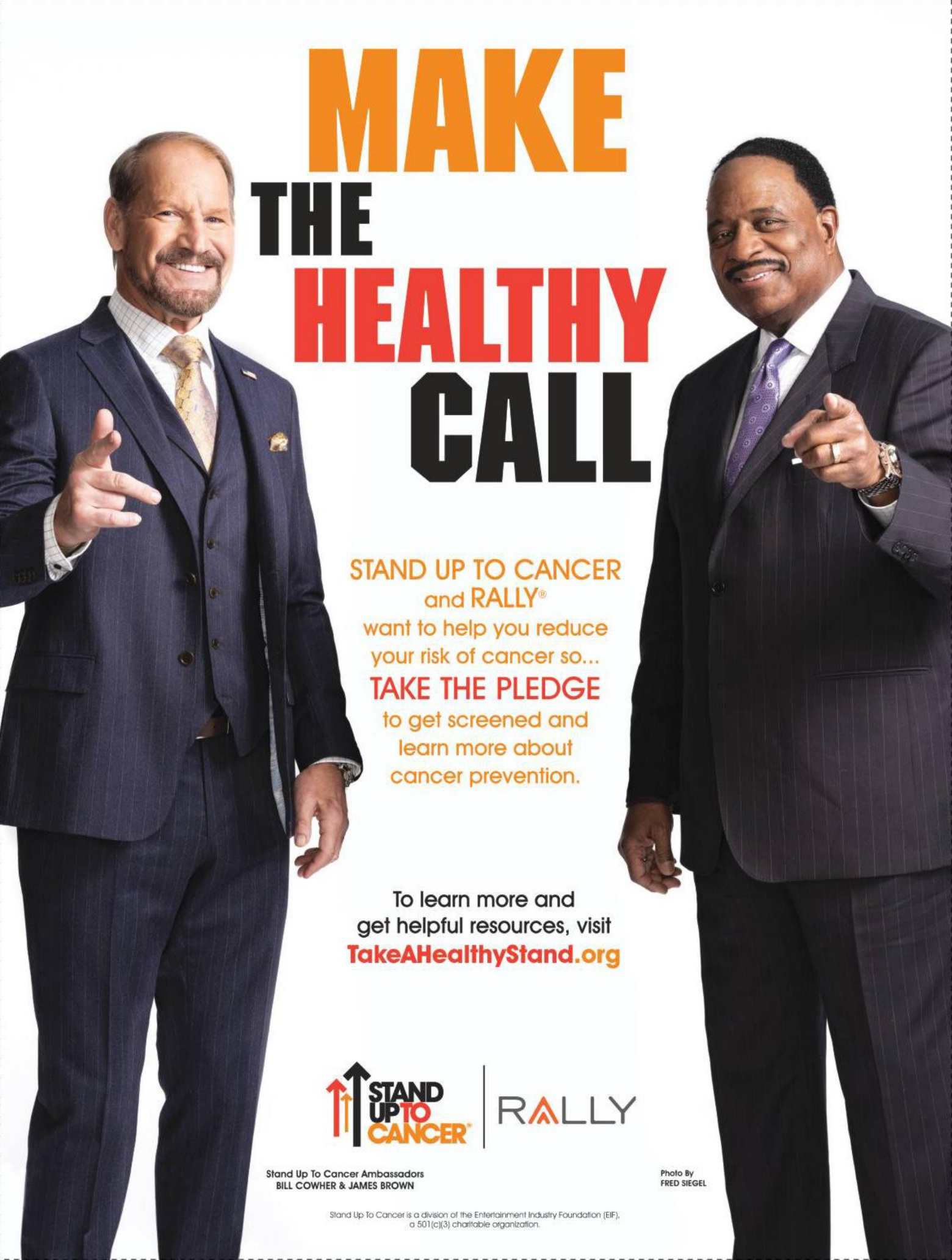
Heavy Metal History

Abrupt changes in lead pollution highlight dramatic world events

Ice cores from Greenland and the Russian Arctic show an ever changing amount of airborne lead pollution that has wafted northward from Europe, Asia and North America each year. Lead levels tracked monumental events in human history, including Phoenicia's expansion in 1,000 B.C., the Roman Empire's rise, terrible plagues and the industrial revolution. From antiquity to the 1800s, emissions came primarily from smelting silver-bearing lead. For example, the Romans wanted silver, so lead "was released to the atmosphere as waste," says Joe McConnell of the Desert Research Institute in Nevada, who led two studies of the data. Burning coal and smelting for leaded gasoline and paint from the 1940s through the 1970s boosted levels far beyond any in history, until regulations such as the U.S. Clean Air Act cut emissions. The COVID-19 pandemic may not leave much of a mark, because many economies are largely deleaded.



SOURCES: "LEAD POLLUTION RECORDED IN GREENLAND ICE INDICATES EUROPEAN EMISSIONS TRACKED PLAGUES, WARS, AND IMPERIAL EXPANSION DURING ANTIQUITY," BY J. R. MCCONNELL ET AL., IN *PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES USA*, VOL. 115, NO. 22; MAY 29, 2018; "PERVASIVE ARCTIC LEAD POLLUTION SUGGESTS SUBSTANTIAL GROWTH IN MEDIEVAL SILVER PRODUCTION MODULATED BY PLAGUE, CLIMATE, AND CONFLICT," BY J. R. MCCONNELL ET AL., IN *PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES USA*, VOL. 116, NO. 30; JULY 23, 2019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FRED SIEGEL
Stand Up To Cancer is a division of the Entertainment Industry Foundation (EIF),
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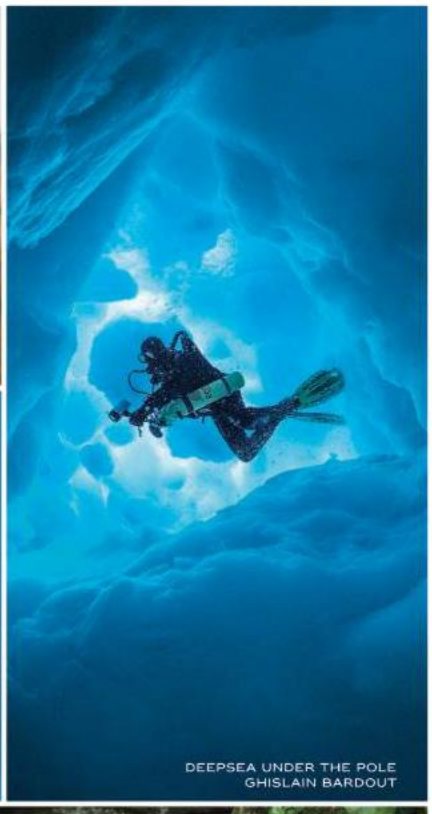

PERPETUAL PLANET

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