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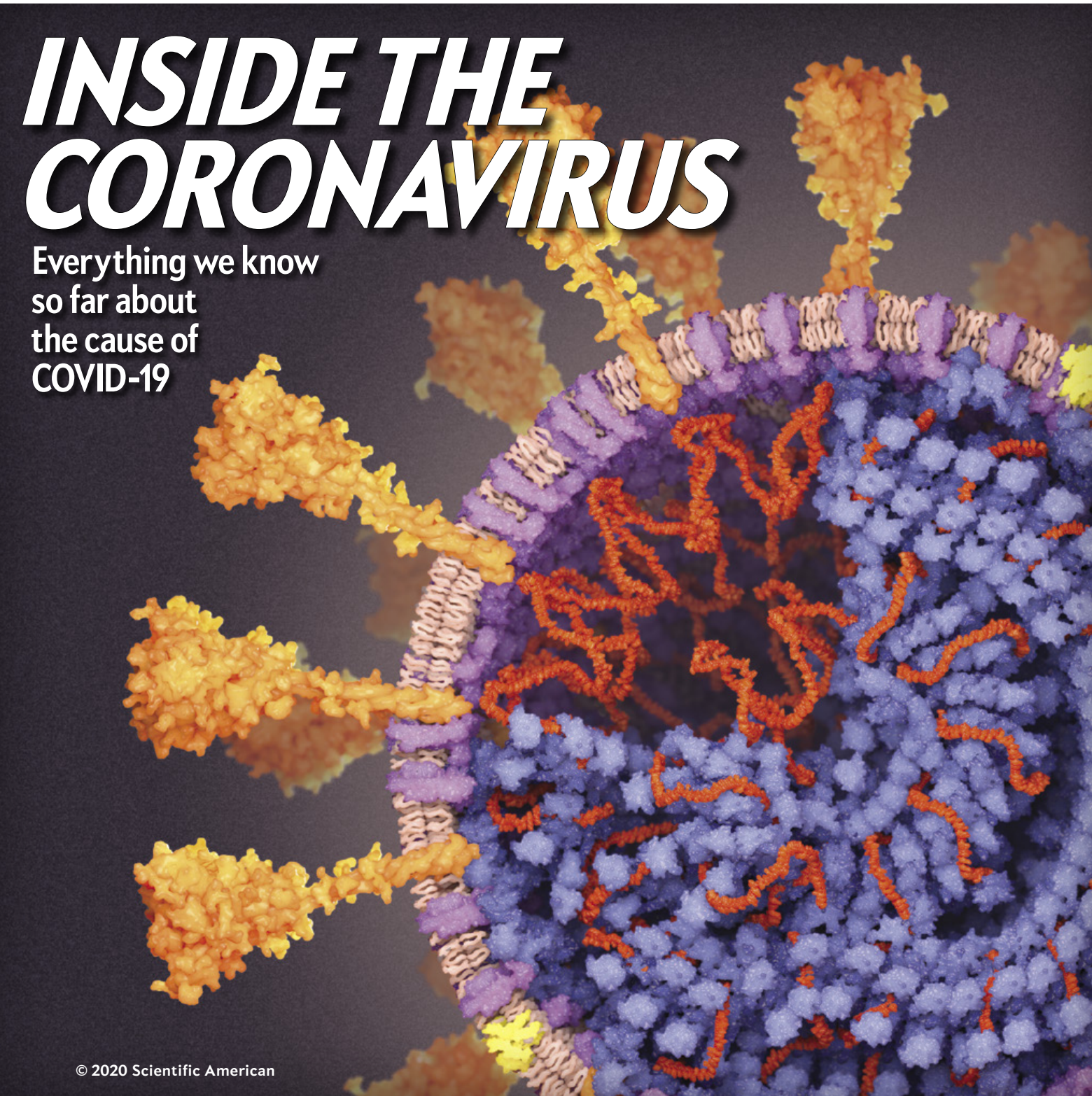

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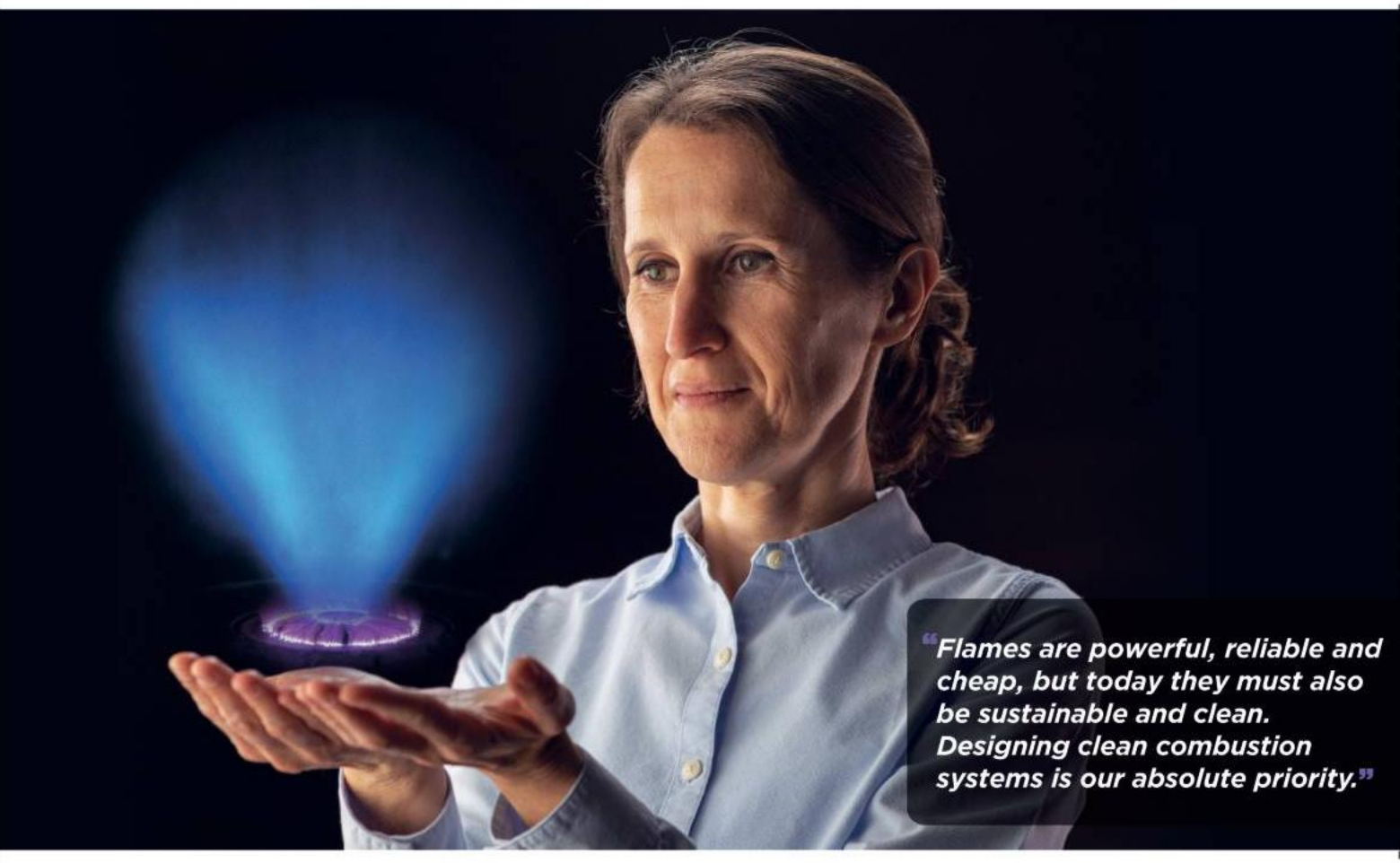

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VOLUME 323, NUMBER 1

SCIENTIFIC AMERICAN

ON THE COVER
Although much remains unknown about the virus responsible for the ongoing global pandemic, scientists have developed a detailed picture of the molecular biology of SARS-CoV-2 in a surprisingly short time. Our synthesis of this work begins on page 32.
Illustration by Veronica Falconieri Hays.

JOHN FINNEY *Getty Images*; COVER SOURCE: LORENZO CASALINO, ZIED GAIEB AND ROMMIE AMARO *U.C. San Diego (spike model)*

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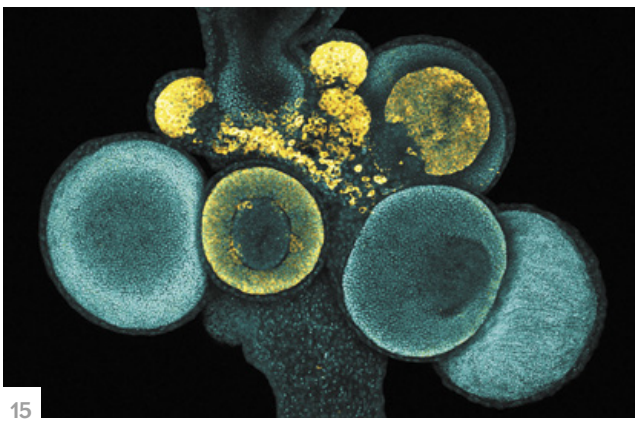
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On a recent trip to Tucson, we spoke with fourth generation turquoise traders who explained that less than five percent of turquoise mined worldwide can be set into jewelry and only about twenty mines in the Southwest supply gem-quality turquoise. Once a thriving industry, many Southwest mines have run dry and are now closed.

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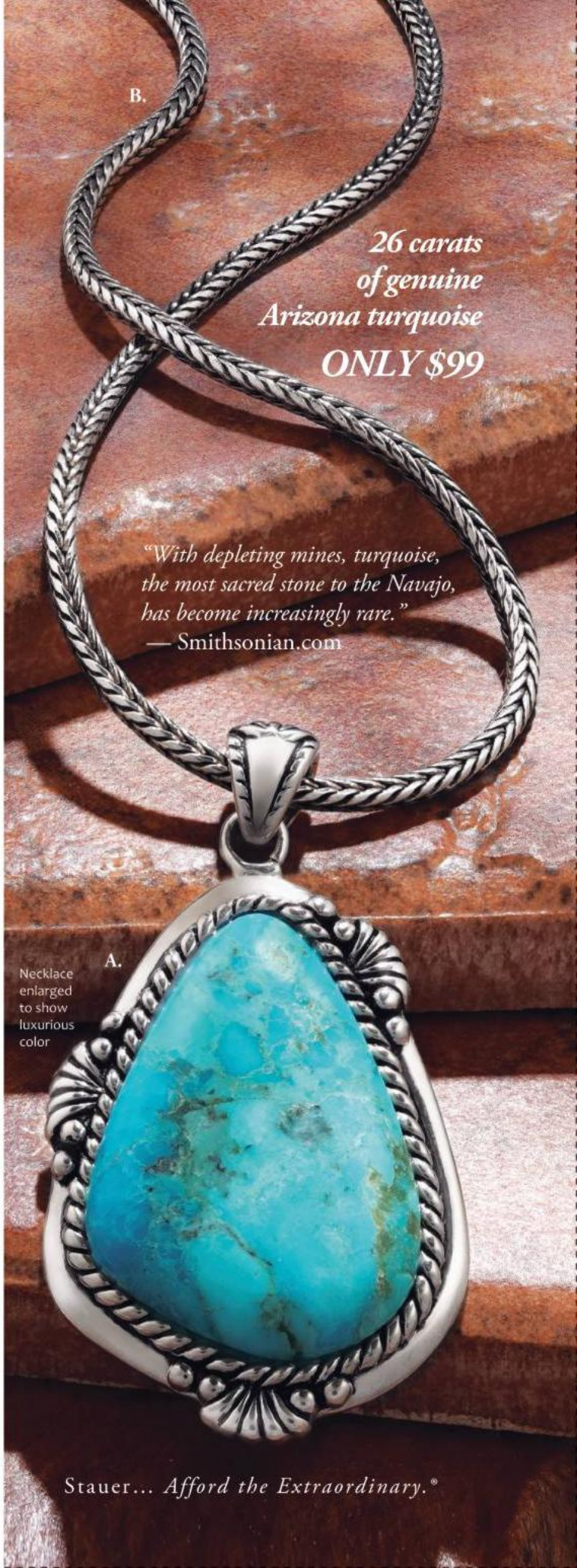

Laura Helmuth is editor in chief of *Scientific American*.
Follow her on Twitter @laurahelmuth

Know the Enemy

The coronavirus that has killed hundreds of thousands of people and staggered the world's economy is just about 88 nanometers in diameter—138 nm if you count its spikes. In this issue of *Scientific American,* we show what scientists have learned so far about the structure and function of the evil genius pathogen SARS-CoV-2. Molecular virologist Britt Glaunsinger worked with artist Veronica Falconieri Hays, senior editor Mark Fischetti and senior graphics editor Jen Christiansen to create a detailed 3-D model of the virus and illustrations showing how it invades lung cells and torments the immune system. Turn to page 32.

The global pandemic has forced us into the largest psychology experiment in history. Researchers are studying the effects of mass isolation, fear and grief and the ways discrimination and poverty make this pandemic even more devastating. Author and contributing editor Lydia Denworth explores what we know about the mental health toll of this crisis and how to promote coping or even resilience during a disaster, starting on page 38.

The pandemic amplifies the need for good data in medicine. Writer Virginia Sole-Smith shows that the evidence for obesity as a risk factor for poor health is actually pretty thin. The stigma against large bodies is dangerous in itself, and the focus on weight can lead to misdiagnoses and improper treatments (*page 22*).

The consensus here at *Scientific American* is that neutrinos are cool. During a stressful time, we all enjoyed working on physicists William Charles Louis and Richard G. Van de Water's article about a possible fourth flavor of neutrino, which could be a key to understanding dark matter and dark energy (*page 46*).

Archaeologists and geneticists are uncovering complex and sometimes disturbing social interactions in ancient Europe, where farming people who migrated from the Middle East may have enslaved or sacrificed hunter-gatherers. Journalist Laura Spinney takes us on their journey, beginning on page 60.

One of the many ways science saves lives is through forecasting. If we know what's coming, we can prepare for it. (That's the whole point of epidemiological models of how diseases such as COVID-19 spread.) Scientists such as Kathy Pegion are now pushing weather forecasts out to 28 days. See how well her recent weather prediction turned out (*page 54*).

I'm thrilled to join *Scientific American* as the next editor in chief in our 175-year history. Like you, I've admired and enjoyed the magazine from the outside, and now I am honored to work with the dedicated, knowledgeable, talented, curious and kind staff. I am grateful to our managing editor Curtis Brainard for leading the magazine brilliantly for the past several months and guiding us through the early chaos of the global pandemic. Everyone is working harder than ever, but we are energized by the mission of producing timely, trustworthy and welcoming science stories, graphics, podcasts and videos. You can see all of our COVID-19 coverage online at sciam.com/coronavirusoutbreak.

Thank you for supporting the magazine and being part of the *Scientific American* community. The pandemic has shown the dangers of misinformation, ignorance and confusion. Together we can elevate sense over nonsense, and perhaps the world will emerge from this crisis with a better understanding of pathogens, public health, the research process and the importance of making decisions based on the best evidence. SA

Illustration by Nick Higgins

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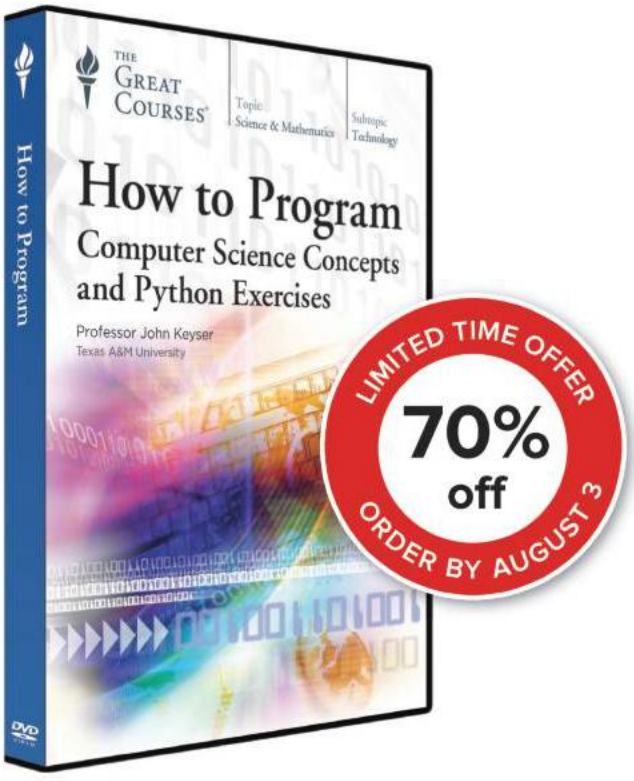

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March 2020

MULTIVERSAL CONFLUENCE

"A Cosmic Crisis," by Richard Panek, discusses possible reasons why the two methods used to measure the universe's rate of expansion find conflicting values—a discrepancy known as the Hubble tension. I am puzzled that the article does not mention forces from outside our universe acting on it. Can't we expect that there are other universes with mass like ours that will have gravitational, and possibly other, effects on us? I don't mean quantum parallel stuff but other big bang results beyond our own. We live in a galaxy that is part of a cluster of galaxies in a universe. Why not a cluster of universes? How do we know we are not in collision with one that is pulling our universe in ways that massively mess with our measurements?

David Farnsworth
via e-mail

PANEK REPLIES: Theorists have indeed been investigating the gravitational (or other) influence of parallel universes as a possible source of seeming anomalies in our universe. A multiverse, in fact, is what inflation theory would imply: one quantum pop creating our universe would almost certainly lead to other universes. But falsifying such a hypothesis would be difficult, if not impossible, so attempts to address the Hubble tension have focused on theories and observations involving effects we can *measure.*

"You just can't explain aerodynamic lift adequately with high school physics."

Chris Chesnakas
Sterling, Va.

BUTTERFLY DECLINE

In "What Is Killing the Monarchs?" Gabriel Popkin seems to overlook a possible contributor to the drastic drops seen in the butterflies' numbers. Could insecticide use across the South and along migration pathways contribute significantly to the discrepancy between summer counts and winter populations?

Local yard signs here in the South seem to indicate an expanded use of mosquito-control and lawn-maintenance companies that apply sprayed insecticides on a regular and recurring basis. And particularly after one neighbor had his yard sprayed for cutworms and another initiated mosquito-control spraying, I saw a great increase in the mortality of the monarch caterpillars I raise each summer. Friends elsewhere in town have commented about a similar experience, especially with regard to the August-September generation of caterpillars.

Robert Newman
Hickory, N.C.

We have been cultivating milkweed plants around our house in San Diego for the past six years in an effort to help preserve these amazing butterflies. In the past two summers we have been alarmed to see that the number of caterpillars, and thus pupae, parasitized by flies (probably *Lespesia archippivora*) seems to have jumped from around 10 to 80 percent. I wonder if this increase might be related to climate change.

Michael Halls
San Diego

CATCH A WAVE

In "Dollars for Dikes," Wade Roush advocates building infrastructure to accommodate a base sea-level rise of up to 2.8 feet (plus a margin for surges and so on)—the top end of the Intergovernmental Panel on Climate Change's estimate for 2100. That estimate, however, is what scientists consider "conservative," meaning that they are careful not to overestimate the rise.

Sea-level rise will almost surely be higher. When engineers design things such as jet aircraft, they use worst-case estimates of critical parameters. That is the only way of assuring the success of the project. If we are to solve the problem of building infrastructure to accommodate sea-level rise, we need to take an engineering approach and use worst-case estimates of how much rise to design for.

Eric Ward
West Palm Beach, Fla.

COMPLEXITIES OF LIFT

I was initially thrilled to see that "The Enigma of Aerodynamic Lift," by Ed Regis [February 2020], concerned a field to which I have devoted 35 years of my life. But I reread its title and summary—"No one can completely explain why planes stay in the air"—with some alarm. Was this article going to expose some major flaw in our understanding of fluid dynamics? I found it said no such thing.

You just can't explain aerodynamic lift adequately with high school physics. (I would argue that even a four-year bachelor's degree in aerospace engineering will not equip you to do so.) Daniel Bernoulli's and Isaac Newton's laws, though essential, are not sufficient. No one working in the field would design or analyze a machine with only these equations.

These problems are hard. They are complex. But they are not an enigma.

Chris Chesnakas
Sterling, Va.

I was an aeronautical engineer for 38 years. My colleagues and I encountered no ambiguity in explaining the flow-induced pressure distribution around lifting surfaces. I would respectfully disagree with Regis's claim that the Navier-Stokes equations or their solutions do not offer interpretable explanations of fluid physics. These equations are the mathematical language that engineers have used to understand fluid mechanics for more than a century. They describe the simultaneous conditions of mass, momentum and energy conservation that govern fluid flows. These conditions determine, for example, velocity and pressure distributions around a lifting surface

and its attendant lift. In general, when understood and properly applied, the Navier-Stokes equations provide a rich explanation of fluid dynamic phenomena.

These phenomena are often complex and cannot necessarily be explained in simple, one- or two-sentence reductions. I suspect this is what John D. Anderson, Jr. (whom I had the good fortune to study under when I was a graduate student), meant in the statement, attributed to him in the article, that "there is no simple one-liner answer" regarding aerodynamic lift.

Joseph F. Slomski, Jr.
Fairfax Station, Va.

As a retired aeronautical engineer, I find Regis's article to be lacking in basic knowledge that every student of aerodynamics learns early on in his or her studies about how wings generate their lift forces. The operative words are "circulation theory." His failure to include the theory in his explanations should be embarrassing to your technical staff.

David Harold Chester
via e-mail

REGIS REPLIES: The diversity of opinions in the 67 letters sent in response to my article aptly illustrates its theme: namely, there is no one simple, nontechnical explanation of aerodynamic lift that is universally acceptable. Several readers proposed alternative explanations of lift. And most of the letters introduced technical matters. I chose not to address such topics in the piece, which was intentionally confined to arguments and principles accessible to nonspecialists. Thus, I did not include a discussion of phenomena such as the Kutta-Joukowski theorem, circulation theory, Ludwig Prandtl's boundary layer theory, the Reynolds-averaged Navier-Stokes equations, the Coanda effect or other staples commonly found in advanced accounts of aerodynamics.

I also avoided touching on even as elementary an issue as whether the same forces that act on a wing moving through stationary air act on a stationary wing around which air moves. That seemingly simple question is a controversial and undecided one among aerodynamicists. Anderson really did say it best in the quote Slomski refers to.

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Justice for Rape Victims

A backlog of unopened evidence kits is growing, despite proof that they could catch more criminals

By the Editors

Across the country a crucial trove of crime-solving data is sitting unused in the form of untested rape kits. These cardboard boxes contain envelopes filled with hairs, skin cells, semen, clothing and other forensic evidence collected from survivors after they report a sexual assault. If the DNA on these items matches DNA in a criminal database, it can lead to an arrest. It is practically criminal, then, to put women through the emotionally and physically difficult, hours-long collection process and then never analyze the kits. Yet more than 100,000 rape kits in the U.S. are collecting dust on shelves in laboratories, hospitals and police stations because states lack the money—or the will—to process them.

We now know that if the kits are analyzed, more criminals are caught and more victims get justice. The Manhattan District Attorney in New York City handed out grants for rape kit testing to 20 states between 2015 and 2018, for example, and 186 arrests were made and 64 convictions won—many of them against serial rapists whose DNA showed up in multiple kits. An ongoing effort to test an archive of old kits in Cuyahoga County, Ohio, has led to more than 400 convictions, mostly in cold cases. "It's dangerous to leave these people on the streets," says Ilse Knecht, director of policy and advocacy for the Joyful Heart Foundation, a nonprofit that supports sexual-assault survivors. "Research shows that the longer they are on the streets the more crimes they commit because they're [often] serial offenders."

More jurisdictions must join these efforts. It's not just money that's needed to fix the problem. Many states act as if the kits are unimportant and have no system to track and process them—they don't even have exact counts of how many are sitting unused.

Along with Washington, D.C., 32 states have now passed bills requiring newly collected kits to be tested, and 25 states require some kind of tracking. Yet the laws are a patchwork—they don't cover all that needs to be done, and they leave many states without legislation addressing the backlog. On the federal level, in December 2019, President Donald Trump signed the Debbie Smith Act, reauthorizing a 2004 bill to make $151 million a year available to test criminal forensic evidence. But the money is for all kinds of DNA evidence, not just rape kits, and its grants help only with untested kits that have already been sent to labs—not with the larger backlog of kits still at police or hospital warehouses.

Because these are only partial solutions, the overall situation is getting worse. A 2019 report from the Government Accountability Office found that between 2011 and 2017 the number of backlogged requests for DNA analysis of crime scenes—mostly made up of rape kits—grew by 85 percent. "What's happening is that the demand [for testing] has increased so much there is in some places a new backlog," Knecht says. Police are using kits more often, in part because there is an increased awareness of how useful forensic evidence is in securing convictions, even as states are still trying to process old kits. "In general, the whole system needs to be ramped up for more capacity," she adds.

Few states are fully tackling all six of the strategies suggested by Joyful Heart to adequately address the problem: (*1*) require an annual statewide inventory of untested kits, (*2*) make testing all untested kits mandatory, (*3*) make testing of all new kits collected mandatory, (*4*) establish a statewide tracking system, (*5*) require survivors to be informed of the status of their kit and (*6*) provide the necessary funding for each of these initiatives.

Doing all these things is the best route to justice that survivors have. We must believe what survivors tell us and treat the crime of rape seriously. We need to honor their courage in reporting crimes and giving evidence by actually using that evidence to catch rapists. SA

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Illustration by Cat O'Neil

Mary Sue Coleman is president of the Association of American Universities, based in Washington, D.C.

How to Stop Science Theft

Universities have created tools to guard research against outside threats

By Mary Sue Coleman

Earlier this year Charles Lieber, then chair of Harvard University's chemistry department and a nanotechnology expert, was arrested and charged with lying to federal law-enforcement officials about secretly working for the Chinese government. (His attorney, Marc L. Mukasey, told SCIENTIFIC AMERICAN that Lieber "maintains his innocence and eagerly awaits the chance to tell his side of the story.") While less extreme than the Lieber story, there have been many more incidents of U.S. researchers allegedly failing to properly disclose relations with outside governments or otherwise safeguard their research from foreign intervention. In fact, officials at the National Institutes of Health have reportedly made inquiries into nearly 200 NIH-funded researchers at more than 60 U.S. institutions for potentially violating NIH conflict-of-interest, conflict-of-commitment or research-integrity rules. Many of these ideas and technologies are important to national security.

U.S. universities and institutions are taking steps to ensure that we protect the intellectual capital generated through taxpayer-supported federal research. My association represents America's most distinguished large research universities, and our institutions take these issues seriously. That is why we, in conjunction with our colleagues at the Association of Public and Land-grant Universities, asked our members to collect their most effective practices to combat these risks. Here is what we found:

Universities are strengthening and enforcing conflict-of-interest policies. For example, institutions once used forms that were not always clear for faculty to disclose funding sources. Now universities are adding more targeted questions and providing faculty with case examples, scenarios and FAQs on what should be included. Some are also requiring much more detail about time that faculty spend consulting with outside organizations, companies and universities to avoid potential conflicts of interest.

Leaders at these universities are also using new Web sites and direct communications to alert all their researchers about possible security threats and to clarify security protocols. And research administrators are directly engaging faculty who have significant levels of foreign research engagement to ensure that they fully understand their responsibilities to disclose such funding and to comply properly with all relevant federal laws, regulations and university policies. Universities are developing new training programs for both faculty and students to educate them about security risks and to make them aware of ethical research practices that must be followed (including what kinds of information can and cannot be taken or shared outside the laboratory). And some institutions are now offering for-credit courses for graduate students on complex ethical decision making and responsible conduct of research.

Crucially, universities are establishing stronger relations with their local FBI offices and other federal law-enforcement agencies; at the same time, the FBI is working to establish clear campus liaisons in their regional and local offices. New processes are now commonplace for monitoring data systems and networks for cyberintrusions, reporting suspected breaches and improving data security. For example, institutions are regularly adding IT security agreements that stipulate where data will be housed and how they will be protected by contracts used with third-party service providers. Visitors to research facilities can likewise make that information vulnerable, so our members are expanding required security screening to cover all visiting scholars.

Universities have put in place additional protections for research involving classified or otherwise sensitive or controlled information. For example, universities have established strenuous technology-control plans and cybersecurity safeguards to appropriately restrict access to such research. Research universities now employ specific staff to secure and manage such data. None of these actions prohibits the exchange of knowledge among legitimate scientific collaborations, which are key to scientific progress. But if universities fail to police themselves adequately in these areas, we face the specter of more draconian reactions from lawmakers.

The good news is that members of the Association of American Universities and others are stepping up to the plate and taking actions to secure sensitive research. We hope all universities will follow our example. We in the scientific community owe it to ourselves to be proactive in pursuing constructive vigilance. SA

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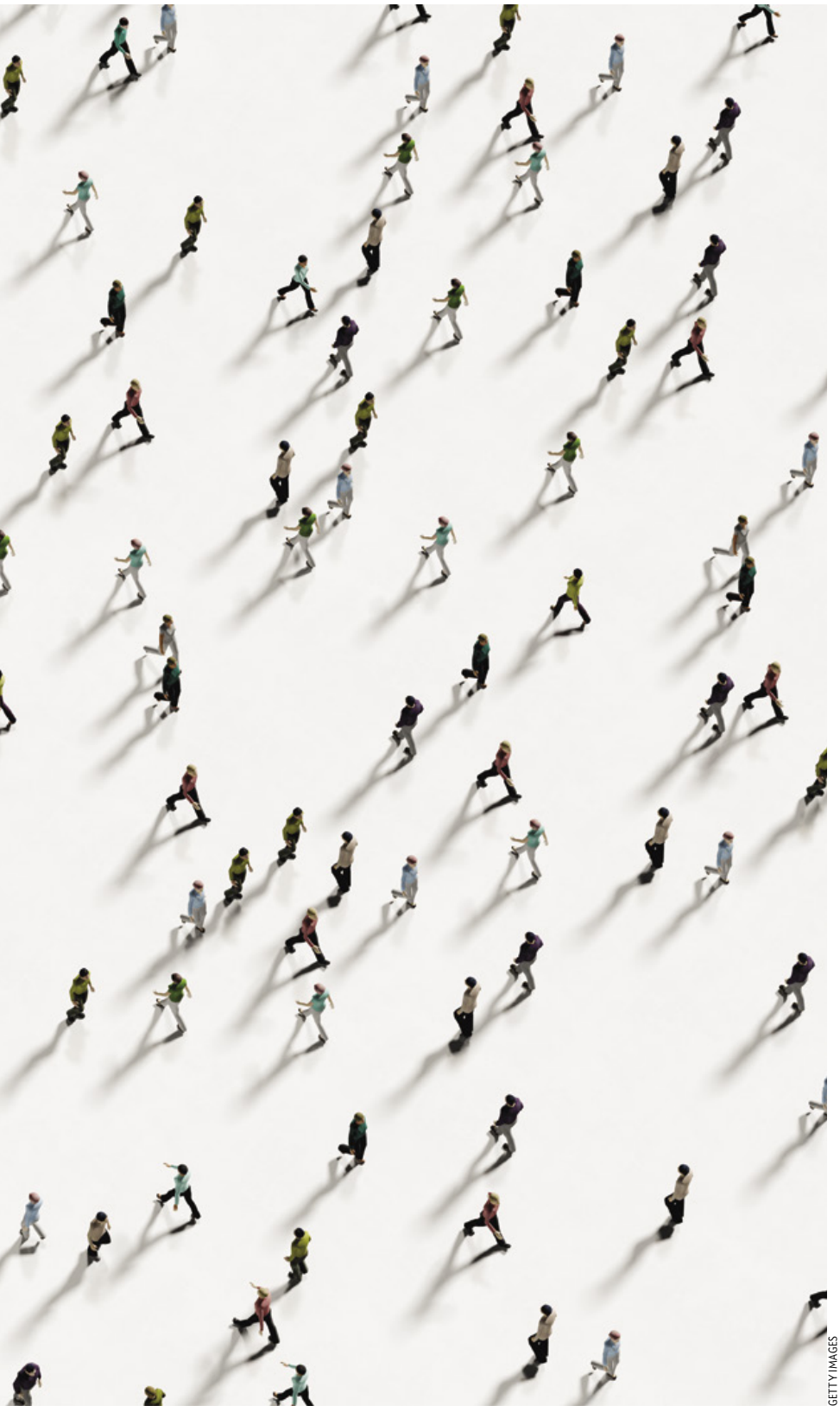
Illustration by Martin Gee

ADVANCES

Each person's walking gait is unique, and a new compact sensor can track many at once.



GETTY IMAGES

INSIDE

TECH

Step Spy

New sensors pick up gait patterns remotely to identify people and monitor health

Fingerprints are not the only biometric traits that set individuals apart. Each person's walking gait is unique—and it can serve not only as an identifier but also as an indicator of mood and health. A team of researchers has developed remote sensors that analyze footsteps by measuring tiny floor vibrations. They used this technology to identify specific individuals walking through a building and to test a new method of hands-off wellness monitoring.

The way you walk is "a very unique signature of yourself," says Hae Young Noh, who initially performed the research as a civil and environmental engineer at Carnegie Mellon University and has since moved to Stanford University. Gait can reveal "who you are, where you are, what kinds of activities you're doing, or even your cognitive state." If hardware sensors detect a pattern of footsteps, software can analyze them to verify an individual's identity. Earlier systems have done so with 95 percent accuracy, says Vir Phoha, an electrical engineer and computer scientist at Syracuse University, who was not involved in the new work.

And walking patterns can provide more than a simple ID, Phoha adds: "There is a lot of information you can learn from a person's gait—specifically, health-related information." If somebody starts placing more weight on one side or another, for example, the change in balance might indicate a neurological problem. This informa-

tion could help doctors monitor seniors and other at-risk people who want to live independently: tracking subjects' gait could keep tabs on health without directly impinging on their space.

To measure this data-rich signature, researchers previously had to outfit subjects with wearable devices or have them walk on special mats or altered flooring. But Noh, along with electrical and computer engineer Pei Zhang of Carnegie Mellon and their colleagues, wanted to develop portable footstep sensors that would work remotely. The scientists took advantage of the fact that typical walls and floors pick up even faint vibrations from activity in the space they contain. "We call this 'structures as sensors,' where we're using these big physical structures like buildings and bridges as a sensing system to indirectly monitor humans and surrounding environments," Noh says.

Sensing vibrations from a mere footstep requires extremely sharp detectors. "To give you an idea of how sensitive our sensors are: when you sit in the chair a meter away, we put the sensor on the ground," Zhang says, and "we can sense your heartbeat." Each sensor—a cylindrical device a few centimeters high—sits on the floor and can monitor a walker at a distance of up to 20 meters, Noh says. The researchers can distribute such sensors as an array throughout an area where they want to detect footsteps.

But first, the team had to "teach" the new system to distinguish these signals from the background of sounds heard in any busy building. "Fighting the noise is the biggest challenge we have," Noh says, and addressing it required both hardware and software solutions. On the hardware side, each sensor has an amplifier that automatically changes how much it boosts a footstep vibration. When a vibration seems to be coming from farther away, the amplifier turns it up. As the signal gets stronger and threatens to overwhelm the sensor, the amplifier decreases its sensitivity.

Once the sensors have picked up a footstep, the software takes over. "We do various signal-processing and machine-learning [techniques] to learn what is the human-related signal versus other noise that we're not interested in," Noh says. Like the data from other footstep-detection methods, such as wearables or pressure mats, walking patterns measured with the new sensors can be used to determine an individual's identity and some potential health issues. The team has presented its work at several conferences and seminars—most recently in February at the Society for Experimental Mechanics' International Modal Analysis Conference.

The system displays walkers' behavior live on a computer monitor, reminding one researcher of the "Marauder's Map," a magical floor plan that tracks people's positions in the *Harry Potter* book and film series. Although the fictional map portrayed only one location, the new footstep sensors could be used in any building, notes Eve Schooler, principal engineer and director of emerging Internet of Things networks at Intel, who was not involved in the project but has previously worked with the researchers. "Some of the algorithms that they've developed make the result transferable, which is what's so interesting," Schooler says. "You don't have to do all this calibration to figure out people's signature across buildings—they have the techniques to do that for you." Once the experimental system "learns" a person's signature gait, the sensor array can recognize that individual whether at the office or home.

Given the devices' affordability—Noh estimates each would cost about $10 to $20 to produce—and the fact that they can be placed every 20 meters to create an image of an entire floor, the wide range of applications indicated by Schooler indeed seems possible.

The ability to conduct this kind of monitoring raises obvious privacy concerns, and the researchers suggest their technology should be used only for consensual health care applications. Such monitoring systems, they note, can help caregivers who need to know when elderly people might be likely to fall. They could also alert children's hospitals to symptoms of chronic diseases, such as muscular dystrophy, as early as possible. The developers contend that in such cases, footstep sensors would preserve privacy better than, say, a camera.

"This [was] actually created because of the privacy concerns of the other type of monitoring mechanisms," Zhang says. And in health-related scenarios, he adds, "I'm willing to trade off a little bit of my data to prevent falls and to detect diseases." —*Sophie Bushwick*

MATHEMATICS

False Positive Alarm

The accuracy of coronavirus antibody test results depends on the infection rate

Scientists working to quell the COVID-19 pandemic have developed tests that detect antibodies in the blood of people who have previously been infected with the new coronavirus. These serology tests can provide important data on how COVID-19 is spreading through a population. There is also hope that the presence of certain antibodies may signify immunity to future infection—a possibility scientists are still investigating. Antibody tests do have potential shortcomings: they may detect ineffective antibodies, they do not indicate if an infection is still active, and they fail to detect infection if administered before antibodies develop. A new test's accuracy can also be difficult to determine because of a lack of data.

Still, such tests have been proposed as a way for individuals to find out if they have already been infected with the novel coronavirus. But a mathematical wrinkle makes these tests—and in fact, all screening tests—hard to interpret: even with a very accurate test, the fewer people in a population who have a condition, the more likely it is that an individual's positive result is wrong. If it is, people might think they have the antibodies (and thus may have immunity), when in fact they do not.

A positive screening test result for other diseases usually prompts follow-up testing to confirm a diagnosis. But for COVID-19 screening, such follow-up has been rare because testing resources are scarce or because other testing methods are prioritized for the sickest patients. Here's a look at the massive impact infection rates can have on the predictive value of these tests for individuals. —*Sarah Lewin Frasier*

With any test that is not 100 percent accurate, there are four possible outcomes for each individual:

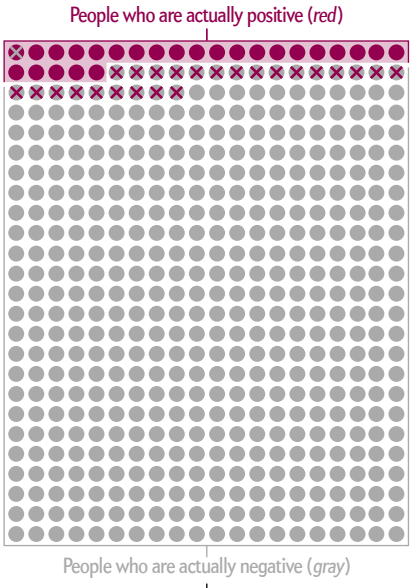
- You are positive and test positive
- You are positive but test negative (false negative)
- You are negative and test negative
- You are negative but test positive (false positive)

A test with a **low** rate of **false positives** has a **high specificity**.

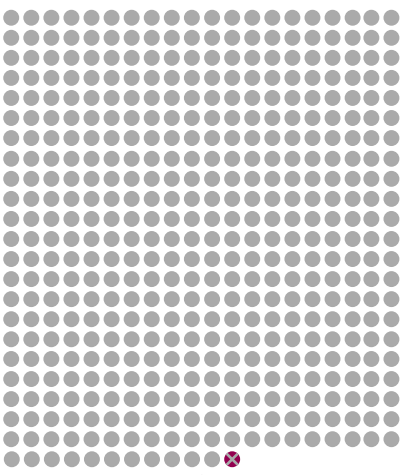
A test with a **low** rate of **false negatives** has a **high sensitivity**.

If a test has **95 percent specificity** and **95 percent sensitivity**, that means it correctly identifies 95 percent of people who are positive and 95 percent of those who are negative. Even with very effective screening tests, depending on the infection rate in the population, an individual's test result may not be reliable.

If a test with **95 percent specificity** and **95 percent sensitivity** is used in a community of **500 people** with a **5 percent infection rate**, the results look like this:

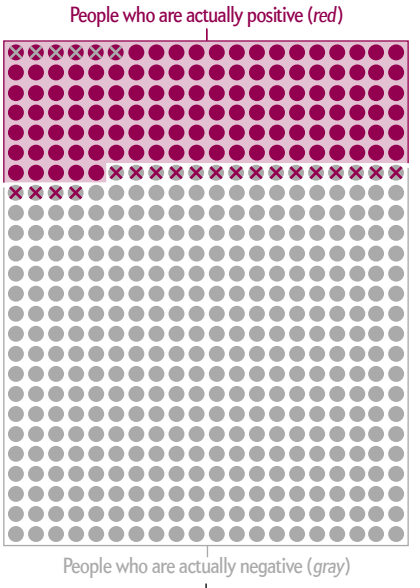


In this scenario, an individual who tests negative has a **99.8 percent** chance of actually being negative.

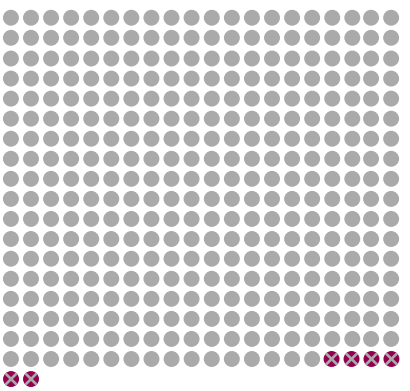


But an individual who tests positive only has a **50 percent** chance of actually being positive.

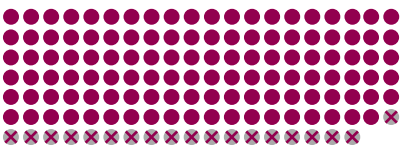
If an equally accurate test is used in a community of 500 people with a **25 percent** infection rate, the results look like this:



In this scenario, an individual who tests negative has a **98.3 percent** chance of actually being negative.



And an individual who tests positive has an **86 percent** chance of actually being positive.



Graphics by Amanda Montañez

Critically endangered red handfish

GETTY IMAGES

CONSERVATION

Out of Hand

A marine fish extinction marks a sad milestone

For centuries humans believed the ocean was so vast that it was impossible to do it measurable harm. But we now know human activities can destroy critical marine habitats, dangerously pollute seawater and make sea environments more acidic. Overharvesting has disrupted food chains and directly pushed many ocean species into the critically endangered category—and has driven some animals, including Steller's sea cow, into total extinction. This past March the smooth handfish, *Sympterichthys unipennis,* officially became the first modern-day marine fish to be declared extinct.

Handfish are a family of 14 unusual bottom-dwelling species related to deep-sea anglerfish. Unlike most other fishes, they do not have a larval phase and do not move around very much as adults; these traits make them sensitive to environmental changes, according to Graham Edgar, a marine ecologist at the University of Tasmania. "They spend most of their time sitting on the seabed, with an occasional flap for a few meters if they're disturbed," Edgar says. "As they lack a larval stage, they are unable to disperse to new locations—and consequently, handfish populations are very localized and vulnerable to threats." In 1996, he adds, another species called the spotted handfish was the first marine fish listed as critically endangered on the International Union for Conservation of Nature (IUCN) Red List.

The smooth handfish was once common enough to be one of the first fish species described by European explorers in Australia. Now none has been reported in well over a century, despite frequent scientific sampling in its known range (including by Edgar and his colleagues). Red List guidelines officially define "extinct" as meaning "there is no reasonable doubt that the last individual has died." Edgar and the members of Australia's National Handfish Recovery Team were forced to that conclusion earlier this year, and the Red List placed it in the extinct category. Scientists are unsure exactly what finished off the species, but others in the region are threatened by trawl fishing, pollution and climate change.

Edgar says additional marine fish species may already be extinct as well, although scientists cannot yet make the call. Many more are critically endangered. "It might be hard to imagine why a little organism occupying a small niche in a place few humans ever visit might be important—but it's an enzyme from an extremophile microbe that's being used in tests to diagnose COVID-19 right now," says Katie Matthews, chief scientist for the nonprofit conservation group Oceana. "Biodiversity matters, even if you can't see it with your own eyes."

Ideally, this news will be a sad wake-up call: "Some remaining species of handfish are endangered," Matthews says, "but with smart action, we can mitigate those threats." —*David Shiffman*

SPACEFLIGHT

Florida Polar Express

Florida will soon reopen to polar space launches

Sixty years ago the U.S. Air Force repurposed its Thor missile as a launch vehicle to put small scientific, weather and military satellites into orbit. Or at least that was the plan. Many of those early satellites ended up in the ocean, along with the remnants of wayward rockets that blew up before reaching space. These vehicles include a Thor Able Star booster that lifted off with a U.S. Navy navigation satellite from Florida's Cape Canaveral Air Force Station on November 30, 1960, and then headed southeast along an unusual flight path.

Rockets launching from the U.S. East Coast usually aim to put satellites in orbits relatively close to the equator; these orbits are within easy reach from Cape Canaveral. But this satellite was set to loop around Earth's poles, a desirable trajectory to view the whole planet that requires much more launch power from Florida to overcome Earth's rotational spin. "Polar orbits are just very difficult to do from this area," says Roger McCormick, a historian at the Cape Canaveral Air Force Space & Missile Museum.

The November 1960 launch

The launch failed and showered debris over Cuba, sparking a cold war confrontation when Cuba claimed falling wreckage killed a cow. A CIA retrospective says Fidel Castro's government paraded another cow through the streets of Havana with a placard addressing the American president: "Eisenhower, you murdered one of my sisters." Lore aside, Florida polar launches were suspended, and the U.S. Air Force later dismantled its ground stations with the capability to remotely track rockets on that path.

Now, however, U.S. officials are reopening the route, thanks to a new generation of rockets that carry along their own flight-tracking systems. These systems can autonomously trigger self-destruct signals should the booster fly off course.

Private company SpaceX aims to launch the first such mission, to put an Argentine Earth-observing satellite into polar orbit, later this year. SpaceX's Falcon 9 rocket will still fly over Cuba, but by then its high-energy first stage will have separated; the second stage will propel the spacecraft roughly 490 kilometers above the island, Federal Aviation Administration officials say. Rockets heading east from Cape Canaveral typically conduct second-stage flight over land as well—so this polar flight is not considered a higher risk to public safety, says Wayne Monteith, who heads the FAA's Commercial Space Transportation office.

SpaceX is looking to eventually fly as many as seven polar-orbiting missions a year from Florida, and other launch operators are watching. "Once you had a company that could successfully demonstrate it," Monteith says, "you would anticipate other companies may follow suit." —*Irene Klotz*

ALAMY

Male hydractinia's sexual polyp. Germ cells are yellow.

TIMOTHY DUBUC, *Swarthmore College*

BIOLOGY

Perpetual Fertility

Scientists identify the gene responsible for a sea creature's rare ability

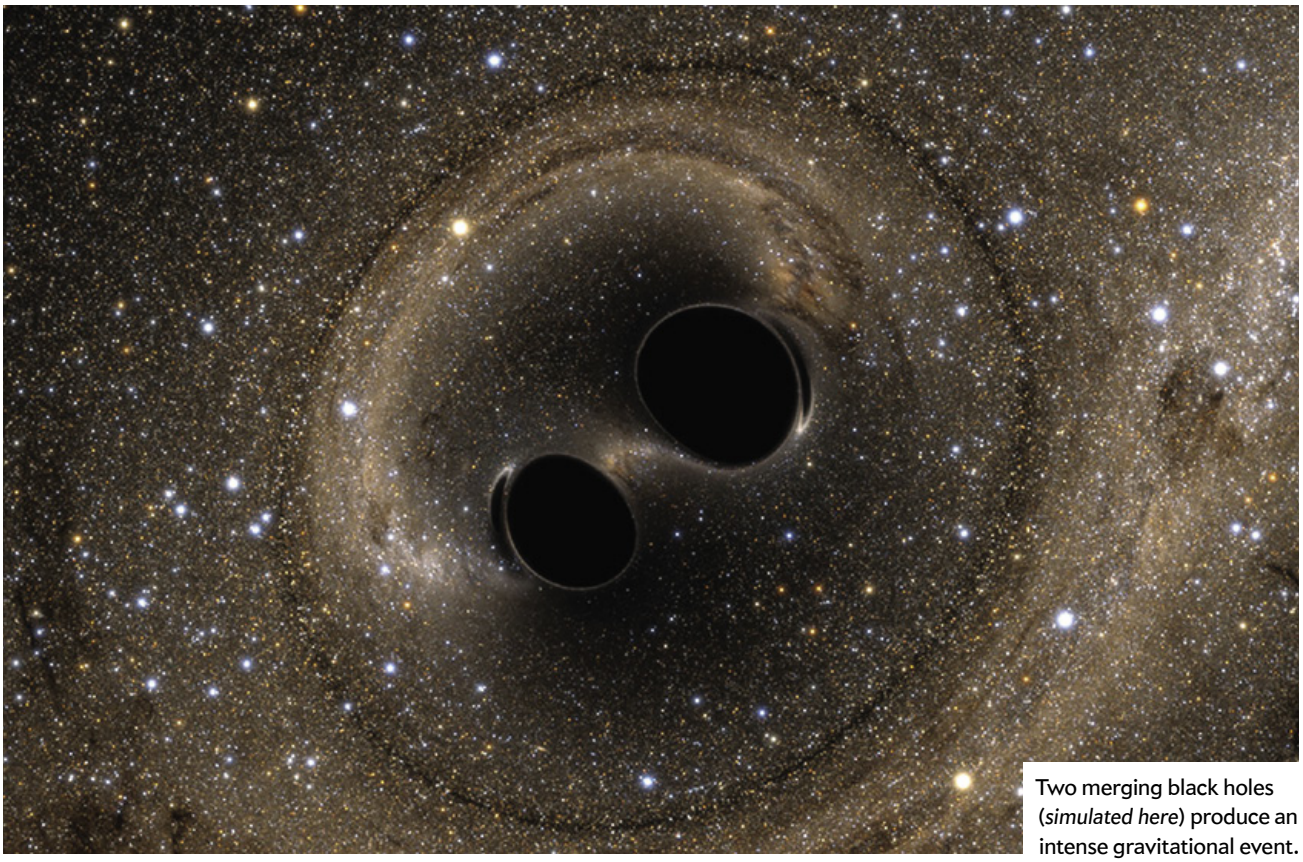
A hairlike, translucent creature that builds colonies on hermit crab shells is strange enough in appearance and living arrangements, but hydractinia's oddities do not stop there. Scientists have now pinpointed a key gene—one also found in humans—that triggers this ocean floor dweller's rare ability to make an unlimited supply of sperm and eggs. It is the first time a gene has been confirmed to solely activate an organism's germ cell production, the researchers say.

Biologist Timothy DuBuc's laboratory at Swarthmore College is one of a handful studying hydractinia, which has multiple genes in common with humans. DuBuc and his collaborators tested new ways to snip a gene called *Tfap2* from the embryonic animal's DNA and manipulate its activity in particular cells, as reported in February in *Science.* Hydractinia's translucent body let the researchers easily observe the effect of removing the gene: once mature, the animal did not produce eggs and sperm. The team also confirmed that the gene's activation in adult hydractinia stem cells turns them into germ cells (precursors of sperm and eggs) in an endlessly repeating cycle.

Cassandra Extavour, a developmental biologist at Harvard University, who was not involved in the research, calls the study's technical advances a "heroic feat." She says the work introduces multiple ways to interfere with hydractinia gene function, as well as the most robust gene-editing protocol to date for cnidarians—hydractinia and their relatives, including jellyfish and anemones.

In other animals scientists have investigated, *Tfap2* triggers germ cells only during embryonic development—and the gene is involved in myriad other developmental processes, too. In humans, *Tfap2* sparks a set number of germ cells just once during development, allowing sperm and egg production. Losing these germ cells results in sterility, and disruption of *Tfap2* has been implicated in maladies such as testicular and ovarian cancer. Watching the gene in action could help researchers better understand and treat human reproductive conditions, according to the study authors.

"For those of us interested in finding the core program that makes a germ cell," DuBuc says, "this could be the animal to do it." —*Stephenie Livingston*



Two merging black holes (*simulated here*) produce an intense gravitational event.

SIMULATING EXTREME SPACETIMES (SXS) PROJECT (WWW.BLACK-HOLES.ORG)

PHYSICS

Glowing Gravitons

Research suggests a new way to pin down particles of gravity

Peer closely enough, and everything begins to look granular. Trees are made largely of quarks. Sunbeams are swarms of photons. Phones run on streams of electrons. Physicists have detected particles of matter, light, and most forces—but no experiment has yet unveiled gravity's grainy side.

Many physicists assume that gravity must come in particles but that these massless "gravitons" interact with familiar particles too weakly to detect. To confirm the existence of gravitons, some theorists suggest searching for them when they gather in hordes surrounding intense gravitational events such as black hole mergers. A recent analysis, published in March in *Physical Review Letters,* hints that such violent cataclysms just might bring gravitons out of the shadows.

Where there is energy, there is gravity. And photons—massless packets of light energy—can, in exceedingly rare cases, spontaneously transform into gravity particles, according to Douglas Singleton, a physicist at California State University, who was not involved with the new study. The reverse happens, too, he says: gravitons can become photons. The new analysis considers a mechanism by which gravitons could unleash many billions of times more photons than earlier research suggested—making it easier to confirm their existence.

"A primitive estimate based on intensities [of gravitons] in the vicinity of black hole mergers came close" to numbers that would produce detectable light, says Raymond Sawyer, the study's author and a physicist at the University of California, Santa Barbara.

Knowing from previous work that other massless particles can abruptly change state in large numbers (a phenomenon known as a quantum break), Sawyer consulted a computer model to see whether gravitons could follow the same pattern. His simulation suggests they do: when gravitons gather densely enough, eventually some of them turn into a burst of light particles. "It's like a storm building, with signs that are nearly invisible," Sawyer says. "You don't see it until it happens."

Events such as black hole mergers should create the necessary conditions to send out photons in the form of radio waves with wavelengths many kilometers long. This signal would be extremely faint but perhaps possible to pick up from Earth. Events somewhat more violent than previously observed mergers could do it, Sawyer says. Scientists would have to tease the glow of the resulting radio waves from that of interfering gases.

First, though, theorists must check if the model holds up. Sawyer hopes future simulations will prove that photon bursts also occur in more realistic models of intense gravitational events, where many gravitons swirl in intricate patterns. Singleton agrees that the problem needs more computational firepower: current analyses are "gross simplifications," he says. "The idea is to get people interested enough to do the heavy calculations." —*Charlie Wood*

IN THE NEWS

Quick Hits

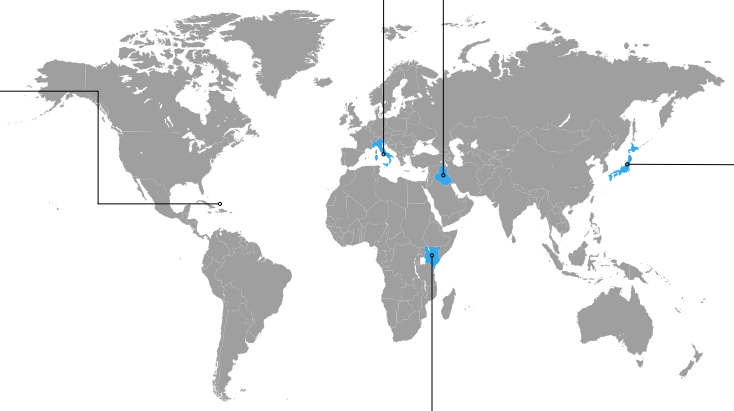
By Sarah Lewin Frasier

ITALY

Sediment samples drawn from the Tyrrhenian Sea off Italy **revealed** hotspots with up to 1.9 million microplastic particles per square meter—the highest concentration ever recorded on the seafloor. Most of this pollution comes from wastewater in sewage systems, researchers say.

IRAQ

Researchers probing the Turkish state archives **found** the earliest known record of a meteorite causing a death. The object struck a hilltop in neighboring Iraq in 1888, killing one man and paralyzing another.



TURKS AND CAICOS ISLANDS

Analysis of anole lizards collected before and after Hurricanes Irma and Maria in 2017, and 18 months later, **revealed** that the surviving lizards and their descendants had larger and therefore "grippier" toe pads. The team examined lizard photographs from natural history collections and 70 years of hurricane data to confirm the trend.

JAPAN

Results gathered from the Kamioka Observatory, which includes an underground detector tank filled with 55,000 tons of water, **suggest** an intriguing discrepancy in how neutrinos and antineutrinos oscillate, potentially violating symmetry between matter and antimatter.

For more details, visit www.ScientificAmerican.com/jul2020/advances

ANTARCTICA

Paleontologists **found** a fossilized 40-million-year-old frog on Seymour Island, near the tip of the Antarctic Peninsula. The frog is related to modern ones living in temperate, humid conditions in the Chilean Andes.

KENYA

Scientists **identified** a malaria-blocking microbe in mosquitoes on the shores of Lake Victoria in Kenya. Every mosquito catalogued with this apparently benign fungus was free of the disease-carrying parasite, and experiments show the fungus prevented its transmission.

BIOTECH

Detox Disguise

Shaped nanoparticles soak up toxins like red blood cells do

Red blood cells are not just vehicles that transport oxygen in our bodies: they also clear harmful substances from the bloodstream. Scientists at Johns Hopkins University recently investigated how synthetic biomimicking (or "biomimetic") nanoparticles, masquerading as red blood cells, can best pull off the same feat in mice. They found that molding these impostors into nonspherical shapes before disguising them improved performance.

Previous work had shown that coating synthetic nanoparticles in membranes borrowed from real red blood cells lets the particles act like cleansing sponges. "By injecting a lot of these particles into the blood, we create decoys that soak up the toxins [so] there's less harm to healthy cells," says Jordan Green, a biomedical engineer at Johns Hopkins and senior author on a new study of the technique, published in April in *Science Advances.*

The researchers first manufactured spherical nanoparticles from a biodegradable polymer that is known to be safe and is widely used in therapeutic devices. They then stretched the particles into shapes resembling tiny, flattened Frisbees and elongated footballs. Finally, they wrapped some of each shape in the membranes, which they stripped from mouse red blood cells.

The team had hypothesized that nanoparticles shaped like disks—as real red blood cells are—would better absorb toxins because of their increased surface area. To test which shape worked best, the researchers injected each variety into mice that had been exposed to a typically lethal dose of toxin from *Staphylococcus aureus* bacteria. Green and his colleagues report that the football-shaped, membrane-coated particles survived the longest before being cleared by the immune system—almost seven times longer than uncoated spheres. Mice treated with spherical particles, even coated ones, did not live much longer than those left untreated. But a third of the mice treated with coated Frisbee-shaped particles, and half of those treated with coated football-shaped ones, were alive and healthy a week later.

Green notes that even though the Frisbee-shaped particles matched red blood cells' shape more closely, the football-shaped ones worked better. "It tells us that there are other things the disk shapes didn't mimic, including the elasticity of [red blood cells] that deform as they flow," he says. He adds that the football-shaped ones most likely move through the blood more easily.

Other studies "have found that [nonspherical] shapes and biomimetic membrane coatings could, separately, enhance the lifetime of synthetic particles in the bloodstream," says Dyche Mullins, a cellular and molecular pharmacologist at the University of California, San Francisco, who was not involved in the research. But "this study now demonstrates a synergy between the two effects." —*Harini Barath*

MATERIALS SCIENCE

Death Metal

Zapping copper with lasers boosts antimicrobial properties

Copper surfaces kill microbes that come into contact with them in a matter of hours. A new technique makes the familiar metal even deadlier—by zapping it with lasers.

Bacteria "are becoming more aggressive and resistant to therapeutics; it's the same thing for viruses," says Rahim Rahimi, a materials engineer at Purdue University and senior author of a paper on the new process, published in April in *Advanced Materials Interfaces.* "There is a lot of interest in how to create surfaces that actually, on contact with the bacterium or the virus, immediately kill the pathogen" because this "eliminates the spread of that pathogen into the environment." (The new research focused particularly on bacteria.)

Copper is a good candidate for such surfaces: humans have been taking advantage of its bacteria-slaying properties for at least 8,000 years. People in some Bronze Age civilizations let their drinking water rest in copper vessels to avoid disease, says Michael Schmidt, a microbiologist at the Medical University of South Carolina, who was not involved in the new research. Copper's germ-destroying power, he explains, comes from its ability to conduct electricity. When a microbe touches a metal surface, the substance carries electrons away from the microbe's cellular membrane. This reaction sets off a chemical process that ultimately forces open the organism's pores and destroys it.

To enhance the process, Rahimi's team hit a copper sample with laser light for a few milliseconds, thereby creating nanoscale pores in the flat metal and increasing its surface area. "They've effectively taken a prairie and made Manhattan," Schmidt says, noting that the added vertical structures "increased the amount of 'square footage' … available to kill microbes." The bumpy surface also made the copper cling more strongly to water—and thus to any bacteria within it.

The researchers tested this newly rugged terrain by placing several bacterial strains, including *Escherichia coli* and a drug-resistant *Staphylococcus aureus* strain, on both flat and laser-treated pieces of copper. As soon as the cells hit the textured metal, their membranes began to suffer damage; that surface completely eradicated the bacteria, in some cases much more quickly than the untreated one. The surface killed some microbes immediately on contact and took from 40 minutes to two hours to wipe out a full colony, depending on the species and concentration.

The laser treatment could also work with other metals, including titanium, which is often used for surgical implants, Rahimi says. He points out that all types of metals display some antimicrobial properties, although titanium, which has little conductivity, kills germs much more slowly than highly conductive ones such as copper. Applying the laser technique, he says, "could actually boost up the antimicrobial properties of that targeted metal."

—*Sophie Bushwick*

Illustration by Thomas Fuchs

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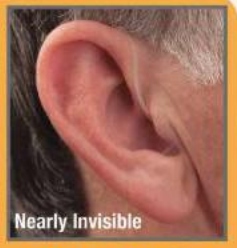

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Rafael Campo teaches and practices medicine at Harvard Medical School and Beth Israel Deaconess Medical Center in Boston. He has published seven collections of poetry and is also the poetry editor for *JAMA*, the *Journal of the American Medical Association*.

PATHOLOGY

The body quantified: at autopsy,
it's always on its back, looks up at me

lips puckered tight, as if it would refuse
one last kiss. How much the liver weighs,

how heavy is the heart, how large the brain.
The body, hungerless, all that remains,

reminds us we are objects absent souls.
I try to animate them, nights alone,

when human company seems necessary,
the lab surrounding us imaginary

as Frankenstein's—any thing's possible.
I talk to this one like she's only ill

and might pull through, remembering my friend
who died of stomach cancer, face so drawn

and bloodless she was almost only breath.
I was among those thankful for my health

who'd visit, but not have to stay. We'd tell
her stories as she winced in pain; meanwhile,

the clock kept warning us no time was left.
How mute the opened thorax, how bereft

the empty bowl of pelvis, how I wish
our fables, in the end, were more than this.

WILLIAM ATTARD McCARTHY *Getty Images*

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.*

How to Boost Your Immunity

Some simple, practical steps can raise your resistance to viruses

By Claudia Wallis

Fear and fraud often travel together. As coronavirus anxiety began to spread across the land, so did bogus nostrums promising protection from this modern-day plague. As early as March 6, U.S. regulators began to issue warnings to companies promoting false claims, such as this one touting the benefits of drinking a daily dose of silver particles: "It's actually widely acknowledged in both science and the medical industry that ionic silver kills coronaviruses." Um, no.

For people who hope to build up their resistance to coronavirus and infections of all kinds, there are no magic formulas—but there are some science-based steps one can take to maintain a healthy immune system. For starters, don't smoke. Cigarette smokers are much more vulnerable to respiratory infections. Second, make sure you are covering all your nutritional bases with a wide variety of vegetables, fruits and other elements of a healthy diet. "Eating an optimal diet reduces the risk of getting an infection and reduces the severity of infections," says Wafaie Fawzi, professor of nutrition, epidemiology and global health at Harvard University's T.H. Chan School of Public Health. Third, practice good sleep hygiene so you can raise your chances of adequate nightly rest. And fourth, get regular exercise, which will also help you sleep.

On the dietary front, several nutrients have been tied to improved resistance to viruses. Taking zinc supplements, for example, has been linked to a reduced rate of respiratory infections and shorter duration of related symptoms. Deficiency in zinc, a mineral found in meat, shellfish, nuts and whole grains, is more prevalent in less developed countries, Fawzi notes, but it can occur in wealthier nations, especially during a time of high unemployment and disruptions to the food supply chain.

Vitamins C and D have also been shown to improve resistance to respiratory infections. Perhaps relevant to COVID-19, vitamin C plays a role in reducing tissue damage from our own immune responses. Oral doses of the vitamin have also been shown to shorten the amount of time in an ICU and on a ventilator for heart surgery patients, according to a 2019 meta-analysis. Could it help COVID patients? Researchers are looking at it, Fawzi says.

As for vitamin D, a 2017 meta-analysis of 25 randomized controlled trials found that vitamin D supplements cut the risk of acute respiratory infection—especially for people with low levels of the vitamin, which is about 40 percent of Americans. The percentage is far higher in African-Americans and Hispanics. Fawzi points out that late winter/early spring, when the pandemic began in the U.S., happens to be when D levels are especially low because we mainly acquire the nutrient via sun exposure.

Fawzi and his colleagues have begun to investigate whether vitamin D might help COVID patients. In the meantime, he suggests taking a basic multivitamin. "A supplement with the recommended daily allowances of vitamins and minerals would be prudent," he says, along with a balanced diet. It might particularly help elderly adults, who are prone to nutritional deficiencies.

As for sleep, scientists have long known that it plays an essential role in bolstering our defenses. Studies show that if you deprive people of sleep after administering a vaccine, they will produce a weaker antibody response than folks who slept. Research suggests that sleep enhances the migration of T cells to the lymph nodes, where they are presented with foreign molecules that trigger antibody production, explains neuroscientist Luciana Besedovsky, who investigates sleep and the immune system at the University of Tübingen in Germany.

A 2015 study that measured average sleep duration for 164 healthy volunteers and then dripped a rhinovirus into their nose found that those who slept six or fewer hours a night were four times as likely to develop a cold as those who slept more than seven hours. Similarly, a study that followed 57,000 women found that those who slept five or fewer hours nightly were 40 percent more likely to have developed pneumonia over a four-year study period than eight-hour sleepers. Prolonged sleep loss, Besedovsky says, can create a state of low-grade inflammation: "This seems to exhaust your immune system in the long run, so that it may not be able to fight infections that well."

Committing to a regular bedtime and nightly routine that helps you sleep, along with a healthy diet—and perhaps a multivitamin—will not necessarily keep the coronavirus at bay. But these steps have a true silver lining of helping you endure whatever health threats blow your way. SA

Illustration by Fatinha Ramos

TREATING PATIENTS WITHOUT THE SCALE

Focusing on weight loss isn't making people healthier. Some doctors are trying a different approach

By Virginia Sole-Smith

Photographs by Dan Saelinger

THE WAITING ROOM AT THE MOSAIC COMPREHENSIVE CARE CLINIC in Chapel Hill, N.C., is as generic as any doctor's office except for a framed sign by the door. "No Wrong Way to Have a Body," it says, above an illustration of different cacti species. The second anomaly of this primary care practice is what is missing from the exam rooms: there are no scales. Louise Metz, the clinic's owner and founder, keeps just one on the premises, tucked in a back hallway. Most patients never even know it is there.

Virginia Sole-Smith is author of *The Eating Instinct: Food Culture, Body Image and Guilt in America* and a regular contributor to *Parents* and the *New York Times*. She last wrote for *Scientific American* about menstruation taboos. Follow her on Twitter and Instagram at @v_solesmith

IN BRIEF

Doctors often suggest losing weight to address health concerns. But that approach often harms more than it helps. **The weight stigma** people face in health care settings contributes to poor health outcomes. **Some doctors** are moving away from a weight-centric model to focus on prescribing healthier behaviors.

Erin Towne, 37, who has come in for her annual physical, does know about the scale; she will stand on it during her examination so Metz can check whether she is continuing to restore her weight after recovering from a restrictive eating disorder. But only Metz will see the number. Towne, a mother of two who works in IT at a local university, is tall and slender, a runner. She wears a long sundress and hunches slightly as she sits in one of the exam room's armless chairs. The chairs are designed to support heavy people comfortably, and not so long ago Towne would have been grateful to see them. This willowy body is still relatively new to her. In January 2017 she underwent bariatric surgery, and she lost 160 pounds.

For most of her life, Towne says, "all of my health care has been focused on me losing weight." After a series of blood sugar spikes at 13 years old, Towne was diagnosed with type 1 diabetes and started getting daily insulin injections. She was an average-sized kid, but her endocrinologist immediately suggested that she lose 10 to 15 pounds—a dictum that became the refrain of every doctor Towne saw as she grew older. It did not seem to matter that her diabetes was well controlled with a very low level of insulin; research dating back to the 1990s has shown an association between weight loss and better blood glucose management for diabetics, so weight-loss protocols are standard. Towne had been dieting since she was a teenager but never sustained the losses for long.

In 2016 Towne saw a new endocrinologist who changed her diagnosis to maturity-onset diabetes of the young, an inherited form of the condition. Even with an accurate diagnosis—and with confirmation that her diabetes was genetic in origin, not linked to weight—the obsession with making her smaller persisted, Towne says. Her doctor prescribed a diabetes medication called Victoza, which is also used for weight loss. Towne tried it for a month but experienced acid reflux so severe that she could not go to work. At that point bariatric surgery seemed inevitable. "I couldn't seem to keep the weight off any other way," she says. "I had confidence that I could take care of my diabetes, but it seemed like no one else could split those two things apart."

Within six months of her bariatric surgery, Towne's body mass index (BMI) had dropped to 19.1, which is at the low end of the "normal" range for a person her height. In May 2017 Towne was able to stop using her insulin pump, a victory her endocrinologist attributed to her weight loss. At a follow-up appointment in her surgeon's office in December 2017, a physician assistant seemed thrilled with the results. "Congratulations, you can eat extra cookies over the holidays!" Towne recalls the PA telling her. But Towne felt out of control around food. She had become obsessed with tracking exercise and calories on fitness apps. "I was restricting so intensely that my body was in emergency mode," she says. "I would stand in front of my kitchen cabinets and picture myself eating everything in there." A few weeks later Towne sought help from a therapist, who diagnosed her with anorexia and referred her to the Mosaic clinic for medical supervision during her recovery. Towne did not quite believe her therapist at first: "The idea that I had a restrictive eating disorder was mind-blowing," she says. "I thought I was just doing what I'd always been told to do."

Unlike Towne's previous doctors, Metz did not praise her patient's dramatic weight loss. In fact, Metz, an internal medicine physician, is suspicious of the long-held belief that weight loss is necessary for optimal diabetes care. "The studies that associate weight loss with improvements in A1C [a blood glucose measurement] are asking the wrong question," she says. Weight may go down temporarily with a restrictive diet, but she believes that it is the changes in eating habits and exercise that cause the improvement, not the pounds lost. "And if those behavioral changes are too restrictive," Metz adds, "they may make the problem worse."

After taking Towne's history, Metz ordered an electrocardiogram—and then repeated it three times to confirm that Towne's resting heart rate had dropped into the low 50s, well below the normal range of 60 to 100 beats per minute. (Although low heart rates are considered healthy in endurance athletes, they are often a dan-

gerous complication of severe weight loss and malnutrition, which can also cause arrhythmia and even death.) Metz also ran bloodwork, which revealed high cholesterol and estrogen that had dropped to menopausal levels, both of which are common side effects of anorexia. Metz showed her patient the test results and said, "None of this is okay." It was a profoundly sobering moment for Towne. "My other doctors had never even noticed," she says. "It was the first time I understood that my health was in more danger now that I was underweight than when I'd been at my highest weight."

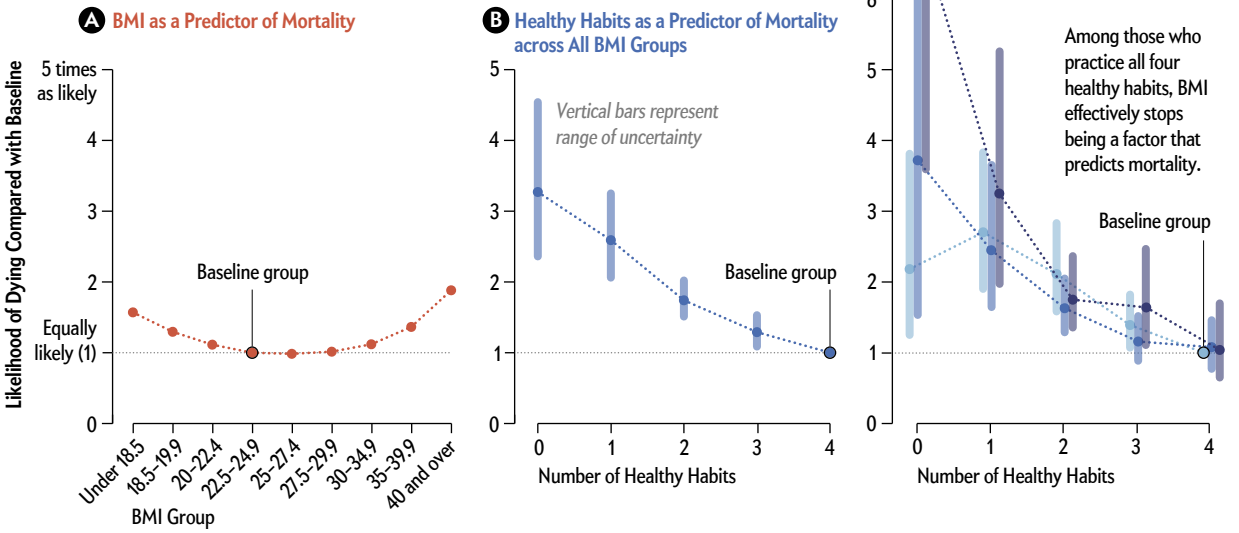
QUESTIONING THE WEIGHT-CENTRIC MODEL OF HEALTH CARE

TO METZ, Towne's lifelong health care experience is a classic example of how negative beliefs about high body weights lead to bias-informed medicine that hurts rather than heals. In Towne's case, her doctors' fixation on weight loss to manage her diabetes led them to miss other red flags and even to reinforce her disordered eating behaviors. In May 2018 a Canadian woman named Ellen Maud Bennett died only a few days after receiving a diagnosis of terminal cancer; in her obituary, her family wrote that Bennett had sought medical care for her symptoms for years but only ever received weight-loss advice. "We see this kind of stigma all the time in the typical medical visit when patients are shamed about their weight," Metz says. "Assumptions are made about their health and lifestyle based on their size, and they often receive recommendations for weight loss rather than evidence-based treatments for their health conditions."

Metz, who attended the Duke University School of Medicine and did her residency in San Francisco before becoming an attending physician in New York, estimates that her first five to seven years as a doctor were spent in that same weight-centric mode. "My private-practice patients all came in asking about weight loss, and I jumped right into it," she says. Indeed, it is what the vast majority of health care providers have long assumed they should focus on since the early 20th century, when the

BMI vs. Healthy Habits

To improve health, doctors often advise their patients to lose weight. Research has shown, however, that it is the behaviors people practice—not the size of their bodies—that have the biggest impact on mortality. Research has found that whereas mortality risk increases for those with the highest and lowest BMIs, there is no increased risk for people in the middle range (overweight and low obesity) compared with that for those with BMIs in the normal range **A**. In another study, when researchers tracked the BMI and four lifestyle habits of 11,761 adults over 14 years, they found that regardless of their weight class, people lived longer when they did not smoke, drank alcohol in moderation, ate five or more servings of fruits and vegetables daily, and exercised 12 or more times per month. "If you're obese and you have a healthy lifestyle, you are no more likely to die early than a person of normal weight," says Eric Matheson, the lead author of this 2012 analysis **B** **C**. The "baseline group" is the reference against which all other groups were measured.



SOURCES: "ASSOCIATION OF BMI WITH OVERALL AND CAUSE-SPECIFIC MORTALITY: A POPULATION-BASED COHORT STUDY OF 3.6 MILLION ADULTS IN THE U.K.," BY KRISHNAN BHASKARAN ET AL., IN *LANCET DIABETES & ENDOCRINOLOGY*, VOL. 6; OCTOBER 30, 2018 *(BMI data)*; "HEALTHY LIFESTYLE HABITS AND MORTALITY IN OVERWEIGHT AND OBESE INDIVIDUALS," BY ERIC M. MATHESON ET AL., IN *JOURNAL OF THE AMERICAN BOARD OF FAMILY MEDICINE*, VOL. 25, NO. 1; JANUARY 2012 *(healthy habits data)*

Graphic by Amanda Montañez

The Racist Roots of Fighting Obesity

By Sabrina Strings and Lindo Bacon

Black people, and black women in particular, face considerable health challenges. Compared with their rates in other racial groups, chronic cardiovascular, inflammatory and metabolic risk factors have been found to be elevated in black women, even after controlling for behaviors such as smoking, physical exercise or dietary variables.

Black women have also been identified as the subgroup with the highest body mass index (BMI) in the U.S., with four out of five classified as either "overweight" or "obese." Many doctors have claimed that black women's "excess" weight is the main cause of their poor health outcomes, often without fully testing or diagnosing them. While there has been a massive public health campaign urging fat people to eat right, eat less and lose weight, black women have been specifically targeted.

This heightened concern about their weight is not new; it reflects the racist stigmatization of black women's bodies. Nearly three centuries ago scientists studying race argued that African women were especially likely to reach dimensions that the typical European might scorn. The men of Africa were said to like their women robust, and the European press featured tales of cultural events loosely described as festivals intended to fatten African women to the desired, "unwieldy" size.

In the eyes of many medical practitioners in the late 19th century, black women were destined to die off along with the men of their race because of their presumed inability to control their "animal appetites"—eating, drinking and fornicating. These presumptions were not backed by scientific data but instead embodied the prevailing racial scientific logic at the time. Later, some doctors wanted to push black men to reform their aesthetic preferences. Valorizing voluptuousness in black women, these physicians claimed, validated their unhealthy diets, behaviors and figures.

Today the idea that weight is the main problem dogging black women builds on these historically racist ideas and ignores how interrelated social factors impact black women's health. It also perpetuates a misinformed and damaging message about weight and health. Indeed, social determinants have been shown to be more consequential to health than BMI *or* health behaviors.

Doctors often tell fat people that dietary control leading to weight loss is the solution to their health problems. But many studies show that the stigma associated with body weight, rather than the body weight itself, is responsible for some adverse health consequences blamed on obesity, including increased mortality risk. Regardless of income, black women consistently experience weightism in addition to sexism and racism. From workplace discrimination and poor service at restaurants to rude or objectifying commentary online, the stress of these life experiences contributes to higher rates of chronic mental and physical illnesses such as heart disease, diabetes, depression and anxiety.

A 2018 opinion piece co-authored by psychologists, sociologists, and behavioral scientists in the journal *BMC Medicine* argued that bias against fat people is actually a larger driver of the so-called obesity epidemic than adiposity itself. A 2015 study in *Psychological Science,* among the many studies supporting this argument, found that people who reported experiencing weight discrimination had a 60 percent increased risk of dying, independent of BMI (and there-

life insurance industry began to collect data showing that a higher body weight predicted a shorter life span. In the 1970s physiologist Ancel Keys published research establishing a correlation between dietary fat and heart disease and proposed the modern BMI system, a measure of body fat based on weight and height that is used by many doctors to categorize health by weight.

By 1985 the National Institutes of Health had adopted the BMI as one of two official ways to assess body fat, and in 1998 an expert panel convened by the NIH put in place guidelines that moved 29 million Americans who had previously been classified as normal weight or just overweight into the overweight and obese categories. "This created the 'obesity epidemic' and really intensified the focus on weight as a risk factor for health," says Jeffrey Hunger, an assistant professor of social psychology at Miami University in Oxford, Ohio, who studies health in stigmatized populations.

Defenders of the 1998 guidance say that research strongly supported the need for that shift and for medicine's increased and laserlike focus on weight as a health risk. "It is virtually incontrovertible that obesity has some negative impact," says David Allison, dean and distinguished professor at the Indiana University-Blooming-

Illustration by Chiara Vercesi

fore regardless of body size). The underlying mechanisms explaining this relationship may reflect the direct and indirect effects of chronic social stress.

Additionally, living in racially segregated, high-poverty areas contributes to disease risk for black women. Low-income black neighborhoods are often disproportionately impacted by a lack of potable water and higher levels of environmental toxins and air pollution. These factors add to the risk for respiratory illnesses such as asthma and lung disease. They also increase the chance of serious complications from the novel coronavirus.

Further, these neighborhoods typically have a surfeit of fast-food chains and a dearth of grocery stores offering more nutritious food choices. Food insecurity, which is defined as the lack of access to safe, affordable and nutritious foods, has a strong association with chronic illness independent of BMI.

Simply blaming black women's health conditions on "obesity" ignores these critically important sociohistorical factors. It also leads to a prescription long since proved to be ineffective: weight loss. Despite relentless pressure from the public health establishment, a private weight-loss industry estimated at more than $72.7 billion annually in the U.S., and alarmingly high levels of body dissatisfaction, most individuals who attempt to lose weight are unable to maintain the loss over the long term and do not achieve improved health. This weight-focused paradigm fails to produce thinner or healthier bodies but succeeds in fostering weight stigma.

Chronic diseases such as diabetes or heart conditions are mislabeled "lifestyle" diseases, when behaviors are not the central problem. Difficult life circumstances cause disease. In other words, the predominant reason black women get sick is not because they eat the wrong things but because their lives are often stressful and their neighborhoods are often polluted.

The most effective and ethical approaches for improving health should aim to change the conditions of black women's lives: tackling racism, sexism and weightism and providing opportunity for individuals to thrive.

Sabrina Strings is an associate professor of sociology at the University of California, Irvine, and author of *Fearing the Black Body: The Racial Origins of Fat Phobia* (N.Y.U. Press, 2019).

Lindo Bacon (formerly Linda) is an associate nutritionist at the University of California, Davis. They are author of *Health at Every Size: The Surprising Truth about Your Weight* (BenBella, 2010) and *Radical Belonging* (BenBella, in press) and co-author of *Body Respect* (BenBella, 2014).

ton School of Public Health. "It's pretty clear that it leads to elevated blood pressure and chronic inflammation, which both lead to problems." But weight stigma (also known as weight bias), which is defined as the set of negative attitudes or beliefs that are expressed as stereotypes, prejudice and even overt discrimination toward people with higher-weight bodies, does harm, too. It can influence how scientists approach their research, leading to gaps in understanding of the relation between body size and health. It contributes to missed or delayed diagnoses and to chronic stress for patients. Meanwhile the medical community's goal of solving America's health problems by fixating on weight loss has proved nearly impossible to achieve.

Although the correlation between larger bodies and higher rates of heart disease, diabetes and other chronic conditions is well known, some of the mechanisms behind the relationship are not straightforward. Mainstream weight researchers argue that high body weight itself causes the elevated blood pressure and inflammation responsible for such conditions. Others, such as physiologist Lindo Bacon, say that the contribution of weight to health is complex and that the root cause of disease is more likely to be an intersection of the patient's genetics, life habits and environment.

In some cases, data have shown that a higher body weight can actually be protective against certain health conditions. In the early 2000s researchers began noticing that heart surgery patients with higher BMIs had better survival rates than their thinner counterparts; this phenomenon was dubbed the "obesity paradox" and has also been documented for patients with osteoporosis (in whom higher body weight is thought to improve bone mineral density), major injuries and some kinds of cancer. The fact that a higher body weight actually helps people survive certain major illnesses could partially explain why individuals in overweight and low-obese BMI categories have an overall lower mortality risk according to the large epidemiology analyses of body weight and mortality correlations in the National Health and Nutrition Examination Survey (NHANES), the first of which was published by scientists at the Centers for Disease Control and Prevention in 2005. This research documents a "J curve" for the relation between BMI levels and mortality, meaning that whereas mortality risk increases for those with the highest and lowest BMIs, there is no increased risk for people in the middle range—overweight and low obesity—compared with that for those with BMIs in the normal range.

"The nadir of that J-shaped curve is getting higher on the BMI scale as we track populations over time," explains Allison, who has studied the "obesity paradox." "It could be that we have better treatments, so obesity doesn't kill you as quickly as it used to." But the very fact that these findings are marveled over and classified as a paradox underscores the role of weight bias in how we think about weight and health, stigma researchers say. "A paradox is something contradictory or seemingly absurd," Hunger notes. "This term only exists because it's considered absurd that fat people could actually be healthy."

Scientific understanding of weight and health developed in tandem with cultural biases about body size, leading to a belief that weight is a matter of personal responsibility and willpower. Numerous studies dating back to about 1960 have documented how children, when shown pictures of kids with various body types, will nearly always rate the fat child as the one they like least. In a 1980 experiment, a public health researcher named William DeJong found that high school students shown a photograph of a higher-weight girl rated her as lazier and less self-disciplined than a normal-weight subject unless

they were told her weight was caused by a thyroid condition. "Unless the obese can provide an 'excuse' for their weight … or can offer evidence of successful weight loss, their character will be impugned," he wrote.

DeJong's and others' early findings of weight stigma were regularly dismissed by mainstream researchers and health care providers alike. Then, in the early 2000s, a wealthy donor named Leslie Rudd, who had made his fortune in the food and beverage industry, approached a group of weight researchers at the Yale School of Medicine and asked them to study the impact of this stigma on people in larger bodies. "I was once a lot more overweight than I am now, and it gave me a firsthand insight into what people who are overweight feel and the discrimination they face," Rudd was quoted as saying in a 2006 Yale press release. "There was very little work happening in this area," says Kelly Brownell, a professor of public policy at Duke and a former director of what became the Rudd Center for Food Policy and Obesity. Rebecca Puhl, then a graduate student of Brownell's, volunteered to lead the effort. "Basically, Rebecca created this field," Brownell says. "And we were pretty quickly dumbfounded by what we found."

Today ample evidence documents how people with larger bodies experience bias not only in health care settings but also in their workplaces, their schools and the media. Puhl, who is now deputy director for the Rudd Center at the University of Connecticut, and other scientists are beginning to show how living with this kind of chronic internal and external weight stigma negatively affects physical and mental health. This past March, Puhl and 35 of her colleagues released a consensus statement in the journal *Nature Medicine* condemning weight stigma as "inconsistent with current scientific evidence demonstrating that body weight regulation is not entirely under volitional control and that biological, genetic and environmental factors critically contribute to obesity." They also issued a pledge, signed by more than 100 medical and scientific organizations, including the American Diabetes Association, to eradicate weight stigma by treating "individuals with overweight and obesity with dignity and respect," especially in the workplace and in education and health care settings.

Yet weight loss continues to be promoted as a medical necessity for reducing mortality and managing chronic conditions such as heart disease and diabetes. That is why a small but growing group of weight researchers is pushing to replace the weight-centric model of health care with a "weight-inclusive" approach being pioneered by Metz and a handful of other medical practitioners around the country. Doctors who have embraced this strategy evaluate a patient's health and medical needs on the basis of blood pressure, cholesterol and other biomarkers, and they focus on the health benefits that can be reaped from improving behaviors related to diet and exercise regardless of whether such changes lower body weight. These factors may be more useful benchmarks for achieving healthy outcomes than BMI. A handful of randomized clinical trials and epidemiological studies have shown that improvements in diet and exercise habits can lower blood pressure and make other physiological gains even when study subjects do not lose weight, as Bacon and weight science researcher Lucy Aphramor concluded in their 2011 evidence review in *Nutrition Journal*. "What we're really doing is looking at patients as complex human beings rather than funneling all of our health concerns through their weight," Metz explains. "We're stepping back to look at how the different organs and bodily systems interact with each other and then how a patient's environment, and even society as a whole, impacts their health." If that approach could lead to healthier outcomes, would the medical and weight-science communities be ready to let go of the number on the scale?

HOW WEIGHT STIGMA HARMS

NEGATIVE ASSOCIATIONS with large body types appear to cause real harm in health care settings. Kimberly Gudzune, an associate professor at the Johns Hopkins School of Medicine, has found that people who have been stigmatized for their weight in a doctor's office are less likely to come back. After analyzing audio recordings of 208 patient encounters with 39 primary care physicians, Gudzune found that doctors established less emotional rapport with their higher-weight patients, according to a study published in 2013 in the journal *Obesity*. In another paper, published in 2014, she found that 21 percent of patients with overweight and obese BMIs felt that their doctor "judged them about their weight"—and as a result, they were significantly less likely to trust their doctor.

This distrust appears to occur regardless of a patient's socioeconomic status. In one 2006 study, 68 percent of high-weight women reported that they had delayed seeking health care because of their weight, even though more than 90 percent of the study participants had health insurance. Gudzune says she observes this clinically all the time: "It's not unusual for me to see a patient who hasn't been to the doctor in 10 years, and now I'm telling them they have diabetes or hypertension. Who knows how many of those issues could have been prevented or at least better managed with earlier care?"

Even when patients with large bodies do continue to seek medical care, their provider's weight bias can compromise the quality of the care they receive. "Think about all the stereotypes we have that people with higher body weights are lazy, lack willpower and are uninterested in their own health," Hunger says. "If that's the lens you walk in with to a clinical encounter, of course it shapes the questions you ask and the attitudes you take toward your patients." Studies show that clinicians may be less willing to provide standard care to patients with high BMIs. In one survey of 1,316 physicians, 17 percent said they were reluctant to perform pelvic exams on patients with obese BMIs. In a 2011 study on patients reporting shortness of breath and several other ailments, medical students tended to prescribe weight-loss strategies rather than symptom management to patients with larger bodies.

Metz says she first became aware of the prevalence of weight stigma in health care 12 years ago while working

in a primary care practice at Duke. She knew that when she treated patients with eating disorders, it was critical to avoid weigh-ins or discussions of weight-loss strategies because any focus on body size could trigger their deeply internalized shame and their propensity toward disordered eating and other destructive behaviors. "But then I'd leave that patient and walk next door to see someone who didn't have a diagnosed eating disorder but really wanted me to help them lose weight," she recalls. Metz could not reconcile the disconnect she felt talking about portion control and calorie counting with larger patients—many of whom were dieting and exercising in extreme ways—when those same behaviors would be cause for concern in her thinner patients.

In fact, research suggests that restrictive eating disorders may be more prevalent in people with larger bodies. Classic anorexia nervosa is diagnosed in just 0.6 percent of Americans, perhaps in part because one of its diagnostic criteria is that patients must have reached an "extremely low body weight." But atypical anorexia, which was added in 2013 to the fifth edition of the *Diagnostic and Statistical Manual of Mental Disorders,* is now used to diagnose patients who would otherwise meet criteria for anorexia but are not underweight; by one recent estimate, 2.8 percent of Americans would qualify for this diagnosis. Other research on eating disorders suggests that patients who develop them at higher weights are as much at risk for medical complications such as dangerously low blood pressure and slow heart rates as thinner patients, and they often struggle longer before receiving treatment, probably because doctors ignore or misdiagnose their symptoms. "It wasn't promoting my patients' health to prescribe weight loss," Metz says. "It was doing harm."

The harm caused by weight stigma appears to go well beyond misdiagnosis. A 2016 analysis of data collected from more than 21,000 American adults in the National Epidemiologic Survey on Alcohol and Related Conditions found a significant association between a person's experience of weight stigma and an increased incidence of heart disease, stomach ulcers, diabetes and high cholesterol even after researchers controlled for their subjects' socioeconomic status, physical activity level and BMI.

Puhl and other weight-stigma researchers have conducted experimental studies that have shown that people randomly assigned to "weight-stigma stimuli" consistently have higher physiological stress responses, such as increased cortisol levels, than those assigned to nonstigmatizing experiences. (One study by psychologists at Rutgers University and the University of California, Los Angeles, involved a researcher telling unwitting volunteers that they could not participate in an exclusive shopping experience, because they were too big and might stretch out the clothes.) These data suggest that weight stigma may be more than just unpleasant to live with; it might actually contribute to some portion of the poor health outcomes disproportionately seen in people with higher-weight bodies. "We know that physiological stress plays a role in body weight because higher levels of cortisol contribute to weight gain," Puhl explains. "Weight stigma is a form of chronic stress. So that has chronic health effects, both physiologically and in terms of how people cope with that stress."

If weight stigma can influence health directly by raising cortisol levels and blood pressure and indirectly by compromising the quality of care that patients with large bodies receive from their weight-biased doctors, is it possible that people with large bodies have worse health not just because of their literal size but also because of the way they are treated by the world for being that size? "Yes," Brownell says without hesitation. He does not dispute the evidence for biological pathways between weight and health. "Obesity causes changes in the body that in turn increase risk factors, which in turn lead to diseases," he explains. "But there are other pathways. And every pathway is exacerbated by the presence of weight stigma."

Doctors focus on health benefits that can be reaped from improving behaviors related to diet and exercise, regardless of whether such changes lower body weight.

LETTING GO OF THE SCALE IS HARD FOR EVERYONE

AT THE MOSAIC CLINIC, Leslie Scott, a 50-year-old woman who is in for her physical, still wants to be weighed. It is what she is used to, she says with a shrug. The medical tech obliges, but Metz does not look at the number before the checkup. She is more concerned about her patient's mental health. During her last visit, Scott mentioned that it was difficult to juggle work and being the primary caregiver for her elderly mother. Today Scott says her brother recently died and that she has been feeling depressed.

Metz closes her laptop and scoots her stool closer to her patient. "I'm so sorry," she says. "That's a terrible loss." They talk for several minutes about Scott's symptoms, such as how she is struggling to sleep and to remember to eat meals. "I know I need to take better care of myself," Scott says. "I should probably start going back to the gym and walking more."

"Do you enjoy those activities?" Metz asks. "And is it doable with your busy schedule, even once or twice a

week?" Scott thinks it might be. Metz moves on to review Scott's vitals; her blood pressure is slightly elevated. "This is not in a range where you need medication, but it's something we'll watch," she tells Scott.

"I think it's my diet and my weight," Scott says. "It used to be high a few years ago. Then I lost weight, but now I've gained it back."

Metz pauses. She chooses her next words carefully, making sure to avoid any hint of criticism of Scott or her previous doctors. "We hear a lot in health care settings that weight loss itself treats conditions like blood pressure," she says. What the medical literature really shows, Metz continues, is it is not necessarily weight loss that helps; more likely, it is how our behavior changes. "So, I wonder: The time before, when your blood pressure got better, did you start to engage in different behaviors?"

"Well," Scott says. "I moved away from a stressful situation." Previously she worked 12-hour night shifts at the local jail; when she began a less dangerous day security job, "my blood pressure got worlds better."

Metz senses an opening. These are the moments when patients often begin to connect the dots themselves and see how fixating so entirely on their weight has gotten in the way of larger health goals. At another medical practice, Metz worries, Scott's body size might have made her depression all too easy to miss. When her blood pressure rose before, nobody asked Scott about her job or her eating habits, let alone her mental health as she struggled to balance night shifts with the pressure of raising three children alone. "It was always just, 'If you lose that weight, you won't have to take medication,'" Scott says.

Metz explains how the stress, lack of sleep and irregular eating habits caused by Scott's old job probably contributed to her previous hypertension. Then she notes how, in the months since her brother's death, Scott has begun struggling again with those same issues, albeit for different reasons. They talk through a plan to start managing Scott's depression with a combination of medication, counseling and some modest physical activity goals. Weight talk is off the table. "My concern for you right now is: Are you eating *enough?*" Metz says. Scott nods and laughs.

Even when doctors such as Metz want to offer an alternative to the weight-centric model of health care, they are often contending with patients who expect a weight-loss prescription. Yet weight is a trait that is far less mutable than experts have long thought. In the journal *American Psychologist,* an evidence review on the effectiveness of weight-loss interventions found that regardless of which diet people followed, they could lose some weight in the first nine to 12 months of any protocol, but over the next two to five years they gained back all but an average of 2.1 pounds. Nondieting control groups also gained weight during that time, though just 1.2 pounds on average. "The dieters had little benefit to show for their efforts, and the nondieters didn't seem

harmed by their lack of effort," says Traci Mann, one of the paper's co-authors, who is now a professor of psychology at the University of Minnesota. "Weight regain appears to be the typical response to dieting, not the exception." Brownell, who studied public policy approaches to obesity prevention during his time at the Rudd Center, agrees that the data on its efficacy and durability are "too discouraging," both because people struggle so much to lose and because their cycling between loss and subsequent weight regains seem to further elevate their risk for health issues.

Indeed, Dana Sturtevant, a registered dietitian, spent seven years managing weight-loss interventions in clinical trials comparing treatment protocols for hypertension. "Everybody on our trials did the same six-month curriculum, and they did lose some weight in those six months," she recalls. "But they were always back up to where they started, or higher, at our two-year follow-up. When I'd bring that up in meetings, the researchers would say, 'Well, it's the participants' fault for not adhering to our protocol.'" It never occurred to her colleagues to question that protocol or whether weight loss should be the goal in the first place. Sturtevant began to "feel unethical" about her work; today she co-owns an organization called Be Nourished that teaches health care providers how to offer trauma-informed and weight-inclusive care. "We have no evidence-based treatment for high body weight that leads to sustained outcomes," Sturtevant says. "If a medication had this kind of failure rate, doctors would stop prescribing it."

Metz laments that there are only a handful of studies that compare weight-inclusive or "nondiet" treatments with weight-loss protocols. A 2005 study randomly assigned 78 women with obesity to either a diet protocol or a Health at Every Size intervention. For the latter, participants were counseled about body acceptance, encouraged to separate their self-worth from their weight, and educated about techniques for intuitive eating and strategies for finding physical activity they enjoyed. The dieters lost weight but regained it; they were more likely to quit the program and saw fewer overall improvements in health outcomes than those using the nondiet intervention. A 2018 study found that following a similar Health at Every Size protocol helped participants improve their psychological well-being, physical stamina and overall quality of life even though they did not lose weight. Such results are encouraging, but Metz says more data are needed to understand and fine-tune the approach.

One such piece of research, which Metz refers to often, is a 2012 analysis of the NHANES data published by Eric Matheson, an associate professor of family medicine at the Medical University of South Carolina, and his colleagues. They found that life habits were a strong predictor of mortality because regardless of their weight class, people lived longer when they practiced healthy habits such as not smoking, drinking alcohol in moderation, eating five or more servings of fruits and vegetables daily, and exercising 12 or more times a month. "If you're obese and you have a healthy lifestyle, you are no more likely to die early than a person of normal weight," Matheson says.

Some discrepancies exist in his data; for example, eating more vegetables was associated with lower mortality for folks in the normal and overweight categories but not for obese people, whereas exercising regularly appeared to help those in the normal and obese groups but not people in the overweight range. Matheson does not know how to explain those findings. But one possible explanation is that the weight classifications themselves are somewhat arbitrary, something that even the mainstream weight researchers acknowledge. "At every level of the BMI, people can have different degrees of body fat or be that size because of entirely different factors or combinations of factors," Allison says. "Their age, race, sex and genetic background all come into play when we try to say whether their level of adiposity will cause health effects. It's not as simple as saying obesity is bad. You have to know for what, for whom, for when."

Metz is not sure that she has figured out the best approach to health care, but she sees patients every day who affirm that she is evolving in the right direction. Midway through her physical, Towne mentions that she has recently been discharged from eating-disorder therapy. "That's wonderful!" says Metz, breaking into a warm smile. They talk a little more about Towne's diet as Metz thoughtfully frames the conversation, asking, "Does your body give you feedback after you eat that?" instead of offering prescriptive advice about what to eat or avoid, as a different doctor might have. One risk of the weight-inclusive model is that conversations about "healthy habits" can still easily turn into more opportunities to judge patients for their ability to comply with doctor's orders; talking about portion control and "lifestyle changes" can come across as a coded way of encouraging weight loss. But Metz is determined to push only changes that are sustainable for her patients and that have clear benefits regardless of whether they lead to weight loss.

Towne tells me later that one of the biggest challenges of recovering from her eating disorder has been accepting that her weight is not something she needs to control. "I don't know if I'll stay in a smaller body. And that's complicated because I have a lot of leftover trauma around how I was treated as a bigger person," she says. But Metz helped her see that fixating on being small, rather than healthy, had led to serious medical ramifications. "Having a doctor who can so totally remove weight from my health care has been literally life-changing." SA

MORE TO EXPLORE

Weight Science: Evaluating the Evidence for a Paradigm Shift. Linda Bacon and Lucy Aphramor in *Nutrition Journal,* Vol. 10, Article No. 9; January 24, 2011.

How and Why Weight Stigma Drives the Obesity "Epidemic" and Harms Health. A. Janet Tomiyama et al. in *BMC Medicine,* Vol. 16, Article No. 123; August 15, 2018.

An Evidence-Based Rationale for Adopting Weight-Inclusive Health Policy. Jeffrey M. Hunger et al. in *Social Issues and Policy Review,* Vol. 14, No. 1, pages 73–107; January 2020.

FROM OUR ARCHIVES

Obesity: An Overblown Epidemic? W. Wayt Gibbs; December 2006.

scientificamerican.com/magazine/sa

SPECIAL COVERAGE

INSIDE THE CORONAVIRUS

WHAT SCIENTISTS KNOW ABOUT THE INNER WORKINGS OF THE PATHOGEN THAT HAS INFECTED THE WORLD

Editor: MARK FISCHETTI
Artist: VERONICA FALCONIERI HAYS
Graphics Editor: JEN CHRISTIANSEN
Consultant: BRITT GLAUNSINGER, molecular virologist, University of California, Berkeley, and Howard Hughes Medical Institute

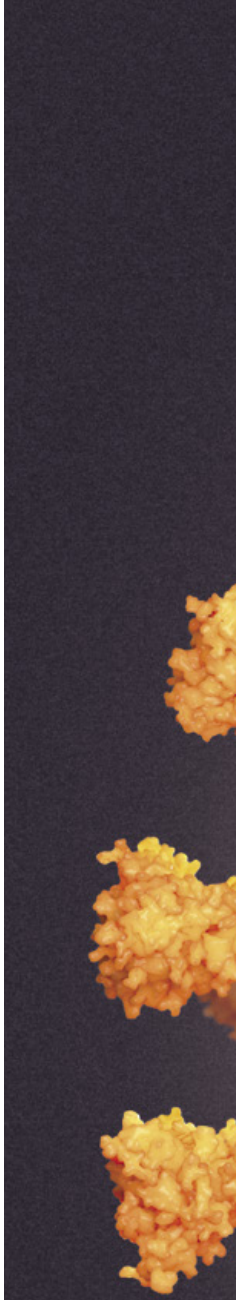
FOR ALL THE MYSTERIES THAT REMAIN about the novel coronavirus and the COVID-19 disease it causes, scientists have generated an incredible amount of fine-grained knowledge in a surprisingly short time.

Thousands of different coronaviruses may inhabit the planet. Four of them are responsible for many of our common colds. Two others have already triggered alarming outbreaks of disease: in 2002 a coronavirus caused severe acute respiratory syndrome (SARS), which killed more than 770 people worldwide, and in 2012 a different strain started Middle East respiratory syndrome (MERS), taking more than 800 lives. SARS burned out within a year; MERS still lingers.

The newest coronavirus, SARS-CoV-2, has created a far deadlier pandemic in part because once it infects a person it can lie undetected for a long time. An individual who had the SARS coronavirus did not transmit it until 24 to 36 hours after displaying symptoms such as fever and dry cough; people feeling ill could be isolated before they made others sick. But people with COVID-19 can transmit the virus before they show clear symptoms. Not feeling ill, infected men and women work, commute, shop, eat out and attend parties, all the while exhaling coronavirus into the airspace of people around them. The virus can remain undetected inside the human body for so long partly because its genome produces proteins that delay our immune system from sounding an alarm. Meanwhile lung cells die as the virus secretly reproduces. When the immune system does hear the call, it can go into overdrive, suffocating the very cells it is trying to save.

In the graphics that follow, SCIENTIFIC AMERICAN presents detailed explanations, current as of mid-May, into how SARS-CoV-2 sneaks inside human cells, makes copies of itself and bursts out to infiltrate many more cells, widening infection. We show how the immune system would normally attempt to neutralize virus particles and how CoV-2 can block that effort. We explain some of the virus's surprising abilities, such as its capacity to proofread new virus copies as they are being made to prevent mutations that could destroy them. And we show how drugs and vaccines might still be able to overcome the intruders.

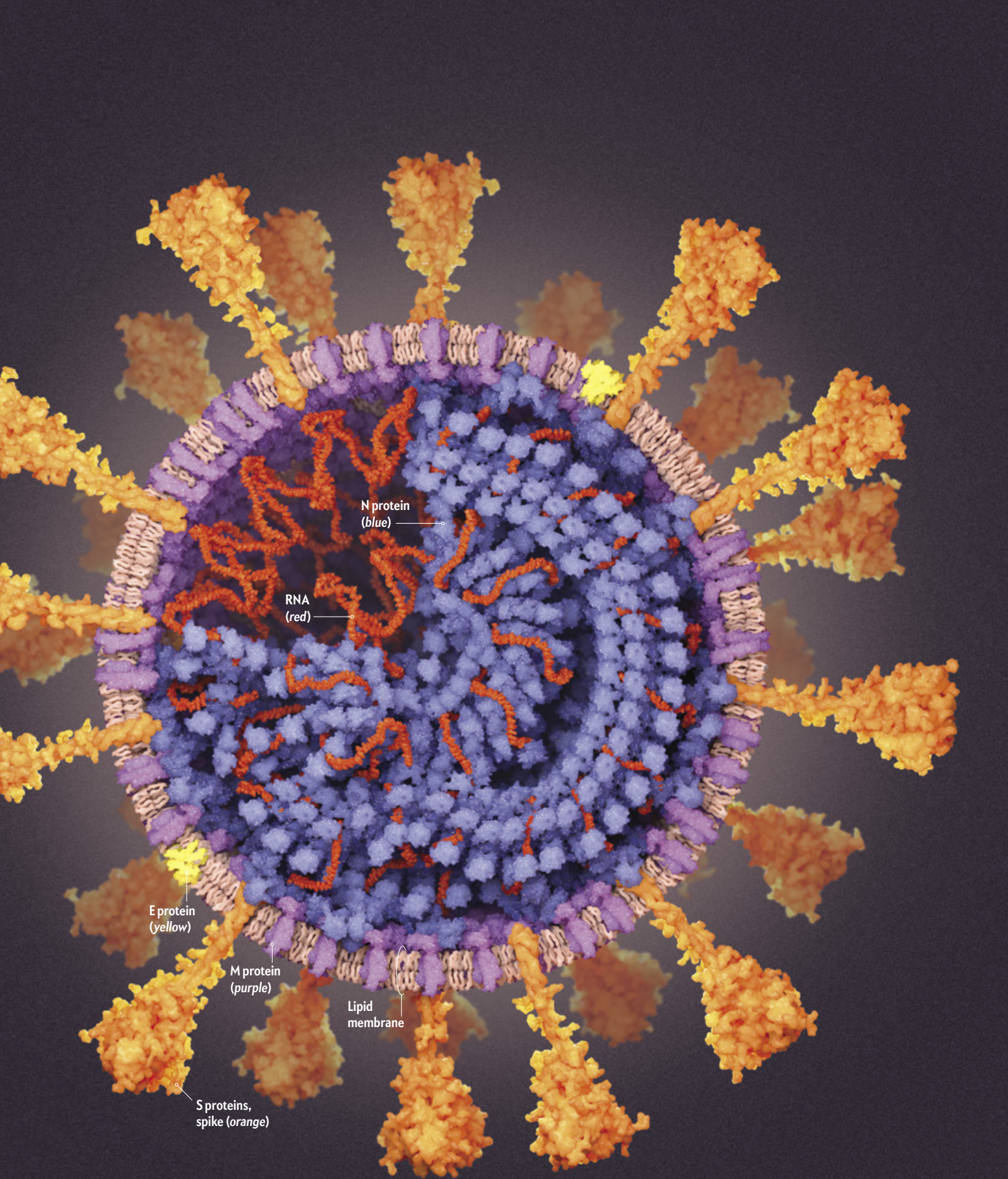
As virologists learn more, we will update these graphics on our Web site (www.scientificamerican.com). Greater knowledge can raise the chances for humans to prevail.



Gene Machine

A SARS-CoV-2 virus particle wafting into a person's nose or mouth is about 100 nanometers in diameter—visible only with an electron microscope. It is a near sphere of protein (*cross section shown*) inside a fatty membrane that protects a twisting strand of RNA—a molecule that holds the virus's genetic code. Proteins called "S" form spikes that extend from the surface and grab onto a human cell, hundreds of times larger, so the particle, or virion, can slip inside; the crown, or corona, appearance gives the virus its name. Structural proteins—N, M and E—move inside the cell, where they help new virions form.

SOURCE: LORENZO CASALINO, ZIED GAIEB AND ROMMIE AMARO, U.C. SAN DIEGO (*spike model with glycosylations*)

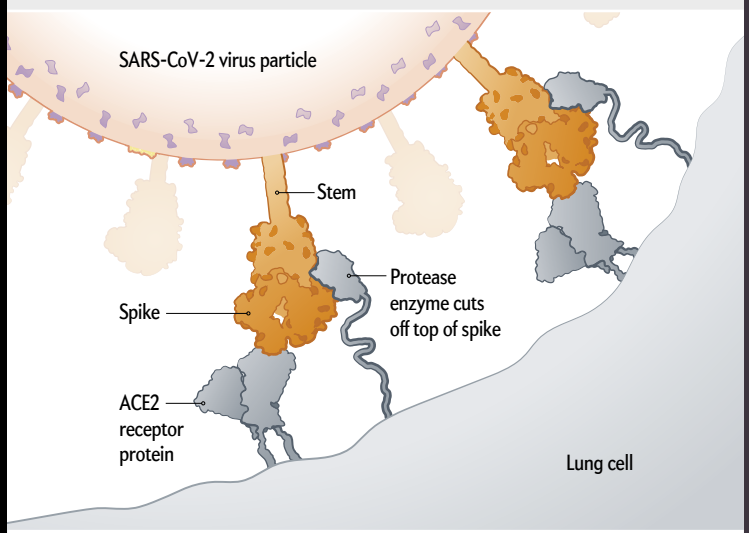


VIRUS INVASION AND IMMUNE RESPONSE

A SARS-CoV-2 particle enters a person's nose or mouth and floats in the airway until it brushes against a lung cell that has an ACE2 receptor on the surface. The virus binds to that cell, slips inside and uses the cell's machinery to help make copies of itself. They break out, leaving the cell for dead, and penetrate other cells. Infected cells send out alarms to the immune system to try to neutralize or destroy the pathogens, but the viruses can prevent or intercept the signals, buying time to replicate widely before a person shows symptoms.

1 BIND TO A LUNG CELL

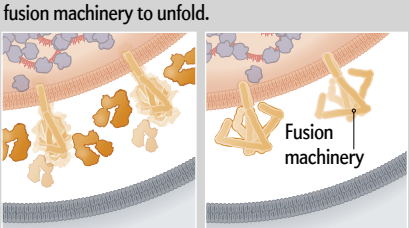
When a virus spike protein latches onto an ACE2 receptor, a protease enzyme slices off the spike's head. This releases fusion machinery, part of the spike's stem that is compressed in a springlike state. ACE2 normally helps regulate blood pressure.



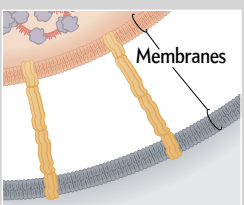
2 SLIP INSIDE

The virus and lung-cell membranes fuse, allowing the virus's RNA—a molecule that encodes the genome (genetic instructions)—to pour into the cell's body.

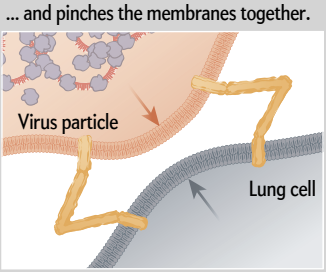
Spike decapitation allows the fusion machinery to unfold.

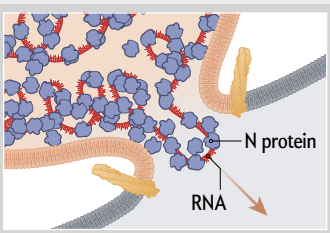


The machinery inserts itself into the cell membrane ...



... and pinches the membranes together.



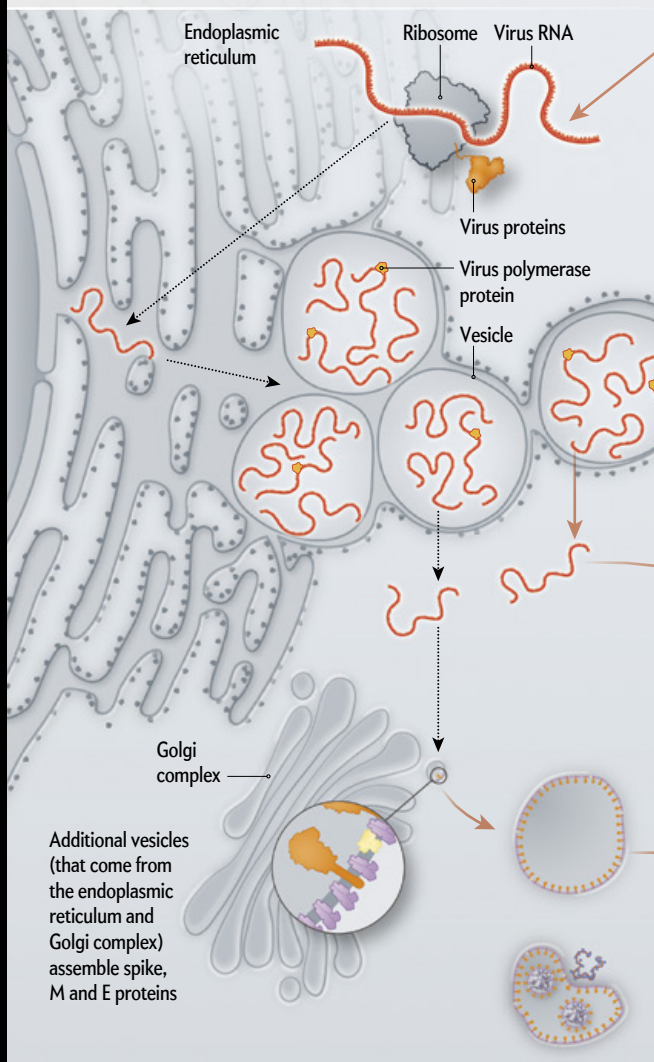


A channel forms, allowing N proteins and RNA to enter the lung cell.

TIME ELAPSED: **ABOUT 10 MINUTES**

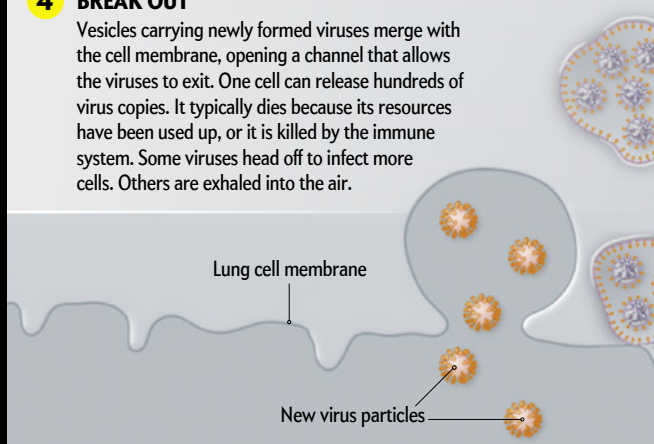
3 REPLICATE

Once virus RNA is inside a cell, it presents about two dozen genes to the cell's ribosomes, which translate genes into proteins. Some of those proteins stretch the endoplasmic reticulum, creating protective vesicles, or sacs. The virus uses its own RNA copying machine, called a polymerase, to make duplicates of RNA inside the vesicles. Some of the copies are utilized to make more viral proteins, such as the spike. Others are packaged into new virus particles, which break out of the lung cell.

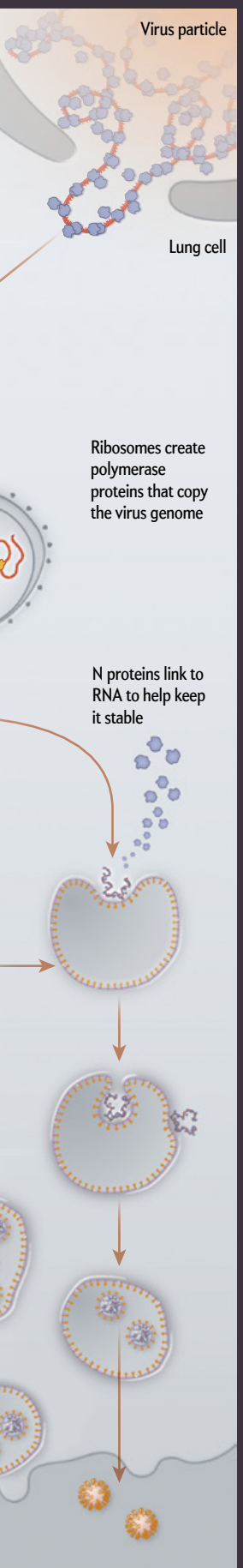


4 BREAK OUT

Vesicles carrying newly formed viruses merge with the cell membrane, opening a channel that allows the viruses to exit. One cell can release hundreds of virus copies. It typically dies because its resources have been used up, or it is killed by the immune system. Some viruses head off to infect more cells. Others are exhaled into the air.



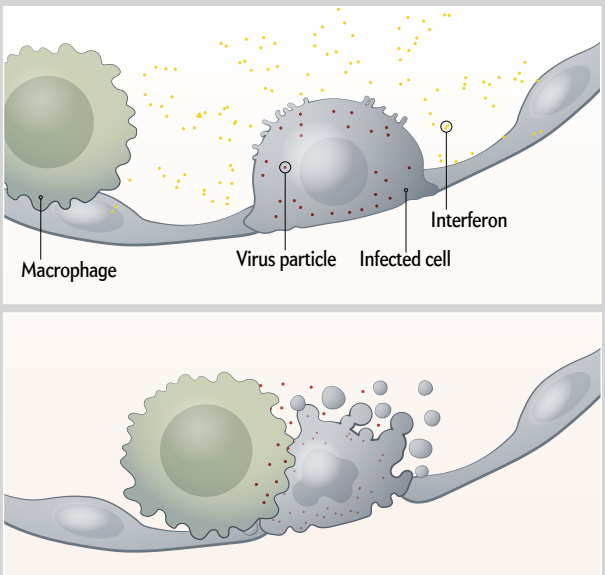
TIME ELAPSED: **ABOUT 10 HOURS**



5 IMMUNE SYSTEM DEFENSE MEASURES

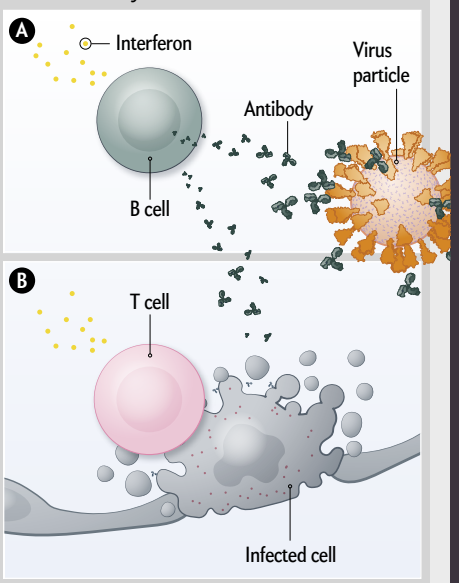
When infection begins, the innate immune system tries to immediately protect lung cells. The adaptive immune system gears up for a greater response.

INNATE IMMUNE SYSTEM: An infected cell releases interferon proteins that alert neighboring cells to create molecules that try to stop virus particles from entering or reproducing. Interferon also beckons cells such as macrophages in the bloodstream that can engulf virus particles.



TIME ELAPSED: **0–3 DAYS**

ADAPTIVE IMMUNE SYSTEM: Interferon also alerts B cells. They produce "neutralizing antibodies" that might recognize parts of the spike protein and bind to it Ⓐ, preventing the spike from grabbing onto a lung cell. Interferon also recruits T cells, which can destroy viruses and also kill infected cells before viruses inside them burst out Ⓑ. Some B and T cells become memory cells that can quickly identify and fight a future invasion by the virus.

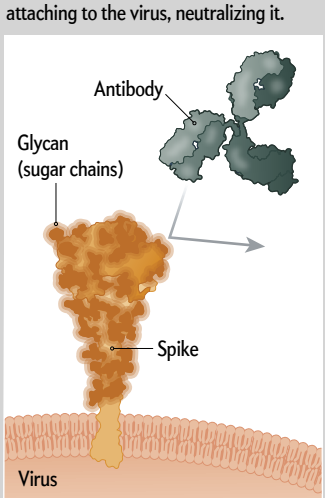


TIME ELAPSED: **6–11 DAYS**

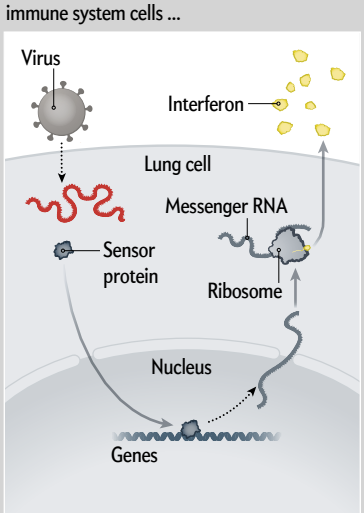
6 VIRUS COUNTERMEASURES

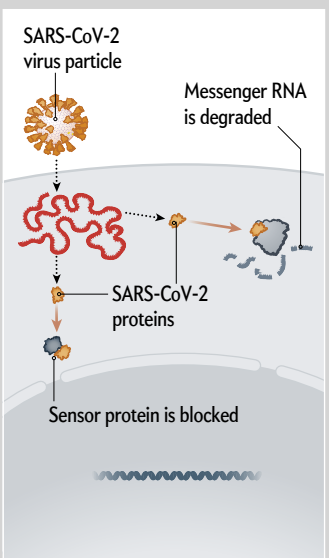
SARS-CoV-2 uses several tactics to thwart the immune system's response.

The virus spike may camouflage itself with sugar molecules. They flex and swing, potentially blocking antibodies from attaching to the virus, neutralizing it.



Normally, sensor proteins recognize incoming viruses as foreign and tell the cell nucleus to turn on genes for making messenger RNA molecules. The molecules deliver instructions to ribosomes to make interferon proteins that exit the cell to alert immune system cells ...





... Several SARS-CoV-2 proteins are thought to block sensor proteins from acting or to interfere with instructions to the ribosome.

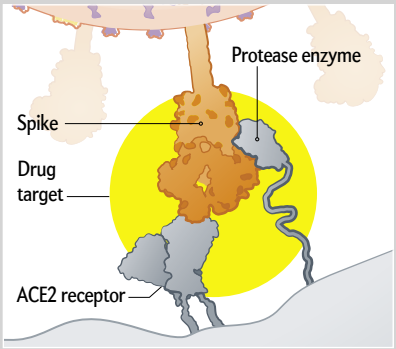
DRUG AND VACCINE INTERVENTION

Commercial and university labs are investigating well over 100 drugs to fight COVID-19, the disease the SARS-CoV-2 virus causes. Most drugs would not destroy the virus directly but would interfere with it enough to allow the body's immune system to clear the infection. Antiviral drugs generally stop a virus from attaching to a lung cell, prevent a virus from reproducing if it does invade a cell, or dampen an overreaction by the immune system, which can cause severe symptoms in infected people. Vaccines prepare the immune system to quickly and effectively fight a future infection.

DRUG TARGETS

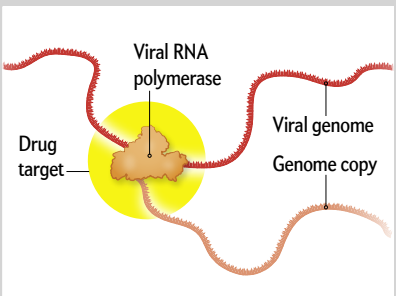
PREVENT THE VIRUS FROM ENTERING A CELL

A drug or therapeutic antibodies could lock onto the spike protein, preventing it from binding to a lung cell's ACE2 receptor. A drug could also attach to the protease enzyme and prevent it from cutting the spike protein so the virus cannot fuse with the cell.



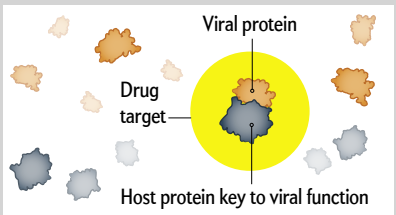
ENCOURAGE DEFECTIVE VIRUSES

A drug could interfere with the viral RNA polymerase enzyme, which works with another enzyme called ExoN (*not shown*) to fix mistakes in copied viruses that would disable those viruses, leading to more bad copies and fewer good ones.



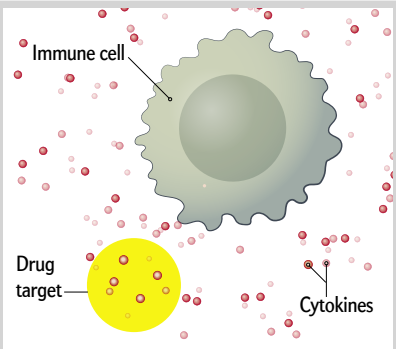
SHUT DOWN VIRUS

A drug could interfere with lung cell proteins the virus needs, such as those involved in making virus proteins or in making the vesicles the virus uses to copy its genome.



REDUCE HYPERIMMUNE RESPONSE

Immune cells can destroy too many lung cells, creating enough mucuslike waste to suffocate the lungs, forcing victims onto ventilators. Overproduction of an alarm protein, or cytokine, such as interleukin-6 can put immune cells into overdrive. Drugs could inhibit some of the cytokines by binding to them.

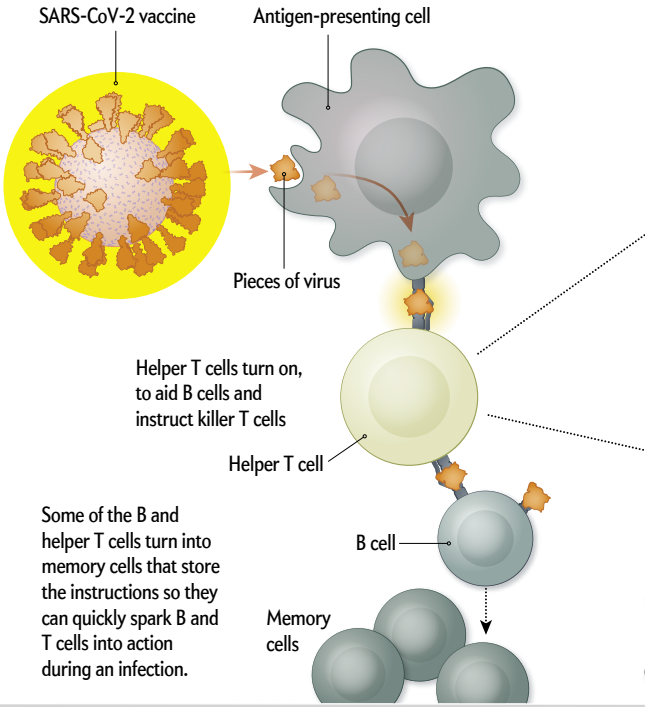


VACCINE OPTIONS

A vaccine exposes the immune system to a safe version of a virus so it can practice making antibodies that will stop the pathogen and commit the exercise to memory so it is ready to fight the real virus during an infection. Vaccine makers are pursuing a variety of strategies for formulating and mass-producing vaccines.

ANTIBODY PREPARATION

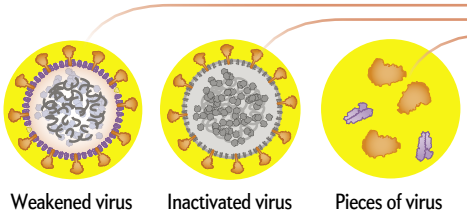
The vaccine version of a SARS-CoV-2 virus presents various molecules called antigens that belong to the real virus. Antigen-presenting cells grab them and provide them to helper T cells and B cells. The T cells help B cells turn on to produce antibodies that could bind to the actual virus. The helper T cells also tell killer T cells to devise ways to destroy lung cells that are infected.



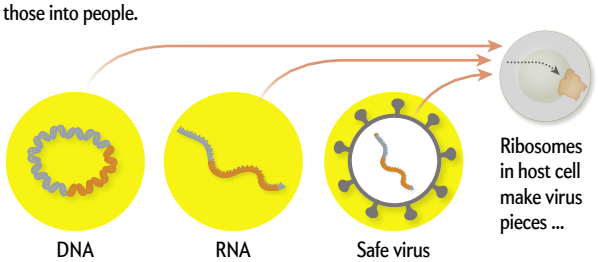
VACCINE STRATEGIES

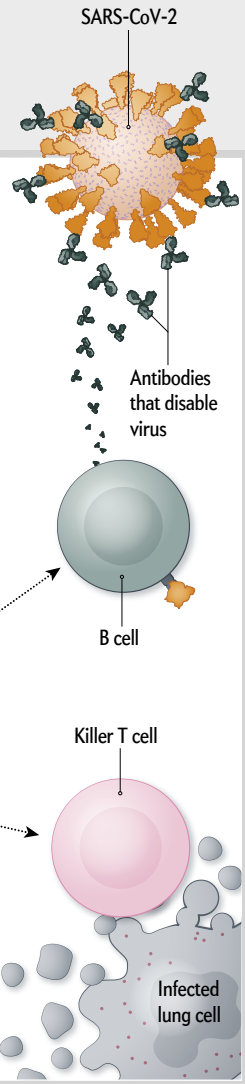
Experts are exploring at least six strategies for making vaccine versions of the virus.

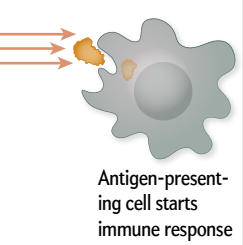
Inject a modified version of the actual virus into people.

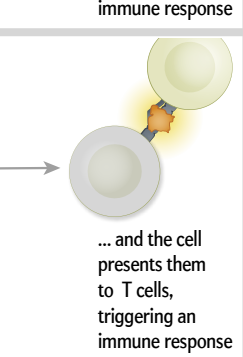


Map genes from the virus, such as those for the spike protein, insert the blueprints into DNA, RNA or a safe virus and inject those into people.









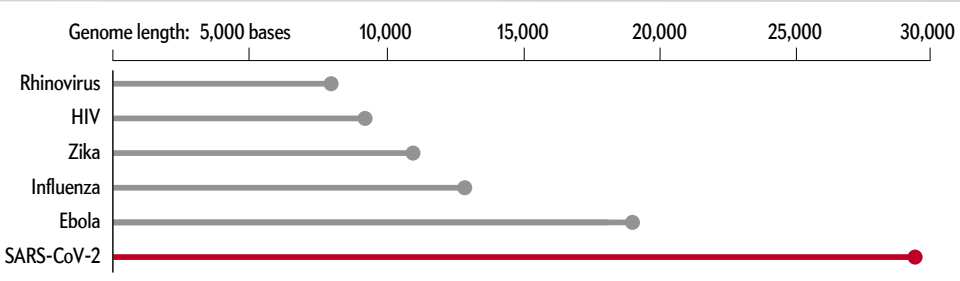
SOURCE: "THE ARCHITECTURE OF SARS-COV-2 TRANSCRIPTOME," BY DONGWAN KIM ET AL., IN *CELL*, VOL 181, MAY 14, 2020 (genome)

THE REMARKABLE AND MYSTERIOUS CORONAVIRUS GENOME

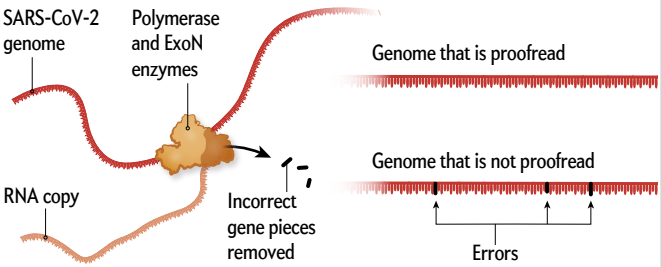
The SARS-CoV-2 genome is a strand of RNA that is about 29,900 bases long—near the limit for RNA viruses. Influenza has about 13,500 bases, and the rhinoviruses that cause common colds have about 8,000. (A base is a pair of compounds that are the building blocks of RNA and DNA.) Because the genome is so large, many mutations could occur during replication that would cripple the virus, but SARS-CoV-2 can proofread and correct copies. This quality control is common in human cells and in DNA viruses but highly unusual in RNA viruses. The long genome also has accessory genes, not fully understood, some of which may help it fend off our immune system.

PROOFREADING

Because the SARS-CoV-2 genome is so long, it can encode a huge amount of information, enabling the novel coronavirus to create more proteins and perhaps carry out more sophisticated replication strategies than other RNA viruses. One of these advantageous proteins is an enzyme called exonuclease (ExoN), which helps the virus proofread and correct copies as they are made. Only viruses with genomes longer than about 20,000 bases make this enzyme.

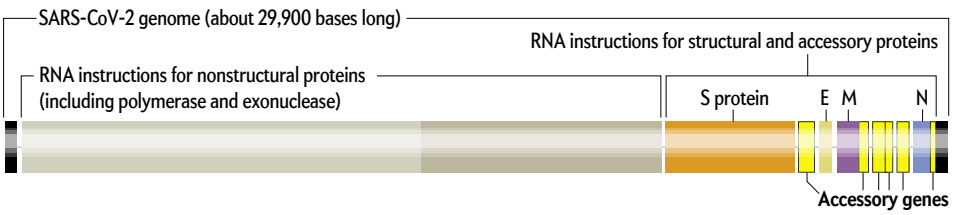


Once a SARS-CoV-2 virus has infected a lung cell, an enzyme called polymerase starts to make copies of its RNA while another enzyme, ExoN, finds random mutations and expels these genetic mistakes from the copies.



ACCESSORY GENES

Unusual, short bits of the genome called accessory genes are clustered with the structural protein genes. Researchers are not yet sure what they do. Several are thought to encode proteins that help the virus evade the immune system.



MORE TO EXPLORE

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FROM OUR ARCHIVES

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SPECIAL COVERAGE

THE BIGGEST PSYCHOLOGICAL EXPERIMENT

WHAT CAN THE PANDEMIC TEACH US ABOUT HOW PEOPLE RESPOND TO ADVERSITY?

By Lydia Denworth

Photographs by Ethan Hill

BERNELL GRIER, who leads a community development corporation in Brooklyn, N.Y., is helping black people affected by the pandemic.

Lydia Denworth is a Brooklyn, N.Y.–based science writer, a contributing editor for *Scientific American,* and author of *Friendship: The Evolution, Biology, and Extraordinary Power of Life's Fundamental Bond* (W. W. Norton, 2020).

THE IMPACT OF COVID-19 ON THE PHYSICAL HEALTH OF THE WORLD'S CITIZENS IS EXTRAORDINARY. By mid-May there were upward of four million cases spread across more than 180 countries. The pandemic's effect on mental health could be even more far-reaching. At one point roughly one third of the planet's population was under orders to stay home. That means 2.6 billion people—more than were alive during World War II—were experiencing the emotional and financial reverberations of this new coronavirus. "[The lockdown] is arguably the largest psychological experiment ever conducted," wrote health psychologist Elke Van Hoof of Free University of Brussels-VUB in Belgium. The results of this unwitting experiment are only beginning to be calculated.

IN BRIEF

Research has shown that when faced with potentially traumatic events, about two thirds of people show psychological resilience. **But the mental health** toll of the pandemic may not fit this paradigm. **Life has been upended** at an unprecedented scope and speed, and researchers see an opportunity to investigate the science of resilience in new ways.

The science of resilience, which investigates how people weather adversity, offers some clues. A resilient individual, wrote Harvard University psychiatrist George Vaillant, resembles a twig with a fresh, green living core. "When twisted out of shape, such a twig bends, but it does not break; instead it springs back and continues growing." The metaphor describes a surprising number of people: As many as two thirds of individuals recover from difficult experiences without prolonged psychological effects, even when they have lived through events such as violent crime or being a prisoner of war. Some even go on to grow and learn from what happened to them. But the other third suffers real psychological distress—some people for a few months, others for years.

Even if most individuals prove resilient, the toll of the COVID-19 disruptions and the sheer numbers involved have experts warning of a mental illness "tsunami." People face a multiple wallop: the threat of disease, loneliness of isolation, loss of loved ones, repercussions of job loss and ongoing uncertainty about when the pandemic will end. Depression, anxiety and post-traumatic stress will undoubtedly follow for some. Mental health hotlines are reporting surges in calls, and early surveys have found high levels of concern. "This pandemic just ticks all the boxes in terms of the kinds of stressors that are going to be difficult," says psychologist Anita DeLongis of the University of British Columbia, who studies psychosocial responses to disease. The deaths by suicide of health care professionals who had been on the medical front lines are powerful reminders of the risks.

Individual resilience is further complicated by the fact that this pandemic has not affected each person in the same way. For all that is shared—the coronavirus has struck every level of society and left few lives unchanged—there has been tremendous variation in the disruption and devastation experienced. Consider Brooklyn, just one borough in hard-hit New York City. Residents who started the year living or working within a few miles of one another have very different stories of illness, loss and navigating the challenges of social distancing. How quickly and how well individuals, businesses and organizations recover will depend on the jobs, insurance and health they had when this started, on whether they have endured hassle or heartbreak, and on whether they can tap financial resources and social support.

The pandemic has laid bare the inequities in the American health care system and economic safety net. Black and Latino Americans are dying at much higher rates than white Americans. "When we talk about preexisting conditions, it isn't just if I'm obese, it's our society's preexisting condition," says medical anthropologist Carol Worthman of Emory University, an expert in global mental health.

Fortunately, the unprecedented pandemic is leading to unprecedented science not just in virology but on mental health and resilience. Behavioral scientists are measuring the psychological toll in real time and striving to identify what helps people cope. Unlike, say, the September 11 terrorist attacks or Hurricane Katrina, which occurred over a finite period even though their effects were drawn out, the open-ended time frame for COVID-19 allows for new kinds of longitudinal studies and research directions. The sudden mass switch to virtual forms of working and socializing is expected to jump-start more nuanced investigations into what makes social interaction satisfying—or stultifying. If researchers meet the challenge of COVID-19, says psychiatrist Dennis Charney of the Icahn School of Medicine at Mount Sinai, "there will be a whole new science of resilience. We could learn how to help people become more resilient *before* these things happen."

WHEN TOM INCK (*top right*) fell ill with COVID-19, his wife, Wendy Blattner (*standing*), cared for him while managing upheavals in her business and their daughters' lives.

BEND BUT DON'T BREAK

RAFAEL HASID ARRIVED in New York City from his native Israel in 2000 to attend the French Culinary Institute. In 2005 he opened a restaurant called Miriam in Brooklyn that became a neighborhood favorite. In the first weeks of March Hasid could see what was coming. "I was following the news in Israel," he says. "We were two weeks behind in every respect. I was saying, 'This is going to happen here.'" When Miriam's popular weekend brunch attracted a third of the usual crowd, Hasid did not spend much time wondering what to do: he gave away all of the restaurant's perishable food to the neighbors. By the time the city required all restaurants to shut down, Miriam had already closed.

Faced with potentially traumatic events, "about 65 percent of people are going to show minimal psychological symptoms," says clinical psychologist George Bonanno of Teacher's College at Columbia University. Bonanno, who is an expert on resiliency, studies the aftermath of hurricanes, terrorist attacks, life-threatening injuries and epidemics such as the 2003 SARS outbreak. His research and that of others consistently show three common psychological responses to hardship. Two thirds of people follow a resilience trajectory and maintain relatively stable psychological and physical health. About 25 percent struggle temporarily with psychopathology such as depression or post-traumatic stress disorder and then recover—a pattern known as the recovery trajectory. And 10 percent suffer lasting psychological distress. These results hold true across diverse populations and socioeconomic statuses. "We're talking about everybody," Bonanno says. On the other hand, the risk of psychiatric disorders is twice as high for people on the lowest economic rungs.

Even if most individuals prove resilient, the toll of the COVID-19 disruptions and the sheer numbers involved have experts warning of a mental illness "tsunami."

But the mental health effects of a crisis so sweeping and insidious may not adhere to this paradigm. Studies show that strict quarantine can lead to negative psychological effects such as PTSD, although few of us have been under true quarantine, which refers to isolating after a possible exposure to infection. Instead much of the world is living with restrictions that Bonanno suspects amount to something more like managing constant stress. "This is the first time in living history we've had a global lockdown that's gone on for such a long time," says epidemiologist Daisy Fancourt of University College London. "We simply don't know how people are going to react to this."

The potential scope of the impact is considerable. "This is different from other forms of stress because it's not just one domain of your life," says health psychologist Nancy Sin of the University of British Columbia. "People are dealing with relationship or family challenges, with financial and work challenges, with health."

Early reports are already showing clear effects. The first nationwide large-scale survey in China, where the crisis hit earliest, found that almost 35 percent reported psychological distress. In the U.S., rising fear and anxiety about COVID have been found in people who already suffer from anxiety. Another study captured worrisome findings in older adults. This is surprising because previous research shows that, for the most part, older adults have better emotional well-being. "During this pandemic, older adults don't have those age-related strengths in emotions that we would typically expect," says Sin, who studies aging and is collaborating with DeLongis in an ongoing COVID-19 study of 64,000 individuals worldwide. "They are reporting just as much stress as middle-aged and younger people."

Sin is still analyzing the causes of the stress but suspects it is caused by older adults' higher likelihood of getting sick and of losing loved ones. Older people are coping with their stress better than younger people, however, and reporting less depression or anxiety. They may be benefiting from the perspective that comes with having lived through more than younger people, Sin says. Adults older than 65 have also had more time to develop skills for dealing with stress, and many have retired and so are less likely to be concerned about work.

Fancourt began a study in mid-March that grew to include more than 85,000 U.K. residents. It is tracking depression, anxiety, stress and loneliness week by week. "We need to know in real time what's happening," Fancourt says. Six weeks in, they found that levels of depression were significantly higher than before the pandemic.

Generally, those with previously diagnosed mental health illnesses, those who live alone and younger people were reporting the highest levels of depression and anxiety. On the positive side, there was a slight decrease in anxiety levels once the lockdown was declared. "Uncertainty tends to make things worse," Fancourt says. Some are frozen by not knowing what is to come, whereas others find ways to carry on.

After Hasid's restaurant had been closed for three weeks, he had not yet received any of the government payments meant to protect small businesses. While his situation was rife with uncertainty, "I was thinking that we have to continue creating business for ourselves," he says. When a few customers e-mailed to inquire if he would consider catering their Passover seders, Hasid developed a prix fixe holiday menu for delivery. Before the pandemic, Hasid was planning to open a delicatessen that would be located in an adjacent storefront. Instead of renovating the new space, he opened the deli inside the restaurant. His biggest worry was whether employees would feel safe. To reassure them, in addition to social distancing, he requires masks and gloves and has someone come in to bleach the restaurant morning and night. Hasid is looking into other sanitizing strategies involving blowers and alcohol that he heard have been used in Singapore.

Hasid recognizes that his ability to adapt is not something every business can do, especially many restaurants that run on tight margins. The new operation is using minimal staff, but Hasid continues to pay—out of his own pocket—any employees who have not been able to get through to unemployment. Serving food via delivery brings in less than a third of Miriam's former income, but he says it is better than nothing. The restaurant is also preparing a weekly meal for a local hospital. "It is not a money maker, but it's the least we can do." Hasid is pleased with Miriam's reinvention and optimistic that the restaurant will ultimately survive. "We are in a much better situation than a lot of other places in New York," he says.

THE COMPONENTS OF COPING

WHEN BROOKLYN RESIDENT TOM INCK developed a persistent fever and dry cough in the middle of March, the psychotherapist and management consultant feared he had COVID-19. Because of the shortage of tests at the time, Inck's doctor first screened for every other known virus (Inck paid for the test panel). Then doctor and patient met on the streets of Manhattan. Standing on Madison Avenue in full protective equipment, the doctor administered the test, which came back positive six days later.

Successfully coping in a crisis means continuing to function and engaging in day-to-day activities. One must solve problems (whether that means getting groceries or a virus test), regulate emotions and manage relationships. There are factors that predict resilience such as optimism, the ability to keep perspective, strong social support and flexible thinking. People who believe they can cope do, in fact, tend to cope better.

During nine days of isolation in a spare room, Inck filled the time with meditating and reading. In some ways, things were harder for his wife, Wendy Blattner, who was managing her husband's care, the transition of her marketing agency to remote work, and the emotions of the couple's two college-aged daughters, who were upset at the loss of their semesters and anxious about their father. Blattner left meals outside her husband's door and got up every three hours throughout the night to record his temperature and blood oxygen level. She was scared but resolute. "I felt like he had excellent care, even though it was remote, and that I had the resources within myself and the support I needed," she says. "That's what I told my kids and what I told myself—that it might get rough, but it was going to be okay."

Most people's coping skills can be strengthened. Several of the new studies are designed to identify successful strategies that buffer the effects of the stress. So far, Fancourt says, people are encouraged to follow classic mental health strategies: getting enough sleep, observing a routine, exercising, eating well and maintaining strong social connections. Spending time on projects, even small ones, that provide a sense of purpose also helps.

In previous work, DeLongis has shown that those who are high in empathy are more likely to engage in appropriate health behaviors such as social distancing and to have better mental health outcomes than people who are low in empathy. But her earlier studies of diseases such as SARS and West Nile were cross-sectional and captured only a moment in time. Her COVID-19 study will follow people's behavior and attitudes for months to capture changes in empathy and coping over time. "This isn't just about a trait of empathy," DeLongis says. Empathetic responses can be learned and encouraged with proper messaging, and her hunch is that increases or decreases in empathetic responding over weeks and months will be associated with shifts in health behaviors and coping mechanisms.

As part of DeLongis's study, Sin is having people record their daily activities and emotions for a week. "So far the picture is that life is really challenging, but people are finding ways to meet that challenge," she says. Many report a great deal of positive social interactions, many of them remote. Older adults are reporting the highest levels of positive experiences in their daily lives, often through providing support to others.

It is striking that remote connections are proving satisfying. Previous research on the effects of digital technology and media focused on the association between time spent on screens and psychological well-being but revealed little about the worth of different kinds of online interaction. Now that the world is relying on the Internet to socialize, investigating those nuances is crucial. Should social media closely mimic face-to-face interaction or can less intense forms of communication leave people feeling connected? We do not know yet, but it is likely those studies will now get funded when previously they weren't. "I think we just skipped a decade of conversation in a month," says psychologist Amy Orben of the University of Cambridge, who studies adolescent mental health and technology use.

Social media is a factor in other kinds of research as well. Psychologist Roxane Cohen Silver of the University of California, Irvine, is assessing the impact of media exposure on people's well-being. "Those who consume a great deal of news about a community-wide crisis are more distressed," she says. Computational social scientist Johannes Eichstaedt of Stanford University is combining large-scale analyses of Twitter with machine learning to capture levels of depression, loneliness and joy during the pandemic.

As Blattner feared, things did get rough for their family. On nights seven and eight, when Inck's fever hovered around 103 and his blood oxygen levels dropped to 93, his doctor (via Zoom) said if the levels stayed there or got worse, Inck should go to the hospital. "I'm not going to have a patient who dies at home," he said, a statement that alarmed the children. "The toughest thing for us was the fear," Inck says. But Tylenol kept the fever in check, and short, shallow breaths kept Inck's blood oxygen level in the safety zone. After 10 days, he began to feel better.

The experience left Inck grateful and energized. He threw himself back into work counseling others who

RESTAURANT owner Rafael Hasid rapidly reinvented his business for takeout and delivery but was paying employees out of his own pocket.

were sick and signed up to be a plasma donor for critical patients. But, unlike others who recovered, he did not initially venture out much. "The world felt like a vulnerable place," he says.

SOCIETY'S PREEXISTING CONDITIONS

EVEN THOSE BRIMMING with personal resilience need outside help if they face challenges on multiple fronts. As executive director of IMPACCT Brooklyn, a community development corporation that serves the historically black neighborhoods of Brooklyn, Bernell K. Grier sees just how hard the pandemic has hit the African-American community. "Daily, I'm hearing of people who are either COVID-positive, recovering from it or have died from it," she says. Three of those deaths occurred in apartments that Grier manages and required her to organize deep-cleaning services. Still, she pressed on. "Seniors are fearful of going out, fearful of anyone coming to their front door," Grier says. "They also are not tech-savvy. A lot of things where they're being told to go on the computer, they need someone to hold their hand and help them through the process."

The pandemic, Fancourt says, "is going to exacerbate the social gradient that we're used to seeing across society. It's crucial that [people] have interventions at a national level that can support [them]." In the U.K., such interventions include the National Health Service and a furlough program that pays up to 80 percent of the salaries of millions of Britons who could not work because of the pandemic. In the U.S., paycheck-protection packages and unemployment exist but proved difficult to access quickly.

Grier's organization provides a variety of services around housing, small business advocacy, and interaction with financial and government institutions. As soon as the pandemic hit, her staff distributed information about public health and economic resources. They introduced webinars to help businesses apply for loans. As of late April, "none of the ones that we helped got anything," Grier says. "It's not reaching our businesses." Only 70 percent of Grier's tenants were able to pay rent in April. "We still have to pay the supers, the porters, the heat and electricity, the taxes and everything else," Grier says. "It's a domino effect. If the residents can't pay, we can't pay."

Worthman, the Emory anthropologist, says the ability to cope with the pandemic's reverberations is not just an individual issue but a societal one. It is also an opportunity. "People have pointed to periods of disaster in American history, after World War I and the Depression, that led to real structural change that benefited people."

Grier is advocating for positive change for her community. In her talks with public health and elected officials, she points out disparities such as the fact that the first test centers were not located in poor neighborhoods. "This is a spotlight on what has existed for too long," she says. "When you're looking at [solutions], make sure that income equality and a racial-equity lens is a filter for everything that's put in place." As Brooklyn reemerges from social isolation, Grier knows the critical role groups like hers play. "We will continue to be here to be that liaison, that credit counselor, that navigator."

Cultivating resilience though community support appears to be more important than ever. As a school nurse in Brooklyn, Marilyn Howard, who immigrated from Guyana as a teenager, worked through the early weeks of March until the public schools closed. She got sick the day after she left work. It took 10 days to get the test results that confirmed she had COVID-19. By then Howard thought she was on the road to recovery. But on Saturday, April 4, she awoke with labored breathing that rapidly worsened. Her brother Nigel Howard, with whom she shared an apartment, called an ambulance. But April 4 was near the peak of the pandemic in Brooklyn, and there was no ambulance available. Nigel drove them to the nearest hospital, but Marilyn's breathing deteriorated on the way. Less than a minute before they arrived, her heart stopped, and she could not be revived. She was 53.

"A couple of simple things could have saved my sister's life," says Haslyn Howard, the youngest of Marilyn's five brothers. If schools had closed earlier or her colleague could have taken a sick day, she might not have gotten sick. If someone had recommended a pulse oximeter, she would have known to go to the hospital sooner. If an ambulance had been available … The Howard brothers arranged a viewing at a Long Island funeral home to provide some closure. Haslyn permitted only three people in the room at a time, but a simultaneous virtual service allowed more than 250 people to celebrate Marilyn's life.

Nigel has since tested positive for COVID-19 and has been isolated at home. "My brothers and I are in the initial phases of trying to plan an organization that targets efforts to help the black and brown community, poor communities, address some of these [issues] on a local and tangible level," Haslyn says. It is something they can do in memory of their sister that would have made her proud. "That's one of the ways that we're coping," he adds. "How do we turn tragedy into triumph?" SA

MORE TO EXPLORE

Trajectories of Resilience and Dysfunction following Potential Trauma: A Review and Statistical Evaluation. Isaac R. Galatzer-Levy, Sandy H. Huang and George A. Bonanno in *Clinical Psychology Review,* Vol. 63, pages 41–55; July 2018.

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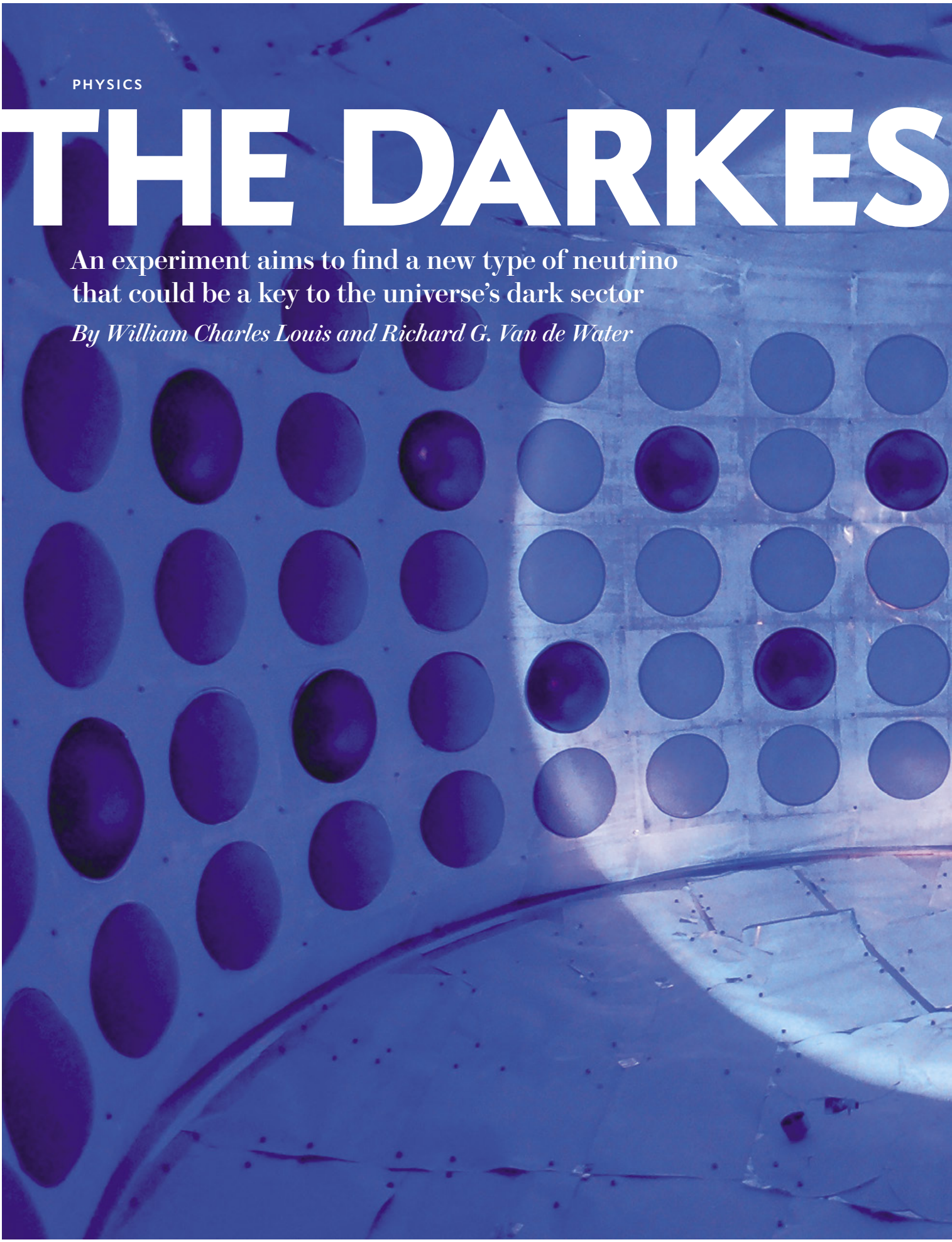
scientificamerican.com/magazine/sa

PHYSICS

THE DARKES

An experiment aims to find a new type of neutrino that could be a key to the universe's dark sector

By William Charles Louis and Richard G. Van de Water



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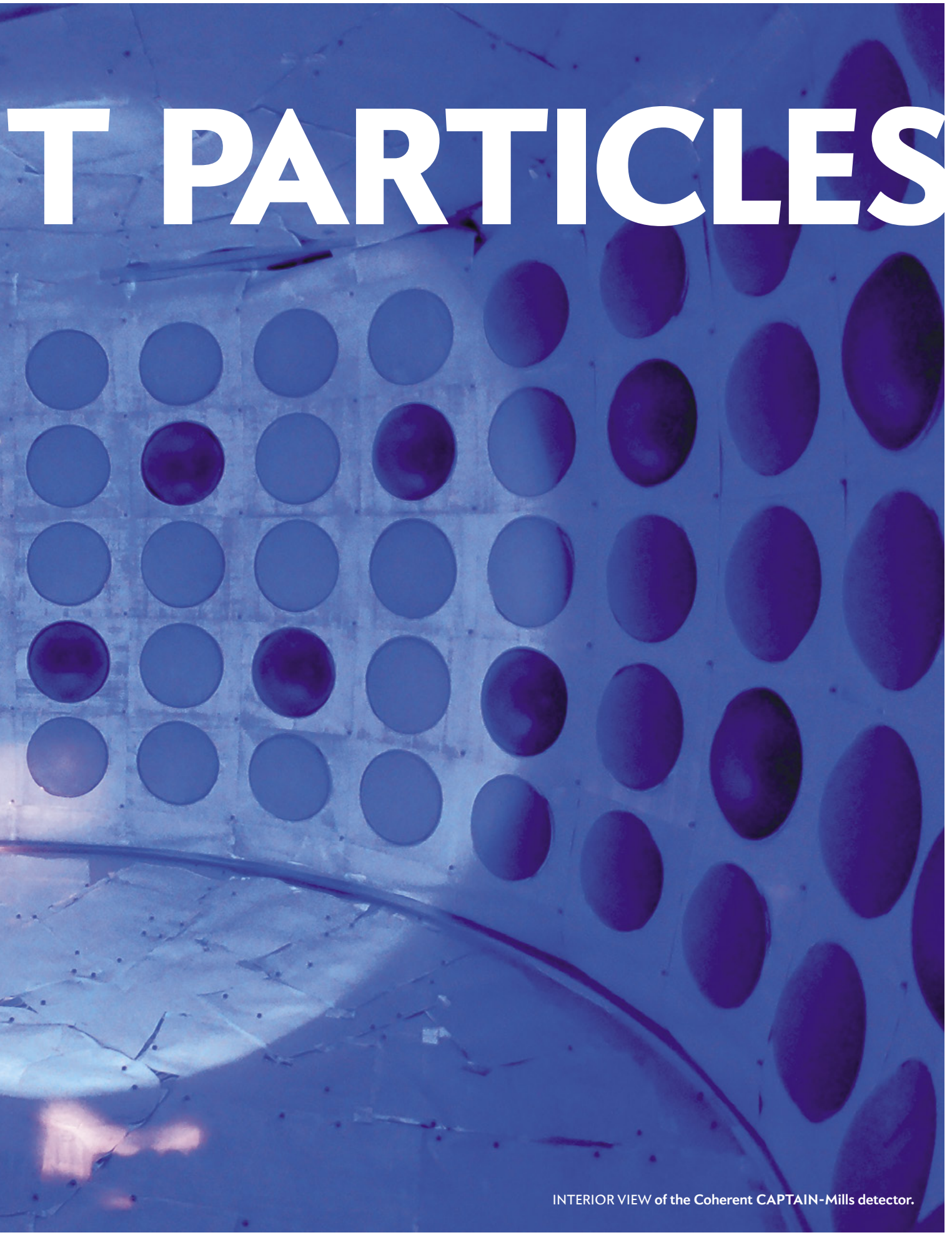
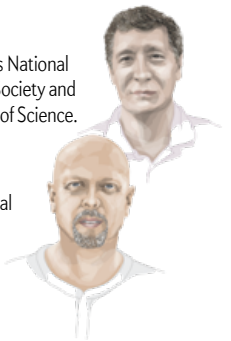


INTERIOR VIEW of the Coherent CAPTAIN-Mills detector.

William Charles Louis is a physicist at Los Alamos National Laboratory and a fellow of the American Physical Society and of the American Association for the Advancement of Science.

Richard G. Van de Water is a physicist at Los Alamos National Laboratory and a fellow of the American Physical Society.



THE PHYSICISTS WHO CAME TO OUR PRESENTATION AT THE 2010 NEUTRINO conference in Athens, Greece, probably expected us to put to rest a controversial finding from a decade prior. Instead we left them in a stunned silence.

The story begins in 1996, when we revealed data, obtained at the Liquid Scintillator Neutrino Detector (LSND) at Los Alamos National Laboratory, suggesting a problem with the widely accepted idea that neutrinos—tiny, ubiquitous particles that pass right through most matter—come in three types, or flavors. Our results showed that there might be a fourth neutrino flavor that had gone undetected. The scientific community was skeptical, and in fact, early data from a follow-up experiment hinted that our 1996 results were off—there was no fourth neutrino flavor after all. That day in Athens it was clear that the audience expected our latest findings to shut the door on the LSND results once and for all. We revealed, however, that the evidence for a fourth type of neutrino had become even more compelling.

We had not discovered the particle, but our work, conducted as part of the Mini Booster Neutrino Experiment (MiniBooNE) at Fermi National Accelerator Laboratory in Batavia, Ill., showed that there was almost certainly a problem with the contemporary understanding of particle physics. The most likely solution was a new neutrino—a "sterile" neutrino, so called because it would not interact with other matter in any way except through gravity. In the decade since our presentation in Greece, data from MiniBooNE have bolstered the case for a fourth flavor of neutrino even further.

We now think there is more than a 99.999999 percent chance that something is going on beyond the scope of known physics, and sterile neutrinos are a strong contender. The idea that our experiments might be detecting a fourth neutrino remains controversial, however, because the Standard Model of particle physics is one of the most tested and thoroughly confirmed theoretical frameworks in history—and it allows for only three neutrinos. Nevertheless, we *know* the Standard Model is not complete, because it cannot explain dark matter or dark energy, the invisible stuff that seems to dominate the cosmos. And a new neutrino flavor might just be a link to that hidden realm. Finally, after years of uncertainty, several projects are beginning around the world—including our own Coherent CAPTAIN-Mills (CCM) experiment—that could put this mystery to bed.

IN BRIEF

Fundamental particles called neutrinos are known to come in three flavors. Now some experiments have shown hints of a strange fourth flavor—a "sterile" neutrino subject to none of the forces of nature except gravity.

If sterile neutrinos are real, they will take us beyond the Standard Model of particle physics and might offer a link to the theorized "dark sector," where dark matter and dark energy reside.

The new Coherent CAPTAIN-Mills (CCM) experiment at Los Alamos National Laboratory aims to find proof of sterile neutrinos if they exist.

WHAT IS A STERILE NEUTRINO?

ALL NEUTRINOS ARE GHOSTLY. Trillions of them fly through you every second at nearly the speed of light. Yet a sterile neutrino would be the ghostliest of them all. Because it does not experience the strong, weak and electromagnetic forces through which other particles interact, it would be essentially undetectable. This quality would render it part of the invisible realm physicists call the dark sector, which includes the dark energy and dark matter that make up 95 percent of the energy density of the universe. Ster-

PRECEDING PAGES: LOS ALAMOS NATIONAL LABORATORY

ile neutrinos may be able to interact with dark matter through new forces of nature. They might even *be* dark matter: some hypotheses suggest that sterile neutrinos make up some or even most of the invisible matter in the cosmos.

If sterile neutrinos exist, it will be the latest in a series of surprises this puzzling family of particles has thrown at physicists. The first came in the 1960s, when experiments designed to catch the neutrinos flying toward us from the sun measured far fewer than scientists expected. All stars are fueled by nuclear fusion reactions in which protons combine to form helium nuclei, which in turn fuse to create heavier elements. Among the products of these reactions are electron neutrinos—one of the three known flavors, along with muon and tau neutrinos. Theory predicted that a steady stream of the particles from the sun would make their way to observatories on Earth, yet experiments measured only a small fraction of the anticipated number. The resulting deficit was known as the solar neutrino problem.

Many physicists initially assumed that we just did not really understand how the sun works. The real issue turned out to be both simpler and a lot more problematic. It was not that the sun emitted fewer neutrinos than expected. It was that the neutrinos were not making it to our terrestrial detectors—or rather they were changing en route.

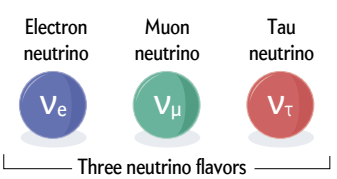
What scientists eventually figured out is that a neutrino is not a pure object. Rather every neutrino consists of a mix of all neutrino types and can oscillate through the various flavors as it travels. This discovery was surprising for a variety of reasons. For starters, the fact that neutrinos can change their flavor means they cannot be massless particles traveling at light speed, as the Standard Model predicted. The reason is a consequence of Einstein's special theory of relativity, which tells us that time moves more slowly for an object in motion than for a stationary one. As an object's speed increases, time continues to slow until it actually stops. That is the point when the object reaches the speed of light—meaning that if you could travel at light speed, time would seem to stand still, with the whole universe frozen in place. If neutrinos alter their flavor, though, they must undergo change and therefore experience time. Thus, they must be traveling more slowly than light, which means they cannot be massless. Particles moving at the speed of light would have no mass, according to relativity, so if they are slower than that, they must

Neutrino Flavors

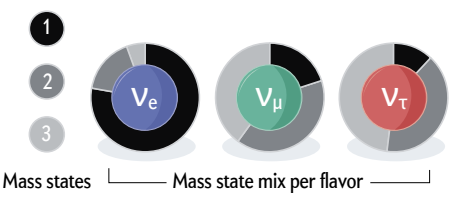
Neutrinos are among the universe's most surprising particles. Predicted to weigh nothing at all, they turn out to have small masses and fly through space at nearly the speed of light, rarely interacting with other matter. These elusive particles play an important role in helping scientists understand some of the most fundamental questions in physics.

Neutrino Properties

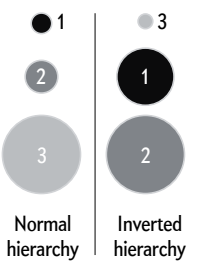
Neutrinos come in three types, or flavors: electron neutrino, muon neutrino, and tau neutrino.



The flavors are not pure states but actually contain a mix of three possible masses, called mass states.



Scientists do not yet know the value of each mass state, except that all three are very small. Theory suggests that there are either two exceptionally tiny masses and one slightly larger or the reverse: one extremely small mass and two slightly larger.



Oscillating Flavors

As neutrinos move through space, the different mass states inside them travel at slightly different rates. Over time this variance changes the mass state mix and causes the neutrino to shift flavor—a process called oscillation. In this way, a particle that starts out as an electron neutrino may end up as a tau neutrino.

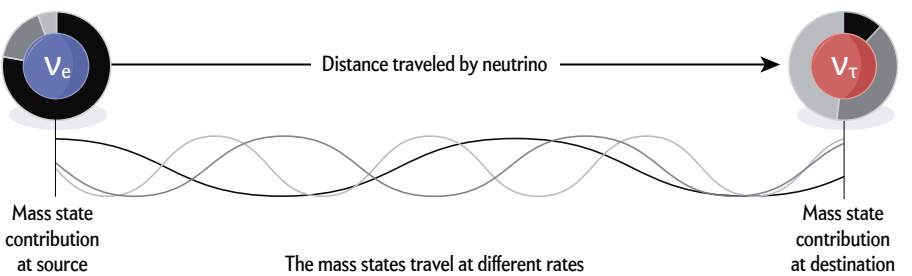
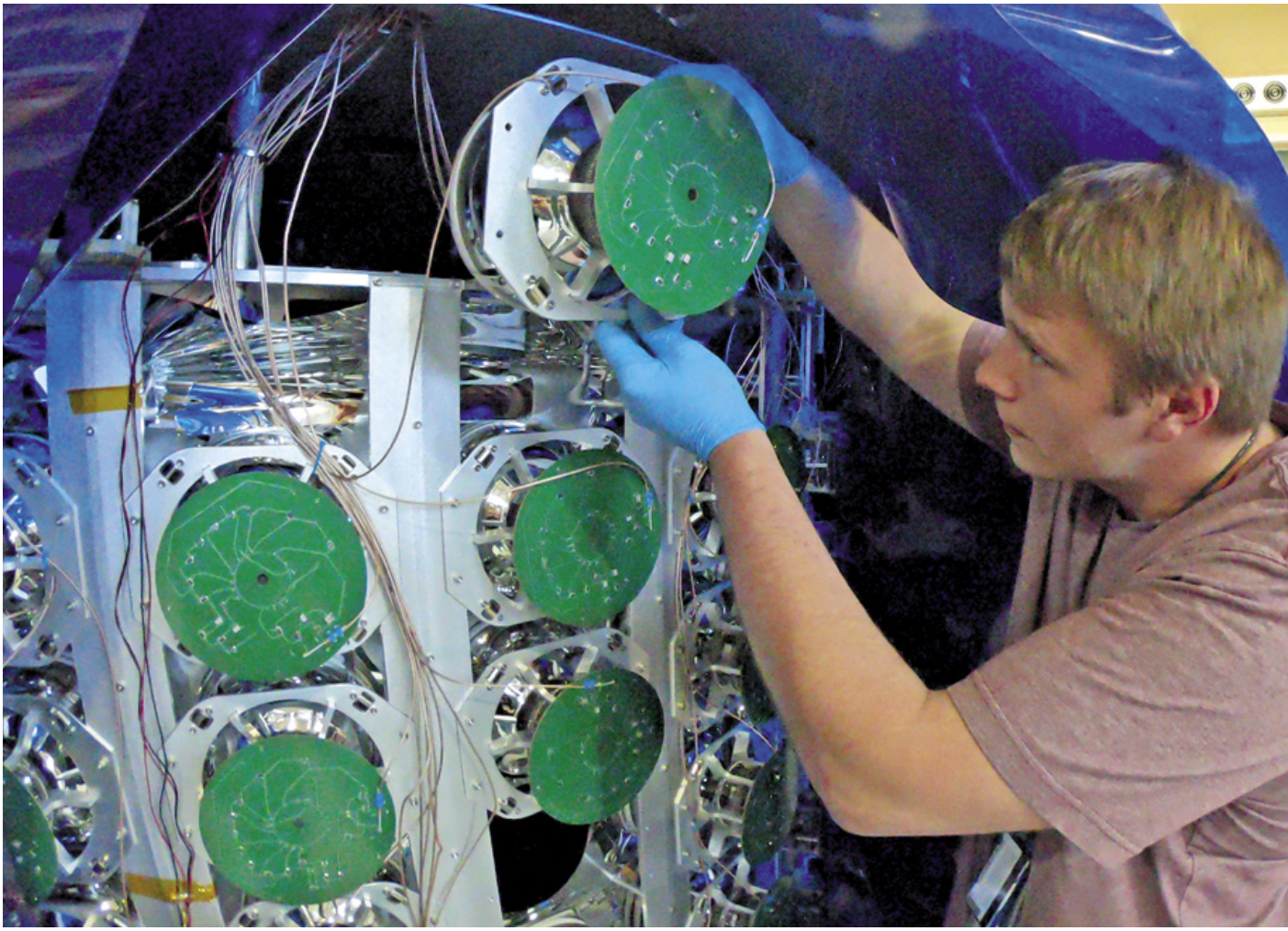


Illustration by Lucy Reading-Ikkanda



COHERENT CAPTAIN-MILLS researcher T. J. Schaub lifts out a photomultiplier tube to be replaced as part of a neutrino detector upgrade.

have some mass—and the Standard Model has a problem. This revelation, and the discovery that neutrinos oscillate, won Takaaki Kajita and Arthur B. McDonald the 2015 Nobel Prize in Physics.

SURPRISING SIGNALS

THE UNEXPECTED ABILITY of neutrinos to switch flavors is what we and others were studying back in the 1990s and 2000s at LSND and MiniBooNE, when we kept finding hints of extra neutrinos. Both experiments were attached to particle accelerators that created steady streams of muon neutrinos, and both used detectors placed some distance away that were tuned to observe electron neutrinos.

If you could sail along beside a single neutrino as it traveled through space, you would see it oscillate from one type to another, cycling through all the flavors. The electron, muon and tau flavors would all be observable, at least in principle. If sterile neutrinos exist, however, neutrinos could also transform into this fourth flavor. To a flying-along observer, the particle would simply seem to disappear for this segment of its flight. In the simplest case, the neutrino would reappear some time later as one of the regular flavors (although there is a theoretical possibility that a sterile neutrino could decay, ending the oscillation cycle entirely).

Oscillations among the three normal neutrino flavors most often take place over long distances. Because sterile neutrinos are likely to be more massive than the regular flavors, however, particles could make the switch to this type more quickly and could likewise change back from sterile to one of the three regular flavors over shorter distances. Thus, if sterile neutrinos exist, they should speed the oscillation process and dramatically reduce the distance that a muon neutrino, for example, would travel before transforming into an electron neutrino.

That is exactly what we found in our earlier experiments: it seemed that muon neutrinos were disappearing much faster than we expected as they traveled from their sources, and electron neutrinos were turning up in numbers higher than anticipated. We observed oscillations over lengths of merely tens to hundreds of meters rather than the tens to hundreds of kilometers that we expected. Such high numbers

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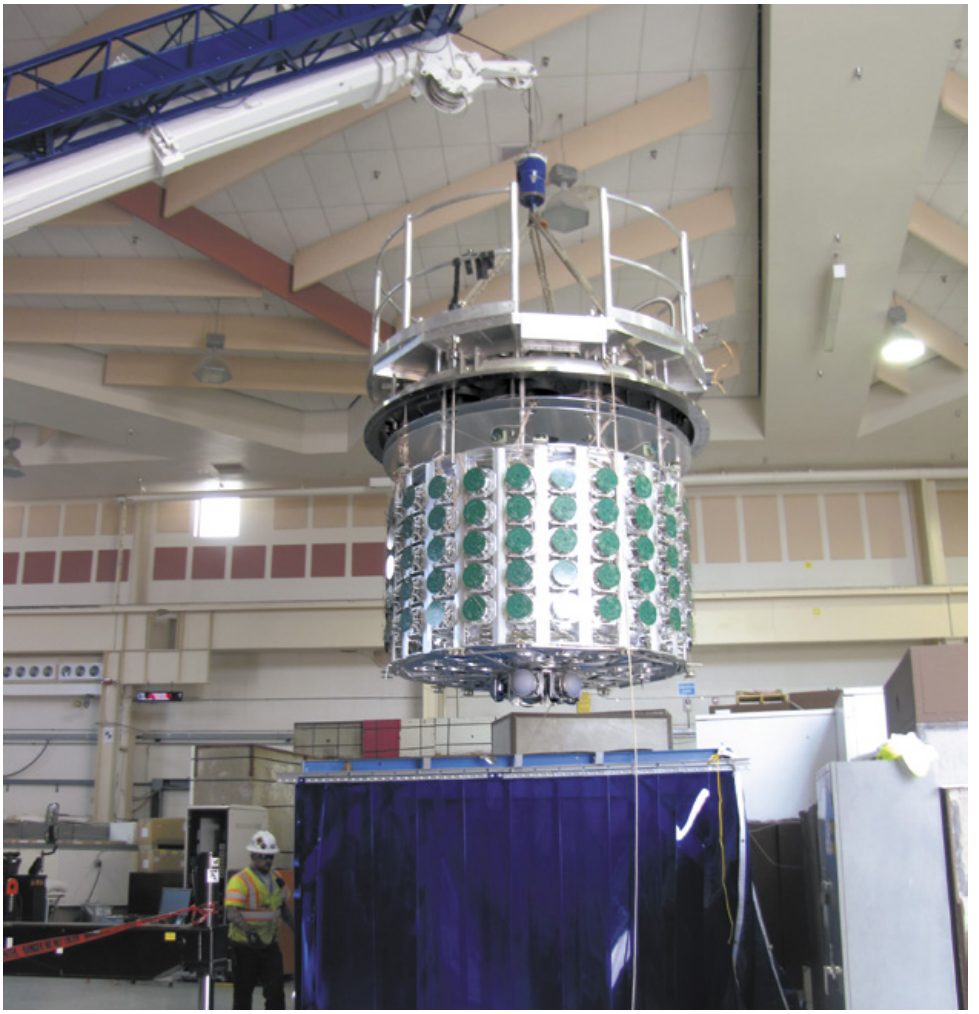


WORKERS raise the CCM neutrino detector out of its container, which is filled with liquid argon when the experiment is running.

of muon neutrinos should not have been able to switch into electron neutrinos over the distance of the experiments unless, perhaps, they were transforming into sterile neutrinos on the way.

Our experiments are not the only ones with anomalous results. Some neutrino detectors set up near nuclear reactors have also found hints of something amiss. Like the sun, nuclear reactors create neutrinos as a by-product, and several experiments have been carried out near them to study the particles. They have revealed fewer neutrinos than expected, which suggests that some of the particles may be oscillating into sterile neutrinos on their way from the reactors. These results are harder to interpret, however, because physicists do not know exactly how many neutrinos should be produced in fission reactors. Therefore, the lower-than-expected neutrino count could be the result of sterile neutrinos, or scientists might have simply overestimated how many particles they should find.

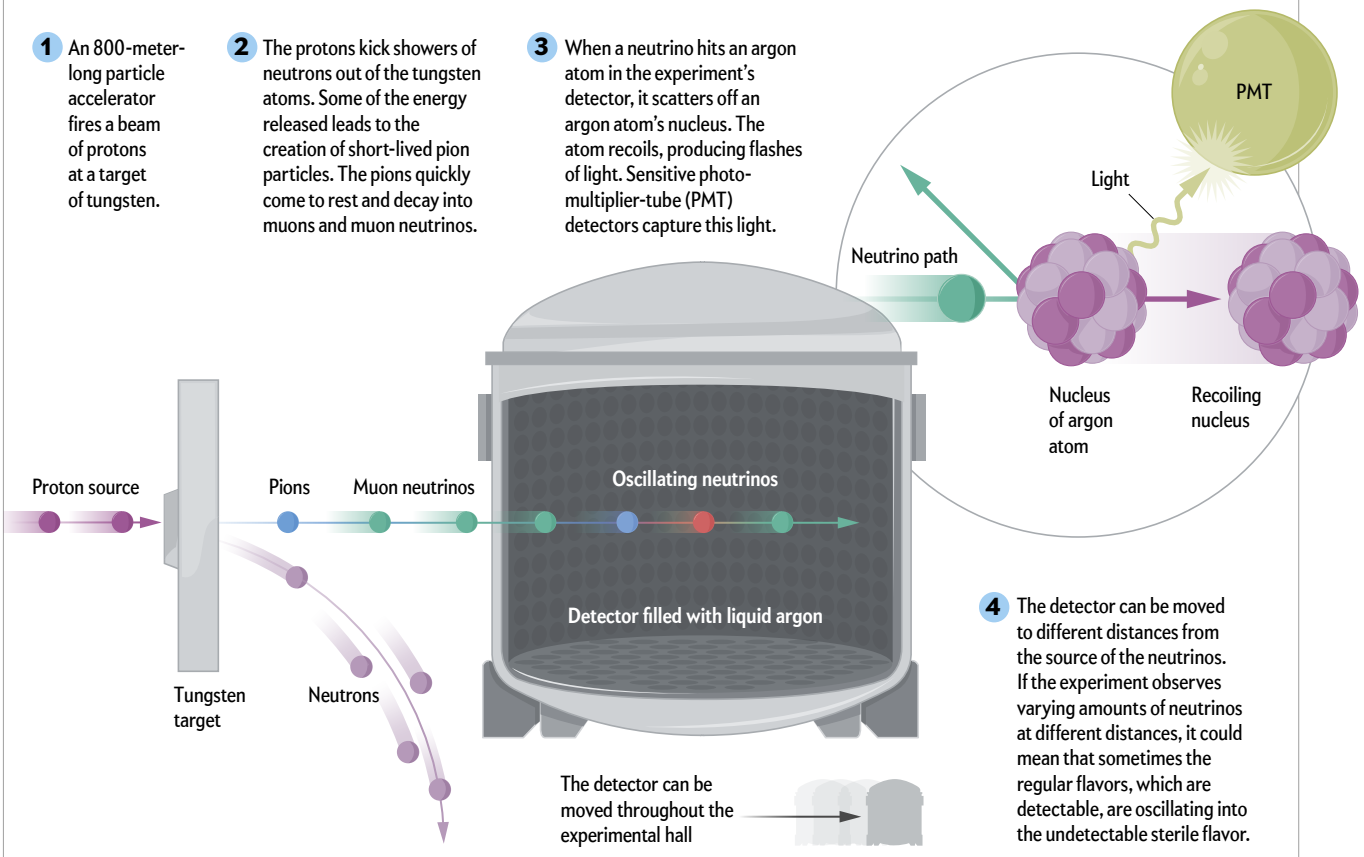
Physicists in Russia are avoiding these uncertainties with an experiment called DANSS (*d*etector of the reactor *a*nti*n*eutrino based on *s*olid-state plastic *s*cintillator). This project takes place underneath a nuclear reactor, but the scientists vary the distance between the reactor and the neutrino detector every few days to see whether the electron neutrinos are truly morphing into other flavors as they move away from their source. This approach may tell the researchers whether short-range oscillations are occurring even if they do not have precise estimates of the number of neutrinos produced in the reactor.

The enormous IceCube Neutrino Observatory in Antarctica is also searching for sterile neutrinos. This cubic-kilometer array of photodetectors buried in the polar ice records a light signal called Cherenkov radiation, created when a high-energy neutrino from the upper atmosphere interacts with ice and sets off a shower of particles. Studying the Cherenkov light collected in the photodetectors tells scientists about the type, energy and flight direction of the neutrino that sparked the particle shower.

The IceCube team will soon report an eight-year analysis of neutrinos passing through Earth to the IceCube array. The study will search for signs of muon neutrinos disappearing, which, if found, could imply

Neutrinos in Action

The Coherent CAPTAIN-Mills Experiment at Los Alamos National Lab is searching for evidence of a possible fourth neutrino flavor: a sterile neutrino. Unlike the regular flavors, which rarely interact with other particles, sterile neutrinos would never interact and would communicate with the rest of the universe only through gravity. If sterile neutrinos exist, regular neutrinos might oscillate into sterile neutrinos and back. The experiment would not be able to detect the sterile flavor but would notice a drop in the neutrinos it found at different distances, providing evidence that normal neutrinos were "disappearing" into their sterile cousins.



the existence of sterile neutrinos consistent with the results from LSND and MiniBooNE.

All of the evidence for sterile neutrinos is intriguing and suggestive, but it is not yet conclusive. The neutrinos studied in IceCube come in a broad range of energies, which makes analyzing their oscillations complex. It is also difficult in reactor experiments to distinguish the neutrinos researchers seek from background neutrinos produced in the sun and from radioactive decays in common detector materials that can masquerade as signals.

In experiments such as those at LSND and MiniBooNE, the accelerators that produce the neutrinos can be turned on and off to determine the level of background noise. Even in those types of experiments, we have been limited in part by our inability to look for neutrinos at more than a small range of distances. Methods for catching neutrinos in the past typically have relied on large, immobile detectors that limit our flexibility. The projects are comparable to taking a frame from a single point in a movie, and what we need is a sequence of frames to get the whole story.

A NOVEL STRATEGY

A NEW BREED of experiment now coming online should be able to capture the multiple frames we need. Ideally, as mentioned earlier, we would fly alongside a neutrino and watch it oscillate. We cannot do that, but these experiments give us a way of taking snapshots during the oscillation process that could reveal traces of sterile neutrinos if they exist. Such projects include the Short-Baseline Neutrino program at Fermilab and the CCM experiment that we are just beginning at Los Alamos.

CCM is housed in a hall in the Los Alamos Neutron Science Center (LANSCE) at the end of an

Illustration by Lucy Reading-Ikkanda

800-meter-long particle accelerator. The accelerator fires a beam of protons at a tungsten target. When the protons hit the tungsten, they kick showers of neutrons out of the target atoms through a process called neutron spallation. Some of the energy released during this process leads to the creation of short-lived pion particles. The pions quickly come to rest and decay into muons and, more important for our purposes, muon neutrinos with a very specific energy.

CCM detects neutrinos through coherent neutrino scattering, an effect that relies on the fact that all particles (including neutrinos) act not just like little marbles but also like waves. This wave-particle duality is a cornerstone of quantum mechanics. The wavelength associated with a particle depends on the particle's energy. High-energy, fast-moving particles have short wavelengths, and slow-moving, low-energy particles have long wavelengths. When short-wavelength neutrinos strike an atomic nucleus, they interact with a single neutron or proton inside it. But something special happens when a neutrino's energy is low enough that its wavelength is comparable to the diameter of an atomic nucleus. Instead of striking a single proton or neutron in an atom, a low-energy neutrino interacts with the entire nucleus. It is somewhat analogous to waves passing a boat. A series of short ripples on water has hardly any effect on the motion of a large boat, but very long waves on the open ocean will lift that same boat dramatically. Because a long-wavelength neutrino interacts with an atomic nucleus as a whole instead of as a collection of small bits, the chances of the neutrino hitting the entire nucleus are much greater at low energies than at high energies.

Unlike high-energy neutrinos, a low-energy neutrino bounces off an atom's entire nucleus. This type of scattering is called "coherent" because the wavelength and the nucleus are similar in size. The atom recoils when it is hit. If the interaction takes place in a suitable material, the recoiling atom produces minute flashes of light, and the neutrino continues on its way, albeit in a different direction than it was heading in initially. By capturing the light flash with a sensitive photomultiplier-tube detector, we can determine when and where the neutrino scattered from the atom, as well as the atom's kinetic energy. Although coherent scattering cannot reveal an individual neutrino's flavor, it can measure the sum of all three known neutrino flavors across interactions. This fact is crucial: if the sum is not the expected number of neutrinos, unmeasured sterile neutrinos—which would not scatter off argon and therefore would not create any flash of light—may be involved.

Given that our chances of a neutrino hitting a whole atomic nucleus are higher than the chances of its hitting just one of its nucleons, we can use smaller detectors in such experiments than the gargantuan ones that have been necessary for many neutrino detectors in years past. In contrast to MiniBooNE's 800-metric-ton detector vat of mineral oil, the CCM detector contains 10 metric tons of liquid argon. And because the detector is compact, we can move it from place to place to observe neutrinos at a range of distances from their source. If neutrinos oscillate frequently enough over the tens of meters available in the LANSCE experimental hall, we will observe the total sum of neutrino interactions to vary by distance. Such an observation would be smoking gun evidence that oscillations into sterile neutrinos are occurring—because with only three flavors, we should see no oscillations at all over such small distances.

The possibility exists, of course, that CCM will find no evidence of sterile neutrinos. In that case, the observations of the known neutrinos would appear to decrease steadily as we moved the CCM detector farther from the tungsten target, much as the apparent brightness of a lightbulb decreases as you walk away from it.

Though disappointing, nondetection would not rule out the existence of one or more sterile neutrinos. It would, however, allow us to place limits on their potential properties. Because neutrino oscillations depend on the relative masses of neutrinos and a parameter known as the mixing angle, a failure to find signs of a sterile neutrino can give us a handle on what the relative masses and mixing angles are not likely to be, effectively narrowing the range of parameters that future searches for sterile neutrinos must consider.

BEYOND THE STANDARD MODEL

EXPERIMENTALISTS WHO OFFER RESULTS at odds with the Standard Model are appropriately deemed guilty until proven innocent because historically scientists who have challenged the Standard Model have been wrong. Nevertheless, it is certain that the Standard Model is not the entire story. Neutrino oscillations alone are proof of that fact.

Neutrino research has been a harbinger of exciting new developments in physics since the first neutrinos were discovered in 1956 by our Los Alamos predecessors Frederick Reines and Clyde Cowan. Although sterile neutrinos remain a controversial topic 25 years after we first found signs of them, experiments are now on the verge of resolving the controversy one way or the other. SA

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Bounds on Non-standard Interactions of Neutrinos from IceCube DeepCore Data. Sergei Vladimirovich Demidov in *Journal of High Energy Physics*, Vol. 2020, No. 3, Article No. 105; March 2020.

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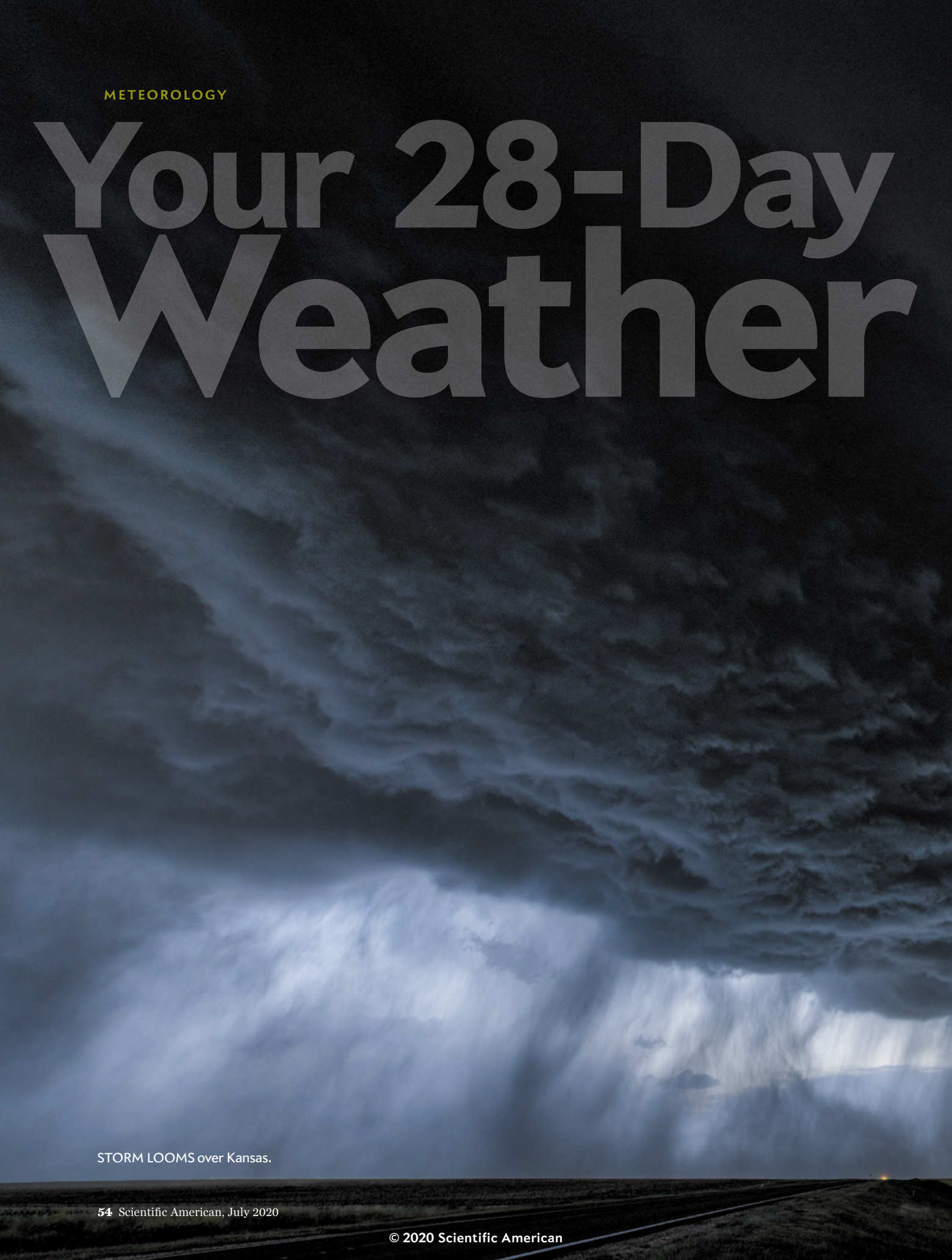
METEOROLOGY

Your 28-Day Weather



STORM LOOMS over Kansas.

Forecast

Meteorologists are getting better at predicting whether it will be warm, cold, wet or dry four weeks from now

By Kathy Pegion

Kathy Pegion is an assistant professor in the department of atmospheric, oceanic and earth sciences at George Mason University. She oversees the SubX Project that produces weather forecasts out to four weeks, as well as research into climate forecasts that could extend several years.

HEY, GOOGLE, WHAT'S THE WEATHER? WE HAVE BECOME COMFORTABLE WITH the idea that we can make decisions based on accurate weather forecasts for the next three, five or seven days. Families plan cookouts for the upcoming weekend. Citrus farmers protect orange trees if a freeze is coming. Emergency managers evacuate towns that will be downwind of wildfires. Communities along rivers prepare sandbags to line homes and businesses if heavy rain looms.

But all kinds of decisions could benefit from accurate prediction that stretched as far as three or four weeks out. Farmers could determine how safe it is to plant crops in early spring by finding out whether a late-season frost is expected. Ski-resort operators could choose to wait to start making snow if temperatures were likely to warm again before they could set a base. Water managers could draw down reservoirs in anticipation of spring flooding—or store water if drought were expected. And, of course, you could plan for what your vacation might be like next month.

In the past several years atmospheric scientists have started to publish "subseasonal" weather forecasts that extend to three and four weeks. A typical seven- to 10-day outlook provides daily high and low temperatures, the percent chance of rain or snow, and wind conditions. A subseasonal projection predicts whether temperatures will be warmer or cooler than average for a given date, based on historical data, and whether it will be wetter or drier than normal. It also foretells hazardous and extreme weather. This time frame fills a big gap between short-term weather reports and seasonal forecasts that anticipate broad trends such as whether El Niño conditions in the Pacific Ocean will bring a warm summer to North America.

Subseasonal forecasts are improving. For example, a set of weather models known as SubX (the Subseasonal Experiment), led by me at George Mason University and one of my colleagues at the University of Miami, accurately predicted several weeks in advance the increased rainfall associated with Hurricane Michael in 2018, a bitterly cold air outbreak in the Midwestern U.S. in late January 2019, and the July 2019 heat wave in Alaska. The SubX project, begun three years ago, combines forecasts from seven major climate and earth research centers in the U.S. and Canada.

As an exercise for this article, on February 27 I used SubX to create forecast maps for the U.S. and for the world for March 21 through March 27—a time span 23 to 29 days out. The maps predicted warmer-than-normal temperatures in the Eastern U.S. and colder-than-normal temperatures in the West. They indicated that early spring conditions would prevail along the East Coast and that prolonged winter would persist in the West. The Southeast would continue to be wetter than usual, following a wet February. Several of the predictions were spot-on. A couple were not.

GLOBAL WEATHER DRIVERS

THE SEVEN- TO 10-DAY weather projections we depend on are based on computer models that simulate how the atmosphere evolves. They contain mathematical equations that estimate how temperature, winds and moisture will change second by second and day to day. Since the birth of weather models in the 1950s, forecasts have steadily improved thanks to better scientific understanding of these variables and to advances in computing power. In 1990 only three-day forecasts were 80 percent accurate or better. Today the three-, five- and seven-day outlooks are at that level.

Many more factors must be considered in a week 3–4 forecast. Like a seven-day projection, this exercise begins with the current weather. Every day large national meteorological and space agencies around the world, including the National Oceanic and Atmospheric Administration and NASA, provide about four million observations of air temperature, atmospheric pressure, winds and humidity from weather balloons, weather stations, airplanes and satellites. Atmospheric scientists combine all these data in a weather model.

To stretch a seven-day forecast to three and four weeks, they incorporate other factors, including the temperatures and cur-

IN BRIEF

Meteorologists are making increasingly accurate weather forecasts up to four weeks out, in part because of more powerful supercomputers.

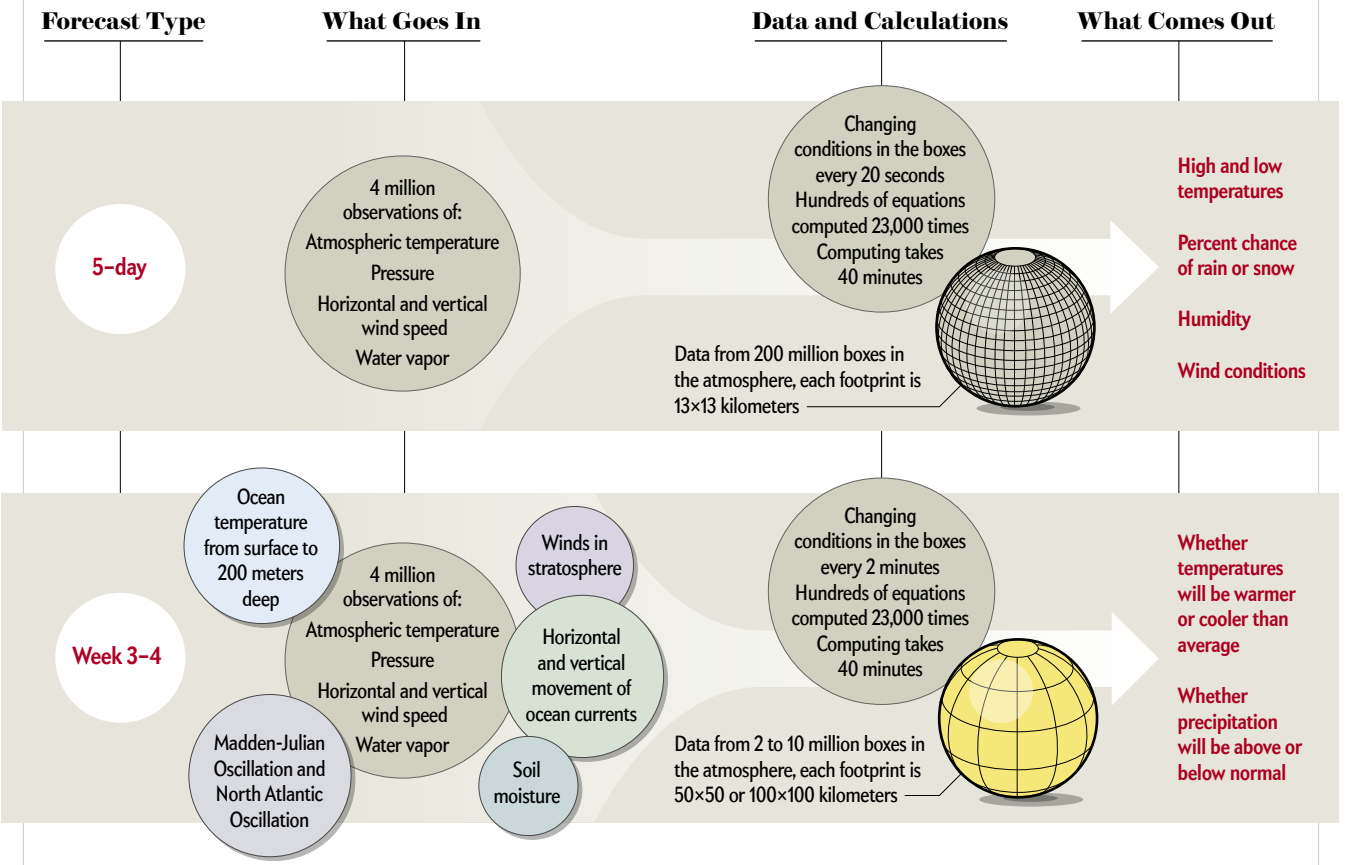
Greater understanding of global climate patterns such as the Madden-Julian Oscillation and the North Atlantic Oscillation is crucial as well.

A four-week forecast done for this article correctly predicted temperature and precipitation anomalies for some U.S. regions, yet it struggled with others.

PRECEDING PAGES: JOHN FINNEY *Getty Images*

Atmosphere In, Forecast Out

Creating a weather forecast that stretches to three or four weeks requires massive data and computing power, yet it starts with the same information as a five-day forecast. Additional aspects of the global climate are added, but the degree of detail is coarsened to make computing practical. The output predicts whether temperature and precipitation will be above or below historical averages.



rents of the oceans. They analyze soil conditions: a few days of warm, dry weather can remove moisture from the soil, which subsequently provides less humidity through evaporation, further reducing precipitation and potentially starting a path toward drought. And they consider winds in the stratosphere, which extends from roughly 10 to 48 kilometers above Earth's surface—higher than where airplanes fly. The winds influence the location and strength of the jet stream, which generally moves storms from west to east across the Northern Hemisphere and determines where extreme temperatures can occur.

The subseasonal models must also take into account certain global weather and climate phenomena. One of these is the Madden-Julian Oscillation (MJO), a large area of clouds, rain and wind that starts in the tropical Indian and Pacific Oceans and moves from west to east around the globe over several months. This event happens four to six times a year, sometimes in succession and sometimes at random. The MJO influences the winds, the locations of low and high atmospheric pressure centers, and where fronts arise in many regions. For example, it has a big impact on where rain falls in western North America in the form of atmospheric rivers—long, narrow bands of heavy rainfall that extend from the central Pacific Ocean to North America's West Coast. Atmospheric rivers can cause devastating floods or can be a source of much needed water. The MJO can also increase wind shear in some places and decrease it in others, on a weekly basis, influencing where tropical cyclones form, which likely was a factor in the successful SubX prediction of Hurricane Michael.

The North Atlantic Oscillation (NAO) is another a factor. It is a persistent coupling of low and high atmospheric pressure in the northern Atlantic Ocean. It can affect the location of the jet stream, as well as the position of the polar vortex, which can drive extremely cold air in the Arctic down into the northeastern U.S. and Europe.

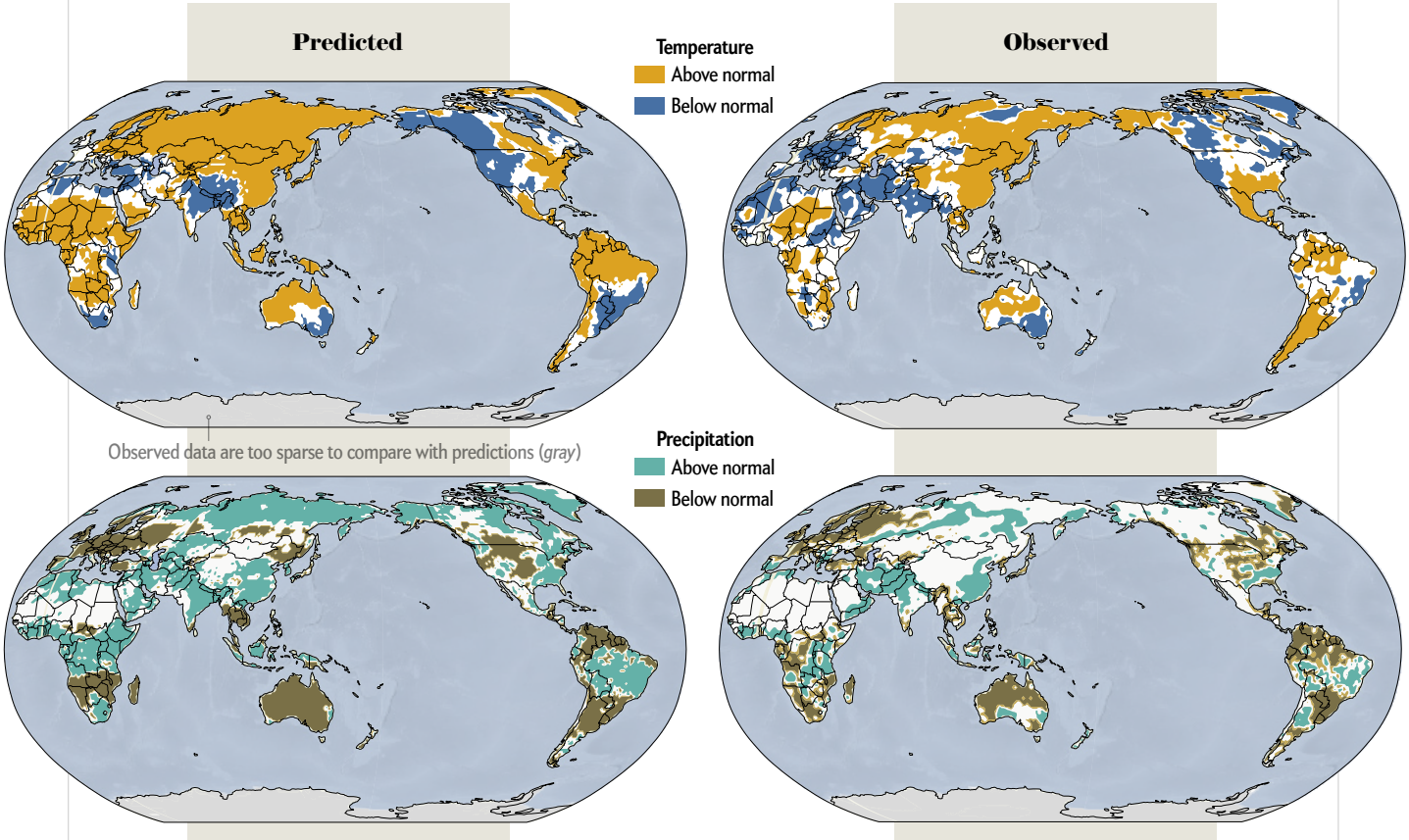
MASSIVE DATA CRUNCH

CALCULATING A SUBSEASONAL FORECAST requires so many operations using so many variables that the exercise taxes even the most pow-

Graphic by Jen Christiansen

Temperature and Precipitation a Month from Now

On February 27 the SubX subseasonal forecast model predicted global weather for March 21–27, nearly a month out. Maps indicated whether temperature and precipitation would be above or below "normal"—the averages from 1999 through 2015. Maps of the actual weather on the March dates show that SubX correctly predicted unusual dryness across Europe and Australia. It accurately forecast a cool western U.S. and warm eastern U.S., but the Northeast was not as warm as projected. SubX predicts how much above or below normal the conditions will be, but values are not very accurate at this time.



erful supercomputers. A model divides the three-dimensional atmosphere into many small computational boxes. For example, NOAA's newest global weather model has about 200 million boxes. The boxes closest to Earth's surface each cover a patch 13 kilometers long by 13 kilometers wide and are 50 meters high. Other boxes are stacked on top of them. As a stack progresses upward, the boxes get taller, reaching 700 meters in height in the stratosphere. The model predicts how the atmosphere will evolve in each box every 20 seconds, using equations that calculate temperature, pressure, horizontal and vertical wind speeds, and moisture.

Like the pixels of an image on your smartphone, when combined, the boxes can give a complete picture of the future weather. To make a five-day forecast, a model computes hundreds of equations about 23,000 times; this run, using all 1,500 computing cores on a large supercomputer, takes about 40 minutes.

Meteorologists must balance the highest possible resolution with a computing time that is quick enough to be useful. Even today's five-day models do not capture certain factors in the boxes, such as individual clouds, thunderstorms and the effects of complex terrains such as mountains and coastlines. If the model's resolution were tightened so that the box bases were six kilometers square—which is what would be needed to effectively represent those features—it would take more than five hours to produce a five-day forecast. Your local meteorologist cannot wait that long to provide timely information.

To create a workable model for four-week predictions that incorporates all the additional large-scale factors such as the MJO, we must make the boxes bigger, thereby reducing the number from 200 million to between two million and 10 million, depending on the model. Expanding the box widths to 50 or 100 kilometers allows us to perform the many complex calculations needed with the same computing power, also in about 40 minutes, but we lose detail. We can think of a week 3–4 forecast as the grainy pixels of a low-resolution image: We can still see the main features, but the fine points are not very clear. The large areas of warm temperatures and rain are like the outline of a

KATHY PEGION

person; the small features, such as a specific rainstorm, are difficult to identify.

Still, our understanding of global phenomena has improved enough, computing has gotten efficient enough and algorithms have become sophisticated enough that the models can now produce a low-resolution picture that meteorologists feel is respectable.

MODELS TEACH MODELS

EVERY WEEK THE SEVEN CENTERS that contribute to SubX create their own predictions out to 32 to 45 days, incorporating several thousand more observations than they would include in a seven-day outlook. The groups send those data to a central database hosted by Columbia University's International Research Institute for Climate and Society. SubX combines the data on computers at George Mason. The SubX team is the only one that integrates multiple models into a public forecast. About 10 other groups worldwide, such as the European Center for Medium-Range Weather Forecasts, produce subseasonal predictions based on single models.

SubX creates a temperature map indicating areas predicted to be warmer or colder than the historical average. It also produces a precipitation map showing whether areas will be wetter or drier than usual. Combining the seven models produces a much better outlook than any of the individual models, in part by averaging their data and in part by taking advantage of what each model does best. For example, every model has to estimate cloud conditions within each box, and they all do it slightly differently. Combining the models creates a best-case estimate. For U.S. forecasts, the SubX prediction is better than the best individual model 60 percent of the time for temperature and 81 percent of the time for precipitation.

Scientists at SubX are exploring ways to better combine the models, and we are also improving them by looking back in time. Over the course of a year, SubX ran numerous week 3–4 forecasts, starting with weekly weather conditions from 1999 to 2015, and produced a database with more than 20 terabytes of information. For each run, we compared the forecast with the actual weather that occurred three and four weeks later. This allowed us to test the effects of many different climate circumstances.

We are now using the accuracies and inaccuracies we identified to improve the models' performance, including how well they can represent the stratosphere, the MJO and the NAO and predict the impacts of such phenomena on weather in various regions. For example, two of the NOAA modeling groups that supply data to SubX sharpened their equations for clouds, thunderstorms and rain to better characterize the MJO. They then reviewed the actual weather from the past and showed that the newly made historical week 3–4 forecasts were more accurate.

THE TEST: MARCH 21–27

SO HOW WELL DID SUBX DO in its February 27 forecast for March 21 to March 27? The maps it created for the U.S. predicted warm temperatures in the East and cold in the West, along with early East Coast spring conditions and prolonged winter in the West. The Southeast was expected to be wetter than normal.

Unusually wet weather did continue in the Southeast. The predictions for rain in addition to spring snowmelt and an already high Mississippi River could have provided valuable information for flood preparedness in this region. Indeed, the Mississippi River at New Orleans was near flood stage on February 27, subsided a little after peaking on March 8, then rose in late March and early April, reaching flood stage again on April 12. SubX did well in part because it successfully predicted warm ocean temperatures in the Gulf of Mexico, a key condition for Southeastern rainfall. SubX also predicted the colder-than-normal conditions along the West Coast, as well as drier conditions in northern California and coastal British Columbia.

Globally, SubX successfully predicted drier-than-normal conditions over Europe and warmer-than-normal weather over Asia by correctly anticipating the locations of low- and high-pressure systems. The accurate temperature forecast for Australia was related to the model's ability to predict the cloudy and sunny regions associated with the MJO.

SubX overestimated the geographic extent of warmer-than-usual weather in the U.S. mid-Atlantic, Northeast and Ohio River Valley regions. Some details of the high- and low-pressure systems were not correctly predicted, which hurt the forecasts. The model also failed to predict the wetter-than-average conditions in Oregon, although the heavy rain was relatively short-lived, occurring on March 24 and 25. Most of the seven individual models that make up the integrated SubX forecast, which we ran again the week before that rain, did not predict it either; the storm that produced the rain was a challenge even for seven-day prediction. Chaos can arise unexpectedly in the atmosphere.

A subseasonal forecast requires so many calculations on so many variables that the exercise taxes even the most powerful supercomputers.

We still have a ways to go before subseasonal projections are as accomplished as seven-day weather outlooks, and they might never be quite that good. But a large group of atmospheric scientists are hard at work trying to make it happen. Every week I publish a global four-week forecast from all seven of the models plus the combined SubX models. NOAA's Climate Prediction Center in turn issues a week 3–4 outlook for the U.S. using guidance from SubX. Perhaps a decade from now, when you catch a glimpse of the weather forecast on your phone, you will see a sun or cloud icon in the corner above a label that says "28-Day Outlook." SA

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ARCHAEOLOGY

How Farmers Conquered Europe

When agriculturists encountered hunter-gatherers, a disturbing hierarchy may have evolved

By Laura Spinney

Illustration by Benoit Clarys

PREHISTORIC GRAVES in Europe sometimes contain a "master" laid out carefully on his side, along with one or more "slaves," possibly sacrificed and thrown in.

Laura Spinney is an author and science journalist based in Paris. Her most recent nonfiction book is *Pale Rider: The Spanish Flu of 1918 and How It Changed the World* (Jonathan Cape, 2017).

EIGHT THOUSAND YEARS AGO SMALL BANDS OF SEMINOMADIC HUNTER-GATHERERS were the only human beings roaming Europe's lush, green forests. Archaeological digs in caves and elsewhere have turned up evidence of their Mesolithic technology: flint-tipped tools with which they fished, hunted deer and aurochs (a now extinct species of ox), and gathered wild plants. Many had dark hair and blue eyes, recent genetic studies suggest, and the few skeletons unearthed so far indicate that they were quite tall and muscular. Their languages remain mysterious to this day.

IN BRIEF

Roughly 9,000 years ago farmers from the Middle East headed toward Europe, seeking new land to cultivate.
The farmers traveled either along the Mediterranean coast or the Danube River, encountering hunter-gatherers who lived in dense forests.
At first, the farmers and hunter-gatherers traded or mated. By 5,000 years ago, however, agriculture dominated the continent and hierarchical societies had evolved.
Genetic studies suggest that individuals with high hunter-gatherer ancestry may have been treated as inferiors.

Three millennia later the forests they inhabited had given way to fields of wheat and lentils. Farmers ruled the continent. The transition was evident even to 19th-century archaeologists, whose excavations revealed bones of domesticated animals, pottery containing remnants of grain and, most intriguing of all, graveyards whose riddles are still being solved. Agriculture not only ushered in a new economic model but also brought about metal tools, new diets and new patterns of land use, as well as novel human relationships with nature and with one another.

For 150 years scholars debated whether the farmers brought their Neolithic culture from the Middle East to Europe or whether it was only their ideas that traveled. In the early 2000s, however, geneticists such as Martin Richards, then at the University of Oxford, and others studied patterns of variation in modern genes to provide irrefutable proof that the farmers came—streaming across the Aegean Sea and the Bosporus to reach Greece and the Balkan Peninsula, respectively. From there they spread north and west. Then Svante Pääbo of the Max Planck Institute for Evolutionary Anthropology in Leipzig, Germany, and others learned to extract DNA from ancient human remains and read it. This technological revolution enabled an unprecedented collaboration between archaeologists and geneticists, who rushed to characterize the DNA of individuals who had died in prehistoric hunter-gatherer or farmer settlements.

Since 2014, when archaeologist Cristina Gamba, then at Trinity College Dublin, and her colleagues found a hunter-gatherer bone in an early farming community in Hungary, a bewilderingly complex and multifaceted picture of the encounters between the residents and the immigrants has emerged. In some places, the two groups mingled from the time they met; in others, they kept their distance for centuries, if not millennia. Sometimes the farmers venerated their predecessors; at other times they dehumanized and subjugated them. Nevertheless, a clear trend is evident. As the decades passed and farmers increased in number, they assimilated and replaced the hunter-gatherers, pushing those who held out to the margins—both geographically and socially. Disturbingly, the progression toward greater inequality culminated, in at least a few places, in societies in which individuals with greater hunter-gatherer ancestry may have been enslaved—possibly even being sacrificed to accompany their masters to the afterlife.

THE EXODUS

ROUGHLY 11,500 YEARS AGO Europe and the Middle East were emerging from an ice age. As the weather grew warmer and the land more bountiful, hunter-gatherers in the so-called Fertile Crescent—an envelope of land around the Euphrates, Tigris and Nile Rivers and the eastern coast of the Mediterranean Sea—gradually became more sedentary. They spent less of their time hunting wild ibex and boar and gathering wild grasses, and they spent more of it tending their own domesticated animals and plants: sheep, goats, wheat, peas and lentils. Archaeobotany—in particular the study of ancient pollen—and archaeozoology, the study of ancient animal bones, revealed this transition. These were the first farmers, people who spoke unknown languages (of which Basque could be a relic), used stone tools and, about 9,000 years ago, headed for Europe in search of new land to cultivate.

The farmers reached the new continent by two routes: in boats via the Mediterranean and on foot along the Danube River from the Balkans into central Europe. Radiocarbon dating of archaeological sites revealed that by about 7,500 years ago, Danubian farmers were building villages in the Carpathian Basin—modern-day Slovakia, Hungary and Romania—and there they began cre-

ating a pottery culture. Archaeologists call it the Linear Pottery culture (LBK, by its German acronym, for *Linearbandkeramik*) because of the distinctive spiral motifs with which they decorated their ceramics.

Traveling rapidly westward across the fertile plains of what is now Germany, the LBK farmers reached the Rhine within just a few centuries, around 7,300 years ago. Fine-grained analysis of the evolution of pottery styles, along with radiocarbon dating, suggests that they practiced a form of leapfrog colonization. They took "stepwise movements with sometimes hundreds of kilometers covered, and then the landscape in between filled up," says archaeologist Detlef Gronenborn of the Römisch-Germanisches Zentralmuseum (Romano-Germanic Central Museum) in Mainz, Germany. At some point they learned how to smelt copper, and a trade in precious copper objects sprang up between farming communities.

On the southern route, the farmers leapfrogged along the Mediterranean coast from Italy to France and on to the Iberian Peninsula. After reaching French shores, 7,800 or so years ago, they migrated northward toward the Paris Basin, the plain between the Rhine and the Atlantic Ocean that forms a kind of continental cul-de-sac. It was there that the two great streams of farmers met, around seven millennia ago. By then their cultures had diverged to some extent—they had been separated for more than 500 years—but they would still have recognized their own kind. They mingled both biologically and culturally.

A cemetery near Gurgy, in the southern part of the Paris Basin, dating from 7,000 years ago provides a snapshot of that mingling. Mitochondrial DNA (mtDNA) is typically inherited via the maternal line, and the mtDNA of about 50 individuals buried there has roughly equal contributions from LBK and southern farmers. From the Paris Basin, this mixed population spread out again—carrying its farming culture to every corner of the continent.

GENETIC STUDIES of burials at Gougenheim, France, suggest that those dumped (*1*) are more likely to have hunter-gatherer ancestry than those whose corpses were arranged with care (*2*).

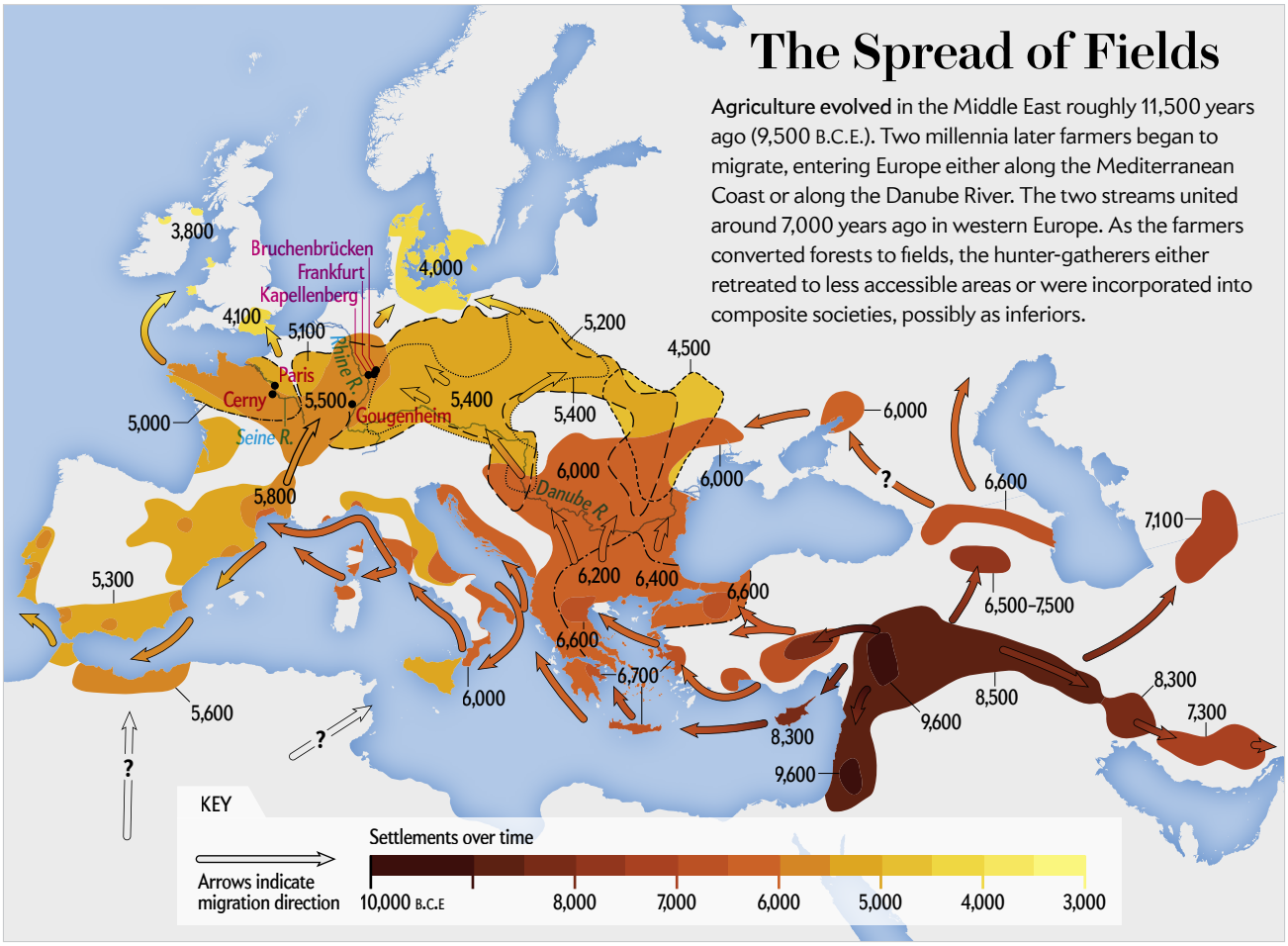
FROM "MULTI-SCALE ANCIENT DNA ANALYSES CONFIRM THE WESTERN ORIGIN OF MICHELSBERG FARMERS AND DOCUMENT PROBABLE PRACTICES OF HUMAN SACRIFICE," BY ALICE BEAU ET AL., IN *PLOS ONE*; JULY 5, 2017 (HTTPS://DOI.ORG/10.1371/JOURNAL.PONE.0179742)

FIELDS OVER FORESTS

THE FIRST FARMERS to enter Europe probably came with their families, as revealed by a 2017 study by Amy Goldberg, an evolutionary anthropologist then at Stanford University, and her colleagues. They analyzed the X chromosomes of 20 Neolithic Europeans. Unlike a Y chromosome, which can be inherited only from a father, an X chromosome can be inherited from either parent. Goldberg's team reported that male and female farmers had contributed X chromosomes to the 20 individuals in roughly equal proportions. Other researchers have concluded that these societies were patrilocal, meaning wealth was passed down the male line and women married in from outside. Clues to the mobility of women come from the ratio of strontium isotopes in their teeth, which reflect their dietary history, and from the constant influx of outside artistic influences into farming communities, as evinced by their pottery. Women are thought to have decorated the pottery, as in agricultural societies of later eras.

Europe then was slightly wetter and warmer than it is today and was heavily forested. As with all immigrants, the farmers might have taken a while to adapt to their new environment, but gradually they learned which plants and animals thrived in Europe's temperate climes. They cleared the forest parcel by parcel and shaped its composition using ancient forest-management techniques such as coppicing and pollarding. (Coppicing involves cutting a tree back to its base and then allowing it to produce multiple new stems; pollarding is pruning of just the upper branches.) The farmers' numbers began to increase. When there was no more room at a farm, the younger generation moved on, settling in what may have seemed to them virgin forest. "The newcomers might not have had the impression of encroaching on anybody else's territory," says Céline Bon, a paleogeneticist at the Museum of Mankind in Paris. But they were.

Sooner or later the immigrant farmers must have met the resident hunter-gatherers—and when it happened, it must have been a shock. Approximately 40,000 years had elapsed since their common ancestors split paths on their way out of Africa—long enough to distinguish them physically, culturally and linguistically. Comparisons of their genes with those of modern Europeans indicate



that the farmers were shorter than the Western hunter-gatherers who occupied most of the continent. They also had dark hair, dark eyes and, probably, lighter skin. There is no evidence of violence between the two groups in the earliest encounters—although the archaeological record is incomplete enough that violence cannot be ruled out. Yet in large parts of Europe, the hunter-gatherers and their Mesolithic culture simply vanished from both genetic and archaeological records the moment the farmers arrived. Where did they go?

For decades archaeologists have wondered whether, in the face of this massive influx, the hunter-gatherers retreated—into the hills, perhaps, where the soil was less fertile and hence less suitable for farming, or deep into the forest, where the farmers were unlikely to interfere with them. "Maybe there were massive pockets of hunter-gatherers surviving there, not for a generation but for 1,000 or 2,000 years after the farmers arrived," suggests Ron Pinhasi, an archaeologist and anthropologist at the University of Vienna in Austria.

The hunter-gatherers must still have been there somewhere because modern Europeans carry their genes, and Europe-wide surveys of ancient DNA have highlighted a so-called Mesolithic resurgence that started 6,500 years ago. Hunter-gatherer genetic elements accounted for more and more of the farmers' genomes as time went on—but the resurgence was not just genetic. "Around the same time, we see the reemergence in the archaeological record of Mesolithic ways of doing things," says archaeologist Thomas Perrin of the Jean Jaurès University of Toulouse in France. The hunter-gatherers themselves were no longer there, except for possible pockets of them hiding deep in the forest—but their genes, and their technology, were.

By the time the farmers started moving out again from that hub of the Paris Basin, they were no longer the same people who had set out from Hungary or beached on Europe's prehistoric Riviera. They carried a little bit of the old Europe within them. And that raises the question: How did the encounter between such disparate peoples unfold?

A KALEIDOSCOPE

THE ANSWER IS: in a kaleidoscope of different ways. There is no clear genetic evidence of interbreeding along the central European route until the LBK farmers reached the Rhine. And yet the groups mixed in other ways—potentially right from the beginning. A tantalizing hint of such interactions came from Gamba's discovery of a

SOURCES: RÖMISCH-GERMANISCHES ZENTRALMUSEUM AND INSTITUTE FOR ORIENTAL AND EUROPEAN ARCHAEOLOGY (*migration*)

Map by Mapping Specialists, after Gronenborn/Horejs/Börner/Ober 2019 (RGZM/OREA)

hunter-gatherer bone in a farming settlement at a place called Tiszaszőlős-Domaháza in Hungary. But there was nothing more to be said about that individual. Was he a member of that community? A hostage? Someone passing through?

With later evidence, the picture became clearer. At Bruchenbrücken, a site north of Frankfurt in Germany, farmers and hunter-gatherers lived together roughly 7,300 years ago in what Gronenborn calls a "multicultural" settlement. It looks as if the hunters may have come there originally from farther west to trade with the farmers, who valued their predecessors' toolmaking techniques—especially their finely chiseled stone arrowheads. Perhaps some hunter-gatherers settled, taking up the farming way of life. So fruitful were the exchanges at Bruchenbrücken and other sites, Gronenborn says, that they held up the westward advance of farming for a couple of centuries.

There may even have been rare exceptions to the rule that the two groups did not interbreed early on. The Austrian site of Brunn 2, in a wooded river valley not far from Vienna, dates from the earliest arrival of the LBK farmers in central Europe, around 7,600 years ago. Three burials at the site were roughly contemporaneous. Two were of individuals of pure farming ancestry, and the other was the first-generation offspring of a hunter and a farmer. All three lay curled up on their sides in the LBK way, but the "hunter" was buried with six arrowheads.

In 1990, when archaeologists first started excavating Brunn 2, they found it littered with thousands of stone fragments, along with ceramic amphorae and clay flutes and figurines. They concluded that it served as a place of ritual or as a Stone Age workshop and trading post, or both. If it was a sacred place, says Alexey Nikitin, a paleogeneticist at Grand Valley State University in Allendale, Mich., who has worked at Brunn 2, the individuals buried there must all have enjoyed high status. For him, the site attests to mutually profitable interactions between the two cultures. "The incomers brought in something the locals didn't have, but the locals had something that the incomers didn't—knowledge of the landscape," he says.

On the southern route, however, those interactions seem to have included interbreeding right from the start. "Within the first two centuries of the first farmers' arrival, we have individuals whose genetic makeup is 55 percent hunter-gatherer," says paleogeneticist Maïté Rivollat of the University of Bordeaux, co-author of a genetic analysis of human remains found at Neolithic burial sites in southern France that was published in May in *Science Advances*. Moreover, by looking at the way the hunter-gatherer component was distributed through farmer genomes, Rivollat and her colleagues could tell the interbreeding had gone on for five or six generations already—perhaps starting as soon as the pioneers landed.

Curiously, French sites where the two groups might have come into contact are absent, although Perrin has searched for them. The closest he and others have come to putting the farmers and the hunter-gatherers in the same place at the same time is the Grotte du Gardon, a cave in the Jura Mountains east of Lyon, which was occupied in quick succession by Neolithic farmers from the south and by Mesolithic hunters, with the latter moving in after the former. "Given the small separation between these occupations in time, we can conclude that they coexisted in the region, at least," Perrin says.

How to make sense of these disparate findings? Polly Wiessner, an anthropologist at the University of Utah, who has long studied hunter-gatherers, says that such regional variation is unsurprising. In more recent history, when immigrant farmers encountered an established group of hunter-gatherers, relations between the two depended on their respective economic goals. "If newcomers [want] to colonize land or resources, they dehumanize the residents," she says. "If there is possibility for cooperation, then the response is to categorize relations to facilitate interaction"—to label the other a friend or a trading partner, that is.

The farmers valued the hunter-gatherers' toolmaking techniques—especially their finely chiseled arrowheads.

More recent colonizations of hunter-gatherer territory by farmers could also help explain why the Mesolithic resurgence—around 1,500 years after the farmers arrived in Europe—took so long. When Bantu farmers started expanding into southern Africa 3,000 years ago, they encountered the forest-dwelling Pygmies, a group of hunter-gatherers from whom they were as genetically distant as they were from Europeans. "For a long time," says evolutionary geneticist Lluis Quintana-Murci of the Pasteur Institute in Paris, who has pieced the joint history of these two groups together using ancient DNA, "there were commercial transactions between Bantu and Pygmies but no in[ter]breeding."

When the interbreeding finally started, more than 2,000 years after the two groups met, it was Pygmy women who married into Bantu communities, where they were—and still are—treated as socially inferior, a lower socioeconomic class that is also differentiated biologically. "Bantus have a double-edged relationship with the Pygmies," Quintana-Murci says. "On the one hand, they treat them like servants; on the other, they are slightly afraid of them. In the Bantu way of thinking, Pygmies are the masters of the forest, and some of them have shamanic powers."

Why did the biological barriers come down when they did? Nobody knows, Quintana-Murci says, but it is likely that some social barrier came down first. Perhaps as Bantu society became richer and more stratified, those at the bottom of the social ladder found an affinity to the marginalized Pygmies.

Did a similar lowering of social barriers allow Europe's early farmers and its hunter-gatherers to mix? It is hard to know, but a possible clue is provided by the Cerny

1

2

FLINT ARROWHEADS (*1*) from Kapellenberg, Germany, display the importance of hunting in Michelsberg culture. A site near Wiesbaden yielded fragments of a clay pot with linear decorations characteristic of the LBK farming culture (*replica shown in 2*).

culture of the Paris Basin. Archaeologists have long regarded Cerny as a last vestige of LBK, developing just as LBK was embracing other elements. If that premise is correct, the inhabitants had farming in their blood—their ancestors were the early farmers of the Carpathian Basin. Yet in cemeteries dating from 6,700 years ago, men of high status were buried lying on their backs, not curled up on their sides, and arranged around them were hunting weapons and ornaments made from red deer antlers, the tusks of wild boars and the claws of birds of prey. "Their funerary rites speak to another world from their day-to-day," says archaeologist Aline Thomas of the Museum of Mankind. "They make reference to the sphere of the wild, things that are more often associated with Mesolithic populations."

Those rites have prompted Thomas and Bon to ask: Who were the Cerny people really? Were they farmers who had adopted Mesolithic ways and come to venerate them, or were they recently converted hunter-gatherers who had never let them go? Bon and Thomas have been analyzing DNA extracted from the Cerny cemeteries to try to answer that question. So far they have analyzed the (maternally inherited) mtDNA and found that it contains Mesolithic elements. At Cerny, therefore, hunter-gatherer women came into the community from outside to marry local men. This influx may reflect what was happening in other farming communities of the period, because by 6,700 years ago the Mesolithic resurgence—the emergence of hunter-gatherer genes in farming genomes—was well underway. So the outstanding question is: Who were the Cerny men? The researchers are analyzing Y chromosomes and whole genomes from Cerny now, in the hope of pinpointing their genetic origins.

Whoever the Cerny people were, their cemeteries seem to provide a freeze-frame of that Mesolithic resurgence in Europe. Within a few hundred years almost everybody in Europe had adopted the farming culture—even if their genes, and occasionally their rituals, told a more complex story.

AN EMERGING HIERARCHY

AROUND 6,500 YEARS AGO a new phase began in Europe. Previously, as at Brunn 2, even important people were buried individually and in the ground. Now, in some regions, huge burial mounds were raised over small chambers in which one or two individuals were interred. Archaeologists think these changes reflect some seismic social shift, perhaps the birth of inequality as farming societies began to generate surplus and distribute it unevenly. If so, those societies now contained people with high levels of hunter-gatherer ancestry who may still have looked different from their "pure" farmer neighbors and whose existence was not necessarily happy.

An example is the Michelsberg culture. Dating from 6,400 years ago, it likely originated in the Paris Basin before farmers moved east toward Alsace and Germany. The people of Michelsberg organized their territory defensively. At the core, typically, was a large fortified settlement inhabited by up to several thousand people. This center was surrounded by a belt of land containing smaller, more dispersed settlements, and beyond that was what Gronenborn calls a "frontier zone" inhabited by even sparser "colonies." This defensive pattern probably reflected tensions between neighboring communities, which clashed as their populations grew.

Michelsberg burials reveal a stratified society. In some of the sites—for example, at Bruchsal-Aue near Karlsruhe—a high-status individual lies curled up on his side in traditional LBK fashion, with other individuals thrown in apparently willy-nilly around him. The ratio of stron-

R. MÜLLER *Römisch-Germanisches Zentralmuseum* (*1*); V. ISERHARDT *Römisch-Germanisches Zentralmuseum* (*2*)

tium isotopes in their teeth indicates that all those buried in a single grave were raised on the same diet—a farmer's diet—but their DNA reveals that those surrounding the central figure generally had much higher hunter-gatherer ancestry than him. Additionally, the remains of those with hunter-gatherer ancestry were often discarded in rubbish pits or ditches. According to Gronenborn, these findings point to a society that discriminated on both social and biological grounds and one in which little value was attached to the lives of those at the bottom. Individuals thrown haphazardly into a high-status grave were probably slaves or war captives who were forced to accompany their master in death, Gronenborn says: "I think these people were killed to be deposited in those graves."

In a 2017 paper, the Bordeaux group reported "probable practices of human sacrifice" at another Michelsberg site, Gougenheim, in Alsace. Several of those whose bodies appeared to have been dumped had severed limbs, and one had traces of burns, suggesting that they had been subjected to rituals. Significantly, the researchers sequenced mtDNA from the teeth of 22 individuals and found differences between those laid deliberately into graves and those thrown in alongside them in "unconventional" positions. "The individuals in the unconventional position had mitochondrial profiles inherited from hunter-gatherers, while those in the conventional position had not," Rivollat says. Because of the small sample size and because mtDNA provides information only about the maternal line, she warns against linking their treatment in death to their ancestry. But the evidence does point to a stratified society that forbade interbreeding between certain strata, she says.

The population of Michelsberg peaked close to 5,700 years ago—when the violence intensified, Gronenborn notes. Neighboring settlements attacked and massacred one another continuously, as reflected in their increasingly elaborate defenses and abandoned settlements, along with spot finds of unceremonious burials of disarticulated human remains. "I picture painted faces, bodies strewn in trees, something not unlike the last scenes of *Apocalypse Now*," he says. At Kapellenberg, a Michelsberg site near Frankfurt, the fortifications—still partially visible today—were raised and reinforced. A stockade was added and later a moat. Then, 5,500 or so years ago, the village these defenses were designed to protect seems to have been abandoned.

APOCALYPSE?

WAS THERE A FINAL, APOCALYPTIC MASSACRE, or did a plague sweep through? It is hard to know, Gronenborn says. Nearly 1,000 years after Kapellenberg was deserted, a new people arrived there and built two ritual mounds. Called the Yamnaya, they came from the steppe in chariots, and the fact that they contributed relatively few X chromosomes to the European gene pool—as Goldberg reported in 2017—suggests that their invasion was overwhelmingly masculine. Researchers, including Kristian Kristiansen, an archaeologist at the University of Gothenburg in Sweden, have found traces of plague DNA in the remains of Yamnaya teeth, leading them to propose in 2018 that the Yamnaya pastoralists laid waste to farming communities by sowing plague among them. They may have done so, Gronenborn says, but archaeological evidence shows that farming communities in central Europe had already been dwindling for 1,000 years by the time the Yamnaya arrived at Kapellenberg. If farmers were in fact declining in number over that time, there must have been other causes—and he thinks violent infighting was one of them.

Before the newcomers made their appearance, did the last of the hunter-gatherers emerge from their hiding places to pick over the farmers' abandoned wealth—their animals, their once vibrant copper trade—and enjoy a new lease on life as forager-herders? It is a theory that Nikitin, for one, favors. There are hints that the hunter-gatherers were still there. In 2013 a group led by paleogeneticist Ruth Bollongino, then at Johannes Gutenberg University in Mainz, reported that as late as 5,000 years ago, hunter-gatherers and farmers who shared the same burial site at the Blätterhöhle cave in Germany maintained distinct ancestral cultures.

These findings point to a stratified society in which little value was attached to the lives of those at the bottom.

That theory, along with many others about what brought the Neolithic to an end, is being tested now as paleogeneticists drill down into Europe's regional genetics at that time and cross-reference their findings with those of archaeologists. However it happened, it is clear that what might have looked like homogeneous farming communities to the marauding Yamnaya concealed a more storied past. With the Yamnaya's arrival, which ushered in the Bronze Age, all the genetic components of modern Europeans were present on the continent for the first time. The people who inhabit it today are a three-way mixture of Mesolithic hunter-gatherer, Neolithic farmer and Bronze Age Yamnaya pastoralist.

The farmers' arrival confirms what we now know about many other periods of prehistory: people have always migrated, borrowed, adapted—and usurped. As Nikitin puts it, "There is nothing static about humanity." SA

MORE TO EXPLORE

The Persistence of Hunting and Gathering: Neolithic Western Temperate and Central Europe. Detlef Gronenborn in *The Oxford Handbook of the Archaeology and Anthropology of Hunter-Gatherers.* Edited by Vicki Cummings et al. Oxford University Press, 2014.

Cheddar Man and Mesolithic Europeans: www.youtube.com/watch?v=0JuK-BApolc

FROM OUR ARCHIVES

How Captives Changed the World. Catherine M. Cameron; December 2017.

scientificamerican.com/magazine/sa

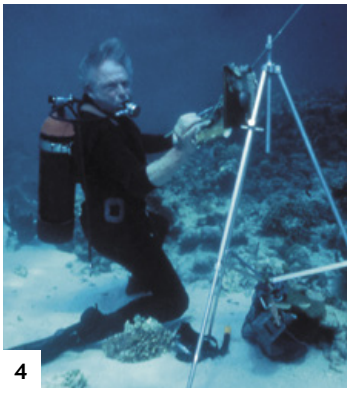
By Andrea Gawrylewski

Stanley Meltzoff: Picture Maker

By Stanley Meltzoff.
The Illustrated Press, 2019 ($44.95)

For the first century of its existence, *Scientific American* was primarily a listing of the latest inventions and patents. But in 1948, the magazine was sold and the new owners wanted to reimagine the publication's mission, hoping to make it more timely and authoritative. As part of this rebranding, they hired freelance artist Stanley Meltzoff to illustrate their covers. A graduate of the Institute of Fine Arts at New York University, Meltzoff had worked as an art director and journalist for an army newspaper during World War II. Afterward he made images for advertising agencies in Manhattan and paperback book covers. His work for *Scientific American*, a total of 65 covers, launched his career as a magazine illustrator, and he went on to create images for *Life*, *National Geographic* and *Argosy*. Meltzoff died in 2006 at age 89.

Meltzoff's paintings, memorialized in this mesmerizing collection, were all done by hand, mostly as oil on board or canvas. He became an avid scuba diver and painted fish and undersea life, which became his most famous artworks. In the autobiography that accompanies the images, Meltzoff adamantly calls himself simply a "picture maker," believing that the practical, photorealistic nature of his work did not qualify as the higher-minded creativity of an "artist." But to examine the images in this collection, it's hard not to feel that he was mistaken.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CELEBRATING 175 YEARS

2

1. *Black Marlin and Two Wahoo*, 1980s. Oil on mounted canvas.
2. *Scientific American* covers (*left to right*): *Photosynthesis*, August 1948; *Insect Metamorphosis*, April 1950; *Fruit Fly and Needle*, October 1949.
3. *Scientific American* cover: *Bird Flight*, April 1952.
4. Stanley Meltzoff poses under the sea, 1969.


3

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).

Are Tech Firms Antiscience?

No, but joining some pro-business groups can make them look that way

By Naomi Oreskes

On April 1 Internet readers were treated to an announcement that appeared to come from Google CEO Sundar Pichai: "Today Google Stops Funding Climate Change Deniers." It explained that Google—the world's preeminent information company—had for many years financed disinformation, but the COVID-19 crisis had made it take stock. Google executives would "stop our funding of organizations that deny or work to block action on climate change."

The Twittersphere lit up as scientists and environmentalists praised the corporate giant for offering the private-sector leadership that has for the most part been missing on this issue. The Web site A Greener Google, where the announcement was published, received more than 100,000 hits, and at least one major news outlet—MarketWatch—reported the story.

Sadly, it was just an April Fools' Day joke staged by the activist group Extinction Rebellion, intended to expose the hypocrisy of companies that boast of green initiatives while supporting institutions that deny or downplay climate science. It was plausible in part because last year more than 1,000 Google employees asked their employer to stop funding these organizations, as have workers at Microsoft, Amazon and Facebook.

Like all good satire, it addressed a real problem. In the past decade Google has contributed to more than a dozen groups that have worked to prevent action on climate change by promoting half-truths, misrepresentations and, sometimes, outright lies about climate research and scientists. These include the Competitive Enterprise Institute (CEI), the Texas Public Policy Foundation and the Cato Institute, all of which have a long paper trail of skepticism, if not outright hostility, toward climate science. CEI has been directly involved in personal attacks on scientists.

So why do large companies fund organizations that attack science? Nearly all leading corporations are part of trade groups that lobby for "pro-business" positions, such as lower taxes, and they typically turn a blind eye to these groups' other activities. Microsoft, for example, participated for years in the American Legislative Exchange Council (ALEC), which describes itself as dedicated to "limited government, free markets and federalism." In 2011 it was revealed that ALEC had lobbied not only for pro-business initiatives but also for antidemocratic ones, such as restrictive voter ID requirements. Over the next few years a bevy of Fortune 500 companies, Microsoft included, began to withdraw support.

Since the New Deal, trade groups have tried to defend the prerogatives of the private sector by claiming that the federal government is a threat to freedom. In the 1980s and 1990s this transmogrified into an attack on science. As Erik Conway and I showed in our 2010 book, *Merchants of Doubt,* trade groups and libertarian think tanks resisted the findings on issues such as acid rain, the hole in the ozone layer, indiscriminate pesticide use and, above all, anthropogenic climate change—because these were problems that *business* created and that *government* was needed to fix. They denied reality to protect their ideology and economic interests.

We saw this on full display in recent months as many American conservatives refused to accept a significant role for government in containing the coronavirus pandemic. An extreme case is the governor of South Dakota. Even as COVID-19 reached her state and hundreds of workers became ill at a meat-packing plant, she refused to implement any form of state control. To be sure, stay-at-home orders *do* decrease personal freedom and hurt the economy. But governments that took early steps to contain the threat have done far better in protecting both personal liberty and their economies. In any case, "freedom" is an empty concept to the dead.

Sam Peinado of Extinction Rebellion told me in an e-mail that many Google employees thought the April Fools' announcement was real because it was "what they expected from their company." And why not? Why shouldn't employees and customers expect corporate leaders in all sectors to disassociate themselves from organizations whose rigid ideologies and pursuit of self-interest have led us into an antiscientific dead end? COVID-19 has proved that denying science protects neither individuals nor the economy. It's time for corporate leaders to step up to the plate and reject the rejection of science. 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.

Denial du Jour

Galileo's fights against science deniers have modern-day analogues

By Steve Mirsky

Galileo could be, let's say, prickly. "Look, he was a genius, and he was a truly unusual person, but he wasn't exactly nice," astrophysicist and author Mario Livio, whose latest book is *Galileo and the Science Deniers,* said by phone. "He was nice to his family, he supported the members of his family … and he had a few extremely good friends. But he could be nasty to his enemies. His sharp pen was just incredible."

The great man shared his lifetime with many people whose understanding, if you can call it that, of the laws of nature was strongly influenced by antiquity's often wrong writers. (You also share your stay on Earth with such individuals.) One such contemporary was a Jesuit priest and scientist named Orazio Grassi, who was known to mix it up in print with Galileo on numerous occasions.

Galileo really didn't like this guy. When he read a Grassi lecture about comets, he wrote margin notes that included *pezzo d'asinaccio* ("piece of utter stupidity"), *bufolaccio* ("buffoon") and *balordone* ("bumbling idiot"). I include the original Italian because, hey, don't be a *jadrool.*

In another work, Grassi, in theorizing about heat, relied on those ancient authors when he claimed that Babylonians could cook eggs by whirling them around at the ends of slings. Livio writes that "Galileo pounced on this fallacy like a cat on a slow mouse." Galileo's retort, written with that aforementioned sharp pen in a work called *The Assayer,* translates to: "If we do not achieve an effect which others formerly achieved, it must be that we lack something in our operation which was the cause of this effect succeeding, and if we lack one thing only, then this alone can be the true cause."

The ball thus teed up, Galileo swings away: "Now we do not lack eggs, or slings, or sturdy fellows to whirl them, and still [the eggs] do not cook, but rather cool down faster if hot. And since we lack nothing except being Babylonian, then being Babylonian is the cause of the egg hardening." You could say this *reductio ad absurdum* left Grassi shelled.

"The more I thought about Galileo and his personality and his fights," Livio told me, "I realized how relevant his fight for intellectual freedom and against science deniers is for today, when we are really facing rampant science denial on many fronts."

Current investigators don't typically have to face the possibility of torture, as Galileo did from the Catholic Church for being "vehemently suspect of heresy." But modern climate researchers, evolutionary biologists and educators are threatened via e-mail and pilloried in social media, sometimes by elected officials.

In 2012 two conservative outlets charged usually respected Penn State climatologist Michael E. Mann with disseminating fraudulent data (and compared him to a pedophile). Mann sued for defamation, and the case is still unresolved. Worse than the personal attacks, of course, is that policy is being made based on nonsense and magical thinking. (I'm writing this in early May. Has the coronavirus just, poof, gone away yet?)

It's an almost comical irony that today's deniers try to assume the mantle of Galileo: people who disagree with the scientific consensus on things such as climate sometimes cite Galileo as a rebel (you know, like themselves) who is now seen as a hero.

"It's really a logical fallacy," Livio said. "Oh, look, here was one who was going against the mainstream, and it turned out to be right; therefore, those few who speak against climate change are right. Galileo was right not because he was one against many—he was right because he was right."

By this point Livio was laughing: "It's not the case now every time that one speaks against the mainstream, he or she is right. Most of the time those people are wrong. In some rare cases, they are right. So to bring that as an argument is just ridiculous." Sadly, two arguments of very different weights can still convince a lot of people at the same rate. SA

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Illustration by Matt Collins

JULY

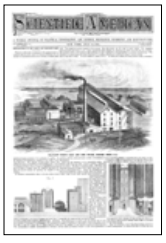
1970 On Nerves and Behavior

"Charles Darwin argued that since man had evolved from lower animals, human behaviors must have parallels in the behaviors of lower forms. Darwin's radical insights stimulated studies of animal behavior, opening the way to experimentation that was not feasible in man. Crayfish, leeches, various insects and snails have the great advantage that their nervous system is made up of relatively few nerve cells (perhaps 10,000 or 100,000 compared with the trillion or so in higher animals). In these animals one can begin to trace, at the level of individual cells, not only the sensory information coming into the nervous system and the motor actions coming out of it but also the total sequence of events that underlies a behavioral response. —Eric R. Kandel"

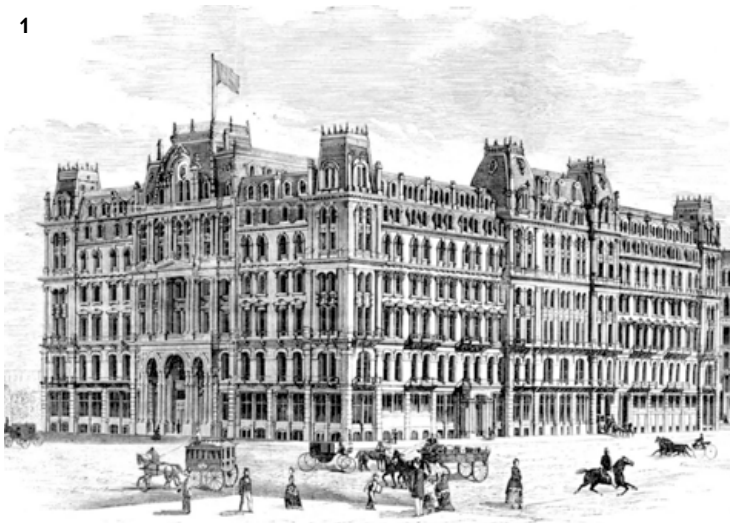
Kandel shared the 2000 Nobel Prize in Physiology or Medicine.

1970

1920



1870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1870: A plan for the Grand Pacific Hotel in Chicago. Construction finished in 1873 in substantially this form. Yet by 1895 the needs of the fast-growing city had eclipsed the need for this once impressive edifice, and much of it was torn down.

1920 A Mineral's Value

"For centuries asbestos was but a curiosity—a mystic mineral paradox, to all appearances a solid rock yet composed of silk-like fibers so rugged in themselves that the millions of years of the earth's cooling, hardening and cracking did not break these slender threads. The almost inestimable economic value of asbestos proceeds from the fact that it possesses such an unparalleled combination of heat- and wear-resisting qualities. The perfection of the heat (and cold) insulations and their application to thousands of America's power plants is saving power and saving fuel—millions of dollars' worth annually."

1870 Debating Darwin

"The Abbe Moigno is a scientific authority and is at the same time a Catholic of unquestioned orthodoxy, which last act adds significance to his publishing in *Les Mondes* the following notes: 'In view of the antagonism developed in some quarters against scientific investigation as tending to infidelity, the expressions of one confessing a faith so conservative, are of interest. The grounds upon which Christian scientific men can stand secure, were admirably stated by Professor Dana in his recent lecture, in which the subject of Darwin's theory was considered. In the course of his remarks he stated that belief in a development theory was not atheism. That the facts of science clearly indicate some plan of development; that Darwin's book was a work of great merit. Let no one fear scientific investigation.'"

SCIENTIFIC AMERICAN, VOL. XXIII, NO. 1; JULY 2, 1870 (1); *SCIENTIFIC AMERICAN*, VOL. 277, NO. 6; DECEMBER 1997 (2)

2

EPIC TALES

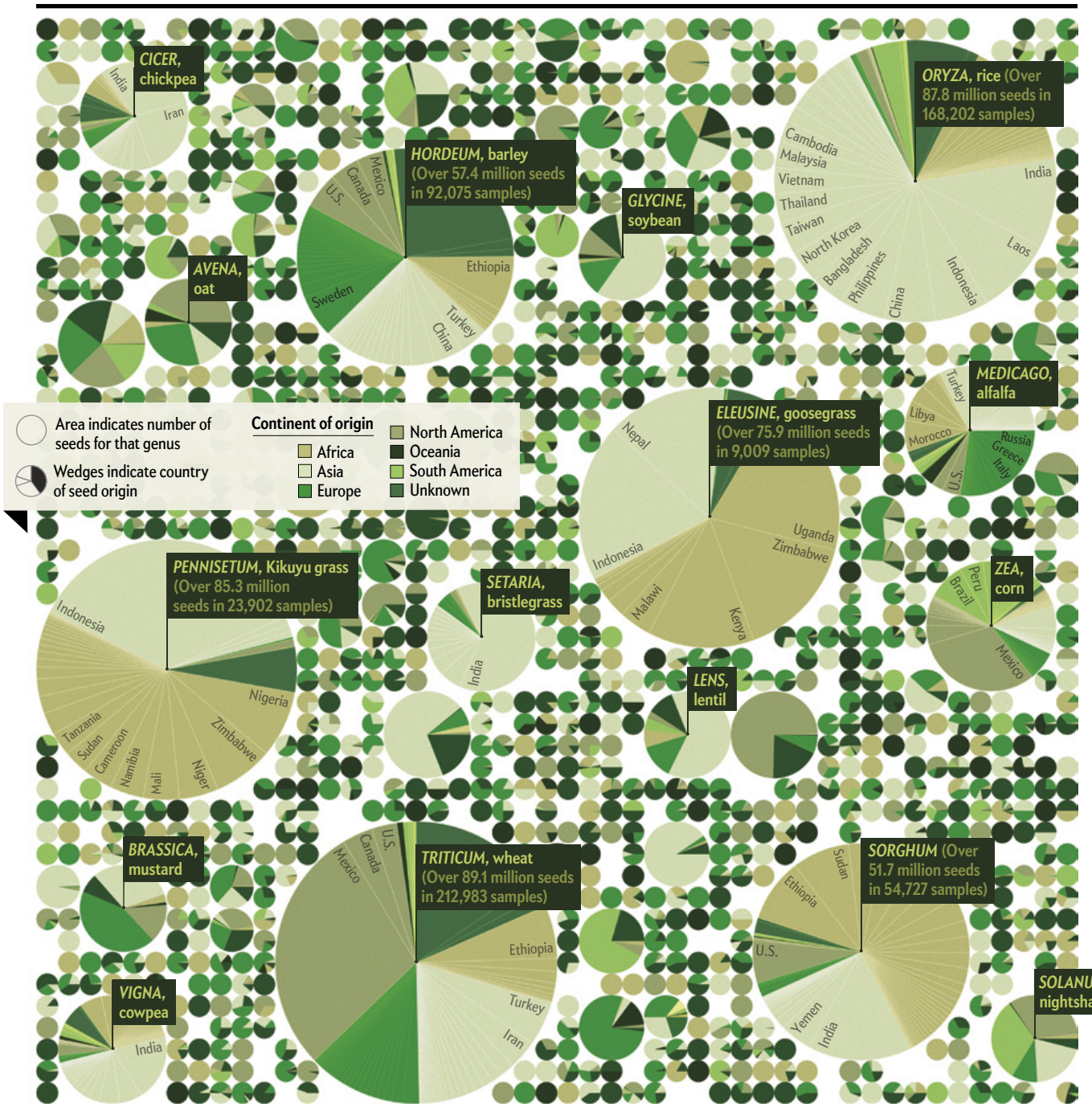
CELEBRATING 175 YEARS

Monumental Buildings

Social cohesion enables people to produce physical testaments to individuals, events or organizations. Humans apparently have a bit of an ego problem, having littered the planet with these—occasionally very beautiful—monumental structures. It is true that more advanced engineering can show off the builder's (and owner's) sophistication, although it must also be noted that accumulating the resources to build on a grand scale is too often the result of inequality within the society, if not the handiwork of enslaved people (and we'll skip over the gory bits of the Colosseum in Rome, shall we?). Still, every great structure is eventually eclipsed by something more glorious or more technically challenging.—*D.S.*

1997: One of the Petronas Twin Towers in Kuala Lumpur, Malaysia, seen under construction. The towers were the tallest in the world from 1998 to 2004.

Text by Mark Fischetti | Graphic by Accurat (Giovanni Magni, Stefania Guerra, Antonella Autuori and Luca Mattiazzi)



SOURCE: SVALBARD GLOBAL SEED VAULT

One Million Seed Types

A frozen, Arctic vault now has samples from nearly every country on earth

The Svalbard Global Seed Vault recently received seeds from 33 countries, pushing the total number of samples stored there to 1.05 million. Each sample is a pouch of seeds belonging to one genotype; pouches sit on shelves in large rooms carved from solid rock 100 meters inside a mountain covered by permafrost and ice on Spitsbergen island far north of Norway. Some 87 gene banks use the vault to store duplicates of seeds from numerous countries and First Peoples that are important to crops and rangeland grasses, their wild relatives, and experimental species from breeders that might improve plant yield or resilience—primarily to back up food supply against threats from climate change and biodiversity loss. The frozen ground keeps the vault at –3 degrees Celsius; cooling systems deepen the chill to –18 degrees C.

Unique species in the vault: **more than 5,000**
One seed sample: **300–500 seeds or more**
Depositors: **87 gene banks worldwide**

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