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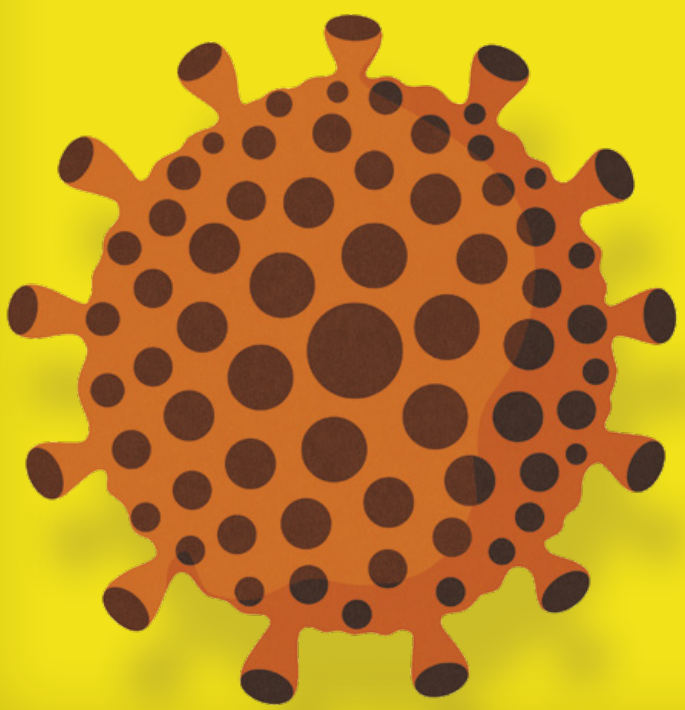
Cosmological Mystery

Testosterone Discrimination

COVID Smell Loss Explained

REALITY CHECK

Four urgent science priorities for the new president



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YURI SMITYUK TASS via Getty Images

ON THE COVER
The new American president taking office in January faces a host of urgent problems, the still raging COVID-19 pandemic being only the most obvious. This month's special report is about the science-based solutions that the Biden administration can begin implementing right away.
Illustration by Egle Plytnikaite.

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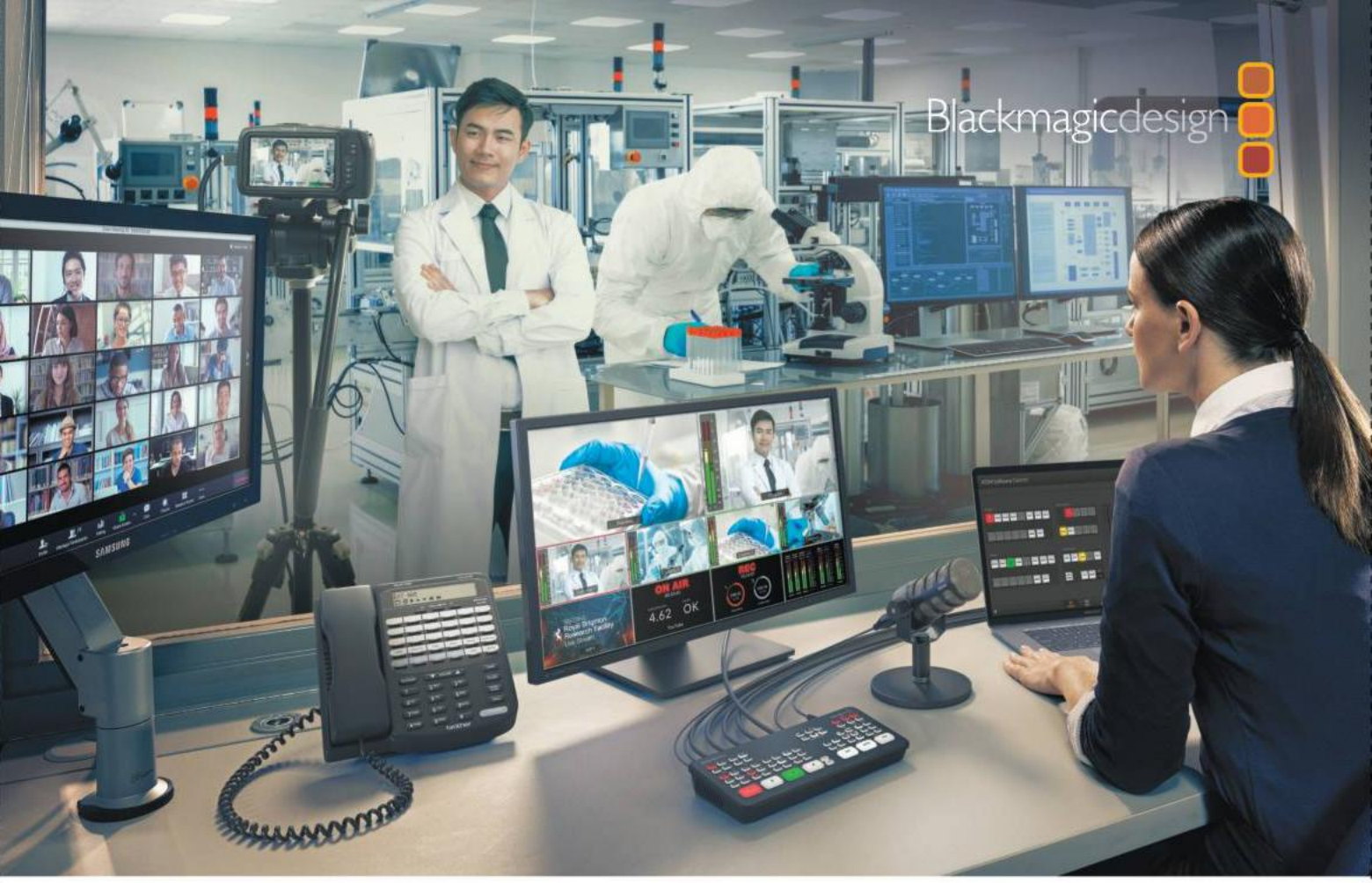

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Create Training and Educational Videos

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

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Live Stream Training and Conferences

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

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

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Blackmagicdesign

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

Zombies and Conundrums

When science is taught in school, it's usually presented as a logical sequence of hypotheses and experimentation. One delightful surprise when you start learning more about the process of science is that it's unpredictable, messy and weird. Some scientists prefer to highlight ways their research worked as expected—but it's a much better story when a scientist tells you everything that was spectacularly strange. Starting on page 42, neurobiologist Kenneth C. Catania explains how a parasitic wasp turns its cockroach prey into a zombie, how the cockroach tries to protect itself from the precision attack, and how the process of studying this conflict became more improvisational and goofy with every discovery. It's appropriate that the wonderful graphic by Matthew Twombly depicting this Battle of the Bugs looks like it's from a comic book.

The more we've learned about the universe in the past 175 years since *Scientific American* was founded, the more mysteries and conundrums we've faced. One of the biggest puzzles right now has to do with three interrelated concepts: vacuum energy (which describes the stuff in otherwise empty space), dark energy (which is pushing the expansion of the universe) and the cosmological constant (Einstein's fix for making the math of relativity work out). The so-called cosmological constant problem is "generally regarded as one of the most awkward, embarrassing, difficult problems in theoretical physics today," physicist Antonio Padilla tells senior editor Clara Moskowitz, who on page 24 guides us expertly through the stubborn challenge of accounting for the state of the universe.

The private space industry is growing quickly, with a lot of experimentation but not a lot of regulation, and to aerospace scientist Martin N. Ross and space journalist Leonard David, it can apply lessons from the early days of commercial aviation. On page 56, they point out the problems with exhaust, particulates and other emissions from rocket launches and argue that the industry will be more successful and sustainable if it controls pollution immediately.

When (and if) the postponed Summer Olympics are held in Tokyo this year, some of the world's best athletes will be prohibited from competing because of their natural levels of testosterone. The Court of Arbitration for Sport claimed that science underpinned its recent decision to require athletes to suppress their hormone levels if they want to compete in certain women's events. Neuroscientist Grace Huckins shows why there's little science to support this form of discrimination (*page 50*).

Muddy Waters and Chrissie Hynde, among other musicians, have played guitars made of "swamp ash," a lightweight wood that grows in Mississippi River lowlands and gives a warm, clear sound. Lately seasonal flooding exacerbated by climate change, as well as an invasive beetle, has threatened these trees. Guitar makers are adapting, reports Priyanka Runwal (*page 64*), but it's another example of how climate change is disrupting basically everything.

As Joe Biden and Kamala Harris take office, they have many problems to solve, and some of the most urgent involve science: climate change, the COVID pandemic, misinformation and mistrust, and rebuilding the science capacity in the federal government. *Scientific American* editors Andrea Thompson, Tanya Lewis and Jen Schwartz, respectively, take on the first three issues, beginning on page 30. A former head of the National Oceanic and Atmospheric Administration, Jane Lubchenco, recounts her experiences with Biden when he was vice president and shares some excellent advice about how he can use science to make the country better.

One of the strangest symptoms of COVID is persistent loss of smell and taste. There's some good news—the virus isn't invading the brain, as people worried at first. Damaged cells in the nose can recover, although the returning sense of smell can sometimes be distorted. For one poor patient, everything tasted like window cleaner. It's one more reason to be careful out there and try to avoid this dreadful virus. Be well. SA

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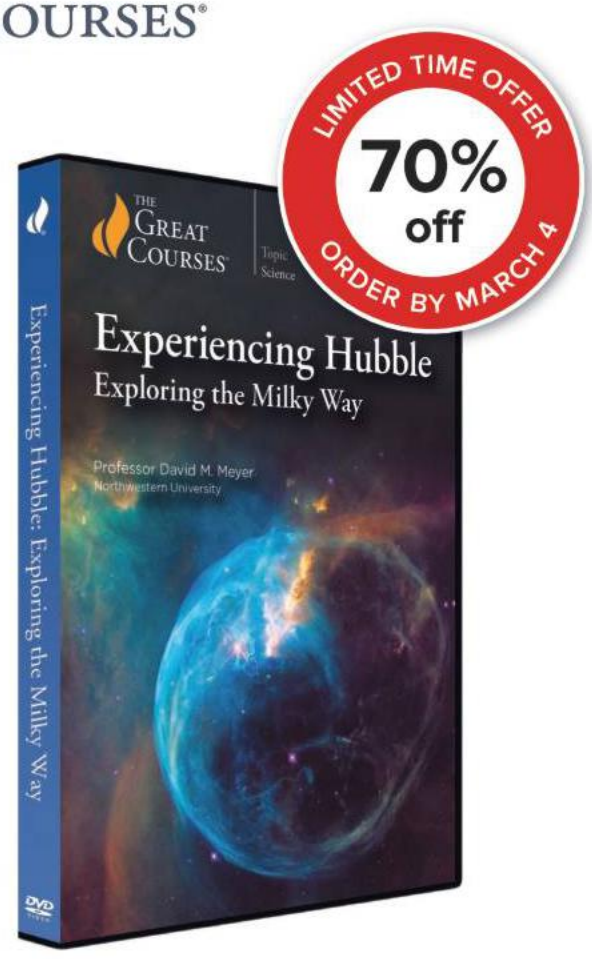

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October 2020

POLITICAL NECESSITY

I do not think *Scientific American* should have endorsed Joe Biden for U.S. president in "From Fear to Hope" [Science Agenda]. I do strongly dislike Donald Trump as a president and understand and share the editors' frustration with a leader whose focus is not on being scientifically correct but on being politically viable. The U.S. will be a better place without his reelection. Yet 175 years of political neutrality should have been more jealously protected. Losing it further divides the country. Trump's supporters will conclude that *Scientific American* is unfairly partisan. If there are no institutions where those supporters and detractors can interact without reminders of their differences, both sides will self-segregate. And unnecessarily ostracizing Trump's supporters amplifies the cohesiveness of his base.

Brendan Rafferty *Philadelphia*

As far back as I can remember, my father was an avid reader of your magazine, although he allowed his subscription to lapse a few years ago. Dad has always been conservative. I never have been. We have fun coming up with arguments to convince each other.

It is confounding how so many otherwise intelligent people stubbornly continue to support our so-called president, no matter how much science he dismisses. I suspect Dad began consuming conservative media. Alarmingly, he trusts just about anything it tells him.

When you issued your first endorsement ever for a political candidate, I forwarded the announcement to my father. He soon called and sounded a bit shaken. Thanks to your bold choice to support Biden, Trump got one fewer vote in Arizona. Thank you, thank you, thank you. The world seems a little brighter now.

Rebecca Thompson
South Pasadena, Calif.

"Thanks to your bold choice to support Biden, Trump got one fewer vote in Arizona. The world seems a little brighter now."

Rebecca Thompson *South Pasadena, Calif.*

In one fell swoop, you trashed an admirable tradition of political neutrality and became a propaganda agent of the progressive movement. The willingness of the editors to break that 175-year policy indicates they are not just biased but obsessed with progressive political views.

Richard Grumm *Arcadia, Calif.*

I am thankful that you stepped away from your norm of not endorsing a political figure because you realized that it was critical for us to understand the significance of this year's election. As a physician with both an M.D. and a Ph.D. in biophysics, I would hope that a majority of those in science and medicine already came to the same conclusions, but this was a wonderful summary of the important points. Sometimes it is critical to take a different path so that what is obvious to some may become obvious to most.

Robert Hootkins *Georgetown, Tex.*

THE EDITORS REPLY: We received hundreds of letters expressing strong approval or dismay in response to our decision to endorse Joe Biden. It was not made lightly. This was an extraordinary election, with a clear choice between a candidate who supports science and evidence and one who has consistently rejected it to promote dangerous policies that hurt people. We hope we will not find it necessary to endorse a political candidate again. But we do intend to be even more engaged in the most urgent social issues of the day.

INTERSTELLAR VISITOR

In "Interstellar Interlopers," David Jewitt and Amaya Moro-Martín write that the shape of 1I/'Oumuamua, the first interstellar object ever observed, was inferred from its light curve, or the plot of how the sunlight it reflected to Earth changed. But could that light curve have instead been produced by a more rounded object with a nonuniform albedo? Are there known or hypothesized mechanisms that could leave an asteroid significantly more reflective on one side than the other?

Martin Schulman *Herndon, Va.*

Reading the article, I was reminded of author Larry Niven's 1966 science-fiction story "Neutron Star." Have astronomers considered tidal forces as a possible explanation for 'Oumuamua's elongated shape? Could it first have become plastic from the heat from a close encounter with a gravitationally dense object and then passed near enough to a body such as a neutron star for the tidal effects of the strong gravitational field to stretch it out?

Dan Graifer *Fairfax, Va.*

THE AUTHORS REPLY: Schulman's suggestion is possible, but based on observations of thousands of solar system asteroids, we think it's unlikely. While small albedo differences do exist on asteroids, they are typically variations of a few percent, not 1,000 percent. Only Saturn's moon Iapetus has very different albedos from one side to the other, and that is a special case likely caused by pollution from another moon hitting a single side of the body. In interstellar space, all sides of 'Oumuamua would be bathed uniformly in starlight and cosmic rays, and it is hard to see why any asymmetry would exist.

Interestingly, an idea like Graifer's was suggested by researchers Yun Zhang and

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Douglas N. C. Lin in the September 2020 issue of Nature Astronomy. *They posited that a planet passing close to a dense star could be shredded and stretched into pieces, one of which became 'Oumuamua. This scenario would require a close approach to the star but not so close as to vaporize all the water ice, which would be needed to supply the nongravitational acceleration detected in 'Oumuamua. As with all such speculative models, the question is "How can it be tested?"*

STOPPING SYSTEMIC DISCRIMINATION

I could not agree more with Naomi Oreskes's conclusions in "Sexism and Racism Persist in Science" [Observatory]. I am a retired part-time professor who taught chemical engineering, materials science and engineering science for 13 years. Many of my best students in these difficult and demanding classes were women and people of color. I have no doubt that we are not utilizing such individuals of talent in the sciences and engineering. I strongly believe that these fields should be free of sexism and racism and that our country will be better served if we spend more time and effort in encouraging scientific talent free of such discrimination.

A. G. Tobin *via e-mail*

SIRI, CAN YOU HEAR ME?

"Siri Is a Biased Listener," by Claudia Lopez-Lloreda [Forum], notes that speech-recognition software more frequently misunderstands people who do not have a "standard" accent. Programs such as Siri share the problem with many of us who have high-frequency hearing loss. Because spoken consonants are mostly high-frequency sounds in the range where we have reduced hearing, we depend more on vowels to understand a speaker. But differences in accents occur mainly in vowel sounds, which makes unfamiliar ones much more difficult for us to understand.

Hearing aids can compensate for this issue by enhancing the high-frequency sounds we hear. I wonder if they could also broaden the vowel frequencies. A similar enhancement of Siri's listening apparatus might help ameliorate its listening bias.

Edgar W. Mills *Chateaugay, N.Y.*

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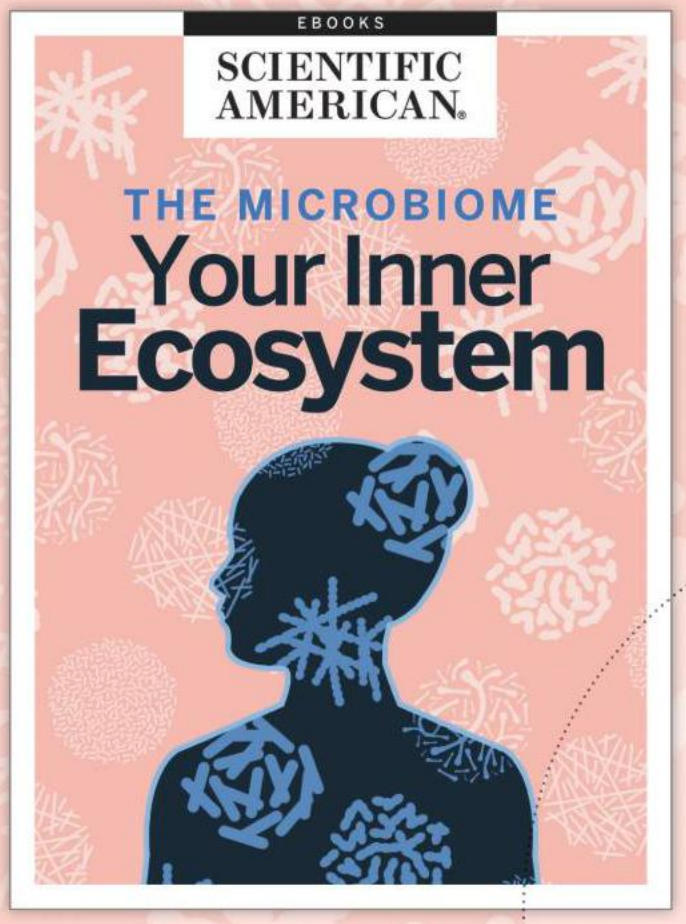

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A Psychological First Aid Kit

Simple skills might ease a COVID mental health crisis

By the Editors

As soon as Joe Biden was elected U.S. president, he made his priorities clear by appointing a panel of distinguished experts to advise him on the coronavirus pandemic. The panel has members who can help the new administration organize vaccine distribution to millions of people and help millions of others who need to be protected until they can get the vaccine. These experts will certainly weigh in on preventive strategies to minimize the likelihood of infection and advise on treatments that can reduce the severity of the disease in those who get sick.

But there is also a need to address a related problem. For months a mental health crisis has accompanied the misery brought on by COVID-19. The U.S. Centers for Disease Control and Prevention reported in August that symptoms of anxiety had tripled and depression symptoms had quadrupled among a group of 5,470 adults as compared with a survey sample from 2019. Meanwhile mental health services have been stretched worldwide. One reason is that mental health personnel and the facilities they work in have been reassigned to COVID-related tasks during the crisis.

All of us need to sustain and enhance our psychological resilience to weather the daily toll of activity restrictions, rising case numbers, hospitalizations and deaths. A set of simple measures known as psychological first aid or mental health first aid can enable people to help family, friends and others in their communities who experience psychological distress from pandemic fatigue, COVID convalescence, or the loss of a friend or relative.

These techniques allow people to become mental health first responders. An analogy to a Red Cross first aid course is apt: both teach trainees what to do when arriving first at the scene—and also flag actions to be avoided. A physical first-aider tries to stabilize the patient; with psychological first aid, a key goal is to restore a person's sense of safety. If someone is terrified that ordinary (and mental health–building) activities such as going outside are fraught with danger, for example, the responder might mention that air currents and sunlight reduce the risk of becoming ill, offering reassurance that being outdoors during a pandemic could be less hazardous than remaining isolated inside.

What the responder does *not* say is equally important. When dealing with a person suffering from a panic attack because of a recent trauma, the first-aider might discourage conversation about the details of the event to avoid reinforcing the memory. Other items on a to-do list might include promoting a feeling of "self-efficacy," or confidence that the person in crisis has the capability to cope with the situation at hand, such as meeting basic needs for food and shelter and establishing contact with family or a mental health professional as needed.

Psychological first aid was used during the SARS and Ebola epidemics. Social service agencies at every level of government and the nonprofit sector should provide more support now for first aid for the psyche because the need has exploded as a result of COVID. Before its arrival, most psychological first aid students at the Institute for Disaster Mental Health at the State University of New York at New Paltz were public safety and health-care workers. But in recent months instructors have taught librarians, who have become frequent confidantes to patrons experiencing extreme stress.

One trainer in the town of Marshfield, England, offered anyone who lives or works there free four-hour courses in mental health first aid because of the prevalence of pandemic-related distress. Mental health first aid is slightly different from psychological first aid because it is targeted at people experiencing issues even before a crisis erupts. The method, created by two educators in Australia, has been taught to 3.6 percent of that nation's 25 million citizens—and its inventors are eager to reach 10 percent, which would match or exceed the country's first aid trainees for physical injuries.

Biden's coronavirus task force needs to do its part by taking into account the mental pain from pandemic fatigue as it devises a national plan for COVID-19. It should recognize that modest but readily achievable efforts such as teaching psychological first aid and other forms of resilience training may have a big impact over a short time. But you may not have to wait on the new administration or your local government. Psychological first aid is accessible now—people can learn it online for free through a Coursera curriculum developed by the Johns Hopkins Center for Public Health Preparedness. Everyone should take it. SA

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Michael Nguyen-Truong is a Ph.D. student at Colorado State University.

Anti-Asian Racism in Science

It existed before the pandemic, but COVID has made it worse

By Michael Nguyen-Truong

Last summer some people posted a listing for a fake Asian restaurant near my university on Google Maps and Instagram, with a name insulting to Asians and a menu that included horrible-sounding items such as "mouse tail salad" and "marinated ostrich foreheads." The fake name, menu and reviews—even if they were intended as a joke—were all despicable examples of anti-Asian racism that has always been present in the U.S. and has been brought to the forefront amid the COVID outbreak.

Such behavior creates a hostile environment for researchers of Asian ancestry such as myself. It turned out that the Instagram account was linked to students who are predominantly from my college. Knowing that my fellow students have such offensive views has heightened my anxiety, which surfaced early in the pandemic.

Because the disease was first reported in China, I have had to struggle with growing bigotry toward Asians in addition to avoiding the virus itself. There have been many reports about Asians facing verbal and physical attacks, fueled by disturbingly common terms like "Chinese virus" and "kung flu," hate-inspiring language frequently used by Donald Trump and others. A recent Pew Research Center survey found that Asian-Americans report a higher level of negative experiences, including racist jokes and slurs or feeling fear of threats or physical attacks, than Black, Hispanic or white respondents in a survey conducted after the pandemic began. Moreover, a recent Stop Asian American Pacific Islander (AAPI) Hate National Report by the Asian Pacific Policy and Planning Council found more than 2,500 reports of anti-Asian incidents across 47 states in a five-month period (from March to August 2020). Of these, 70 percent involved verbal harassment, and 9 percent of them were physical assaults. More undoubtedly go unreported.

When news of these attacks became public, my family and friends warned me to be alert and careful when I was anywhere outside my home. At the beginning of the pandemic, mask wearing was not required, but to protect people and myself against the spread of the coronavirus, it was something I wanted to do in our laboratory and around campus. But I didn't, because I was told that co-workers and colleagues might avoid or harass me. My family and friends cautioned me not to stay out late and to avoid sparsely populated areas on campus; they and I worried other people might hurt me because I was Asian. I ended up going home early most days, shortening my time for experiments and work.

I endured these limitations because of the xenophobia toward Asians worldwide, but the heightened anxiety became burdensome and made research (as well as nonresearch and leisure activities) more difficult. And I kept quiet about my concerns around the lab because I thought that speaking up could make me a target of jokes among colleagues and lead to alienation and loss of collaboration.

These concerns were magnified because I had faced frequent microaggressions even before the outbreak, such as being asked about where I am "originally from," although I am from the U.S., or if I was related to someone because we shared a common name. Non-Asians too often presume—and say—that my Asian peers and I are pursuing STEM careers because we were forced to by our families. Asians are also often (inaccurately) viewed as the model minority and falsely thought not to suffer from discrimination.

I am thankful that my institution and college have condemned racist behavior. They have contacted Google and Instagram to remove the fake restaurant listing; have expressed concern and willingness to take action against racism; and are holding journal club discussions and diversity symposiums about race. I deeply appreciate these efforts and the care taken to create a more inclusive and safe space. Institutions in general should require bias training and should develop spaces such as "life issues" groups (my department has one), journal clubs and symposia designed to educate the community about racism. Faculty and administration should welcome discussions about race issues and be more transparent in addressing them. I also think that social media campaigns by institutions have the potential to raise awareness and educate others.

We have a lot of work ahead of us, but inclusion and positive change within our institutions and in STEM are achievable if we unite against racism. Greater inclusion will lead to more sharing of ideas that will help science, technology and medicine flourish, at a time when we dearly need them. SA

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ADVANCES

Solar-thermal technologies could process seawater and groundwater to make it drinkable at less cost.

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INSIDE

WARREN KEELAN

TECH

Solar Water

A new generation of tech uses heat from the sun to provide clean, salt-free water

In an increasingly hot and crowded world, clean water is becoming a precious commodity. Two thirds of the global population will have problems accessing fresh water by 2025, and removing salt and contaminants from the oceans and groundwater is one way to slake humanity's thirst.

Today's large desalination plants, though, cost millions of dollars to build. Most use reverse osmosis, which forces seawater through salt-blocking membranes. The required electricity accounts for up to half of a plant's expenses, and the process leaves behind a supersalty, chemical-laced soup that can harm local ecosystems. Such facilities are typically powered by carbon-emitting fossil fuels; efforts have been made (especially in the Middle East, Asia and Africa) to use solar panels instead, but that also comes at a cost and does not address the toxic discharge.

So researchers are trying to use the sun's heat more directly to remove salt and other contaminants. The simplest option is to let water evaporate, leaving behind salts and chemicals, and then condense the vapor

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into clean water. Humans have used versions of this technique, called solar distillation, for hundreds of years. Today Saudi Arabian engineers plan to build a plant with giant mirrors that concentrate sunlight and superheat water within a steel-and-glass dome more than 50 meters across.

But by using novel materials and designs, researchers are trying to make the process cheaper, simpler and portable enough to make high-quality desalination far more accessible worldwide. "The needs for clean water in developing countries are enormous," says Naomi Halas, an electrical and computer engineer at Rice University. "Solar-thermal technologies should allow you to lower the energy needs of desalination but also to do it in remote locations where you are completely off the grid."

The U.S. Department of Energy will soon announce semifinalists for its Solar Desalination Prize. The goal: a system that produces 1,000 liters of usable water for $1.50. "No technology today can handle high-salinity water at these costs," says Qilin Li, a civil and environmental engineer at Rice.

Such systems could surmount a big downside of reverse osmosis: it typically desalinates only half of the input saltwater, and the solution left behind eventually builds up enough salt to clog the membrane, says Craig Turchi of the DOE's National Renewable Energy Laboratory (NREL). This noxious by-product, called a brine, is typically dumped into the ocean or injected underground. Solar-thermal desalination systems can purify water with salt concentrations at least twice that of seawater. This would include brines from reverse osmosis plants and brackish groundwater from places such as the U.S. Southwest, as well as some industrial and agricultural wastes that reverse osmosis cannot handle, says NREL spokesperson Meghan Hughes: "Generally, only thermally driven technologies, like the ones we're working to develop through this program, can treat these highly concentrated brines."

Li, Halas and their colleagues have built a solar desalination device with a porous plastic membrane that lets water vapor through but not liquid. One side of it is coated with tiny carbon particles that heat up in the sun, vaporizing the salty water as it contacts them. This vapor passes through and condenses as clean water on the membrane's other side. Halas's group recently boosted the system's efficiency by 50 percent by using plastic lenses to focus sunlight on the membrane, producing more heat.

The team's calculations show that meeting the DOE's cost target, with a square-meter-sized device that produces up to 20 liters of water an hour, should be possible in a few years. "We're at the Ford Model T stage—not the Mustang stage yet," Halas says. "But it's good enough that we're starting to get commercial interest."

Civil and environmental engineer David Jassby's group at the University of California, Los Angeles, integrated heat-conducting materials into the membrane in a similar setup. Underneath it, the researchers added a fine aluminum mesh that heats up in sunlight. "So you can

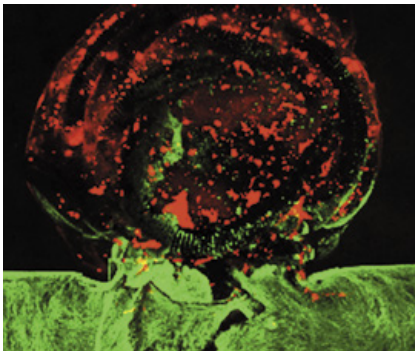
HEALTH

Aneurysm in a Dish

Scientists operate on a 3-D-printed model of a ballooning blood vessel

Brain aneurysms, which affect as many as one in 50 people, occur when a blood vessel wall weakens and bulges, setting the scene for a potentially deadly rupture. Now scientists have created a 3-D-printed aneurysm model in the laboratory and "operated" on it: they inserted a device to seal it off and prevent it from bursting. Such models could be tailored to replicate an individual patient's blood vessel, letting doctors try different treatments and find the best solution.

To treat an aneurysm, brain surgeons sometimes operate to install a metal clip on the ballooning vessel that prevents the pooling of blood. A less invasive method involves inserting tiny metal coils into the aneurysm via a catheter to induce a blood clot that seals it off. Most treatment devices are tested in animals, whose blood vessels do not perfectly resemble those in humans. And previous lab-dish aneurysms could not mimic the properties of living blood vessels. "We thought maybe there could be a better way of testing those [treatment] devices," says Lindy Jang, a biomedical engineering graduate student at Texas A&M University, who led the new study, published in *Biofabrication*.



An induced blood clot (*red balloon*) is visible in a 3-D-printed model of a brain aneurysm.

ELISA WASSON *Lawrence Livermore Laboratory*

Jang and her colleagues 3-D-printed an aneurysm structure with a water-based gel and populated it with human cells that line the brain's blood vessels. They then operated on the aneurysm, injecting platinum coils into the bulging vessel. Finally, they filled the blood vessel with plasma (the liquid component of blood), which formed a clot that sealed off the bulge.

"We're trying to streamline the treatment of aneurysms and take the guesswork out," says William "Rick" Hynes, a study co-author and biofabrication research engineer at Lawrence Livermore National Laboratory who performed the surgery. "The goal is to use these devices to validate models so someone could take a 3-D scan, recreate it in the simulation, then try adding [blood] flow and determine if they need to treat the aneurysm or leave it alone."

"I think it's really significant," Matthew Gounis, a biomedical engineer at the University of Massachusetts Medical School, says of the new model. Other groups have developed aneurysm models, but this one is exciting because it better replicates a human blood vessel by adding living cells, says Gounis, who was not involved in the new study. Surgeons could practice on such models before operating on a real patient, he says: "If you have a particularly challenging case, you can print out the case, and you can basically practice before you get to the patient, in their anatomy." —*Tanya Lewis*

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roll the membrane into spiral modules because you don't have to have large surface areas directly exposed to the sun," he says. In rooftop tests, the device produced eight liters of fresh water per square meter of membrane in an hour.

Wang's team boosts its device's efficiency by "reusing energy over and over," Zhang says. It includes 10 stages, each a nylon frame holding a black sun-absorbing layer, a paper towel and an aluminum film. When heated, the black layer evaporates salty water as it wicks up into the paper towel, and the vapor condenses on the aluminum. Condensation releases heat, which rises to the next paper towel layer and aids evaporation instead of being lost. The $100 setup yields almost six liters an hour in the lab and about half of that outdoors; with more sophisticated materials and stages, Zhang says, the efficiency could be doubled.

"Solar-thermal technologies should allow you to lower the energy needs of desalination [and] to do it in more locations where you are completely off the grid." —**Naomi Halas *Rice University***

Such systems could lend themselves to compact units suitable for off-grid villages in Asia and Africa, communities with brackish groundwater, and emergency uses almost anywhere. But they will need to pick up the pace and convert more solar heat into vapor, says Lenan Zhang, a graduate student in mechanical engineer Evelyn Wang's laboratory at the Massachusetts Institute of Technology.

Another intriguing approach takes advantage of humidification by passing air through a saltwater spray. "Air absorbs the water and leaves behind solid salts," says Oregon State University mechanical engineer Bahman Abbasi. His system uses solar radiation to heat, compress and eject a mix of saltwater and air through nozzles at high speed, thereby creating a vortex that pushes salts and other solids to the device's walls as the humidified air rises for collection and condensation. Abbasi says the backpack-sized device can clean water with salinity up to three times higher than that of seawater and produce about 20 liters an hour.

All these relatively low-cost technologies could unlock new markets for portable water cleaners or off-grid uses—and beyond. They may eventually lead to large-scale solar-thermal systems to provide cities with drinking water, Turchi says. For now they "will complement reverse osmosis and be a key player in niche applications where reverse osmosis may not work." —*Prachi Patel*

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ECOLOGY

A New Wrinkle

Researchers identify an intriguing insect-defense mechanism in leaves

A drop of beeswax affixes a sensor to a beetle tasked with navigating a silicone leaf surface.

FROM "SPATIO-TEMPORAL DEVELOPMENT OF CUTICULAR RIDGES ON LEAF SURFACES OF *HEVEA BRASILIENSIS* ALTERS INSECT ATTACHMENT," BY VENKATA A. SURAPANENI ET AL., IN *ROYAL SOCIETY OPEN SCIENCE*; NOVEMBER 4, 2020 (*https://doi.org/10.1098/rsos.201319*)

Plants have evolved an impressive range of strategies to ward off hungry, leaf-chomping insects. Well-known defenses include foul-tasting toxins, sticky resins and sharp thorns, and now scientists have identified yet another example: microscopic wrinkles that make leaves harder to walk on.

Wrinkles form in many leaves' cuticles—coatings that limit water evaporation, mediate gas exchange, and protect the plant from pathogens. The new research, published in *Royal Society Open Science*, finds that along with the cuticle's inherently slippery surface, its tiny wrinkles also help discourage insects. The wrinkles most likely become more pronounced as the leaf matures and its cuticle builds up, eventually expanding and buckling.

"Plants are really good at surviving," says Dana MacGregor, a molecular botanist at Rothamsted Research in England, who was not involved in the new study. "There are excellent ways by which they can change their structure, their chemistry or their physiology to hinder herbivores from eating their leaves. This is another example of plants changing their shape to make sure they survive."

For the experiment, the researchers created silicone replicas of leaves from a rubber tree at various stages of development. This step let them measure the effects of the leaf's structural properties alone—without the slippery influence of the cuticle's waxy coating.

The scientists fastened minuscule sensors to the hard forewings of eight Colorado potato beetles, then measured the traction forces as the insects meandered along a synthetic leaf; the beetles walked more easily on the "younger" and smoother replicas but slipped on the "older" ones' wrinkles.

"We were surprised by the way such wrinkles developed on plant leaves, and the significant effect they had on insect attachment at different growth stages," says Venkata A. Surapaneni, a biomechanist at the University of Freiburg in Germany and lead author on the study. Surapaneni, who is a part of a multicenter research program called PlaMatSu, is interested in developing polymers that mimic these microscopic wrinkles to produce insect-deterring surfaces. And maybe, he says, plants could be bred or engineered to have more wrinkles, possibly paving the way for reducing pesticide use in agriculture.

—Monique Brouillette

PSYCHOLOGY

Impact, Inc.

Messaging matters in motivating diverse entrepreneurs

Leadership in the tech industry continues to lack diverse voices, but new research suggests that a simple shift in recruitment messaging could attract a greater variety of entrepreneurs. A study, published in *Management Science*, shows how altering descriptions of funding opportunities might draw in more women, as well as more socially minded business pioneers.

The project targeted potential applicants to the Massachusetts Institute of Technology's Inclusive Innovation Challenge (IIC), a worldwide competition that awards money and other support to small tech companies with strong growth potential. The researchers invited 13,000 founders to register. Some of these e-mailed invitations emphasized cash, with the subject line beginning "More Than $1.6 Million in Prize Money…" Others focused on social impact, with the line "Create Greater Shared Prosperity…"; still others used neutral phrasing. The researchers counted how many times people clicked on links in the e-mail and subsequently on IIC page links.

Men clicked about 55 percent more times total when presented with a money message than a social one, whereas women clicked about 46 percent more times with the socially motivated wording—an unexpectedly big effect, says study co-author Jorge Guzman, a Columbia Business School researcher. Neutral messages performed similarly to money messages. The researchers also noticed a location-based pattern: in countries and U.S. states where residents had previously been found more likely to say they would make charitable donations, the respondents proved more motivated by the social message than the one emphasizing money.

In an 800-person subset of the first group, gender and location were similarly associated with patterns in who ultimately applied for the IIC competition. "You see that by this simple messaging, you can increase people's submitting," says University of Massachusetts Amherst economist Ina Ganguli, who was not involved in the study. "I think that's really impressive."

Guzman says targeted messaging is important, whether recruiting entrepreneurs for competitions or teaching students at business school; although the study examined motivations among founders of existing companies, Guzman says would-be entrepreneurs would likely follow similar patterns. Future research, he adds, might look at combining directives: "Get rich *and* save the world!"

—Matthew Hutson

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BIOLOGY

Snake Eyes

Scientists examine how certain snakes "see" in the dark

Some snakes, including pit vipers and pythons, are known to hunt in the dark by sensing the heat their prey radiates. But how do snakes convert this warmth into the thermal images they "see"? A model proposed by University of Houston and Rutgers University researchers suggests a potential answer. Their paper, published in *Matter,* may also help in developing soft artificial materials that convert heat to electricity, useful for applications such as sensors and energy harvesting.

The snakes' pit organ—a vase-shaped indentation with a thin membrane stretched across it, positioned near each nostril—seems to act like a thermal "eye." The organ is exquisitely sensitive and detects animals about 40 centimeters away within half a second in pitch darkness. Biologists had previously identified channels for conducting charged ions, activated by temperature changes, in the membrane's nerve fibers. Scientists knew this membrane heats up very rapidly, but it was still unclear how thermal variations in the pit organ became electric signals that travel to the brain.

"Pyroelectric materials, which convert heat to electricity, do exist in nature. But they're rare, and they're hard crystals; no such crystals have been found in snakes," says Pradeep Sharma, a mechanical engineer at the University of Houston and co-author of the paper. "What we show is that soft materials like biological cells can also act as weak pyroelectrics under some special circumstances."

Sharma and his team developed a mathematical model to show how static charges would move in a material that is deformable and responsive to heat. They modeled the pit membrane as a film that is made up of such a material and that thickens if heated. Most biological cells (including those that make up the real membrane) naturally generate a small electric voltage across their outer surface. The researchers found that when the membrane thickens, the charges on its cells should shift slightly, resulting in a voltage change that can be picked up by nerve cells.

They tested this theoretical model with real-world values, and found that it corresponded with how quickly real snakes can detect prey—as well as how close, and how much warmer than its environment, the prey animal must be.

Yale University neuroscientist Elena Gracheva's work had previously exposed the role ion channels play in snakes' heat-sensing abilities. Now, says Gracheva (who was not involved in the new study), this pioneering look at signal conversion "lays the foundation for future experimental work by biologists to verify the model."

It could also lead to new technology, Sharma says: "We can use the same model to create artificial materials that have pyroelectric properties for exciting applications in materials science." —*Harini Barath*

JONNIE SEIJDEL *Getty Images*

Pit vipers like this one have extremely sensitive heat vision.

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Photo Illustration by Chris Line

Charles Darwin. Born Feb. 12, 1809.

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AVIATION

Tight Flight

A birdlike formation would save fuel for planes

Commercial planes could soon mimic migrating birds by traveling in tandem, with one airliner following close behind the other to gain some free lift. European manufacturing giant Airbus says this initiative, called fello'fly, could reduce the follower aircraft's fuel requirements by up to 10 percent per trip.

Fello'fly was inspired by the way birds such as geese fly in formation to save energy. As a bird does, a moving airplane leaves a wake of disturbed air as its wings generate swirling vortices. These vortices circle outward as they dissipate, creating an updraft around the wake. If a second aircraft follows at a specific distance and just beside the wake's center, this updraft provides extra lift.

Such a boost lets the follower reduce engine thrust, saving on fuel costs and decreasing emissions. But the airliners have to position themselves carefully: if the follower gets too close to the center of the leader's path, the vortices will push it downward instead of up. Planes must also greatly reduce the distance they usually maintain—from a standard 55 kilometers in oceanic airspace to just three.

Airbus conducted three tests of the system last summer. Two A350 aircraft flew in France's western Atlantic airspace, remaining three kilometers apart for four hours, according to Airbus. "These tests demonstrated that it is possible to stabilize the aircraft within the wake updraft on autopilot and that the fuel savings are significant," says project leader Nick Macdonald, an Airbus senior engineer.

Fello'fly is intended to work with compatible craft from different airlines that travel in the same airspace at the same time. Airbus recently signed agreements with two airlines for the next testing stage, set for as early as this year; multiple international air navigation agencies plan to take part as well.

Participating aircraft must coordinate meticulously—starting on the ground—to prevent accidents and excessive turbulence. Airline pilot David Mrak, who is not affiliated with the project, says challenges would most likely include setting rules of engagement between the two planes, determining the role of air traffic controllers, maintaining communication, planning for emergency situations and bad weather, and divvying up economic benefits. "For example," he says, "with two different airlines envisaged in a fello'fly flight, the issue becomes 'Who gets to save the gas?' "

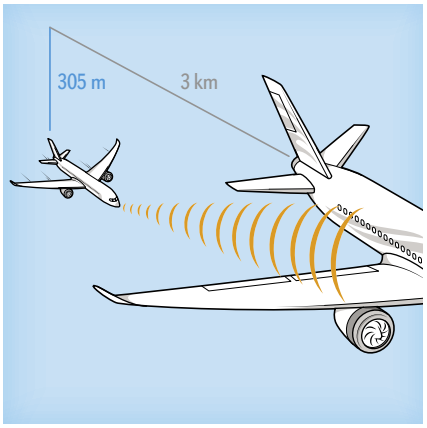
Belgium-based EUROCONTROL, a partner in the project, will focus on codifying predeparture requirements and procedures. Air traffic controllers are currently largely responsible for maintaining horizontal separation between two aircraft at the same altitude, says Giovanni Lenti, head of EUROCONTROL's network operations services. But with the proximity fello'fly needs, he says, "it will have to be done by using new onboard technology, embedded in aircraft avionics, by the pilots."

Although the minimal separation might sound risky, Mrak suggests that operating planes so closely may not be out of the question. "As aviators, we undergo extensive training," he says. "Flying aircraft in formation is a matter of proper training and protocol." As a further fail-safe, Lenti says, air traffic controllers would keep a dedicated flight route empty about 305 meters below both aircraft in case one encounters a problem.

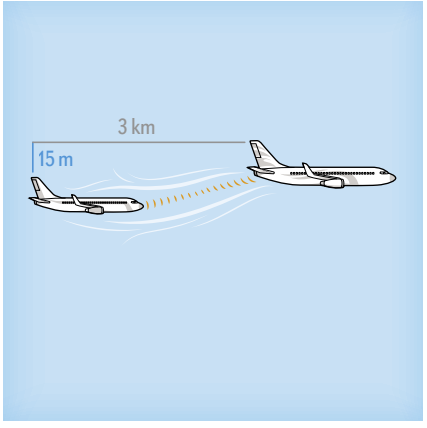
Airbus hopes to roll out fello'fly in commercial operations around 2025, and Lenti says it would initially avoid heavier air traffic by focusing on oceanic routes.

—Dhananjay Khadilkar

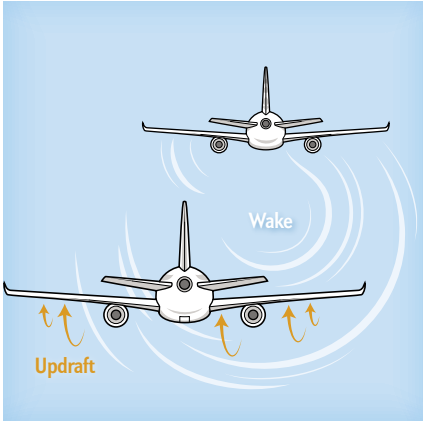
1 Software selects two aircraft to pair up based on their flight plans. They take off separately and enter the same flight path, guided by air traffic control.



2 Pilots activate onboard technology to couple the planes together with a mere three kilometers of distance between them while maintaining a vertical separation of 305 meters.



3 The follower plane then moves into a position 15 meters below, and just to the side of, the lead plane.



4 The wake of the lead plane produces an updraft that provides extra lift to the follower plane, allowing it to save energy and fuel.

SOURCE: AIRBUS

Illustration by Brown Bird Design

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Even a spider with four shortened legs on one side (*shown here*) could spin a perfect web.

ANIMAL COGNITION

Arachnid Architects

Researchers decode spiders' web-building skills for use in robots

Spider legs seem to have minds of their own. According to findings published in the *Journal of the Royal Society Interface*, each leg functions as a semi-independent "computer," with sensors that read the immediate environment and trigger movements accordingly. This autonomy helps the arachnids quickly spin perfect webs with minimal brain use. The study authors simulated surprisingly simple rules to govern this complex behavior—which could eventually be applied to robotics.

"The novelty of this paper is really to lay out an interesting and potentially very important paradigm to study and test new ideas about the next generation of robots," says University of Oxford biologist Fritz Vollrath, lead author of the paper. "The spider's web-building behavior is a perfect example to study these kinds of questions in detail."

The study revolves around "morphological computation," the idea of a function being encoded in a body part instead of relying on the brain for instructions. Examples include the human knee-jerk reflex and the act of walking. "Basically there's a shortcut, and the brain doesn't even know what's happening down there," Vollrath says. This outsourcing spares the brain from overseeing standard actions honed by evolution or practice.

Roboticists are intrigued by morphological computation for the same reason: it saves computing power and time. But few studies have deeply examined the phenomenon in nature. Spiders, Vollrath says, were ideal for an experiment to fill in this gap—not only because it is easy to spot design changes in their geometric webs but also because molting spiders regenerate broken-off legs.

Vollrath and his co-author, Thiemo Krink, then a computer scientist at Aarhus University, filmed and digitized the movements of several cross spiders, each with partially regenerated, half-length legs at certain positions. These spiders built webs as quickly and perfectly as those with eight full-length legs; if the brain were computing how to compensate for shorter legs, the researchers say, they would have seen tiny but measurable delays in operation. Instead the study suggests a spider's leg receives basic brain commands but adjusts its movements based on local input from sensors, which include hairs and slits in the body covering.

By comparing shorter and longer legs' actions, the researchers also inferred underlying rules for how the legs automatically move to measure angles and lengths when building webs. They tested the rules by programming a simulated virtual spider, and Vollrath says the next step is to build a physical spider robot.

"I find this work extremely interesting, telling us more about spiders and also about morphological computation," says Cecilia Laschi, a bioroboticist at the Sant'Anna School of Advanced Studies in Italy, who was not involved in the study. "You never know what remarkable innovations basic science like this could bring." —*Rachel Nuwer*

FROM "SPIDER WEBS INSPIRING SOFT ROBOTICS," BY FRITZ VOLLRATH AND THIEMO KRINK, IN *JOURNAL OF THE ROYAL SOCIETY INTERFACE*; NOVEMBER 11, 2020 (*https://doi.org/10.1098/rsif.2020.0569*)

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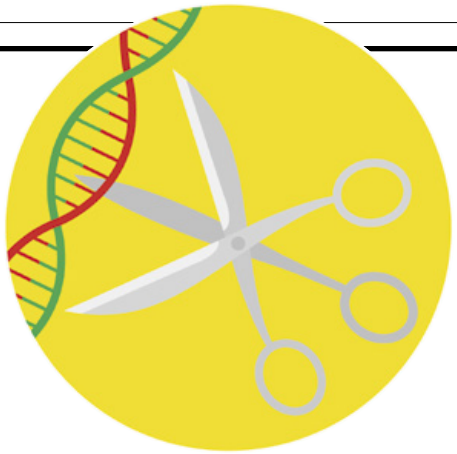
BIOCHEMISTRY

DNA Cutters

A catalog of Cas9 proteins could expand gene-editing options



The DNA-editing system CRISPR-Cas9 is revolutionizing how scientists approach genetic problems and diseases. Most researchers use a particular version of the Cas9 protein, derived from the bacterium *Streptococcus pyogenes*, to alter DNA. But other microbes carry their own versions, which cut genes at different locations and could help researchers design more precise and flexible therapies. For a new study published in *Nature Communications*, researchers analyzed dozens of Cas9 varieties, uncovering broad diversity in how these "molecular scissors" recognize and snip DNA.

To slice genetic material, Cas9 needs a "guide" RNA molecule that directs the protein to a specific DNA sequence—and that sequence needs to end with a short string of DNA code called a protospacer adjacent motif (PAM). Cas9 can cut DNA only in places where its particular PAM happens to already exist. This stringent requirement limits the locations where researchers can edit genes, says Vilnius University biochemist Virginijus Šikšnys, the study's lead author.

To broaden their options, Šikšnys says, the biologists searched through "thousands of sequences of Cas9 proteins in databases" and settled on 79 candidates from different bacteria. They built each Cas9 in a liquid that simulates the cellular interior, and then they added snippets of DNA with random PAM codes to each mixture.

Most Cas9 proteins ended up recognizing a unique PAM sequence—a feature that could let bioengineers cut DNA in more places, says Patrick Pausch, a CRISPR researcher at the University of California, Berkeley, who was not involved in the study. The proteins' varying sizes (one, from a Yellowstone geyser microbe, was 30 percent smaller than standard) could also fit different delivery systems, Šikšnys says.

And having more Cas9 options could potentially help researchers circumvent immune responses to some gene-editing therapies. A prior study found that in 125 blood donors, 58 percent had antibodies against Cas9 derived from *S. pyogenes*. Cas9 proteins from more innocuous bacteria might be less likely to trigger a bad reaction.

"I think that they are providing a real service to the community by characterizing such a huge range of different proteins," says Iowa State University biochemist Dipali Sashital, who was not involved in the research. Sashital says there is potential for new tools but notes that the work is foundational; the team has not yet shown that the proteins will work in real-world gene editing.

The researchers next plan to test some of the proteins in living organisms. Regardless of their performance, this large collection illustrates the remarkable diversity of these DNA cutters, Šikšnys says: "It's like having multiple scissors instead of a single pair." —*Niko McCarty*

IN THE NEWS

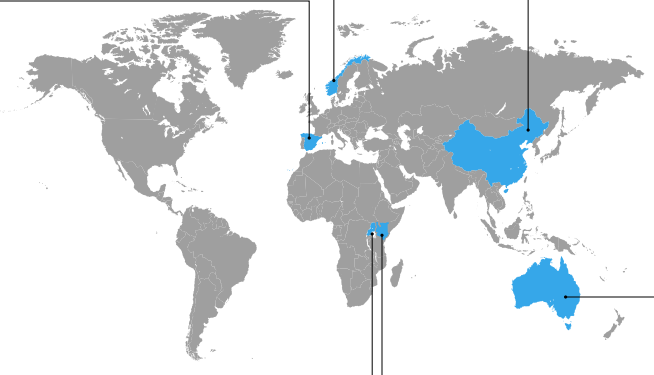
Quick Hits

By Sarah Lewin Frasier

NORWAY
A melting mountainside ice patch revealed more than 60 arrow shafts, along with arrowheads and other artifacts, dating from 4100 B.C. to A.D. 1300. Scientists also found that almost 300 shards of reindeer antler or bone had accumulated there, suggesting the location was a prime hunting area.

CHINA
Scientists found that some *Fritillaria* plants have evolved gray and brown camouflage to match rocks in their mountainous habitats—especially in areas where herbalists have heavily harvested them for use in traditional medicines.

SPAIN
Scientists analyzed groupings of juvenile Megalodon teeth, found in quarries in Tarragona province, which suggest an ancient nursery. Bone remains indicate the enormous prehistoric sharks did not reach maturity until age 25, so such sites may have been essential to their survival.



AUSTRALIA
A landing capsule from Japan's autonomous Hayabusa2 spacecraft, carrying a cache of material gathered from asteroid Ryugu, successfully came down in South Australia's Woomera Prohibited Area. The spacecraft probed the asteroid from 2018–2019, and after this drop-off near Earth it continues to another asteroid mission.

UGANDA
New research suggests that when female banded mongooses are in heat, they encourage fights between their own groups and rival ones—and mate with enemy males in the ensuing chaos.

KENYA
Researchers fitted a GPS tracker on the world's last known white giraffe, an adult male, aiming to protect it from poachers. A white female and calf were killed in the same conservation area last March.

For more details, visit www.ScientificAmerican.com/feb2021/advances

Illustration by Thomas Fuchs

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Kit Wienert, author of *Analogs of Eden* (White Dot Press, 2015), has been making and publishing poems for almost 50 years. He lives in Chapel Hill, N.C., having retired from a writing and editing career in medicine, telecommunications and scientific R&D.

A UNIFIED THEORY OF LOVE

$(1 + 1 = 3 \text{ or } 1 + -1 = \infty)$

Should I walk the Planck
length between my heart

and yours, drown in the
liquid abyss of space-time

deep within my sea dreams
that scope and chart macro

geometries of love by
star arc in night sky,

heaven's whirls of light and
elemental fire would still

shimmer through unfathomed
depth and distance to mark

in micro beats of time
our bodies' magnetic needs.

In bottomless dark we flicker
into being, instant inflation

of nothing into something's
minute entanglements forever

trading quantum places,
to fuse and emanate

our invisible human essence
in and out to infinitude.

NASA, JPL AND CALTECH

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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*.

It Looks Like COVID. It's Not

A vaping-related lung disease poses a threat to young people

By Claudia Wallis

The first sign that something was wrong was trouble breathing. "I thought my lungs were giving out on me," Marcus recalls. "When I breathed in, my lungs hurt." About a week later he began vomiting violently, unable to hold down food. It was the beginning of an ordeal last October that landed the otherwise healthy 18-year-old (who prefers to keep his last name private) in an intensive care unit. Doctors at Utah Valley Hospital in Provo found that the teenager's blood oxygen level had plummeted into the 80s (normal levels are 95 and above). A CT scan showed a hazy "ground-glass" pattern of white flecks in his lungs—an indication of severe damage often seen in patients with COVID-19. With the pandemic raging, doctors tested Marcus three times for the coronavirus. All results were negative. Marcus himself suspected another culprit: something noxious he had inhaled from a vape pen.

His hunch proved right. Marcus was diagnosed with a life-threatening condition recognized only since 2019: e-cigarette or vaping product use–associated lung injury, or EVALI. The first known cases appeared in Wisconsin in June 2019. Before long the Centers for Disease Control and Prevention was receiving reports of this mysterious illness from all 50 states. By mid-February 2020, 2,800 people had been hospitalized with it, and 68 had died. Two thirds of the afflicted were male, and most were young adults.

Fortunately, science moved almost as fast as the outbreak. By early October 2019 the Food and Drug Administration had linked the cases to vaping products containing tetrahydrocannabinol (THC), the main psychoactive component of marijuana, and issued a public warning to avoid such products. FDA investigators began sampling THC vape liquids and discovered that half contained vitamin E acetate, a substance used commercially to thicken skin creams. Its effects when inhaled had not been examined. At the CDC, a research team studied lung fluid samples from 51 patients and found vitamin E acetate in 48 of them. "That helped us connect all the dots from what was in the product and what was in the body of the individuals," says epidemiologist Brian King, who helped lead the agency's emergency response team and co-authored a report on the findings in the *New England Journal of Medicine*.

Questions remained as to whether other vaped compounds were also playing a role, but mouse studies settled the issue. "A couple of research groups had mice inhale pure vitamin E acetate for a few days, and it induced crazy amounts of lung damage, so it was very clear," says pulmonologist Laura Crotty Alexander, who studies EVALI at the University of California, San Diego.

In a period when public health authorities have been struggling to contain a global crisis, it is good to be reminded of how well their efforts can work. EVALI cases such as Marcus's continue to be reported, but the numbers have fallen dramatically since the cause was identified. "We had a peak in September 2019, and it's been declining since then," King says. He and other experts believe that public warnings raised awareness and may have prompted producers of THC vape liquids to stop cutting their wares with the vitamin, which was used to add volume and make a cheaper product.

EVALI is one of at least three diseases caused by vaping and e-cigarettes. Scarring of the lung's tiny air sacs known popularly as popcorn lung has been traced to vape liquids containing diacetyl, a flavoring that used to be added to popcorn. Nicotine vapes are associated with a type of pneumonia. "So many people think vaping in general is safe, but there are thousands of chemicals being added for flavor, for mouthfeel, for the look of the [exhaled] cloud," Crotty Alexander says, and the risks of many additives are unknown.

About 20 percent of U.S. high school students say they use some kind of e-cigarette or vaping device, down from 27.5 percent in 2019. The drop most likely reflects federal regulatory actions, including raising the minimum age for buying tobacco products from 18 to 21 and outlawing the fruity and candy-flavored cartridges that attract young users. But THC vapes are tougher to regulate, Crotty Alexander says, because most are made by small, informal producers—legally or illegally, depending on the state.

She and others are investigating the long-term outcomes of EVALI. Most patients respond well to steroids and oxygen support, if needed, and seem to make a good recovery. Marcus is one of them. "We are very lucky that EVALI was already recognized when COVID hit," Crotty Alexander says. Otherwise the signal of this risky lung disorder might have been lost in the noise of the pandemic. SA

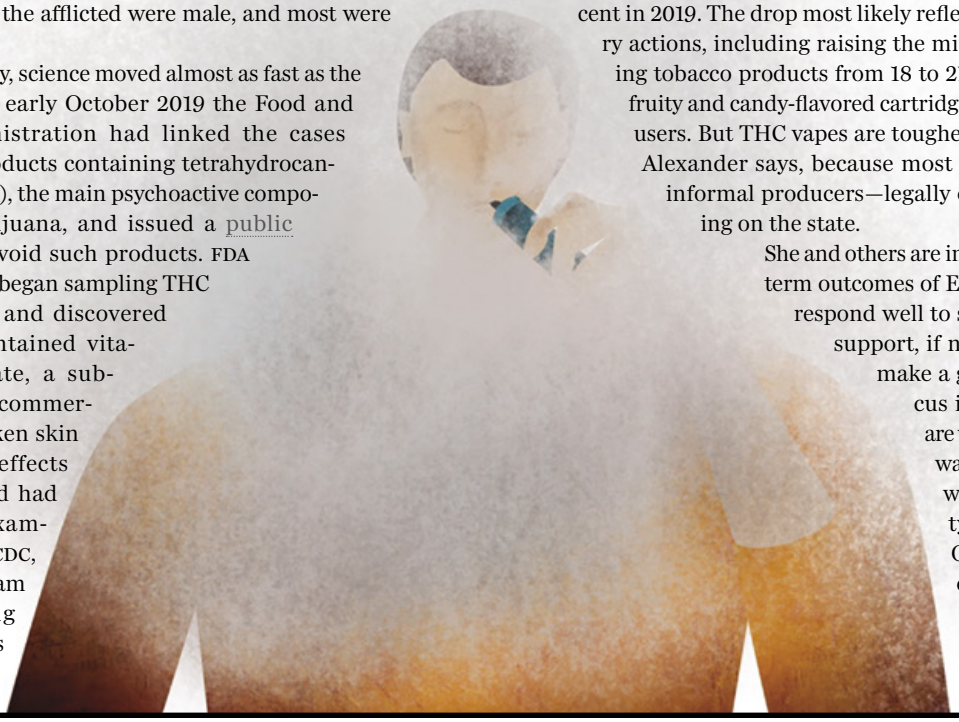

Illustration by Fatinha Ramos

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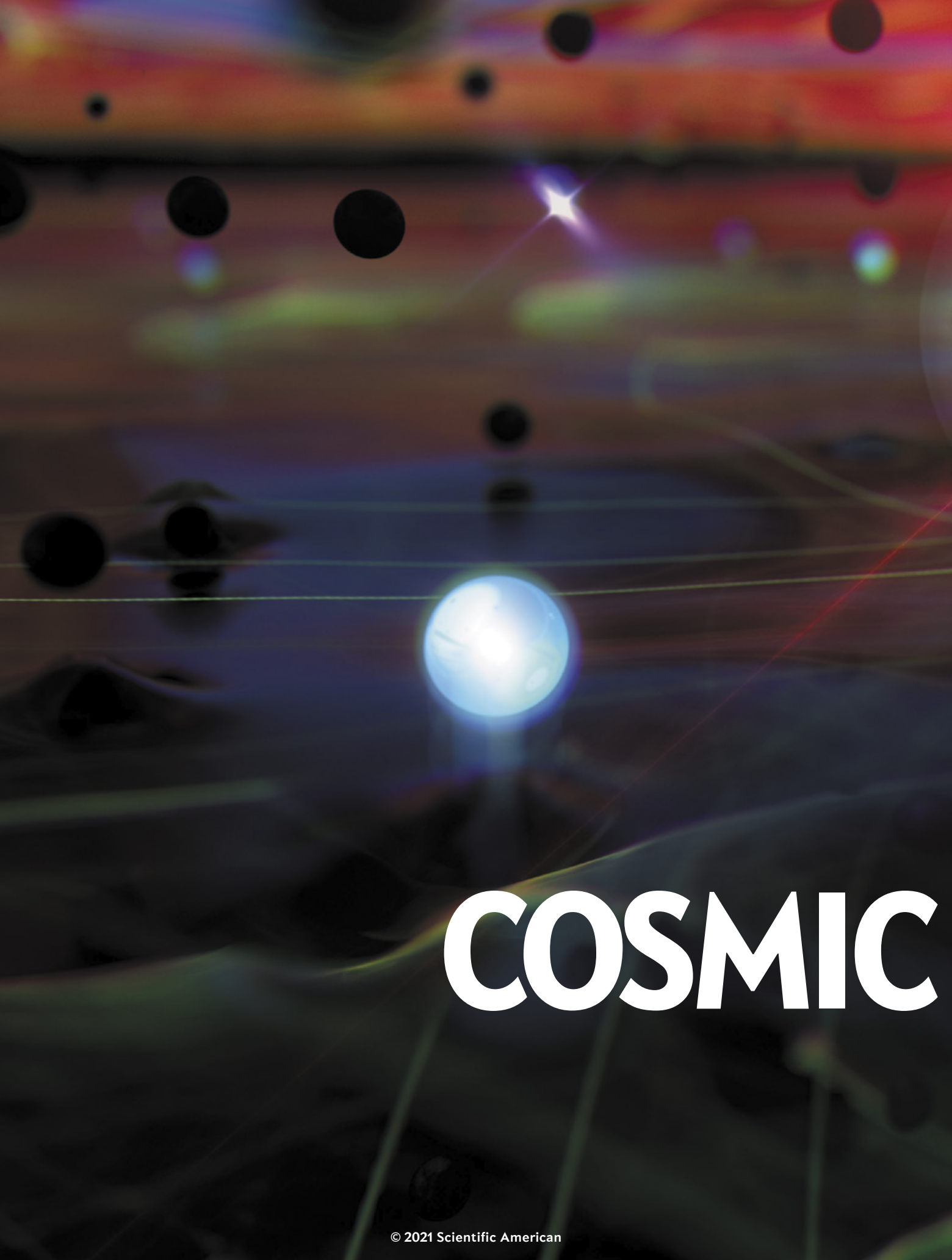

COSMIC

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PHYSICS

CONUNDRUM

The strangely small value of the cosmological constant is one of the biggest unsolved mysteries in physics

By Clara Moskowitz

Illustration by Mark Ross

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Clara Moskowitz is a senior editor at *Scientific American,* where she covers space and physics.

In every bit of nothing, there is something.

If you zoom in on empty space and take out all the planets and stars and galaxies, you might expect a pure vacuum, but you'd be wrong. Instead you would find a dynamic scene, with particles sparking to life and disappearing almost immediately.

Quantum mechanics, the theory governing the infinitesimal world, doesn't allow for nothingness. At any given moment in time and space, energy can never be perfectly zero—there is always some wiggle room. Out of that wiggle room, "virtual" particles can arise—specifically, a pair made of a particle and its antiparticle, which annihilate each other and are gone as quickly as they came. As bizarre as this may seem, experiments have observed the real-world effects of virtual particles. When particle accelerators first measured the mass of the *Z* boson, it was slightly off from its pure mass because it was sometimes turning into a virtual top quark—one of many observations proving that virtual particles exist.

The effect of all these particles wiggling into and out of being is a thrumming "vacuum energy" that fills the cosmos and pushes outward on space itself. This activity is the most likely explanation for dark energy—the reason the universe, rather than staying static or even expanding at a steady rate, is accelerating outward faster and faster every moment.

The problem with vacuum energy is that there's not enough of it. When scientists first started thinking about the concept, they calculated that this energy should be huge—it should have expanded the universe so forcefully and quickly that no stars and galaxies ever formed. Because that is clearly not the case, the vacuum energy in the universe must be very small—about 120 orders of magnitude smaller than what quantum theory predicts. That's like saying that something weighing five pounds should really weigh five-with-120-extra-zeros-after-it pounds. The discrepancy has prompted some scientists to call vacuum energy "the worst theoretical prediction in the history of physics."

Vacuum energy is thought to be the main ingredient in the "cosmological constant," a mathematical term in the equations of general relativity. The enormous discrepancy between the predicted amount of vacuum energy and the measured amount is often called the cosmological constant problem. "It's generally regarded as one of the most awkward, embarrassing, difficult problems in theoretical physics today," says Antonio Padilla, a physicist at the University of Nottingham in England, who has spent 15 years trying to figure it out. "It suggests there's something missing in our story. I find it exciting—why would you not want to work on that?"

The riddle has enticed some of the greatest minds in physics and elicited a plethora of ideas to solve it. Last year New York University physicist Gregory Gabadadze spent an hour summarizing all the concepts theorists have come up with so far in a talk at the Brown University physics department. At the end, one of the audience members asked him which of the ideas he favored. "None of them," Gabadadze replied. They are all too "radical," he said, and all require "giving up sacred principles."

But some physicists say new theoretical work is injecting excitement into the quandary. And recent advances in precision laboratory experiments that probe gravity, as well as the advent of gravitational-wave astronomy, offer hope that some of the proposed solutions to the problem could finally be put to the experimental test—or, at the very least, ruled out.

THE BIRTH OF A PROBLEM

THE COSMOLOGICAL CONSTANT has a checkered history. "It was what you could call a nonsolution to a nonproblem," says physicist Rafael Sorkin of the Perimeter Institute for Theoretical Physics in Ontario. Albert Einstein first invented it in 1917 as a mathematical kludge to force his general relativity field equations to predict a static universe, as he and most scientists then believed the cosmos to be. But in 1929 astronomer Edwin Hubble measured the speeds of many galaxies and found, to his surprise, that they are all moving away from us—in fact, the farther away the galaxy, the faster it was going. His measurements showed that space is expanding everywhere, and no matter where you look, it will seem as if all galaxies are receding because the distance between everything is constantly growing. Faced with this news, Einstein decided a couple of years later to remove the cosmological constant from his equations, calling it "my biggest blunder," according to physicist George Gamow.

For a while the cosmological constant was a footnote of history, but it was quietly preparing for a comeback. In the late 1990s two teams of astronomers were competing to measure how much the expansion of the universe was slowing down as a result of gravity pulling matter inward. In 1998 and 1999 they published their results, based on measurements of special supernovae whose distances could be determined very accurately. The most distant of these supernovae turned out to be much dimmer, and therefore farther away, than expected. The expansion wasn't slowing down at all—it was speeding up. This alarming discovery won three of the teams' leaders a Nobel Prize and prompted

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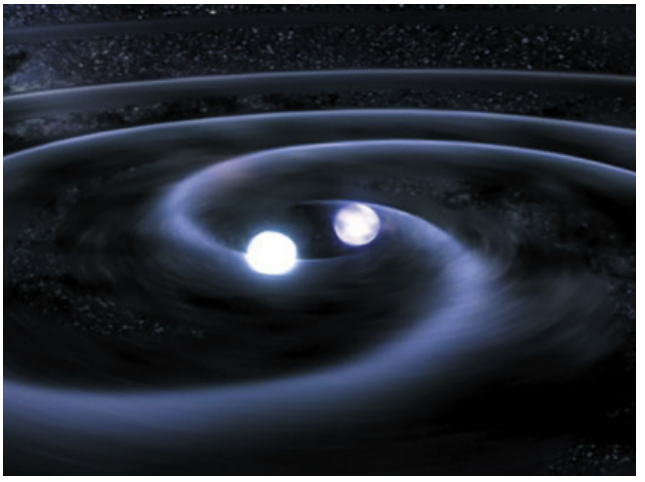
cosmologist Michael Turner to coin the term "dark energy" for the mysterious force causing the acceleration. Immediately physicists suggested that the source of dark energy might be the cosmological constant—in other words, vacuum energy. "Perhaps there was more insight in Einstein's blunder than in the best efforts of ordinary mortals," Saul Perlmutter, one of the discoverers of the acceleration, later wrote.

Although the cosmological constant allowed scientists to balance the Einstein field equations again, making them predict an accelerating universe like the one astronomers had observed, the value of the constant didn't make sense. It actually worsened a problem that had been bothering scientists for a while. In the years that the constant lay on the cutting-room floor, physicists had linked this term from general relativity with the concept of vacuum energy from quantum mechanics. But the vacuum energy was supposed to be huge.

One of the first people to notice something was amiss was physicist Wolfgang Pauli, who found in the 1920s that this energy should be so strong that the cosmos should have expanded long past the point where light could traverse the distance between any of the objects in it. The whole of the observable universe, Pauli calculated, "would not even reach to the moon." He was reportedly amused by his estimation, and no one took it seriously at the time. The first to formally calculate the value of the cosmological constant based on quantum theory's predictions for the vacuum energy was physicist Yakov Zel'dovich, who found in 1967 that the energy should make the cosmological constant gigantic. But at the time, scientists thought the universe was expanding at a steady or slowing rate, and most believed the cosmological constant to be zero. The cosmological constant problem was born.



WHEN NEUTRON STARS collide, the gravitational waves they create could help physicists studying the cosmological constant.

NASA, GODDARD SPACE FLIGHT CENTER

Thirty years later, when astronomers realized that the expansion of the cosmos was accelerating, the problem didn't go away. The amount of acceleration, though shocking at the time, was still minuscule compared with what quantum theory said it should be. In a way, reviving the cosmological constant made the predicament worse. It was one thing to try to imagine why the constant might come out to precisely zero. It became more difficult to understand why it might be just slightly more than nothing. "Its value is very weird," says theoretical physicist Katherine Freese of the University of Texas at Austin. "Even weirder than zero."

Not everyone agrees that this is a problem in need of fixing. The cosmological constant is technically just a constant of nature, a number in an equation that can take on any value, says Sabine Hossenfelder, a theoretical physicist at the Frankfurt Institute for Advanced Studies in Germany. The fact that it has the value it has is just a numerical coincidence. "You could just take the constant and be done with it," Hossenfelder says. "All these debates about why does it have the value it has are not scientifically good questions," she says. Nothing about quantum field theory was falsified when its prediction didn't match astronomical measurements, and the theory is still as useful as it ever was. "I think most people in the cosmology and astrophysics community believe it's a problem because they've been told that for a long time."

Yet many physicists cannot let it go. The unexpected smallness of the cosmological constant is a thread that needs pulling. "It bothers me a lot," Gabadadze says, "and I want some answers."

THEORIES GALORE

DESPITE THE ZEAL many physicists have for attacking the question, the pace of progress has been frustratingly slow. "It's been more than 50 years since Zel'dovich really pointed out what the problem was, and there's certainly no established, accepted explanation," Padilla says. "Ideas come and go, but generally very little sticks."

Most proposed solutions to the cosmological constant problem fall into three categories: change the general relativity equations that describe the expansion of the universe, modify the quantum field theory equations that predict the amount of vacuum energy, or throw something entirely new into the mix.

Tweaking general relativity could change the mathematical role the cosmological constant plays—or cut it out altogether. Freese and her colleagues, for instance, sought to eliminate the need for the constant to explain the acceleration of the universe by altering the way general relativity calculations should be applied to the expanding cosmos. "Matter and photons might be enough, without adding any new component to the universe, if their role in the equations is different," she says. Her model is based on the idea that extra dimensions, beyond the three of space and one of time that we witness, might be hidden out of sight.

Another angle on updating general relativity is called sequestration, proposed by Padilla and his colleagues. They modify Einstein's theory in a way that seals gravity off so it cannot feel the effects of vacuum energy. "I'm not going to pretend this is the established model," Padilla adds, "but no one's been able to rule it out."

If general relativity isn't the problem, though, maybe quantum mechanics is. Some theorists have suggested that the quantum field theory method of calculating vacuum energy is off. Stefan Hollands of the University of Leipzig in Germany and his colleagues take issue with applying the regular quantum equations to curved spacetime, saying they were designed with flat space in mind. If physicists could correctly modify them for curved space, they argue, the cosmological constant problem would go away.

But the resolution might require more than just mathematically finagling the traditional equations. One recent unorthodox idea is a proposal by Steve Carlip of the University of California, Davis, that spacetime is fundamentally made of "foam." In this picture, the curvature of space would constantly fluctuate on extremely small scales, well beyond anything we could hope to measure. All

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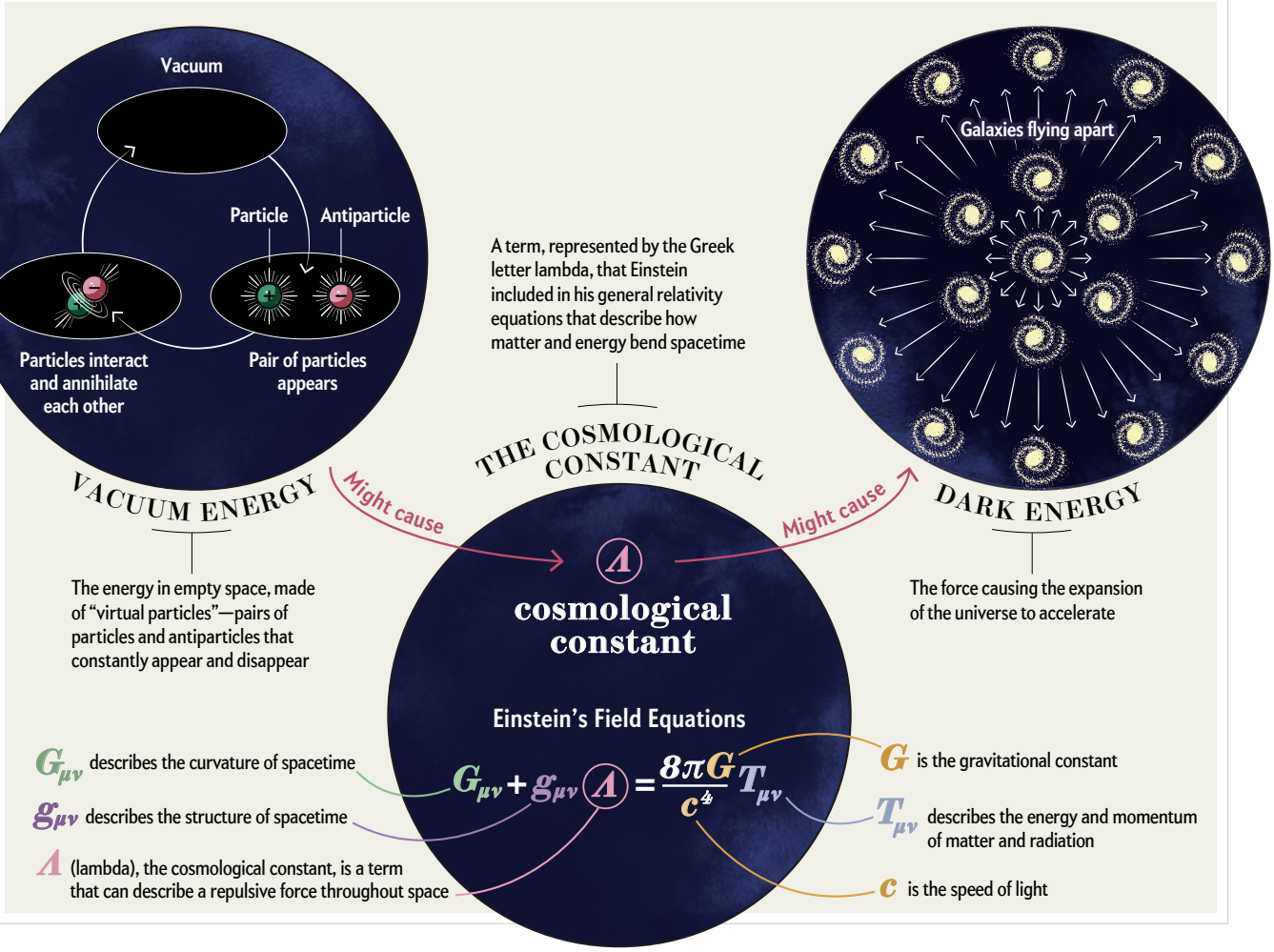
Three Pieces of the Puzzle

The cosmological constant problem is a major mystery in physics: the value of the constant, part of Albert Einstein's general relativity equations, seems to be much, much smaller than theories predict it should be. At the heart of this puzzle are three intertwined concepts—vacuum energy (the energy in empty space), dark energy (the cause of the accelerating universe) and the constant itself.



this complicated topology would cancel out much of the impact of the cosmological constant, making it very small at the local level. "It's kind of a wild idea," Carlip says. "It is a desperate measure, but so is every other attempt to deal with the cosmological constant, and these are desperate times."

Sorkin, who says Carlip's spacetime foam is "going in the right direction," also has his own entry in the field. He works on an approach to unifying quantum mechanics and gravity called causal set theory. According to this model, spacetime is fundamentally discrete—meaning that instead of being a smooth, continuous expanse, it is broken up into tiny chunks, individual units of space and time that represent the building blocks of the universe just as atoms are the building blocks of matter. If this is the case, calculating the cosmological constant involves dividing by the number of spacetime units in the universe, leading to a value much closer to what astronomers observe.

One of the most prominent—and, by some, most hated—solutions to the cosmological constant problem is called the anthropic principle. This line of thinking agrees that the cosmological constant in our universe has an unlikely value but explains it by saying we live in a multiverse. If ours is just one bubble in a cosmic sea, with different physical laws and constants in each, then there was bound to be one with this value. Most of the others would not lead to a universe with galaxies, stars, planets or life, so the fact that we find ourselves in one of the outliers is only to be expected. Because string theory requires a multiverse, string theorists tend to regard the cosmological constant problem as essentially solved by this reasoning. Other physicists, though, consider this philosophy a cop-out. "It's giving up on the problem," Sorkin says.

All these strategies tend to involve rather dramatic revisions of established physics. "Every single one of them calls for a major revamping of basic principles, either of spacetime, say, or the number of dimensions of the universe," Gabadadze says. "They are all distasteful in some way." No single theory has clearly risen

Illustration by Federica Fragapane

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above the rest. "At this point it becomes a matter of taste," Carlip says. "Probably the answer is something that nobody's thought of."

CONSTANCY OR QUINTESSENCE?

THE COSMOLOGICAL CONSTANT remains the best explanation for dark energy—the mysterious force causing the expansion of space to accelerate. But what if dark energy isn't actually related to the cosmological constant or vacuum energy at all? What if the universe's vacuum energy is somehow perfectly canceled out and the cosmological constant is zero? In that case, dark energy might be the work of something called quintessence.

The notion of quintessence was introduced in 1998 by physicists Robert Caldwell, Paul Steinhardt and Rahul Dave as an alternative explanation for the accelerating expansion of the universe. Quintessence would be some form of energy throughout space with a negative pressure. In contrast to the cosmological constant, quintessence could change over time. One version of quintessence, called phantom energy, postulates an energy whose density increases with the age of the universe, leading to an ultimate "big rip" when space is torn apart by runaway expansion until the distance between particles becomes infinite.

To test whether dark energy is caused by quintessence or the cosmological constant, scientists must determine whether the strength of dark energy has changed over time. Various projects have been gathering data about the expansion rate of space at different cosmic epochs. One example is the Dark Energy Survey, a six-year effort to map galaxies at many distances across a large area of the sky using the Victor M. Blanco Telescope in Chile. The survey's data are in, but scientists are still analyzing them—so far all signs point to dark energy being constant. Another way to find out whether quintessence is real is to look for evidence that this energy has caused the fundamental constants of nature to change over time. No indications of inconstant constants have yet emerged.

Over the next couple of decades experiments should give scientists a better idea of whether the cosmological constant (and the vacuum energy behind it) is the source of dark energy. The Vera C. Rubin Observatory Legacy Survey of Space and Time, planned to begin in 2022 on a telescope currently under construction in Chile, should dramatically improve the precision of current measurements of the history of cosmic expansion. Soon scientists should be able to say much more clearly whether there's room in the data for quintessence or whether an unchanging force has been at work.

SPACETIME RIPPLES AND NEUTRON STARS

IF, AS THE EVIDENCE SEEMS to show so far, dark energy is truly a result of the cosmological constant, there is still some hope of sorting through the various proposed explanations for its unexpected smallness. Upcoming experiments and astronomical observations may offer a way to discriminate between the proliferation of theories, weeding out some and, just maybe, offering support for others.

Five years ago scientists gained a whole new lens to study the cosmos when they began to detect gravitational waves, the ripples in spacetime produced by the collision of huge masses such as black holes and neutron stars. Gravitational-wave observatories such as LIGO (the Laser Interferometer Gravitational-wave Observatory) in the U.S. and Virgo in Europe are now regularly spotting waves produced by cosmic cataclysms, and these waves may prove useful in probing the nature of vacuum energy. Some attempts to solve the cosmological constant problem rely on changes to general relativity that would cause gravity to travel slightly slower than the speed of light. The fact that gravitational waves seem to arrive simultaneously with light from the same events has quashed that idea, ruling out a few theories already. "We had a model 10 years ago called the Fab Four that was aimed at solving the cosmological constant problem," Padilla says. "I'd already started to doubt it, but gravitational-wave data killed it."

Gravitational waves are also revealing strange activity inside neutron stars. These compact remnants of supernovae are so dense that atoms have collapsed, their protons and electrons smashing together to form a mass of almost pure neutrons. This bizarre state gives rise to strange phenomena—for instance, the core of a neutron star might contain a novel phase of matter that would cause a jump in the amount of vacuum energy inside it. Gravitational-wave observatories might be sensitive to the gravitational effects of the extra vacuum energy here, potentially revealing secrets about the nature of vacuum energy.

And while astrophysics experiments search for clues on a cosmic scale, experiments a bit closer to home might also help researchers sort through the cosmological constant hypotheses. Lab setups that probe the universe at the smallest possible distances could be sensitive to some of the alterations of general relativity that physicists are proposing.

An example is the work of the Eöt-Wash group at the University of Washington, where scientists are using an extremely sensitive balance experiment to conduct precision tests of gravity. Their instrument is called a torsion balance: a metal disk with holes cut out of it hangs down from a fine wire, with a similar disk right below it that rotates at a constant rate. The two are separated by distances akin to the width of a piece of paper, and as the bottom disk rotates, its gravitational force causes the upper disk to twist back and forth.

This extremely sensitive experiment allows researchers to track how gravity behaves on scales down to tens of millionths of a meter. If the gravitational force weakens at such close quarters, as some ideas suggest—or if extra, minute dimensions of space are discernible there—the Eöt-Wash team will find them. So far gravity has followed Newton and Einstein's laws to the letter in their tests, and no hidden dimensions have been seen, but the scientists keep adjusting their balance to probe smaller and smaller separations. Even if the group never detects deviations that affect vacuum energy, that won't necessarily be conclusive: it is possible that such changes occur only at distances beyond our reach.

"We'll keep trying," Gabadadze says of attempts to test cosmological constant hypotheses with experiments. "Every generation of physicists since 1960 or so has seen new solutions emerging. Maybe one day some of them will have observational predictions that can be tested, but at this point we're not there." Despite the difficulty of the puzzle, he and other physicists still hope for a solution soon. Perhaps these efforts to understand the cosmological constant problem will reveal deeper truths about quantum physics and general relativity. Or maybe scientists will discover a simpler fix. And even while they're seeking a solution that may never materialize, many physicists revel in the quest. SA

FROM OUR ARCHIVES

The Puzzle of Dark Energy. Adam G. Riess and Mario Livio; March 2016.

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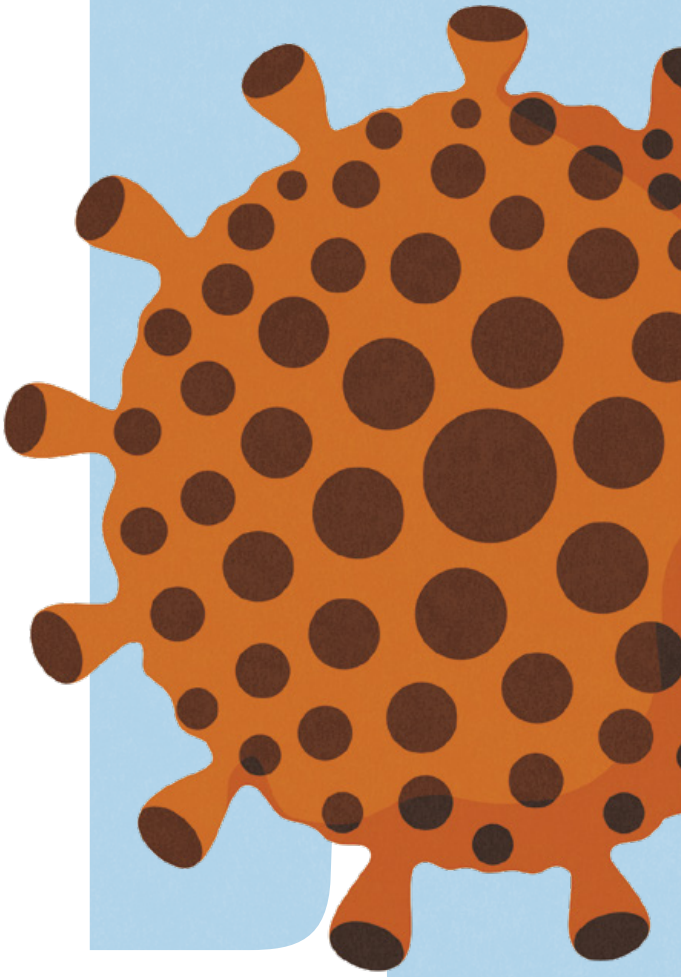

The Four Most Pressing Science Priorities for the Next President

JOE BIDEN AND HIS ADMINISTRATION FACE THE ENORMOUS TASK OF REPAIRING damage from a predecessor who was hostile to science, dismissed evidence, spread conspiracy theories and rejected reality itself. Meanwhile a plague is raging. The planet is warming. Social trust is abysmal; a substantial fraction of Americans have bought into the lie that Biden's decisive win in the 2020 election was somehow fraudulent. Digging out of this hole will take years. But there is much the new administration can do immediately, starting with the steps laid out in the pages that follow.

—The Editors

Illustrations by Egle Plytnikaite

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Tanya Lewis is an associate editor covering health at *Scientific American.*

Controlling COVID

The new U.S. president must help more people see benefits in masks, as well as persuade Congress to spend more money on testing and protective gear

By Tanya Lewis

AS JOE BIDEN TAKES OFFICE, HIS MOST IMMEDIATE PRIORITY IS DEALING with the catastrophe of COVID-19, which has killed hundreds of thousands of people in the U.S.—the highest toll of any country—and sickened and harmed millions. He is inheriting a dire situation from his predecessor, who resisted some of the most important measures to contain the new coronavirus, such as prompt testing and tracing and mask wearing, and who appeared unconcerned as a winter surge of infections devastated the country.

Biden and Kamala Harris, the new vice president, have outlined a COVID-19 plan to reverse this neglect. In addition to promoting more testing and mask wearing, the new administration wants to boost the production of personal protective equipment (PPE), provide economic support for small businesses, ensure a trustworthy vaccine rollout, and address racial and ethnic disparities in COVID's impact. Looking ahead, Biden's team has to get the country ready to handle the next pandemic better than it has dealt with this one.

Some of these goals are likely to face severe headwinds from Republicans in Congress and among millions who voted for Donald Trump. Both groups have fought against masks. Many opposed restrictions on business and personal activity. Congressional Republicans have signaled opposition to funding some of Biden's efforts—especially if, in early January, they retain their majority in the Senate after Georgia's runoff elections. So any amount of money Congress offers will probably be less than what Biden asks for.

One of Biden's responses has been to say he is "not going to shut down the economy—period. I am going to shut down the virus." The incoming administration sees restrictions as a "dial" rather than an on-off switch. "That's a perfect metaphor," says Monica Gandhi, an infectious disease physician at the University of California, San Francisco, School of Medicine. "It's triggering to use the word 'lockdown.'" Biden aims to direct the U.S. Centers for Disease Control and Prevention to provide guidelines for ways to dial up or down restrictions on businesses, schools and gatherings. The evidence is clear that COVID transmission is higher at restaurants, bars and gyms but not so much at schools, so it makes sense to dial down restrictions on the last, Gandhi says.

There are also highly effective measures Biden can take that do not require congressional sign-off. Nearly every expert I spoke with agreed that one of the simplest and most important things Biden's team can do is encourage people to wear masks or face coverings. Despite extensive evidence supporting this measure's effectiveness, Trump made it a political statement not to wear one, mocking people—including Biden—for using them. Biden can try to change that. "President-elect Biden and Vice President–elect Harris have always modeled responsible behavior throughout the campaign," Robert Rodriguez told me in November. He is an emergency physician at the U.C.S.F. School of Medicine and a member of the Biden-Harris administration's new coronavirus task force. "They're going to continue to promote the concept that wearing masks is noble—it's a civic duty that shows you care about the country and about others," he said. Because masks have become so political, however, the messaging needs to strike a careful balance, Gandhi says. Like "lockdown," the phrase "mask mandate" seems to really rile people up, she points out, "whereas 'mask guidance' doesn't." Biden plans to work with governors and mayors to implement state and local mask rules and has asked Americans to wear masks for his first 100 days in office. And he does intend to make masks mandatory in federal buildings and on interstate public transportation.

A second key step will be to overcome some people's reluctance to get a coronavirus vaccine when shots become widely available later in 2021. Refusals will prolong the outbreak. According to a Pew survey in November, 42 percent of Black Americans said they would get a shot, slightly up from 32 percent in September. Much of this resistance stems from a history of racism and mistreatment of Black people in medicine. "We can't do anything without first reconciling that history," says Nneka Sederstrom, director of clinical ethics at Children's Minnesota. Biden and his officials need to admit there is legitimate reason for distrust, and they must work to earn that trust back. Saying "we're acknowledging that history of racism ourselves" is the most important thing the Biden-Harris administration can do, Sederstrom says.

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To convince skeptical populations, the new president and his team also need to reach out to community leaders who have the trust of their constituents, Sederstrom adds. Rodriguez says that is already in the works; further, the Biden administration has said it plans to address the pandemic's unequal effects on people of color by establishing a separate task force on racial and ethnic disparities in COVID, headed by Harris.

Vaccine skepticism is also linked to political affiliation. Just 50 percent of Republicans or Republican-leaning respondents said they were likely to get vaccinated, compared with 69 percent of Democrats or Democrat supporters, according to the November Pew survey. To reach Republicans, Biden will need to get the help of conservative leaders as well.

More tests alone will not be enough. People who test positive must be able to safely isolate, and they must be given the resources to do so.

Both vaccine acceptance and mask wearing depend on the new president's ability to restore trust in science. "One of the biggest reasons that trust has been lost is [the Trump administration] essentially not letting science and scientists direct the pandemic response efforts," says Angela Rasmussen, a virologist and affiliate researcher at the Georgetown Center for Global Health Science and Security. Political meddling at health agencies and repeated announcements that undercut public health measures exacerbated the problem. The Biden team can start to reverse the damage by showing that it is following scientific advice and delivering it in a clear, consistent message, Rasmussen says. "Some of that trust will be earned back, but it's not going to happen overnight."

BEYOND WINNING BACK TRUST, Biden needs to scale up COVID testing. Until vaccines reach most Americans, the virus will continue to spread, and testing is the way to identify and contain outbreaks. Yet it is still hard for most people in the U.S. to get a test and receive results quickly. Biden is going to have to increase the number of places for individuals to procure a diagnostic molecular test (something he has promised to do in part by doubling the number of drive-through testing sites). A national pandemic testing board, akin to the War Production Board that President Franklin D. Roosevelt created during World War II, could marshal resources for this initiative, and Biden has said he plans to create one.

Another promising approach is to have companies produce millions of so-called rapid antigen tests. These work well when people are most infectious. They can be taken at a local testing site and yield results in less than 30 minutes. The U.S. Food and Drug Administration has issued emergency authorization for eight such tests as of this writing, but they are not widely available. Michael Mina, an epidemiologist at Harvard University's T. H. Chan School of Public Health, has been an avid proponent of producing tens of millions of them for at-home use. "We have still failed to recognize that it's frequency of testing, not sensitivity," that matters, he says. "You could have the best test in the world, but if it's not available or it takes four days, it's not useful." The Biden administration should work directly with companies to develop and produce more tests, Mina says, the way the government contracts with Lockheed Martin and Raytheon to manufacture airplanes and military equipment. The tests should then be made freely available to homes, schools and businesses.

More tests alone will not be enough. People who test positive must be able to safely isolate, and they must be given the resources to do so, says Stefan Baral, an infectious disease epidemiologist at the Johns Hopkins Bloomberg School of Public Health. "If we want people to not go to work when they're sick, we need to provide paid leave," he says. "If we want to prevent them from infecting their household, we need to provide them a place to isolate." One way to do that is to let infected people who live in crowded housing or who are homeless stay in a hotel for a few weeks. Some states have already taken this approach. Just as important, contact tracing should be used to stop single cases from becoming clusters or big flare-ups. Currently there are not enough tracers working in the U.S., but the Biden administration aims to hire more as part of a Public Health Jobs Corps of at least 100,000 people. Obtaining financing for this project, as well as for more isolation facilities, would require legislation, however. This effort—like other spending plans—could face an uphill battle in the Senate.

Biden also needs to drastically increase the availability of PPE—such as face masks, face shields and gowns—to protect health care workers. To do so, Biden has said he will quickly use the Defense Production Act of 1950, which Trump as president invoked late and sparingly. If Biden employs the act more aggressively and on companies all along the PPE supply chain, it could lead to the development of a more robust centralized stockpile.

And even as he tries to quell the current pandemic, Biden needs to ensure that the U.S. is better prepared for the next one. Restoring commitments to the World Health Organization (Trump planned to leave it in July 2021), as well as a stand-alone National Security Council directorate for global health security, is a good way to start.

Biden also needs to relaunch the U.S. Agency for International Development's PREDICT project to strengthen abilities to detect pathogens with pandemic potential; it ended in 2020. PREDICT was built on the concept of "One Health," which focuses on connections among the health of people, animals and their shared environment.

"The Biden administration has a real opportunity to bring a One Health approach to the pandemic because it's clearly not just about humans," says Christine Kreuder Johnson, one of PREDICT's leaders. A professor of epidemiology and ecosystem health at the University of California, Davis, School of Veterinary Medicine, Johnson notes that changes to the environment are forcing animals out of remote habitats and into closer contact with humans, and people, driven by population and economic pressure, are moving closer to wild animals. Aggressive global surveillance for dangerous pathogens that live in these animals is one way to prevent the catastrophes of 2020 from repeating in coming years.

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Committing to Climate

The new administration has to install carbon emissions cuts that more than make up for ground lost under Trump

By Andrea Thompson

ONE WORD SUMS UP WHAT THE BIDEN ADMINISTRATION MUST DO to address climate change: restart.

In 2015 nearly 200 nations committed to the Paris Agreement, which aims to prevent the worst impacts of climate change by limiting global warming by 2100 to less than two degrees Celsius above preindustrial levels. The U.S. pledged to reduce its greenhouse gas emissions to 26 to 28 percent below 2005 levels by 2025. Then Donald Trump was elected president. He soon announced that the U.S. would pull out of the accord, and his administration spent four years relentlessly rolling back regulations intended to curb emissions and protect the environment. Dozens of coal-burning power plants, the worst carbon polluters, shut down anyway as market forces expanded the role of cheaper, cleaner natural gas, wind and solar power. And various states, cities and industries cut emissions. Yet even with that progress, Trump's rollbacks could add the equivalent of 1.8 billion metric tons of carbon dioxide to the atmosphere by 2035, according to the Rhodium Group, an independent research organization.

Joe Biden must now make up for lost time, and last November he said the U.S. would rejoin the Paris Agreement immediately after he became president. This commitment is important because the U.S. is still the world's second-largest emitter, behind China, and it can return as a world climate leader. But Biden will also have to ratchet up the original U.S. pledge because warming—and its effects—has only sped up since the Paris Agreement was established. Biden promised to issue an executive order calling for net-zero emissions by 2050, but he will need to set specific interim targets. The World Resources Institute says reducing emissions to 45 to 50 percent below 2005 levels by 2030 could put the country on track.

Congressional legislation is the most effective way to create the concrete policies needed to achieve those goals because it gives federal agencies clear priorities, is much harder to override with presidential actions, and can better withstand legal challenges that might be brought by industry or special-interest groups. But the divided U.S. Senate will make sweeping laws hard to pass. Biden will have to work through executive orders and will have to charge federal agencies such as the Environmental Protection Agency with issuing new regulations under existing laws such as the Clean Air Act. He will need to "turn every stone possible," says Narayan Subramanian, an environmental lawyer working with the Center for Law, Energy & the Environment at Berkeley Law. The most immediate focuses are transportation, power plants, methane emissions and pesky hydrofluorocarbons (HFCs).

With coal plants retiring, transportation has surpassed power generation as the country's largest carbon emitter. The quickest action Biden can take to tackle those emissions is to reinstate California's waiver to the Clean Air Act, allowing the state to enforce its Advanced Clean Cars regulations. The regulations set fuel-efficiency standards for cars and light-duty trucks that are tougher than federal rules, which means fewer emissions. In the past, automakers have built their nationwide fleets to meet the state's standards to avoid making two versions of their vehicles, and some states, such as New York, typically follow California's lead. The Rhodium Group estimates that reinstating the waiver would save about 573 million metric tons of emissions by 2035.

To expand on that action, Biden could charge the EPA and the Department of Transportation with rescinding Trump's Safer Affordable Fuel-Efficient Vehicles Rule, which undercut more stringent national standards set under the Obama administration. Even then, to stay on course to meet the two degrees C goal, 90 percent of U.S. passenger cars and light-duty trucks would need to be electric by 2050, according to a recent study published in *Nature Climate Change*. Because cars last 12 to 15 years on average, new EPA and DOT rules that encourage or require zero-emissions vehicles by 2030 or 2035 would help the U.S. fleet turn over in time. Some major U.S. car companies, including General Motors and Ford, are increasingly investing in electric vehicles. And Ford, along with several leading international companies, opposed the Trump administration's rollbacks because the moves were likely to end up in court, creating regulatory uncertainty.

In the electric-power industry, market forces will not cut emissions fast enough to meet the temperature goal, according to Dan Lashof, U.S. director of the World Resources Institute. Biden has set an ambitious goal for the power sector to be net

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zero by 2035. If achieved, it would reduce emissions by up to 1.38 billion metric tons of CO_2 a year by 2030 and 1.51 billion metric tons a year by 2050, according to the Asia Society Policy Institute and the nonprofit climate science and policy institute Climate Analytics.

Reaching those numbers will require replacing Trump's Affordable Clean Energy rule with a more aggressive version of the Obama-era Clean Power Plan, which was suspended by the U.S. Supreme Court before it could go into effect. The plan, an EPA regulation, would have set strict limits on emissions from power plants. Biden could carefully enact new EPA regulations that can better withstand any future federal court challenge.

ALTHOUGH CO_2 EMISSIONS are abundant and stay in the atmosphere a long time, scientists are paying increasing attention to curbing methane emissions because new studies show they are rising fast, and methane is a more potent greenhouse gas. The Trump administration recently rolled back several methane regulations, including, notably, EPA rules requiring oil and gas companies to monitor and repair leaks in their infrastructure. The Rhodium Group estimates that leaks would increase emissions by 592 million metric tons through 2035. As with power-plant rules, Biden will have to work through the EPA to repeal the rollbacks and install new, tougher requirements.

Hydrofluorocarbons, used in refrigeration and air conditioning, also pack a major warming punch. Here is one case where Congress could play a role. Republican senators, among them John Kennedy of Louisiana, have backed a bill called the American Innovation and Manufacturing (AIM) Act. The bill, supported by industry, would cut HFC use 85 percent by 2035. As of this writing, Congress had not passed it during the 2020 session, but the bill could be taken up again in 2021. If eventually passed, the AIM Act would be in line with the 2016 Kigali Amendment to the global Montreal Protocol, which calls for a more than 80 percent reduction in HFC production and consumption in the next 25 years.

Biden can also expand on legislation that has already garnered bipartisan support, for example, by maintaining tax incentives to encourage the expanded use of renewable energy and electric vehicles.

Any pandemic-related stimulus packages could include funding for green infrastructure projects such as the construction of more electric-vehicle charging stations to help grow that market or the sealing of abandoned oil and gas wells that leak methane. Moreover, the federal government can use its considerable purchasing power to help bolster parts of the clean-energy sector, such as by buying electric delivery vans for the U.S. Postal Service.

In tandem, the Biden administration can strengthen rules under the National Environmental Policy Act that require all federal agencies to consider the environmental impacts of actions they might take or of projects up for approval such as oil drilling on federal land. The Trump administration said the act requires consideration only of direct, noncumulative impacts, which effectively took climate change off the table. The Council on Environmental Quality, which ensures that federal agencies adhere to the act, could specify that future climate change impacts should be considered. That step could make it less likely that emissions-intensive projects, such as drilling, would be approved by agencies such as the Department of the Interior.

One important leadership change the Biden administration and its agencies can make is to help cities, states and companies play greater roles in reducing emissions quickly by alerting them to planned federal rules and regulations. That way they can begin to adapt sooner. "At the end of the day," Subramanian says, "one of the biggest tools the Biden administration has is sending signals."

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Jen Schwartz is a senior editor of features at *Scientific American*. She writes about how people are adapting, or not, to a rapidly changing world.

Reestablishing Reality

How to agree on the evidence—so we can disagree on what to do in light of it

By Jen Schwartz

THE SAFEGUARDS OF DEMOCRACY—INCLUDING THE EXHAUSTING, underappreciated work of so many people who uphold them—have stopped the U.S. from descending into authoritarianism, but the facts of our division remain bleak. Institutional distrust has been rising for decades. A Monmouth University survey found that 77 percent of 2020 Donald Trump voters believe that Joe Biden won the presidency through fraud. Trust in Congress is in the basement. Until recently, a majority of Americans at least trusted one another. But in a 2019 Pew survey, 59 percent of Americans reported little or no confidence in the wisdom of their fellow citizens to make political decisions. It's not hard to imagine that number might be even higher now.

The Biden administration is faced with reviving a sense of collective fate. Big infrastructure projects that help people feel safe, healthy and more secure both economically and socially could go a long way toward easing the underlying conditions of uncertainty and fear that drive "us versus them" thinking. Some have referenced the New Deal and other social safety-net policies of the past, looking to the supposed conditions of national solidarity that made them possible. Others caution against romanticizing history. "Let's not forget that this idyllic idea of solidarity, especially in a wartime modality, is created by making an enemy of someone else," says Alondra Nelson, president of the Social Science Research Council and a professor at Princeton University. What we're facing now, she says, is a polarization internal to the nation. We've made enemies out of one another. "The challenge for Biden is creating solidarity without a war mode and helping us feel the interconnectedness of our lives with others," Nelson says. "We haven't had leadership able to craft that national story for us."

To sell a narrative of shared fate, Biden and his team will first need to restore a sense of shared reality. To start, Nelson and others emphasized the need for executive orders that "reset the clock" by publicly supporting the independence and integrity of science. Behind the scenes, the administration should incorporate more behavioral science into policy decisions, to better understand how beliefs and motivations influence policing and mask wearing, for instance. While acknowledging the damage of conspiratorial delusions and paranoid thinking, many of the experts I spoke to insisted Trump's absence alone would help quell the uptake of extremism and false ideas. Conspiracies lose some of their allure, especially to new adherents, when high-ranking leaders go away. A paper published in November in the *Harvard Kennedy School Misinformation Review* echoes this sentiment. Without the "willingness to accept misinformation by prominent elites (like the president), many dubious ideas would likely fail to gain traction," the researchers write.

Many agreed that the most immediate thing Biden can do to reset reality is to be transparent, take responsibility for how government can do better and encourage visionary leadership at all levels of society. Restoring basic norms and decency, such as honoring facts and speaking with compassion, will go far. There are also strategies and signals the administration could deploy to address our disordered information environment. Many science communication experts emphasize the need for consistent, clear communication across the Biden administration that separates out the best available scientific facts from what we should do in light of the facts.

This messaging should be paired with the principles that guide such decisions, to anchor people in the bigger picture. For example, an update about how to best contain the spread of the coronavirus should remind the public that when research leads to more precise strategies for keeping people safe while balancing different goals, that's a sign science is working—it doesn't mean that earlier recommendations were lies and that scientists can't be trusted. Scientific updates should be presented as evidence, and the steps to be taken (a shorter quarantine period, perhaps, or reducing indoor activities) could be discussed as the resulting decisions, with transparency into the rationale for making such choices. This strategy could be applied to all evidence-based decision-making to help get people more comfortable with the nature of probabilistic outcomes while keeping larger goals in mind. Uncertainty isn't going away, and Biden would do well to help Americans live with it better.

Of course, our disordered information environment hampers more than just coronavirus recovery. Private technology companies such as Facebook that facilitate the spread of conspiracy theories and oth-

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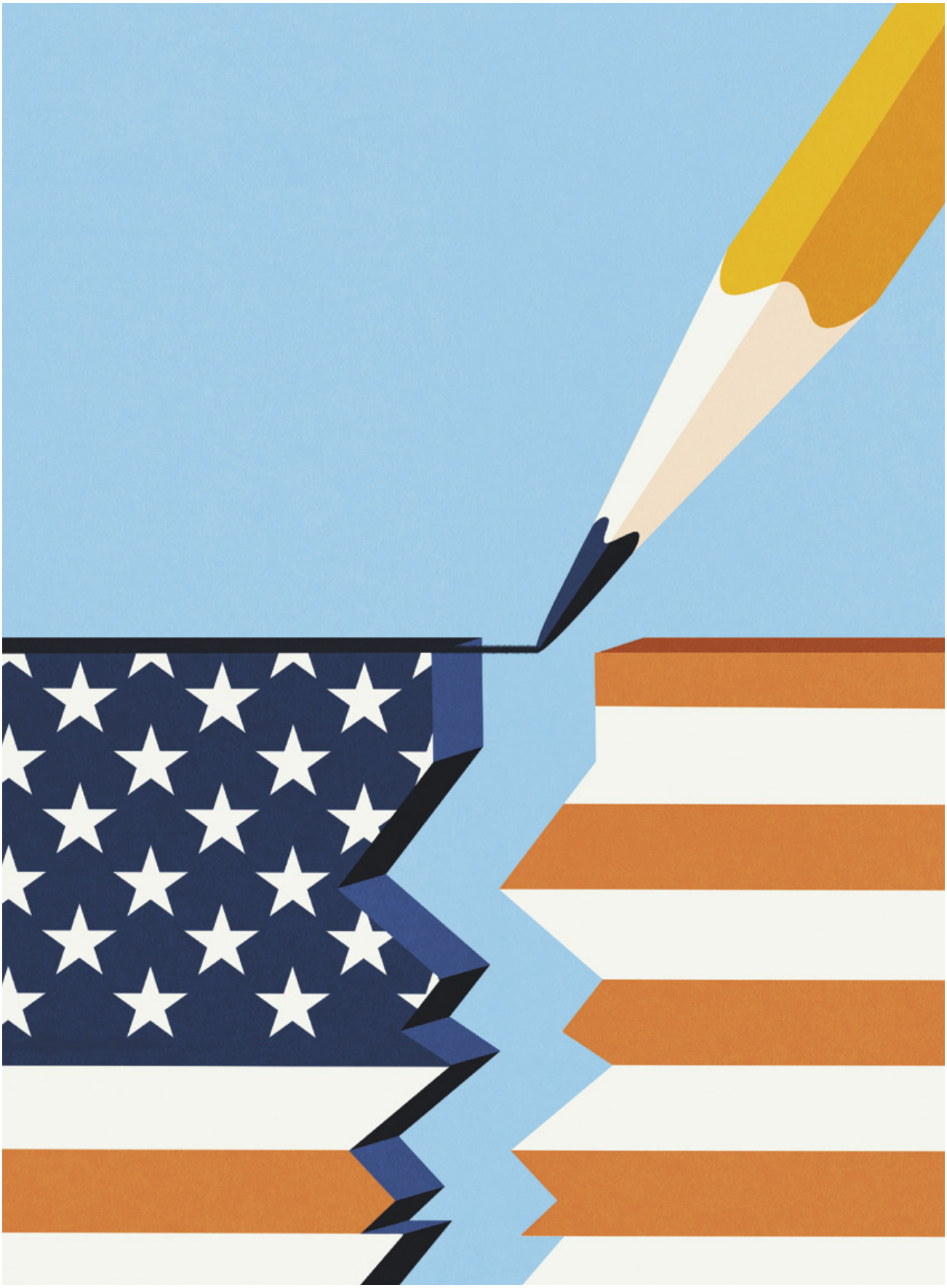

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er false content should be regulated. Congress should also take steps to ensure social media companies actually comply with their own standards for avoiding harm, such as blocking hate speech, harassment and calls for violence. Many Republicans have tried to paint such efforts as a threat to First Amendment rights; Biden and his team could reframe the issue from one of censorship to one of exploitation. As researcher Renee DiResta has often said, freedom of speech is not the same as freedom of reach. These companies rely on algorithmic amplification as their business model, which has created a massive economy of personal data while feeding people ever narrower versions of whatever ideology appeals to them.

The Biden administration should also speak to the consequences of rampant misinformation on our relationships and communities and how we are all susceptible to false belief. They should immediately establish a task force on media manipulation and digital disinformation, stacking it with experts in sociology, design, surveillance and justice, in addition to technologists and lawyers. To further inform policy, Biden's team could dedicate funding for research to understand how disinformation affects behavior both online and off. That won't be truly effective, however, unless independent research groups can access the troves of anonymized data held by private companies. We can't measure how social media usage is driving behavioral changes if the data remain off-limits, and Biden's team could exert pressure with precision.

Putting the onus of monitoring misinformation on government regulation would lighten the load for journalists and researchers who have been stretched thin by the task. At the same time, the disappearance of newspapers and radio stations across the country has devastated the ability of people to connect to their communities and has put too much focus on the national level, making people feel even more powerless and vulnerable to algorithmic echo chambers on the Internet. (It has also led to dangerous concentration in the ownership of local news outlets.) Research shows that the decline of local news is associated with higher polarization.

The Biden administration should consider various policies that would help build a robust network of editorially independent local and nonprofit newsrooms, while remaining sensitive to the inherent conflicts at stake. One plan, from Rebuild Local News, a coalition that represents more than 3,000 newsrooms, builds on a bipartisan bill that would give taxpayers a $250 refundable tax credit they could use for news subscriptions or donations.

Trump didn't just block journalists from doing their jobs and call coverage that made him look bad "fake news." He attacked the very premise of press freedom and endangered journalists' lives. The Committee to Protect Journalists has suggested that Biden emphatically vocalize support for a free press and define for the country why it is vital to have accurate, trusted information that holds power to account. It also recommends that the president appoint a Special Presidential Envoy for Press Freedom, similar to how Biden has already appointed John Kerry as a Special Envoy for Climate. Alan C. Miller, founder of the News Literacy Project, suggests that the Biden administration bring back daily press briefings and make the president available for a wide range of media appearances where he speaks truthfully, thereby helping to restore trust.

Speaking of "fake news," the Biden administration (and everyone else) should stop using a term that Trump turned into a linguistic weapon for attacking the legitimacy of the press, among other institutions and people he perceived as a threat. Biden and his people can help unwind the chaos of false equivalency by letting Trump's ugliest phrases rot away. Research has shown that repeating lies, even in the context of explaining why they are wrong, solidifies them in people's minds.

AMERICANS, AS EVER, remain optimistic that relations can improve. Last year the American Academy of Arts and Sciences published a bipartisan report called "Our Common Purpose" that offered dozens of proposals for repairing democracy, combining quantitative data with listening sessions around the U.S. It cites a Pew poll showing that 86 percent of Americans think we can "improve the level of trust we have in one another, particularly if we can reduce political partisanship, make the news more factual and less sensational, spend more time with people instead of on social media, and practice empathy."

National leaders can leverage this willingness to heal by encouraging civic identity that isn't Republican or Democrat and that focuses more on local engagement. "We need a massive cultural education in how to do politics," says political scientist Eitan Hersh, who recently wrote a book about so-called political hobbyism and the dangers of universal punditry. "Most people who perform politics on Twitter are just getting an emotional discharge. They blame Citizens United for everything, but have they ever been to a statehouse meeting? There's this totally weird and false reality on the left that if gerrymandering or the Senate just didn't exist, they'd get all of their dream policies." Hersh wants to see Biden encourage citizens to learn about local issues, to put pressure on state senators and city councils for policy on climate, policing and public health, and to gain empathy by listening to competing interests at a town hall meeting.

The White House cannot manufacture solidarity alone. Indeed, the larger lesson of the New Deal, wrote Harvard University professor Lizabeth Cohen in the *Atlantic* last spring, "is that recovery is a complex and painful process that requires the participation of many, not directives from a few."

Nonpartisan grassroots activism might not be plausible in this moment of ideological division and physical distance. But the Biden administration could transcend Pollyannaish calls for unity by giving Americans examples of values they truly do have in common. Recent research from the Knight Foundation and Gallup, for instance, shows the majority of Americans agree that misinformation on tech platforms is a problem. Similarly, exit poll data showed that 67 percent of *all* voters think climate change is a serious issue. For years atmospheric scientist and communicator Katharine Hayhoe has urged leaders and media to stop focusing on the tiny, loud minority of people who have staked their identity on dismissing evidence. "By falling for the illusion that climate deniers can be convinced with more facts, we are distracted from engaging with a much larger group of people who want to understand why and how we should move forward with solutions," she told *Scientific American* in 2017. "And that's exactly what the deniers want."

We will disagree, sometimes vehemently, over what solutions to pursue—but debate based on evidence-based reality is the foundation the new administration must prioritize. Joe Biden should remind Americans, too, that it goes both ways: truly inclusive shared reality is possible only when we all participate in democracy.

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Restoring Expertise

Four ways President Biden can bring expertise to the U.S. government

By Jane Lubchenco

DURING THE 2010 BP DEEPWATER HORIZON OIL SPILL DISASTER, I FLEW on Air Force Two with Vice President Joe Biden to the Gulf of Mexico to join him in meetings with fishing communities to hear their concerns and share what the federal government was doing. Although I had been in high-level group meetings with the VP, it was the first time he and I had an extended one-on-one exchange. Our plane conversation covered a range of topics and apparently intrigued him enough that, as we landed, he asked me to please join him in his VPOTUS car so the two of us could continue talking about what scientists had learned about the spill and what the National Oceanic and Atmospheric Administration was doing to help.

As he peppered me with questions, it was abundantly clear that he respects science and looks to scientists to help understand complex issues and chart a smart path forward. It was equally clear from his subsequent remarks to fishing communities that he was unusually adept at integrating scientific knowledge into an empathetic message with honesty, substance and sensitivity. In his meetings and speech, the point was how to make science relevant to people's lives.

Ten years later his presidential campaign pledged to restore the place of science in government and to heed science in tackling urgent problems. In his acceptance speech on November 7, 2020, he said, "America has called upon us to marshal the forces of decency, the forces of fairness, to marshal the forces of science and the forces of hope in the great battles of our time." These battles include the pandemic, economic recovery, health care, racial justice, systemic racism and climate change.

Now that Biden is on the eve of his presidency, what specific actions should he take to restore the scientific expertise needed for our collective good? A comprehensive list would take too many pages, so I have bundled my priorities into four categories, drawing on my four years as Undersecretary of Commerce for Oceans and Atmosphere and administrator of NOAA and my two years as the first U.S. Science Envoy for the Ocean with the U.S. State Department.

1. MAKE SCIENCE AND SCIENTISTS prominent. Show they are respected. Create transparent mechanisms to ensure science is part of every major decision. If the president takes these steps early on, that tone will be emulated across the executive branch.

President-elect Barack Obama announced his "Science Team" in mid-December of 2008, shortly after announcing his selections for cabinet-level positions. Elevating science so early on made an unmistakable statement about his priorities. Most modern presidents have had a science adviser, but announcing a Science Team was new and noteworthy. I was fortunate to be an inaugural member of that team. That early visibility sent a clear signal to other political appointees: these folks matter, give them access, listen to them. Biden should name a Science Team and make his science adviser a cabinet member. Doing so would make an unambiguous declaration of the importance of science to this administration.

Any major special team—for example, a new White House Climate Team—should have a visible lead scientist. A scientist need not be in charge of the team (although that is fine, too!), but having a scientist vested with the responsibility of ensuring that science is at the table will help inform key decisions. In the Obama administration, numerous interagency teams were created in response to various needs. During the BP Deepwater Horizon disaster, the national incident commander who led the interagency group of mostly cabinet-level principals routinely began each daily meeting by asking me to recap the latest relevant scientific information. Placing science at the top of the daily agenda made it visible, present and respected.

Announcements of major decisions or actions should include summaries of the relevant science. This should help instill confidence in the decisions taken. For example, when NOAA and the National Weather Service changed the language used to issue extreme weather watches and warnings, we made it clear that we did so because social science findings told us that the previous language was insufficient in communicating when there was a life-threatening situation that warranted immediate action, such as an imminent tornado.

2. RESTORE AND STRENGTHEN the conditions that enable science to thrive and inform decisions.

The president should issue scientific integrity (SI) guidance that applies across the executive branch and direct agencies to cre-

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ate or strengthen SI policies within a specified time frame. A policy should forbid anyone in the executive branch from cherry-picking, manipulating, suppressing or distorting scientific information. Agency scientists should be free to speak to the media about their scientific findings (as distinct from opining on agency policies) without having to go through a gatekeeper or be scripted with politically constrained talking points. SI policies must apply to everyone, career and political employees. NOAA's already strong SI policy, for example, should be updated based on violations of that policy by political appointees who tried to provide cover for President Donald Trump during the so-called SharpieGate scandal, when Trump showed a hand-altered map to support a false claim he had made about Hurricane Dorian's predicted path. NOAA's policy had a mechanism for investigating violations, but there were no real consequences for serious violations. An SI policy should be a living document, part of the active culture of an agency, owned and embraced by employees.

Because SI policies are the bedrock of a healthy, thriving scientific enterprise within the federal government, basic principles should be enshrined in law, not just in agency policy. Some members of Congress agree and are keen to act. Biden should work with them to pass a robust SI law.

External advisory committees bring outside expertise to agencies, but many were eliminated or weakened under the previous administration. Biden should reverse Trump's executive orders on Federal Advisory Committees and empower agencies to take full advantage of the scientists who voluntarily share their expertise to complement agency knowledge or act as a check on agency decisions.

During my time at NOAA, I was constantly impressed with the knowledge, dedication and integrity of its scientists. Today, however, the scientific workforce across the federal government has been reduced and demoralized. Reconstituting that capacity with diverse, stellar, early-career scientists should be initiated immediately and will bring decades-long benefit to the nation. Agencies should ensure that there are vibrant career paths for scientists and that scientists have a strong voice within the agency. At NOAA, we created clear science tracks, a science council, and annual all-scientists meetings to empower scientists and enable them to deliver what the nation needed.

Persistent national and global challenges require periodic, refreshed syntheses of relevant scientific information. Biden should ensure that the next National Climate Assessment, which is just getting underway, is well led and free from political interference. In addition, he should consider a similar interagency mechanism that engages outside scientists for a periodic National Assessment for the Ocean, for Biodiversity, for Environmental Justice and for Health.

3. MODERNIZE THE USE of science across the agencies. Today's problems require more holistic approaches, drawing on complex adaptive systems thinking and integrated socioeconomic approaches. Solving many problems requires actions across multiple agencies, but the mechanisms are often ineffective. Climate change is an obvious example, which is why President-elect Biden is creating a cross-agency team anchored in the White House. Obama created a National Ocean Council to coordinate the 26 federal agencies and offices that relate to the ocean and help implement a National Ocean Policy. Trump upended the policy and weakened the council. Biden should listen to emerging scientific information about powerful opportunities for healthy ocean ecosystems to help address climate change, economic recovery, biodiversity protection, coastal resilience and equity, and he should empower a new National Ocean Policy and Council to harness the power of the ocean.

4. DEPOLITICIZE SCIENCE—it is not partisan. A persistent, smart effort is needed to share the awe and demonstrate (not just assert) the importance and relevance of science.

I believe that a major reason Americans across the political spectrum reacted negatively to SharpieGate was that they understood how important it is to have accurate lifesaving information, free from political interference. They appreciate the fact that hurricane forecasts are based on science, and they want to know what the experts think is likely to happen.

A vibrant democracy requires informed citizens. Decision makers will typically consider a range of factors—values, economics, politics, and opinions of peers or family. But science should also be at the table. Opportunities to participate in science can help demystify science and make it more accessible. Seeing how it is used in making decisions can help the nation move beyond polarization of science. Messages and actions from the country's leader matter.

In short, Mr. President, on my imaginary flight with you on Air Force One today, I ask you to please tap, elevate and empower scientists to deliver knowledge and solutions, create the conditions to protect the integrity of science and enable it to thrive, embrace and use science, even when it is inconvenient, and explain why and how science matters. The nation and the world will thank you. SA

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ANIMAL BEHAVIOR

Attack of the Zombie

The emerald jewel wasp is a cockroach's worst nightmare

By Kenneth C. Catania

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Maker

EMERALD JEWEL WASP targets the American cockroach to supply food for the wasp's young.

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“You still don’t understand what you’re dealing with, do you? Perfect organism. Its structural perfection is matched only by its hostility.... I admire its purity. A survivor, unclouded by conscience, remorse or delusions of morality.” That is how the android Ash famously describes filmmaker Ridley Scott’s extraterrestrial monster in the 1979 blockbuster *Alien*. The movie provided nightmare fodder for an entire generation of science-fiction fans with its tale of an alien creature that attaches itself to the face of a crew member of the spaceship *Nostromo* and implants an embryo that later bursts from his chest. Technically speaking, the alien is a parasitoid, an organism that, unlike most parasites, ultimately kills its host. No one who has seen the film will ever forget how it reproduces, even if they want to.

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Recently I have come to share some of Ash’s sentiments about chest-bursting parasitoids. But don’t judge me too harshly. I am not talking about monster parasitoids from outer space. I am referring to what seems to be the closest thing we have here on Earth: the parasitoid emerald jewel wasp, *Ampulex compressa,* which makes zombies (and worse) out of the American cockroach.

To give you a little background, I am a neurobiologist, and every fall I teach a course about animal brains and behavior at Vanderbilt University. On Halloween I like to showcase an appropriately creepy bit of biology as a memorable way for students to learn some basic neuroscience. When I began teaching about the emerald jewel wasp, I became so intrigued by the species that I just had to bring some of the wasps to my laboratory to see their behavior for myself. I started with a simple plan to take pictures and make some videos for my class, but soon I found myself carrying out research on this striking insect. The jewel wasp was already well known for being a parasitoid, but through my experiments over the past few years, I have learned that it is even more remarkable than researchers previously understood. And the roach, it turns out, has a nifty trick of its own.

TAKING CONTROL

Before I tell you what I discovered that filled me with admiration for this creature, I should explain how it first gained notoriety. Every female jewel wasp is on a mission. To reproduce, the wasp needs to find a host that will supply the necessary food for her young. Like many parasitoid species, the emerald jewel wasp is a specialist with only one option for a host—in this case, the American cockroach, *Periplaneta americana*. This target is one reason the jewel wasp is so popular even among insectophobes: as the proverb goes, the enemy of your enemy is your friend.

Among biologists, however, the emerald jewel

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wasp elicits respect for its remarkable attack strategy. Frederic Libersat of Ben-Gurion University of the Negev in Israel and his colleagues—including venom specialist Michael Adams of the University of California, Riverside—have conducted a series of elegant studies that tell a story rivaling science fiction. It all starts when a female wasp locates an unfortunate cockroach.

The jewel wasp has an incredibly nuanced attack. It takes a neurosurgical approach to paralyzing its host, first stinging the cockroach directly in a part of the central nervous system called the first thoracic ganglion. This structure houses the motor neurons that control the roach's front legs. The wasp's venom contains gamma-aminobutyric acid (GABA), an inhibitory neurotransmitter that shuts down the motor neurons, temporarily paralyzing the legs. This first surgical strike leaves the roach unable to protect its head from the next sting, which the wasp directs through the soft membranes of the roach's throat and straight into its brain. This second dose of venom has the insidious effect of changing the roach from a violently struggling (and dangerous) opponent into a compliant and pacified host—that is, a zombie.

From there things go predictably downhill for the roach. The venom injected during the brain sting includes the neurotransmitter dopamine, which causes the roach to incessantly groom its legs and antennae when it should instead be trying to escape. In the meantime, the wasp goes in search of a crypt in which it can entomb the roach with an egg. Once it finds a suitable location, the wasp returns to the roach and does something that might seem gratuitous in a horror movie. It grasps one of the roach's sensitive antennae and bites off most of its length, leaving only a bleeding stump. It then does the same to the other antenna, and it uses the stumps like straws to drink the cockroach's blood. You can think of roach blood as the wasp's favorite supplement, providing energy and nutrients after the intense struggle (I do not see the fad catching on). Next, the wasp grasps one of the antenna stumps and, walking backward, pulls the cockroach forward. The cockroach follows like a dog on a leash. Once they are inside the tomb, the wasp glues a single small egg on one of the roach's two middle legs. Then it exits the tomb and uses nearby debris to securely block the entrance before departing.

Take a moment to consider this astounding product of evolution. For any predator, it is plenty hard to stalk, catch and kill elusive prey. The emerald jewel wasp has an even greater challenge—taking its prey prisoner so it can serve as a living larder for the larva when it eventually hatches. To do so, the jewel wasp must deliver venom to two small neural targets inside the armored body of an insect that specializes in escaping from threats. No other animal that scientists know of has such a sophisticated means of manipulating another animal's nervous system. And yet there is more to the story.

JEWEL WASP LARVA eats the living cockroach from inside (*1*) and emerges from the roach on reaching maturity (*2*).

EMANUELE BIGGI, *Science Source*

A MOTHER'S TOUCH

IT IS SAFE TO SAY that no one ever walked away from watching *Alien* wondering about the trials and tribulations of the poor little chest-bursting parasitoid that scurried off the lunch table in the *Nostromo*. Much the same could be said for the typical view of the jewel wasp's larva. Even scientists studying the wasp usually cut to the credits once the wasp seals the cockroach in the tomb. It is assumed that the larva will hatch from the tiny egg, find a soft spot from which to feed and break through the cuticle to eat the living cockroach from the inside, later emerging from the roach triumphant in a familiar, *Alien*-parasitoid fashion.

But life is not so easy for a hopeful chest burster, as I had occasion to learn when I was distracted by other projects and my wasp colony almost died out. It was only then that I tracked each larva, hoping I

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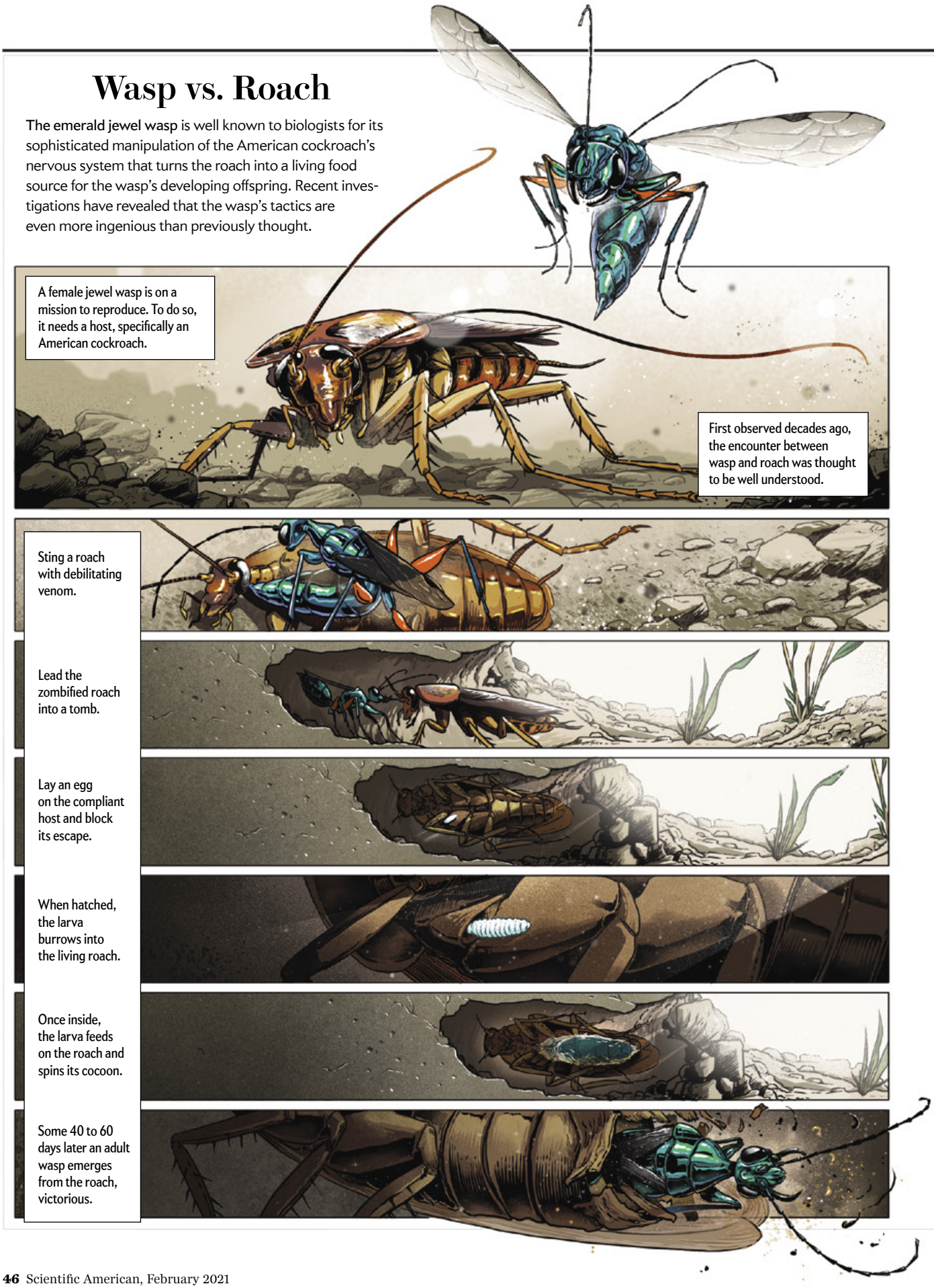
Wasp vs. Roach

The emerald jewel wasp is well known to biologists for its sophisticated manipulation of the American cockroach's nervous system that turns the roach into a living food source for the wasp's developing offspring. Recent investigations have revealed that the wasp's tactics are even more ingenious than previously thought.



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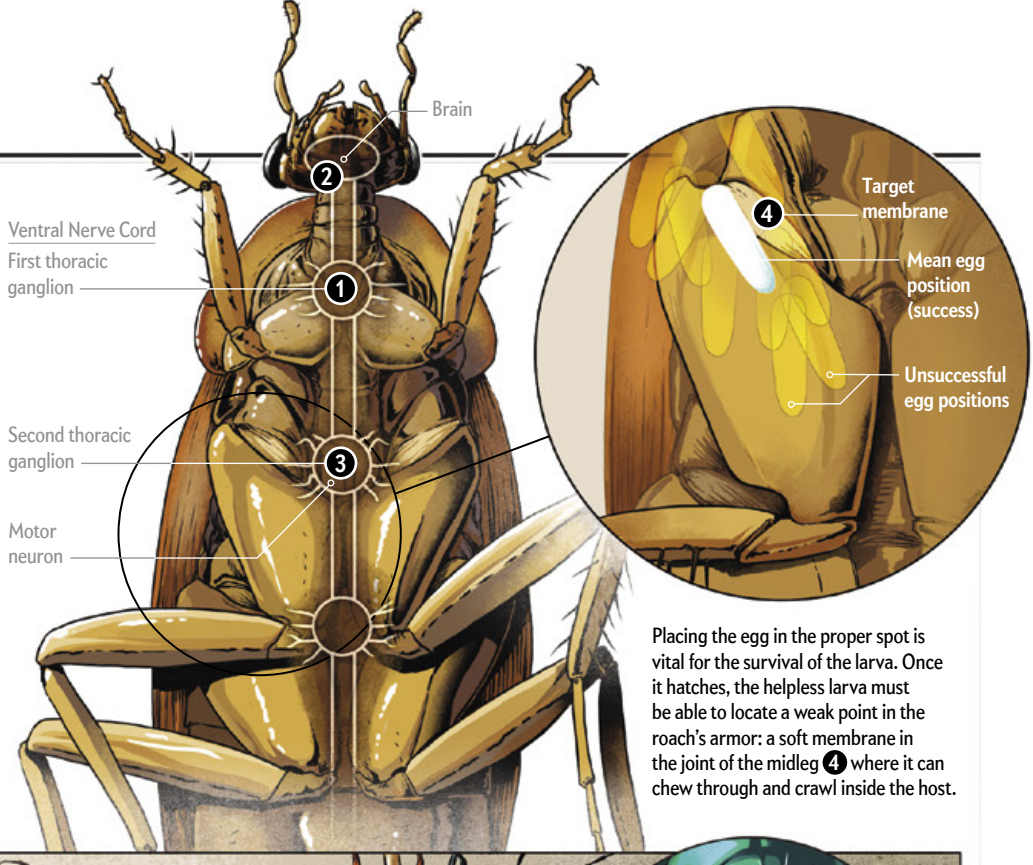
Previous studies found that the wasp stings the roach twice in its attack:

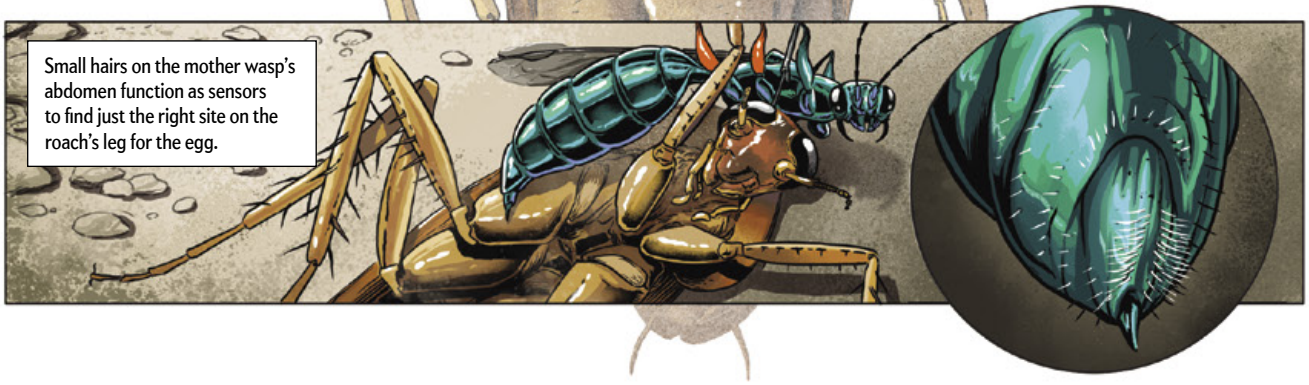
First it stings the roach in a part of the central nervous system called the first thoracic ganglion ❶ to immobilize the front legs, then it delivers a second sting directly to the brain ❷, "zombifying" the roach.

New research has revealed additional stings.

Just before the wasp deposits its egg on the roach, it stings the roach in in another part of the central nervous system called the second thoracic ganglion ❸. This sting activates motor neurons that extend the roach's middle legs, exposing the prime location for the wasp's egg.



Placing the egg in the proper spot is vital for the survival of the larva. Once it hatches, the helpless larva must be able to locate a weak point in the roach's armor: a soft membrane in the joint of the midleg ❹ where it can chew through and crawl inside the host.



Small hairs on the mother wasp's abdomen function as sensors to find just the right site on the roach's leg for the egg.

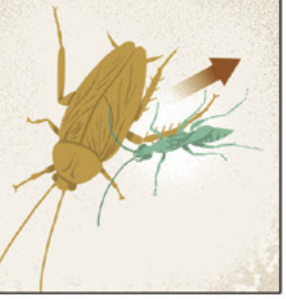
The roach's counter-strategy is simple: do not let the wasp get close.

It keeps careful track of the wasp with sensitive antennae.

And it uses its size and strength to its advantage.

Spin to keep away from lunging jaws.

Pry off a grasping wasp with spiny legs.



Stand tall on long legs to maintain distance. At just the right moment, deliver a stunning kick to the wasp's head.

A famously adaptable survivor, the cockroach can, with a few simple maneuvers, fend off one of nature's most sophisticated predators.

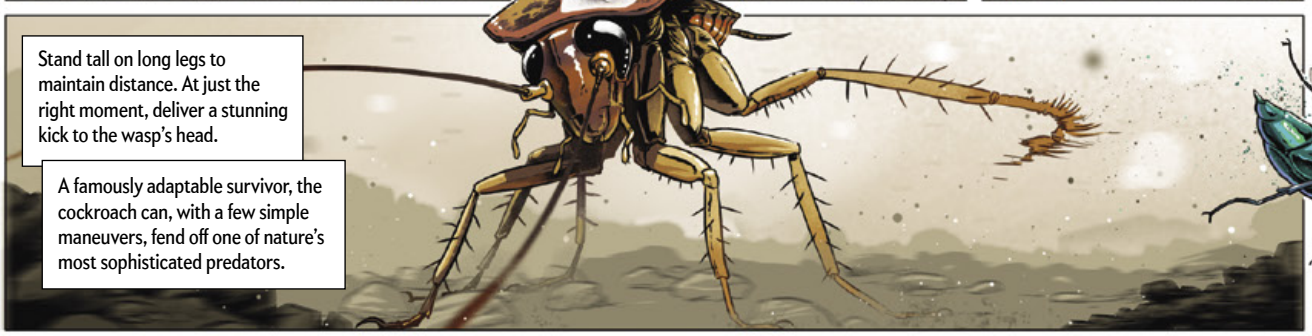


Illustration by Matthew Twombly

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SOME ROACHES prepare to fight back when a jewel wasp approaches, adopting the so-called stilt-standing posture that is akin to a fencer's en garde stance.

KENNETH C. CATANIA

would end up with enough wasps to resurrect the colony. The colony survived, but from this experience I learned that the tiny, soft-bodied wasp larva is not very competent. Unlike the frighteningly dexterous face huggers in *Alien,* a wasp grub moves slowly, if at all, and it can feed successfully only at one soft membrane on the cockroach. If it misses the target by a fraction of a millimeter, it dies (and the lucky roach recovers from the brain sting after about a week).

The grub's fragility puts a lot of pressure on the mother wasp, who must glue its egg in just the right location for its young to survive. How does the wasp do it? To explore this question, I flipped a microscope upside down and bolted it to a table, and then I arranged a clear-bottomed chamber as a tomb for the wasp to find. This rig allowed me to get a close-up recording of the entire egg-laying process. The video showed the wasp making a very thorough investigation of the cockroach leg with the tip of its abdomen before laying the egg right next to a weak spot in the roach's armor. (Like all insects, cockroaches have a tough exoskeleton, but just like medieval armor, the exoskeleton has weak points at the joints.) When I looked at the tip of the wasp's abdomen under a scanning electron microscope, I noticed an array of minuscule hairs, almost like a set of miniature whiskers. Could these be the sensors the wasp uses to find the right location for the egg?

To test this possibility, I anesthetized wasps and trimmed off the hairs. That might sound simple enough to do, but it is a comically delicate operation that I could carry out only by holding the groggy (soon to be very angry) wasp with two bare fingers while gently shaving the equivalent of its private parts with an ultrasharp obsidian scalpel. It is a good setup for the ultimate fail. But it worked, and the results confirmed my suspicion: hairless wasps had trouble finding the right spot to place the egg. This observation not only revealed a key sensor used in the egg-laying process but also confirmed the critical importance of proper egg placement—a larva that hatched in the wrong place usually died without finding the roach's weak spot.

CHANCE DISCOVERY

WHILE I WAS STUDYING the wasp's sensory hairs and larval survival, I discovered something else that was entirely unexpected. Before each female wasp found the sweet spot for its egg, it extended the tip of its abdomen and repeatedly probed the center of the cockroach in front of the middle legs. In response, the cockroach often extended the middle leg on the side where the wasp was, as if annoyed by having its underside poked.

At first I did not know what to make of this behavior. It seemed like a distraction from the wasp's egg-laying mission, as well as from my own mission of trying to understand the role of the wasp's sensory hairs. But eventually I decided to look more closely at the wasp's probing behavior by increasing the magnification of my microscope. I was astounded to see that the wasp was not just feeling around under the roach. Rather I could see the wasp's stinger as it extended below the roach's partially transparent cuticle. How could this be? Everyone who studies the jewel wasp knows it stings the roach twice—once in the first thoracic ganglion to paralyze the front legs and once in the brain to zombify the roach. Perhaps I was seeing a confused wasp, an outlier that was behaving abnormally.

I decided to change my focus, both literally and figuratively, and follow up on this observation. I soon learned that before laying an egg, every female jewel wasp delivers three stings to the central portion of the roach's body under a very specific part of its armor called the basisternum. This structure is situated directly over the second thoracic ganglion, another part of the cockroach's central nervous system. Recall that the wasp's first sting goes into the first thoracic ganglion, paralyzing the front legs during the initial attack. The second thoracic ganglion, as you might guess, houses the motor neurons that control the second pair of legs, one of which the wasp will choose as the site for its egg. I realized that the odd leg-extension behavior I had noticed occurred within a few seconds of the newly documented stings. It seemed that the wasp's sting was

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somehow forcing the roach to move its leg. Could this be one more stage in the wasp's process of establishing mind control over the cockroach?

It seemed possible, but how could I ever tell whether the sting was actually directed into the second thoracic ganglion, which is inside the roach's body? The same question had been asked about the wasp's first sting into the first thoracic ganglion, and it was a matter of long-standing debate until Libersat finally solved the mystery once and for all with an ingenious approach. He made the wasp, and thus its venom, radioactive. After the wasp stung the cockroach, he was able to show that the first thoracic ganglion contained the radioactivity.

I confess that I am not so brave as Libersat when it comes to making wasps radioactive—or to undertaking all the paperwork involved in getting the necessary permission to do such a thing. Fortunately, there was a more direct way to find out where the wasp was stinging. I anesthetized a cockroach and cut a small window into its cuticle so that the ganglion was visible. Then I increased my microscope's magnification and watched as the wasp stung. Sure enough, the sting was directed into the ganglion. (This approach would not work for tracing the first sting, which occurs during a pitched battle with the wasp.) Better yet, the sting was aimed at the side of the ganglion controlling the leg on the same side as the wasp—the side where it would later glue its egg. It is pretty clear that the wasp's venom during these later stings contains a component that activates the motor neurons in the second thoracic ganglion, thus causing the leg to extend.

But why would such a remarkably specialized behavior evolve? In other words, how does extending the roach's leg help the wasp reproduce? This time the answer was obvious. When the cockroach folds up its middle leg, the wasp cannot explore the surface with its sensory hairs to find the sweet spot for its egg where the larva can later feed and break into the cockroach. By hijacking the neural circuit that causes leg extension, the wasp removes the last barrier the roach might use to defend itself from a ghastly fate. How the venom causes this response is unknown, but we do know which neurotransmitter probably activates the target neurons: acetylcholine. Many wasps have acetylcholine in their venom, and it would likely be sufficient to activate the motor neurons and cause the observed leg extension. More study is needed to determine whether this simple explanation is correct, however, or whether some other venom component is involved.

Perhaps you can now see why I am so impressed with the jewel wasp. It has evolved the behavior and the venom needed to sequentially target three small spots in the roach's nervous system. Each sting has a different effect, and each allows the wasp to bend its victim to its will, ultimately leaving the usually elusive and dangerous cockroach alive and at the mercy of a delicate little grub. It all seems pretty hopeless for the roach, much as it did for the crew of the *Nostromo* in *Alien*. But the Alien met its match in Ellen Ripley, famously played by Sigourney Weaver. What happens when a wasp meets the Ripley of the cockroach world?

MAKING A STAND

SO FAR I HAVE TOLD YOU how a wasp defeats a cockroach with multiple stings to its central nervous system. The outcome seems inevitable if the roach is surprised by the wasp or if it runs. In those cases, the wasp easily gets the upper hand either by grabbing the roach immediately or by chasing it down—a roach cannot outrun a flying wasp. Once the wasp's jaws have closed on the cockroach, it can usually deliver the first sting within about a second, paralyzing the front legs, and—well, you know the grim story from there.

But some roaches have an attitude. They are vigilant, watching and feeling with their long antennae for an approaching threat. When a wasp closes in, these roaches do not run. Instead they get ready for a fight, raising themselves to full height by extending their long, spiny legs. In this so-called stilt-standing posture, the roach appears very much like a fencer in the en garde position, and in fact the stance seems to serve a similar purpose: it raises the roach's body away from the wasp, making it a more distant and difficult target. At the same time, the roach's legs present a phalanx of sharp spines to the wasp as it tries to reach the roach's vulnerable body. The wasp cannot deliver the first sting until it has grabbed hold of the roach. The two contestants circle each other, advancing and retreating in turn. Often the wasp will make a lunge at the cockroach, which bobs and weaves to avoid the clamping jaws before reestablishing its defensive stance.

But the real surprise for me (and seemingly for the wasp) during my observations of such encounters came in the form of powerful kicks delivered by the cockroach with its spiny hind legs. These kicks often landed squarely on the wasp's head and shoved the wasp through the air until it crashed into the nearest object. The wasp inevitably dusted itself off with a quick bout of grooming and resumed the attack, at least after the first kick. But if the cockroach managed to land multiple kicks, the wasp usually broke off its attack. Apparently, to avoid becoming zombies and then having an alien burst from their bodies, roaches have to use the same strategy as many a science-fiction character: stay vigilant, don't run and aim for the attacker's head. SA

FROM OUR ARCHIVES

Shock and Awe. Kenneth C. Catania; April 2019.

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On the Basis of Testosterone

Hormone levels are being used to discriminate against women athletes

By Grace Huckins

OLYMPIC GOLD MEDALIST Mokgadi Caster Semenya of South Africa runs in a heat of the women's 800 meters at the 2015 World Athletics Championships. She might never again race the event competitively.

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Grace Huckins is a doctoral student in neuroscience at Stanford University and a graduate of the master's programs in neuroscience and women's studies at the University of Oxford.

IN FEBRUARY 2016 DUTEE CHAND BECAME THE BEST WOMAN SPRINTER IN INDIA. THE RECORD SHE set on an indoor track in Qatar during a qualifying heat stands as the fastest time an Indian woman has ever achieved in the 60-meter race, and she soon became the first Indian woman in decades to race the 100 meters at the Olympics. Just a year earlier, however, Chand had faced the possibility of never again running competitively.

In 2014, as Chand was making her mark on the junior-level track world, the Athletics Federation of India (AFI), with the support of its international parent body World Athletics, barred her from competing in women's events because of atypically high levels of testosterone occurring naturally in her body. (There is no evidence Chand ever took banned substances to alter her hormones.) According to the AFI, which runs India's track-and-field competitions, her higher-than-average testosterone level gave her physical advantages enjoyed by male athletes. Chand disputed the idea that this hyperandrogenism—an elevated level of androgens, the class of hormones that includes testosterone—made her more like a male sprinter than a female one, and in 2015 the Court of Arbitration for Sport agreed with her. It determined that World Athletics, which sets the rules governing international track-and-field competitions, had not presented enough scientific evidence to defend its claims—and Chand could run again.

But World Athletics now contends that it has found an adequate scientific basis for barring women with high testosterone from competing in races between 400 meters and one mile unless they take medication to lower their testosterone levels or opt to compete against men. This policy does not apply to Chand, because she runs shorter distances, but it could end the athletic dreams of Mokgadi Caster Semenya, an Olympic gold medalist and a hero in her home country of South Africa. In 2019 the Court of Arbitration for Sport accepted World Athletics' argument, and the Swiss Supreme Court upheld this decision in September 2020. Rather than undergo medically unnecessary treatment to suppress her testosterone levels, Semenya has decided to compete only in the 200-meter race, an event without limits on testosterone levels, at the 2021 Tokyo Olympics.

This sequence of controversial decisions has prompted a public debate about fairness and discrimination in sports. Throughout the Olympics' modern history, rules about who counts as a woman have shifted as the scientific understanding of sex has progressed. Disqualifying athletes on the basis of natural testosterone levels is one of the last legal forms of discrimination in sports.

As an interdisciplinary scholar trained in both biology and gender studies, I have examined the ways in which scientists take social categories such as "woman" and "man" and attempt to turn them into fundamental truths. For as long as scientists have been trying to figure out the biological basis of sex and gender, nature has presented divergences from their theories. ("Sex" refers to biological characteristics; "gender" refers to social roles and identification.)

Most men have XY chromosomes and developed testicles in utero that, later in life, secrete relatively high amounts of testosterone into their bloodstreams. In contrast, most women have XX chromosomes, which drives the production of ovaries and lower levels of testosterone. Some women, however, have XY chromosomes as well as external female anatomy; these women are affected by the World Athletics policy. Such attributes reflecting variation beyond the rigid male/female binary are known as intersex traits.

According to interAct, an intersex advocacy organization, 1.7 percent of the population may be intersex, although many never realize it. And they may be overrepresented in the world of elite sports: in its published decision, the Court of Arbitration for Sport repeatedly referenced the statistic that among elite athletes, women with XY chromosomes are far more common than they are in the general population.

It seems, then, that intersex women may have an edge in athletic competitions. But so, too, do athletes with natural advantages such as, say, height in basketball tournaments. The important question here is not whether some sex traits can confer athletic advantages but whether those advantages are so meaningful and so incontrovertible that they should prevent a woman athlete such as Semenya from competing against other women.

CHROMOSOMES AND HORMONES

SEX HAS NEVER been a simple binary. Nevertheless, Olympic regulators have tried for decades to apply overly simplistic rules to this messy reality. From the 1960s until the 1990s dozens of women were singled out and even disqualified because of their chromosomes. The first was Ewa Kłobukowska, who was deemed a woman based on genital examination in 1966 but was disqualified from the 1968 Olympics because of her XY chromosomal makeup. Kłobukowska's story is not so surprising: Some intersex women are anatomically so similar to other

PRECEDING PAGES: OLIVIER MORIN *AFP via Getty Images*

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JEWEL SAMAD *AFP via Getty Images*

DUTEE CHAND (*right*) of India races in a heat of the women's 200 meters at the 2018 Asian Games. A few years earlier she had been barred from competitive women's athletics.

women that they never discover their XY chromosomal makeup.

Chromosomal testing thus disqualified some people who had every trait of the female sex except for XX chromosomes. This contradiction, coupled with the invasiveness of some testing and the dire social consequences for those who failed the tests, eventually led the International Olympic Committee to abandon sex testing in the 1990s. But its concern about ensuring the apparent fairness of women's competitions did not disappear, and it reserved for itself the option to test people on a case-by-case basis. Recent cases of sex testing have focused not on chromosomes but on an aspect of sex ostensibly more related to athletic ability: testosterone levels.

Athletes have been using artificial testosterone since at least the 1950s in the hopes of improving their performance, but until the 1990s the medical community did not hold that the link between supplemental testosterone and athletic ability had adequate scientific support. That might have influenced the International Olympic Committee's choice not to use testosterone levels in its sex-verification era. The paradigm changed after 1996, when a study demonstrated that testosterone supplementation, in combination with weight training, could increase both muscle size and strength in men.

Since then, endocrinologists have greatly expanded their understanding of the relation between testosterone and muscle mass. The evidence shows that testosterone both increases the number of muscle cells that the body produces and enhances muscle size. There is some evidence that testosterone may also influence athletic ability through other mechanisms. In one experiment, men who took high levels of testosterone (but not those who took lower levels) had increased levels of hemoglobin in their bloodstreams, a change that allows blood to carry more oxygen to the rest of the body. Testosterone could also exert influence on bone mass because low testosterone levels, much like low estrogen levels, are correlated with osteoporosis, and both hormones have a role in maintaining bone structure.

In fact, androgens ("male" hormones, including testosterone) and estrogens ("female" hormones) are much more tightly linked than most people imagine. For starters, everyone naturally produces both hormones. And all naturally occurring estrogen in humans was once testosterone, transformed into estrogen by the enzyme aromatase. Scientists debate how much of a given hormone is "normal" and how those levels should be measured—one recent study even concluded that "normal" testosterone levels for women should be adjusted to better accommodate female athletes. And men's and women's estrogen levels can actually overlap, especially during some phases of the menstrual cycle. Even so, testosterone levels do vary considerably between men and women: younger men's levels tend to range between 10 and 40 nanomoles per liter of blood, whereas women's levels tend to range between 0.5 and 3 nmol/L.

Taken together, the available evidence—the gap in between most men's and women's testosterone levels, the established connection between testosterone doping and increased muscle mass, and the approximately 10 percent advantage that elite men have

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over elite women in track events—seems to imply that women with high testosterone levels will run like men. Nevertheless in Chand's case, the Court of Arbitration for Sport found that she could not be banned from competition, because there was not yet any direct evidence of the relation between natural testosterone levels and athletic ability in elite women.

The court decided differently in Semenya's case four years later, partly because it believed that such evidence had been produced. Stéphane Bermon, head of World Athletics' scientific team, had recently published a paper that analyzed data from two international athletics competitions and found that women with higher levels of testosterone performed better, on average, than women with lower levels. Because this study is based on real-world data from elite female runners, it arguably represents the most relevant findings in the hyperandrogenism controversy to date.

I spend some of my research time trawling the scientific literature to find cases of researchers making statistical errors, particularly when their studies pertain to marginalized groups. So I was intrigued to read that a group of scientists had questioned the validity of this key study on the basis of issues with the data. In response to their concerns, Bermon updated the study, and although he still observed some effects, his conclusion was markedly weakened by the correction. When I performed a procedure called correcting for multiple comparisons—a statistical method that takes into account the increased probability of finding at least one false positive when many statistical tests, as opposed to only one, are conducted—on his reported results, these effects disappeared.

This complication does not imply that there is no relation between testosterone and athletic performance in women. What is certainly the case, however, is that far more research is needed before a firm conclusion can be reached.

SUPPLEMENTAL IS NOT NATURAL

IF TESTOSTERONE taken illegally and testosterone produced naturally had the same impact on all bodies, one would assume that male-typical levels of testosterone necessarily confer a male-typical athletic advantage. But to understand what such studies mean for women like Semenya, we must understand how their bodies work. All the women targeted by World Athletics' policy on testosterone levels are intersex, with a similar set of sex traits: they have XY chromosomes, but their bodies do not respond to androgens in the same way most XY individuals do. Because of the complexity inherent in the function of hormones, it is extremely difficult to determine the precise effect that testosterone will have on these intersex people.

Even if androgens did have a completely typical effect on them, the link between testosterone and athletic ability would remain far more tenuous than it might seem. Taking *supplemental* testosterone may tend to give someone bigger muscles, but that does not automatically imply that a person with *naturally* higher testosterone levels will be better at sports than someone with lower testosterone levels. Even the original, contested version of Bermon's study hints at a nuanced connection: whereas testosterone showed a positive effect on athletic ability for a couple of events, no effect was observed for 16 other events, and the data suggested that higher testosterone levels may be associated with worse performance in several events.

One study of elite Swedish athletes found no association between testosterone and athletic performance, and a recent study of teenage athletes in Australia showed a strong negative correlation between testosterone levels in women and performance. Men, too, do not necessarily gain an enormous advantage from high testosterone levels: almost 17 percent of elite male athletes measured in one study had testosterone levels *below* the typical male range, and nearly 10 percent of them had testosterone levels under 5 nmol/L.

The clear effect of testosterone supplements on the body and the average differences in muscle mass between men and women make it easy to assume that higher testosterone levels automatically confer superior athletic ability regardless of other factors. But the science shows that, at least among elite athletes, the link between testosterone and athletic performance is far from straightforward.

One of the first things a person learns when studying the science of sex and gender is how difficult it is to disentangle biological and social influences. For me, this issue came into stark relief when I studied apparently sex-linked advantages in areas such as spatial ability. Because men tend to experience both higher levels of testosterone and more encouragement in STEM fields than do their female counterparts, it is difficult to determine whether biological or social factors cause these differences. To answer these questions, scientists study people who have high testosterone and do not experience a masculine social environment—that is, women with particular intersex traits—and examine their behavior to differentiate between biological and social causes.

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PETER MARTEL *AFP via Getty Images (1)*; AL BELLO *Getty Images (2)*

The story gets far more convoluted when we try not only to distinguish between biological and social causes but also to investigate how those factors interact. One fascinating example comes from the work of neuroscientist Melissa Hines, who studied girls with congenital adrenal hyperplasia, a condition in which intersex traits arise in XX females because of unusually high levels of androgens. Hines showed that these girls tend to engage in play behavior seen relatively more often in boys, such as horseplay. More recently, however, she demonstrated that the girls do not necessar-

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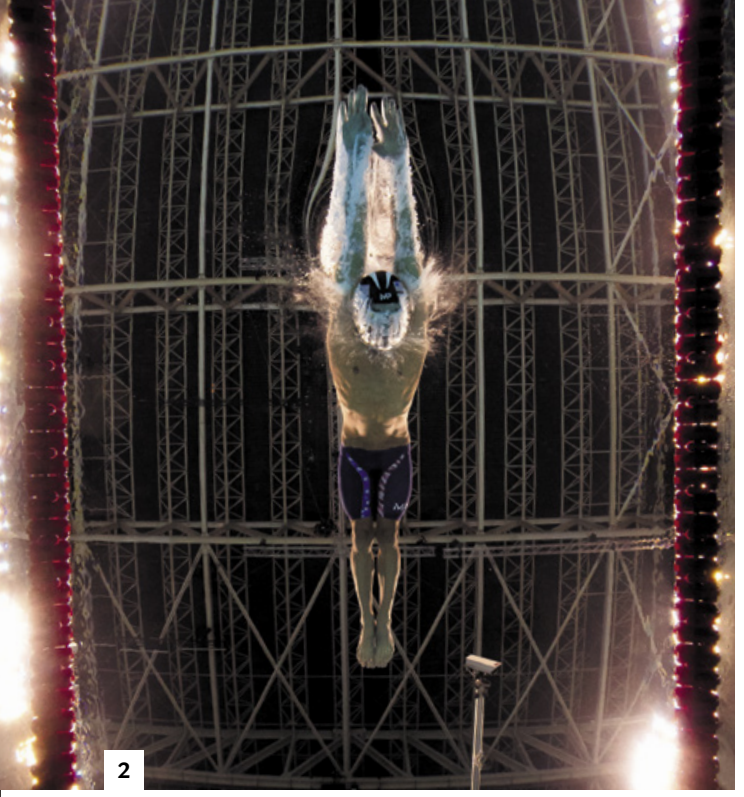

UNUSUAL ATTRIBUTES such as the 2.3-meter height of basketball player Manute Bol (*1*) and the resistance to muscle fatigue of swimmer Michael Phelps (*2*) do not normally disqualify athletes from competitive sports.

ily prefer horseplay over dolls: they just do not care about what other girls tend to do. Most young girls will prefer to play with a red ball over a blue ball if they see that other girls are playing only with red balls, but girls with congenital adrenal hyperplasia will happily play with either toy. Testosterone does not make girls more likely to wrestle than to read; it simply changes the extent to which they respond to social cues about gender.

In terms of its effects on behavior, testosterone is thus quite complex: it seems to work together with social cues such that neither factor can be isolated from the other. Although these apparently psychological observations may be irrelevant to the question of athletic ability, even Bermon and his colleagues have suggested that dominance and aggression, long associated with testosterone levels, could have a role in winning races. In one of the only studies that systematically examined the effect of taking testosterone on women's physical ability, those who took high levels of the hormone saw modestly increased muscle mass and dramatically increased strength. The researchers hypothesized that some unmeasured psychological factor allowed their slightly more developed muscles to make extraordinary athletic gains.

But it is also far too simplistic to assume that testosterone causes aggression or competitiveness, even though women might be more likely to enter competitive situations when their testosterone levels are higher, and men who respond more strongly to androgens might be more confident about their chances in competition. In fact, numerous studies have demonstrated that a person's testosterone levels will increase after, rather than before, they have won a competition or otherwise shown dominance, and one 2015 study suggested that this effect might be stronger in women than it is in men. Behavior, which is affected by social norms about men and women, exerts an influence on hormone levels—demonstrating yet again the intricate and perhaps inextricable links between the social and the biological.

When critics argue that intersex women are basically "biological men" who just happen to have clitorises and labia, they are completely neglecting the enormous influences that the categories "men" and "women" have on all of our lives—and on all of our bodies. Testosterone is not some mysterious entity that comes from nowhere to exert a huge influence on our bodies and our minds: it both changes and is changed by gender norms.

Despite being just a single element in a knotty, sometimes circular network of factors that contribute to athletic ability, testosterone is unlikely to be completely irrelevant. Somehow XY women seem likelier to achieve physical feats than XX women. This observation does not imply, however, that intersex women should be forced to compete in the men's category against men, against whom they will surely lose. Arguing that biology instructs us to divide athletes at a threshold of five nanomoles of testosterone per liter of blood, as World Athletics has done, implies that this threshold splits humans into the two fairest, most equal competitive groups possible.

Given that testosterone affects athletic ability in a complex, nonlinear fashion, this suggestion is not supported by the evidence. It would be far more sensible to split basketball into two separate height divisions: no current player in the NBA is shorter than 5'9", whereas both low-testosterone men and low-testosterone women can be extremely successful athletes. Nor is there any cogent reason to identify intersex conditions as conferring unique genetic advantages in a domain such as elite athletics, where a variety of unusual traits lead to success. Why should swimmer Michael Phelps's low lactic acid production (which helps stave off muscle fatigue) or the late NBA player Manute Bol's uncommon height be rewarded while Semenya's somewhat higher testosterone level is disqualifying?

If biology cannot give us a firm basis for dividing athletes into two distinct categories, we might wonder why we have men's and women's divisions at all. Although testosterone levels might not divide all of humanity neatly into better and worse athletes, it is the case that, at the most elite level, men outperform women in sports such as track. Making sports coed and thus de facto barring women from Olympic races would not be intrinsically unfair—after all, plenty of groups of people, such as those with poor cardiovascular health, can never dream of becoming elite runners—but it would be regrettable. We would lose women such as sprinter Allyson Felix, swimmer Katie Ledecky and the extraordinary U.S. women's soccer squad, all of whom inspire countless young women.

Biology alone is too limited a tool to tell us how to divide up the athletic field—but it can help us gain a greater understanding of natural human variation. Particularly in a domain as convoluted and controversial as sex and gender, science often uncovers more ambiguity than it resolves. And if science does not inform the issue of intersex women in sports, we can still revert to the values of diversity, inclusion and acceptance that make elite women's sports so extraordinary in the first place. SA

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Olympic Officials Should Tell Women "High T" Is No Hurdle. The Editors; August 2016.

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OXIDIZING SOOT makes the plume of this Russian Soyuz-FG rocket glow during a 2015 launch from Kazakhstan.

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SPACEFLIGHT

SPACE POLLUTION

The new private launch industry can learn a lot from aviation about sustainability

By Martin N. Ross and Leonard David

THE SPACE INDUSTRY IS GROWING AND innovating at a pace not seen since the days of the moon landings. Fifty years ago nearly everything related to space was a government-sponsored project. In 21st-century space, rockets and satellites are most often corporate investments or public-private partnerships.

Untethered from government leashes, the global space industry looks and operates increasingly like global aviation. Reusability. Regular flight cadence. Mass production of spacecraft and launch vehicles. Analysts predict that the space industry's contribution to global GDP could cross the 1 percent threshold by 2040. We can reasonably construct future scenarios where the space and aviation industries have comparable economic clout.

A great deal of aviation's remarkable airframe and propulsion developments since World War II have been guided by sustainability concerns, mainly focused on jet engine emissions. Modern jet engines emit much less soot and gas pollutants than engines emitted 50 years ago. The pressure to reduce jet emissions has been good for aviation because honing turbine combustion to near theoretical maximum efficiency has had the

NASA VIA GETTY

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benefit of reducing fuel consumption. Good for corporate bottom lines and good for planet Earth.

Sustainability has not been much of a concern for space systems development. Just like their jet engine cousins, rocket engines emit a variety of gases and particles into the atmosphere that can have regional and even global consequences. Even so, the environmental impacts of launch vehicles are typically disregarded by comparing jet and rocket fuel consumption in an overly simplified way.

The argument goes like this: Rockets burn only 0.1 percent of the fuel that aircraft burn every year and are therefore only 0.1 percent of the emissions problem that aviation presents. But this is a case of false equivalence. Careful understanding of every phase of space flight shows that space emissions can change the atmosphere in ways that are wholly different from, and in some cases worse than, aviation emissions.

Unlike with aviation, emissions produced by the space industry affect every layer of the atmosphere. Whereas jet emissions into the troposphere are quickly washed to the surface by precipitation, rocket emissions into the stratosphere are cleared away only slowly. Stratospheric emissions accumulate year over year, adding up exhaust from all of Earth's launches and reentries over the past four or five years. In fact, the fragile ozone layer resides in the stratosphere, near where rocket emissions accumulate.

Prospects for space travel have never been more thrilling. Advances in the space industry, including high-performance smallsats, low-Earth-orbit (LEO) mega constellations, new rocket propellants and lunar resource extraction, are driving the 21st-century "New Space" growth. These developments could realize the long-held ambition to make space travel as commonplace as air travel. But are these new space technologies on a sustainable path?

GAS EXHAUST

ROCKET ENGINE EXHAUST, like jet exhaust, is mostly carbon dioxide and water vapor, and the global impacts of these emissions are well understood. Carbon dioxide emitted at any altitude is a "long-lived" greenhouse gas (GHG), adding to the atmospheric GHG burden. Water vapor is a "short-lived" GHG. These components of rocket exhaust are a small fraction of 1 percent of aviation's CO_2 and H_2O outputs. Even though their current consequences are small, some minor rocket exhaust components require closer inspection.

Solid-rocket motor (SRM) oxidizer, ammonium perchlorate, contains chlorine, the most serious threat to stratospheric ozone. Direct plume sampling 20 years ago by NASA aircraft showed that SRM plumes create dramatic ozone "mini holes" that persist for several days after a launch. The mini holes disappear, however, as the chlorine-laden plumes mix into the global stratosphere, and all the chlorine emitted by SRMs every year is small and short-lived compared with the chlorine released by the notorious chlorofluorocarbons. Chlorine from SRMs is most likely not a serious threat to the ozone layer.

Scientists well understand how the CO_2, H_2O and Cl gas emissions from rockets affect climate and ozone. And all this research indicates that these impacts are insignificant compared with other pollution sources and are buried in the noise of the global atmosphere. Even if these launch emissions increased by an order of magnitude, their consequences would be small. Still, there is another component to rocket exhaust that could be significant: particles of black carbon (BC) soot and alumina.

PARTICLE EMISSIONS

ROCKETS FAMOUSLY DISPLAY BRILLIANT EXHAUST PLUMES. The "flame" of a hydrocarbon-fueled rocket engine is mostly the incandescent glow of soot particles oxidizing in the hot plume. Soot production in rocket engines is complicated and not very well understood. Soot forms in fuel-rich combustion chambers, fuel-cooling nozzle walls and turbopump gas generators and is partly consumed in the hot plumes. Jet engines have none of these complexities and burn very clean compared with rocket engines. Some types of hydrocarbon-fueled rocket engines emit hundreds of times more soot for each kilogram of fuel burned than do their jet engine cousins. And jets only occasionally fly in the stratosphere; rockets fly there every launch.

What is the concern about soot in the stratosphere? Black carbon soot very efficiently absorbs sunlight. The absorbed energy is transferred to the surrounding air, so that BC soot acts as a heat source, warming the stratosphere, which can in turn slightly change the circulation of the global atmosphere. And because ozone concentration is inversely proportional to temperature, a warmer stratosphere equates to depletion of the ozone layer. Is the BC soot emitted by the current fleet of rockets great enough to have a significant effect on the atmosphere? We do not yet know. The required climate models are only now being assembled.

Solid-rocket motor plumes are even more brilliant than hydrocarbon-fueled plumes. White-hot alumina droplets leaving the nozzle are the source for the SRM flame. As with the chlorine gas emission, SRM plumes diffuse and eventually mix into the global atmosphere so that rocket alumina particles are found in random stratospheric air samples from equator to poles. In the 1990s researchers discovered how ozone-destroying chemical reactions occur on the surface of SRM alumina particles, but alumina's significance as a source of ozone depletion is not known. SRMs emit ozone-destroying chlorine gas, too, of course, and the double-sided nature of SRM ozone depletion is poorly described. The 2018 World Meteorological Organization ozone assessment acknowledged the large gaps in our understanding and noted that further research is "warranted."

The space shuttle SRMs were the largest ever flown, and it is often mistakenly assumed that the use of large solid rockets ended when the space shuttle retired. In fact, SRMs are finding increasing launch applications around the planet. The Space Launch System's 144-inch-diameter SRMs will be the most massive ever flown when the next-generation NASA heavy-lift vehicle lifts

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off for the first time in November 2021. Even that rocket will be eclipsed by a Chinese 156-inch SRM planned for a 2025 debut. SRMs present a growing and poorly known hazard to stratospheric ozone.

WHAT GOES UP COMES DOWN

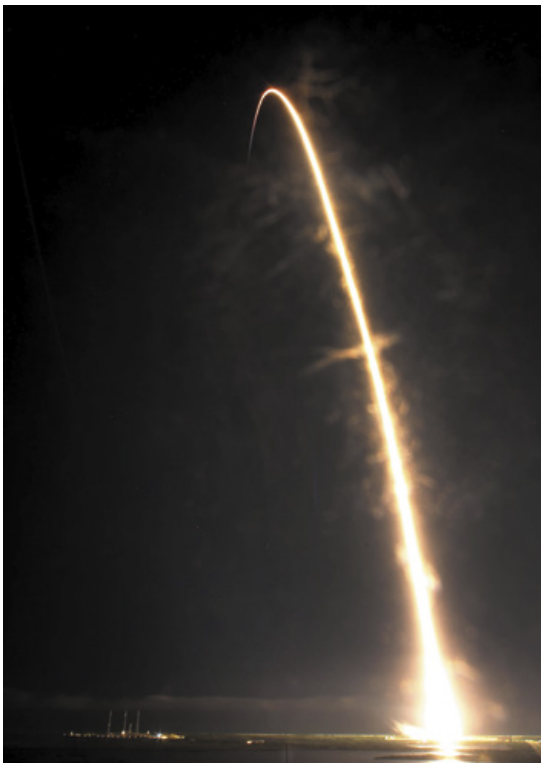
SPACE POLLUTION DOESN'T STOP when a rocket leaves the atmosphere. Contrary to many media stories about the latest spectacular space junk reentry, orbital debris returning to Earth does not "disappear" or "burn up" on reentry. Some parts of derelict spacecraft will survive reentry and reach the surface. Most of the reentering mass vaporizes into a hot gas that quickly condenses into a spray of small particles, however. Thus, as with launch, bright plumes mean particle production. Unlike the chemically simple particles from launch, particles from reentering space junk will be a zoo of complex chemical types. Particles from vaporizing propellant tanks, computers, solar panels and other exotic materials will form around an 85-kilometer altitude, then drift downward, accumulating in the stratosphere along with the launch's soot and alumina. Reentry is as much of an "emission" as a launch.

The growing low-Earth orbit mega constellations, with thousands of satellites in each constellation, use reentry vaporization as the satellite end-of-life disposal mechanism. Once these constellations are deployed, hundreds of tons of nonfunctioning satellites will be "brought in" for disposal every year. Most of this mass will become particles in the middle atmosphere. Very little is known about reentry dust production, the microphysics of the particles, and how reentry dust could affect climate and ozone.

Space has entered a growth phase reminiscent of aviation's early days. Once a technology becomes a normal part of the market economy, there is no limit to potential new applications. And like its aviation industry big brother, the space industry emits gases and particles into the atmosphere from propulsion systems. But a comparison between aviation emissions and space emissions must account for the vastly different ways that the two industries affect Earth's atmosphere.

Carbon dioxide emissions from jet engines will be much larger than CO_2 emissions from rocket engines for any foreseeable future. This is reflected in well-meaning but misguided calculations of a conventional "carbon footprint" for space. But CO_2 is not where the action is for space pollution. The particles emitted by rocket launches and space debris reentries cause much larger changes in atmospheric chemistry, dynamics and radiation than rocket CO_2 emissions. For the space industry, the carbon footprint is a complicated story that is yet to be appropriately defined.

The recent controversy over the brightness of LEO satellites highlights how sustainability needs to become a fundamental aspect of space system development. It will be easier to guarantee unimpeded use of space systems if the environmental impacts of every stage in a system's life cycle are evaluated ahead of time. This is how aviation contemplates sustainability. Environmental concerns that appear after deployment encourage regulation. Full and complete analysis before deployment inoculates against regulation.



ASTRONAUTS launch toward the International Space Station onboard a SpaceX Crew Dragon craft propelled by a Falcon 9 rocket in November 2020.

RED HUBER *Getty Images*

Ironically, only space can provide the perspective required to manage humanity's stewardship of our planet. *Apollo 8*'s view of Earthrise is often associated with the beginning of global environmentalism. And yet space industry emissions themselves are too poorly known to answer fundamental questions about space's environmental impact and sustainability. As we look to aviation, an appropriate scientific program would include measurements of launch and reentry plumes, detailed modeling of plumes from fresh emissions to steady state global mixing, and laboratory measurements of the microphysics of all the different particle types generated from launch to reentry. The effort should be a government and commercial partnership.

The space industry is poised to become a more significant part of the global economy just at a time when sustainability is becoming a common goal across the world. What would a sustainable space industry look like? What are the future regulatory threats to space development? We will not know the answers to these questions until we carry out a sustained, globally coordinated scientific research program on space industry emissions. SA

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Birth of a Rocket. David H. Freedman; June 2015.

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PUBLIC HEALTH

HOW COVID SCRAMBLES THE SENSES

Explanations begin to arise at the molecular level for this vexing but commonplace phenomenon

By Stephani Sutherland

Photograph by Rahim Fortune

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Stephani Sutherland is a neuroscientist and science writer based in southern California.

IT DAWNED ON EIAN KANTOR ON A SATURDAY IN EARLY APRIL AS HE BREWED A CUP OF TEA FROM FRESH mint leaves: he had lost his sense of smell. The tea suspiciously smelled of nothing at all. Kantor proceeded to rifle through the fridge, sniffing jars of pickles, chili sauce and garlic—nothing.

Ever since New York State went into lockdown in late March, Kantor, age 30, and his girlfriend had stayed isolated in their Queens, N.Y., apartment. So he did not suspect he had COVID-19 despite running a slight fever that he chalked up to seasonal allergies. When he was finally able to get tested weeks into his loss of smell, or anosmia, he tested negative. But months later, he says, several tests showed that his antibodies to the novel coronavirus were "off-the-charts high, which affirmed that I had had it."

An estimated 80 percent of people with COVID-19 have smell disturbances, and many also have dysgeusia or ageusia (a disruption or loss of taste, respectively) or changes in chemesthesis (the ability to sense chemical irritants such as hot chilies). Smell loss is so common in people with the disease that some researchers have recommended its use as a diagnostic test because it may be a more reliable marker than fever or other symptoms.

One lingering mystery is how the novel coronavirus robs its victims of these senses. Early in the pandemic, physicians and researchers worried that COVID-related anosmia might signal that the virus makes its way into the brain through the nose, where it could do severe and lasting damage. A suspected route would be via the olfactory neurons that sense odors in the air and transmit these signals to the brain. But studies have shown that this is probably not the case, says Sandeep Robert Datta, a neuroscientist at Harvard Medical School. "My gestalt read of the data to date suggests that the primary source of insult is actually in the nose, in the nasal epithelium," the skinlike layer of cells responsible for registering odors. "It looks like the virus attacks, predominantly, support cells and stem cells and not neurons directly," Datta says. But that fact does not mean that neurons cannot be affected, he emphasizes.

Olfactory neurons do not have angiotensin-converting enzyme 2 (ACE2) receptors, which allow the virus entry to cells, on their surface. But sustentacular cells, which support olfactory neurons in important ways, are studded with the receptors. These cells maintain the delicate balance of salt ions in the mucus that neurons depend on to send signals to the brain. If that balance is disrupted, it could lead to a shutdown of neuronal signaling—and therefore of smell. The sustentacular cells also provide the metabolic and physical support needed to sustain the fingerlike cilia on the olfactory neurons where receptors that detect odors are concentrated. "If you physically disrupt those cilia, you lose the ability to smell," Datta says.

In a study in *Brain, Behavior and Immunity,* Nicolas Meunier, a neuroscientist at Paris-Saclay University in France, infected the noses of golden Syrian hamsters with SARS-CoV-2, the virus that causes COVID. Just two days later about half of the hamsters' sustentacular cells were infected. But olfactory neurons were not infected even after two weeks. And strikingly, the olfactory epithelia were completely detached, which, Meunier says, resembled skin peeling after a sunburn. Although olfactory neurons were not infected, their cilia were entirely gone. "If you remove the cilia, you remove the olfactory receptors and the ability to detect odorants," he says.

Disruption of the olfactory epithelium could explain the loss of smell. Yet it remains unclear whether the damage is done by the virus itself or invading immune cells, which Meunier observed after infection. Widespread reports of anosmia with COVID are not typical of other diseases caused by viruses. "We think it's very specific to SARS-CoV-2," Meunier says. In a previous study with other respiratory viruses at his laboratory, he found sustentacular cells infected only rarely, whereas with SARS-CoV-2, about half of cells contained the pathogen. With other viruses, smell is usually compromised by a stuffed-up nose, but COVID does not usually cause nasal congestion. "This is very different," Meunier says.

Researchers have found a few clues about the loss of smell, but they are less certain about how the virus causes a loss of taste. Taste receptor cells, which detect chemicals in the saliva and send signals to the brain, do not contain ACE2, so they probably do not get infected by SARS-CoV-2. But other support cells in the

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tongue carry the receptor, perhaps providing some indication of why taste goes away. (Although taste can seem to disappear with anosmia because odors are such a key component of flavor, many people with COVID truly develop ageusia and cannot detect even sweet or salty taste.)

The loss of chemical sensing—the burn of hot chilies or the refreshing sensation of mint—also remains unexplained and largely unexplored. These sensations are not tastes. Instead their detection is conveyed by pain-sensing nerves—some of which contain ACE2—throughout the body, including the mouth.

More clues to how the virus obliterates smell come from people recovering from anosmia. "The majority of patients lose smell like a light switch going off and recover it rapidly," Datta says. "There's a fraction of patients that have much more persistent anosmia and recover on longer time scales." The olfactory epithelium regularly regenerates. "That's the body's way of protecting against the constant onslaught of toxins in the environment," Meunier says.

"Nothing is accurate, and the odors are all unpleasant," says Freya Sawbridge, a 27-year-old New Zealand woman. "All my food tastes like it was sprayed with window cleaner."

Still, more than seven months after he first experienced anosmia, Kantor falls in the second group of patients: he has yet to detect any odors at all. "It's hard because you don't realize how much you relate to smell until you lose it," he says. "If the house were on fire, I wouldn't know it. It's very concerning." And then there is what anosmia does to the joy of eating. "Foods that used to be good now taste 'meh,'" Kantor says.

Carol Yan, a rhinologist at the University of California, San Diego, says that anosmia poses a real health risk. "It actually increases mortality. If you can't smell and taste food, it can predispose you to harm, like rotten food or a gas leak," she says. "It can also cause social withdrawal or nutritional deficits."

The variation on sensory themes extends to another symptom called parosmia, a possible sign of recovery in people with long-lasting anosmia. Freya Sawbridge, a 27-year-old New Zealand woman, is such an individual. She contracted COVID-19 in March. After several weeks of anosmia and ageusia, when everything tasted of "ice cubes and cardboard," she says, Sawbridge began to regain the most basic tastes—sweet, salty, sour—but no nuance of flavor, which comes from foods' aromas. "Chocolate tastes like sweet rubber," she says.

Then, after about five months, some odors returned but not as expected. For a while, all foods smelled of artificial strawberry flavor. But now "everything smells hideous and distorted," Sawbridge says. "Nothing is accurate, and the odors are all unpleasant." The smell of onions, she says, is unbearable, and a strange chemical flavor permeates everything. "All my food tastes like it was sprayed with window cleaner," Sawbridge adds.

Parosmia may occur when newly grown stem cells that develop into neurons in the nose attempt to extend their long fibers, called axons, through tiny holes in the base of the skull and connect with a structure in the brain called the olfactory bulb. Sometimes axons connect to the wrong place, causing erratic smell, but the miswiring can potentially correct itself, given enough time.

That news is welcome for people such as Sawbridge. But the question she wants answered is: How long will her condition last? "We don't know the final time course of recovery for those with anosmia," Yan says, but it is usually from six months to a year. "With long-term postviral smell loss from the flu, after six months, there is a 30 to 50 percent chance of spontaneous recovery" without any treatment, she adds. "There have been case reports of recovery after two years. But after that, we think the regenerative capability may be hindered. And the chances of recovery are quite slim, unfortunately."

Kantor has tried every avenue imaginable to regain his sense of smell: a course of high-dose steroids to reduce inflammation; a smell-training program with essential oils; beta-carotene supplements for nerve regeneration; acupuncture. Nothing has made a difference. Yan recommends "irrigation" of the sinuses with budesonide, a topical steroid shown to improve outcomes in a Stanford University study of people with postflu smell loss for more than six months. Another promising treatment Yan and others are investigating is platelet-rich plasma, an anti-inflammatory concoction isolated from blood that has been used to treat some types of nerve damage. But with any treatment, Yan says, the results "are not amazing. It's not like you'll wake up and say, 'Wow, I can smell again.' But if you can smell soap again or enjoy the taste of some foods, that's a big gain."

There is one final worrying note about anosmia: it has been identified as a risk factor for some neurodegenerative diseases. "After the flu pandemic of 1919, we saw an increase in the prevalence of Parkinson's disease," Meunier says. "It would be really concerning if something similar were happening here." But Yan thinks that fear is overblown. "There is certainly a link between anosmia and diseases, but we think that viral-induced anosmia is [working by] a totally different mechanism," she says. "Having postviral anosmia doesn't put you at higher risk for disease. These are two completely separate phenomena." That should reassure Sawbridge and Kantor—and the millions of others worldwide affected with COVID-related smell loss. SA

FROM OUR ARCHIVES

The Immune Havoc of COVID-19. Akiko Iwasaki and Patrick Wong; January 2021.

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ENVIRONMENT

THE DAY THE MUSIC DIED

"Swamp ash," the wood behind the world's most famous guitars, is vanishing because of flooding and a tree-boring beetle

By Priyanka Runwal

Photograph by Gregory Reid

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CLASSIC FENDER GUITARS, such as this 1959 "Toploader" Telecaster, use swamp ash wood.

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Priyanka Runwal is a science and environmental journalist living in New York City.

EVERY WINTER AND SPRING, RAINS ACROSS THE CENTRAL U.S. COMBINE WITH snowmelt along the northern reaches of the Mississippi River to inundate the hardwood-dominated bottomlands of the lower Mississippi. When the floodwaters recede and soils dry up in summer, logging crews move in. One of their targets has been swamp ash. These wetland trees have thin-walled cells with large gaps between them, creating a low-density wood—and some say a special sound—that has made it the material of choice for some of the most famous guitar players in rock and roll.

Starting in the 1950s, iconic guitar maker Fender Musical Instruments embraced this type of ash. Bluesman Muddy Waters, rockers Keith Richards of the Rolling Stones and Chrissie Hynde of the Pretenders, and other music legends have loved their Fenders; many say this wood gives the instruments a warm but crystal-clear twang. Swamp ash—also called "music ash" or "punky ash"—is primarily green ash, but the term can encompass other species that grow in bottomlands, such as black ash and white ash. The wood became an integral part of Fender's DNA over the decades, says Mike Born, former director of wood technology at the U.S. company, and it once was cheap and readily available.

But last year an acute shortage forced Fender to announce it would move away from using swamp ash in its famous line of Stratocasters and Telecasters—reserving the wood for high-priced vintage models only. Fender blamed the dwindling supply on longer periods of climate-fueled flooding along the lower Mississippi—which is endangering saplings and making it harder for lumber companies to reach standing trees—as well as the looming threat of an invasive tree-boring beetle. Another renowned U.S. manufacturer called Music Man raised similar sourcing concerns in 2019, which the company described as having "one of the worst harvests in recent history."

The ominous situation shows how climate change consequences can reverberate through all aspects of society—even rock and roll. And the swamp ash supply could soon become still more tenuous because experts expect global warming to continue to make floods worse. "The average player just won't be able to afford it," Born says.

INUNDATION AND INVASION

IN THE LOWER MISSISSIPPI RIVER, these trees are capable of enduring seasonal flooding. As soon as the bottomlands are dry enough, logging crews set out to harvest the timber. "Once the river goes back within its banks, the ground is just as safe to cross with heavy logging equipment as a Walmart parking lot," says Norman Davis, former president and a current adviser for Anderson-Tully Lumber in Vicksburg, Miss. The company was once Fender's biggest supplier of swamp ash, Davis notes, but increasingly intense flooding events have made things difficult. "The bottomlands have been pretty much inaccessible the past two and a half years," he says.

Between June 2018 and July 2019, the U.S. experienced its 12 wettest months on record, according to the U.S. National Oceanic and Atmospheric Administration. The agency found that the 2019 spring floods along the Mississippi were among the most damaging in modern history. And a 2018 study in *Nature* showed the area's flooding has become more frequent and severe over the past 150 years. "We've got intense rainfall from climate change that's increasing the amount of water going into the river," says Gerald Galloway, an expert on Mississippi River hydrology and a civil and environmental engineering professor at the University of Maryland, College Park. And an expanding system of dams, walls and levees—originally intended to prevent floods—may instead be making the situation even worse.

Green ash, one particularly prized swamp tree, is a fast-growing species, and it has adapted to seasonal flooding. But lengthening periods of high water can still mean trouble, especially for seedlings. "If you're talking about an early-growing-season flood that flushes out in a couple of weeks, it's not really a problem for ash," says Brady Self, a forestry specialist in bottomland hardwoods at the Mississippi State University Extension Service. But they are not geared to withstand year after year of long-duration floods. "If the water stays on for months, at a time when the seedlings just don't have their heads above the water, they might have trouble surviving," Self says. Lee Jones of J. M. Jones Lumber Company in Natchez, Miss., says he has witnessed some damage. "The river has been up for so long, and for so much, that it's killed a lot of the trees," he says.

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Another threat is also lurking: the emerald ash borer. The larvae of this invasive beetle, native to Asia, tunnel through wood and disrupt trees' ability to transport water and nutrients. Since it was first spotted in this country (in Michigan in 2002), the pest has spread to 35 U.S. states and five Canadian provinces and killed millions of native ash trees. "I think it's the most rapid-spreading insect we've seen attacking trees in the U.S.," says Jennifer Koch, a U.S. Forest Service biologist.

The emerald ash borer has not reached the lower Mississippi floodplains, but Koch says "it's only a matter of time" until the beetle does so. Aware of this threat, several lumber companies started harvesting any adult swamp ash trees they could find in areas selected for annual logging in 2015. Previously, they would limit the take to about 30 percent of adult ash trees in those designated spots. Koch says the decision makes sense under the current circumstances, although it leaves fewer trees for the future.

FLOODS in Mississippi lowlands have endangered swamp ash trees (*1*). Their wood, now hard to find, produces a special look for guitars such as this Fender Telecaster, which is being shaped at a company factory (*2*).

A PLAYER'S PICK

FENDER'S ANNOUNCEMENT about moving away from ash has triggered some dismay in the guitar world. For Richie Kotzen, who rose to fame decades ago with the heavy metal bands Poison and Mr. Big, the ramifications are personal: he recently learned that his signature Fender guitar models, crafted with swamp ash bodies since the 1990s, will now need to be made with a different type of wood. "Many years ago I had decided what my favorite woods were on a guitar. I learned that I liked a swamp ash body with a maple neck, and I stuck with it," he says. "Now I'm going to have to figure out a replacement wood for ash."

There are a handful of options, including red alder, which is native to North America's West Coast. Since the late 1950s Fender has used alderwood to make less expensive versions of many of its swamp ash guitar models. But many aficionados think ash wood's blond hue and open grain make for a prettier-looking instrument—and for nuanced differences in sound tonality that set it apart from alderwood. "Ash has a very fast attack. Think of a bright clap," says Brian Swerdfeger, vice president of Fender's guitar R&D wing. "Alder has a warmer, softer attack. Still a clap, but it's rounder."

Koch and other researchers are also trying to breed green ash (and other ash species) that might resist the emerald ash borer and replace disappearing tree stands. The project will take decades, but with climate change continuing largely unabated, future flooding problems in the bottomlands are unlikely to wane. The plight of the trees troubles musicians as well as scientists. "I can adapt to a new wood," Kotzen says. "But I'm much more bothered by the environmental issue."

The area of the Mississippi River near where Jones's and Davis's companies log receded this past summer, and logging crews have returned to the bottomlands. The region's ash will remain a precarious commodity in the foreseeable future, however. "There's great demand, but I don't think we're going to have much punky ash to sell," Jones says. "There just aren't as many trees left."

Because it may get harder for future generations to lay their hands on swamp ash Fender guitars, music fans may have to content themselves with the wood's legacy—perhaps by cranking up the *Stairway to Heaven* solo that Led Zeppelin's Jimmy Page shredded on his swamp ash Dragon Telecaster. SA

FROM OUR ARCHIVES

The End of Orange Juice. Anna Kuchment; March 2013.

scientificamerican.com/magazine/sa

W. NORMAN DAVIS (1); FENDER (2)

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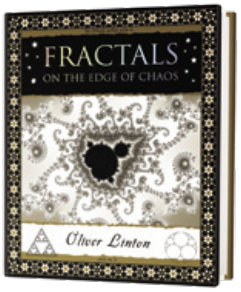
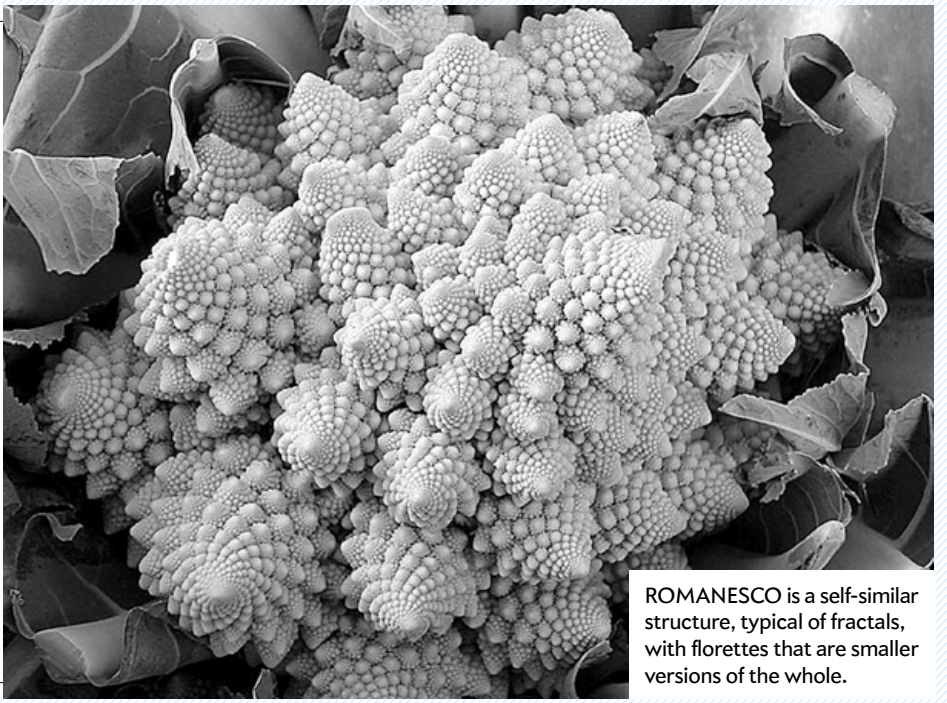
RECOMMENDED

By Andrea Gawrylewski

Fractals: On the Edge of Chaos

by Oliver Linton. Bloomsbury, 2021 ($14)





ROMANESCO is a self-similar structure, typical of fractals, with florettes that are smaller versions of the whole.

Most of the shapes found in nature cannot be described mathematically using classical geometry. Rather than simple straight lines, cones or circles, natural shapes, such as a coastline or the billows of a cloud, often reveal more angles the closer you view them. Such is the nature of fractals, writes former physics teacher and mathematics enthusiast Linton in this visually absorbing collection. Magnified fractal shapes and their components are often self-similar, meaning the whole has roughly the same shape as its smaller pieces—think of the repeating pattern of branches on a tree or the fronds of a fern. The field of fractal geometry was officially named in 1982, although many mathematicians worked on these concepts earlier. In 1904 Swedish mathematician Helge von Koch described the self-similar patterns of a snowflake, showing that math is truly behind the tiniest natural wonders.

Strange Bedfellows: Adventures in the Science, History, and Surprising Secrets of STDs

by Ina Park. Flatiron Books, 2021 ($27.99)

An epidemic other than COVID-19 has been growing in the U.S.: sexually transmitted infections (STIs). Stigma, writes physician Park, prevents people from discussing them and thus stifles any hope of curbing the current trend. Through intriguing anecdotes, she covers the science behind the treatment and prevention of STIs. She recounts kissing her young son to infect him with common oral herpes, hoping he would build antibodies against genital herpes. And she jokes that *Pthirus pubis,* the pubic lice commonly referred to as crabs, could be at risk of going extinct because pubic hair grooming has become more popular. The stigma could be defeated, Park writes, if only "the 'ick' factor around STIs might gradually be replaced with a bit of wonder and fascination." —*Karen Kwon*

Under a White Sky: The Nature of the Future

by Elizabeth Kolbert. Random House, 2021 ($28)

The danger of the term "Anthropocene," which many scientists have lobbied to use to describe the current geologic period of Earth's history defined by human impact, is that it sounds clinical and detached. It seems to belong in a forgotten dusty geology tome. In reality, writes journalist Kolbert, our species is altering the planet in infinite and messy ways, in some cases irreparably. This intimate natural history is both a sober assessment of the ecosystems we have harmed and an exciting description of some of the discoveries that could help undo that damage. To cure Earth of ourselves, we must use our own ingenuity to devise solutions such as breeding extinction-resistant fish and shooting diamonds into the stratosphere to curb global warming. If we humans write the Anthropocene, let's hope the final story is one of redemption.

The Mission: A True Story

by David W. Brown. Custom House, 2021 ($35)

The Mission is not a paint-by-numbers book about space exploration. Rather than focusing on the technical details of its topic—NASA's multibillion-dollar Europa Clipper mission, currently set to launch in 2025 to search for alien life—the book zooms in on the personalities behind it. Journalist Brown labored (with obvious love) for seven years interviewing a small army of scientists, engineers and bureaucrats, and the result is a magnificent portrait of the people responsible for making scientific dreams come true, via the decades-long process of transforming PowerPoint presentations into real spacecraft awaiting liftoff on a launchpad. This book cannot answer the question of what—if anything—lurks in Europa's dark abyss, but it masterfully reveals with remarkable clarity what lies within the hearts of the men and women determined to find out. —*Lee Billings*

OLIVER LINTON *Bloomsbury*

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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).

Is Science Too Mean?

Mutual critique is a necessary part of the game—but it needn't be cruel

By Naomi Oreskes

One unanticipated consequence of the current pandemic is that many scientists are cutting one another some slack. Journal editors have become more relaxed about deadlines, funding agencies are granting extensions with little or no explanation needed, and universities have given graduate students more time—and in some cases even more funding—to finish their Ph.D.s. And many scholars are working productively from home relieved of the pressure to appear in person when the work does not actually require it. In a piece in *Nature* last April, Gemma Derrick, a senior lecturer in higher education at Lancaster University in England, wondered whether in the future such kindness might not be sustained. Derrick's scholarly work "focuses on building a kinder, gentler, more inclusive research culture by modifying one of its harshest processes, peer review," and she proposes we use the "momentum of COVID-19" to "firmly embed kindness into research practice."

In my experience, most scientists are gracious and generous most of the time. But it is also true that science is highly competitive, that the pressure to succeed is great, and that rude, inappropriate, discriminatory and even illegal behaviors may be excused on the grounds that the perpetrator is "a great scientist." Too often we permit the alleged importance of our work to justify a neglect of basic human decency and compassion.

Being kind is viewed as secondary to being successful. One scientist I knew when I was an assistant professor told me that after she got tenure, she had to "learn how to be nice again." (To her credit, she was by then actively engaged in mentoring younger women, myself included.) If we want to nurture talent, particularly among those who have been historically underrepresented in science and may therefore feel uncertain as to their place in the endeavor, it behooves us to consistently treat students and coworkers with dignity and respect. But research practice also refers to how we evaluate scientific claims at workshops and conferences and how we evaluate grant proposals or act as reviewers for papers submitted to professional journals. Here things get trickier. Because how do we know if a scientific claim is right? How do we know whether the methods a group has used are reasonable and have been applied with rigor? How do we know if the conceptualization behind a model reasonably reflects the real world?

The answers to these questions rest heavily on the peer-review process and, more specifically, on the critical processes of vetting scientific claims that peer review entails. This occurs in a formal way when we sit on panels that review grant proposals or papers submitted by our colleagues for publication. It also occurs informally when we meet at conferences, departmental seminars and

workshops and discuss research either before or after it has been published. Through these activities, scientists scrutinize one another's evidence and arguments, rejecting the ones that do not hold up.

We can think of peer review as a kind of sifting: not all false or erroneous claims are detected and rejected, but many are. Individual scientists do commit fraud and engage in sloppy and stupid practices, but peer review lets others point such problems out. Recent debates about *p*-hacking—that is, selectively reporting statistics favorable to an author's hypothesis—in science, particularly in psychology, prove the point: yes, many scientists have used statistics badly, but a vigorous debate has ensued, and remedies are being identified and applied. Philosopher of science Helen Longino of Stanford University has called this process "transformative interrogation"—transformative because it transforms a claim into knowledge and interrogation because it is not always gentle.

It hurts when a paper is rejected. It smarts when a reviewer says that a proposal is not sufficiently well thought through. But it is essential. Think of it as tough love: scientists take the time to review colleagues' work because they are committed to the production of reliable knowledge. If we are doling out criticism, we should try our best to do it as kindly as we can. But if we are on the receiving end, we need to dig deep and accept it, even (or especially) if it hurts. It is through taking and responding to criticism that we make our own work better and, with a bit of luck, find durable truths about the natural world. SA

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Illustration by Jay Bendt

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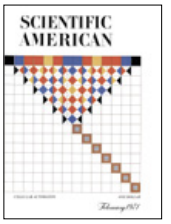
1971 Computer Architect

"The computer ILLIAC IV, which is now nearing completion, is the fourth generation in a line of advanced machines that have been conceived and developed at the University of Illinois. ILLIAC I, a vacuum-tube machine completed in 1952, could perform 11,000 arithmetical operations per second. ILLIAC II, a transistor-and-diode computer completed in 1963, could perform 500,000 operations per second. ILLIAC III is a special-purpose computer designed for automatic scanning of large quantities of visual data. ILLIAC IV, employing the latest semiconductor technology, is actually a battery of 64 'slave' computers, capable of executing between 100 million and 200 million instructions per second. Unlike its predecessors, which solve problems by a series of sequential steps, ILLIAC IV is designed to perform as many as 64 computations simultaneously. For such a computing structure to be utilized efficiently the problem must be amenable to parallel, rather than sequential, processing. —Daniel L. Slotnick"

1921 Rocket Science Wins

"The value of the multiple charge rocket for high altitude research is obvious when it is realized that, save for a projectile fired from a gun, which would produce forces too great to be withstood by a delicate apparatus, this method is the only one that does not require the presence of air. Next, as to the question of propulsion beyond the predominating gravitational influence of the earth, the one that has given rise to most discussion is, perhaps, 'What is the value of such performance, even granted that it is physically possible?' This question suggests others: 'How are you ever going to recover anything that is sent off in this way?' 'How can any "volunteer" (of which there have been 18) return?' And the speed of 604 miles per second, of which Mr. Morrell speaks as causing the rocket to 'vanish in an incandescent wisp of flame and smoke' would not be reached before an altitude of over 700 miles, at which height there must exist practically a complete vacuum.—R. H. Goddard"



1971

1921

1871

Four Dimensions of Being

"From the winning essay for the Eugene Higgins Five Thousand Dollar Prize by 'Zodiaque' (Lyndon Bolton, London): 'Lengths and times therefore have not the absolute character formerly attributed to them. As they present themselves to us they are relations between the object and the observer which change as their motion relative to him changes. Time can no longer be regarded as something independent of position and motion, and the question is what is the reality? The only possible answer is that objects must be regarded as existing in four dimensions, three of these being the ordinary ones of length, breadth and thickness, and the fourth, time.'"

1871 Selling Wildlife

"The bird trade seems to be in a flourishing condition. Over 40,000 canaries are brought in every year, and probably 10,000 more are raised in this country. The number of bullfinches, goldfinches, thrushes, robins, and larks annually imported rise as high as 500 or 600 for each variety. There are fully 3,000 Java sparrows brought to the U.S. by vessels from that region, and fully as many parrots are yearly sold in this city alone. Waxbills and other minute varieties are scarce, and seldom arrive in quantities of more than 100 or 200 each year. Parroquets and love birds from Australia follow parrots in their relative importance."

Lethal Cargo

"The steamship *England,* which cleared from Queenstown on January 12th, with 200 passengers on board, was obliged to put back to harbor in consequence of the breaking, during a heavy storm, of a number of barrels of bleaching powder in the hold. The heavy sea washed into the ship, and thus liberated chlorine gas in such quantities as to nearly suffocate all on board. Attempts were made to remove the powder, but it was found to be impossible for anyone to live in the hold long enough to put on the grappling hooks, and the captain decided to put back to port as fast as he could sail."

1921: A newly developed flexible steel hydraulic hose carries fluid power to a drill, increasing its versatility in construction.

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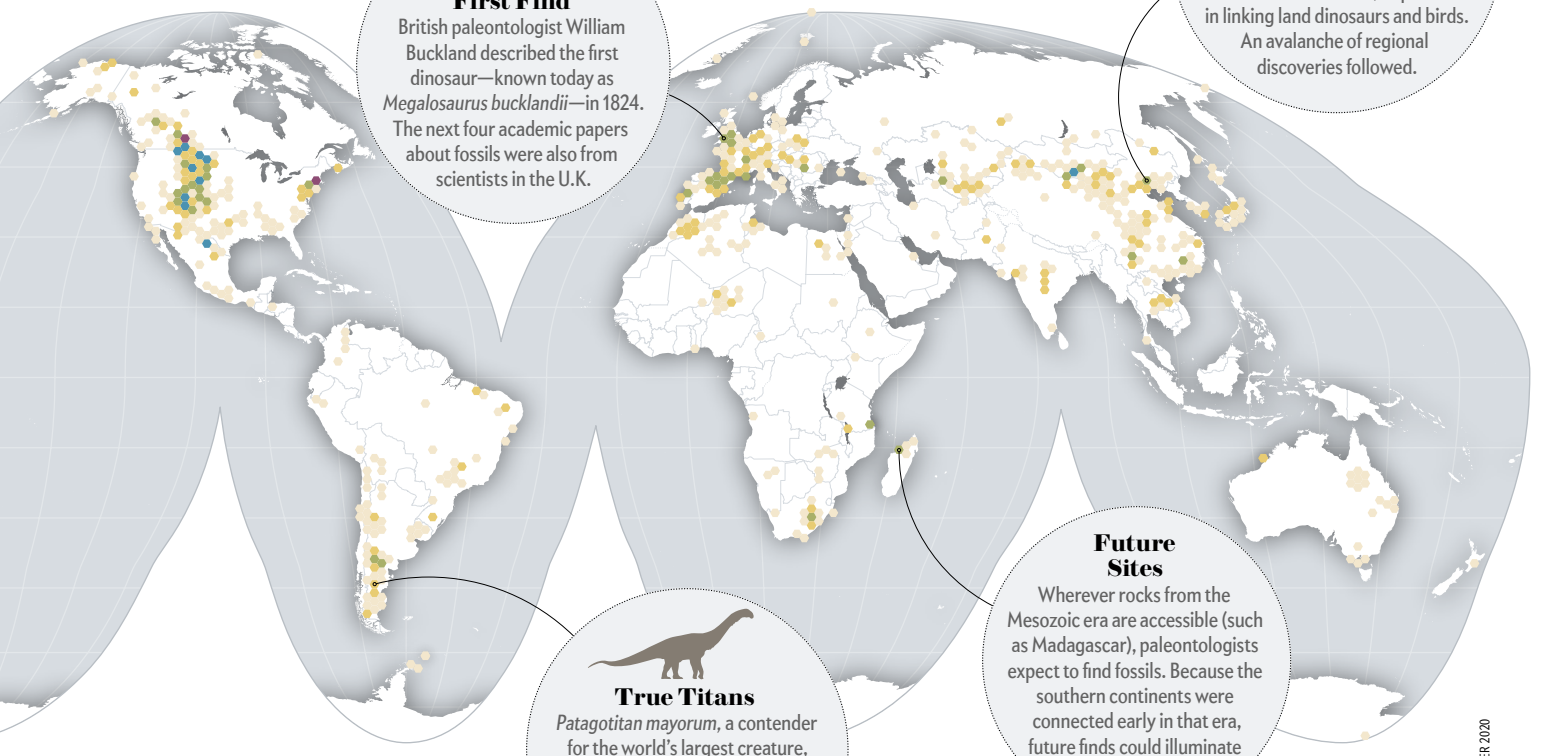
Text and Graphic by Katie Peek

Where the Dinosaurs Are

Discovery is booming, and there are plenty more bones to find

In the two centuries since the first dinosaur bones were identified in England, nearly 11,000 dinosaur fossils have been unearthed worldwide, two thirds of them in North America and Europe. Most of the finds have been made in the home countries of paleontologists; the ease of local fieldwork has led to a concentration of discoveries in well-traveled areas. Samantha Hopkins of the University of Oregon points out that more digs happen along her state's paved roads than along dirt ones. Fossil encounters have been expanding geographically, however, notably in East Asia and southern South America. Widening the scope depends on building local expertise—a tricky task for a fairly niche (and not particularly lucrative) field. Investment could be fruitful: paleontologists have identified about 1,000 dinosaur species and estimate that at least that many more have yet to be found.



First Find

British paleontologist William Buckland described the first dinosaur—known today as *Megalosaurus bucklandii*—in 1824. The next four academic papers about fossils were also from scientists in the U.K.

China's Boom

In 1996 a farmer in northeastern China discovered *Sinosauropteryx*—the first nonavian dinosaur with featherlike attributes, important in linking land dinosaurs and birds. An avalanche of regional discoveries followed.

Future Sites

Wherever rocks from the Mesozoic era are accessible (such as Madagascar), paleontologists expect to find fossils. Because the southern continents were connected early in that era, future finds could illuminate dinosaur evolution.

True Titans

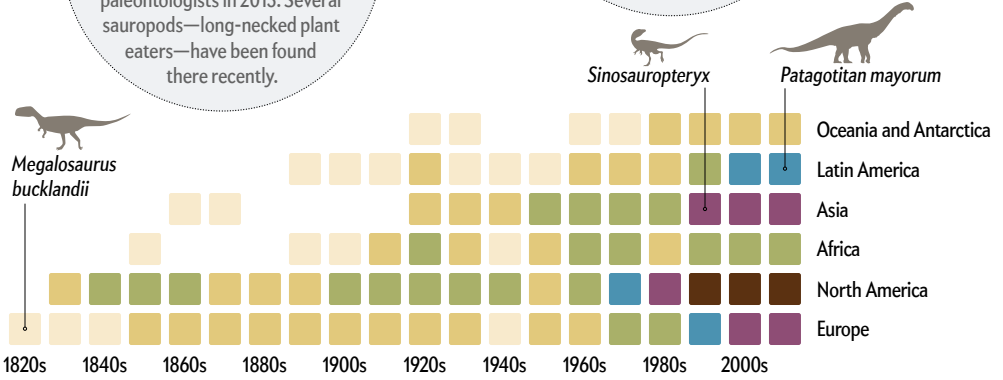
Patagotitan mayorum, a contender for the world's largest creature, was unearthed by Argentine paleontologists in 2013. Several sauropods—long-necked plant eaters—have been found there recently.

Number of Dinosaur Fossils Found

1–11	180–419
12–59	420–839
60–179	840–1,544

When Fossils Have Been Uncovered

Some 10,851 dinosaur fossils—tallied on the map and in this time line—have been documented since 1824, including everything from a single femur bone to an entire skeleton. In recent decades discoveries have accelerated in Latin America, Asia, North America and Europe.



SOURCE: PALEOBIOLOGY DATABASE (PALEOBIODB.ORG); DATA AS OF DECEMBER 2020

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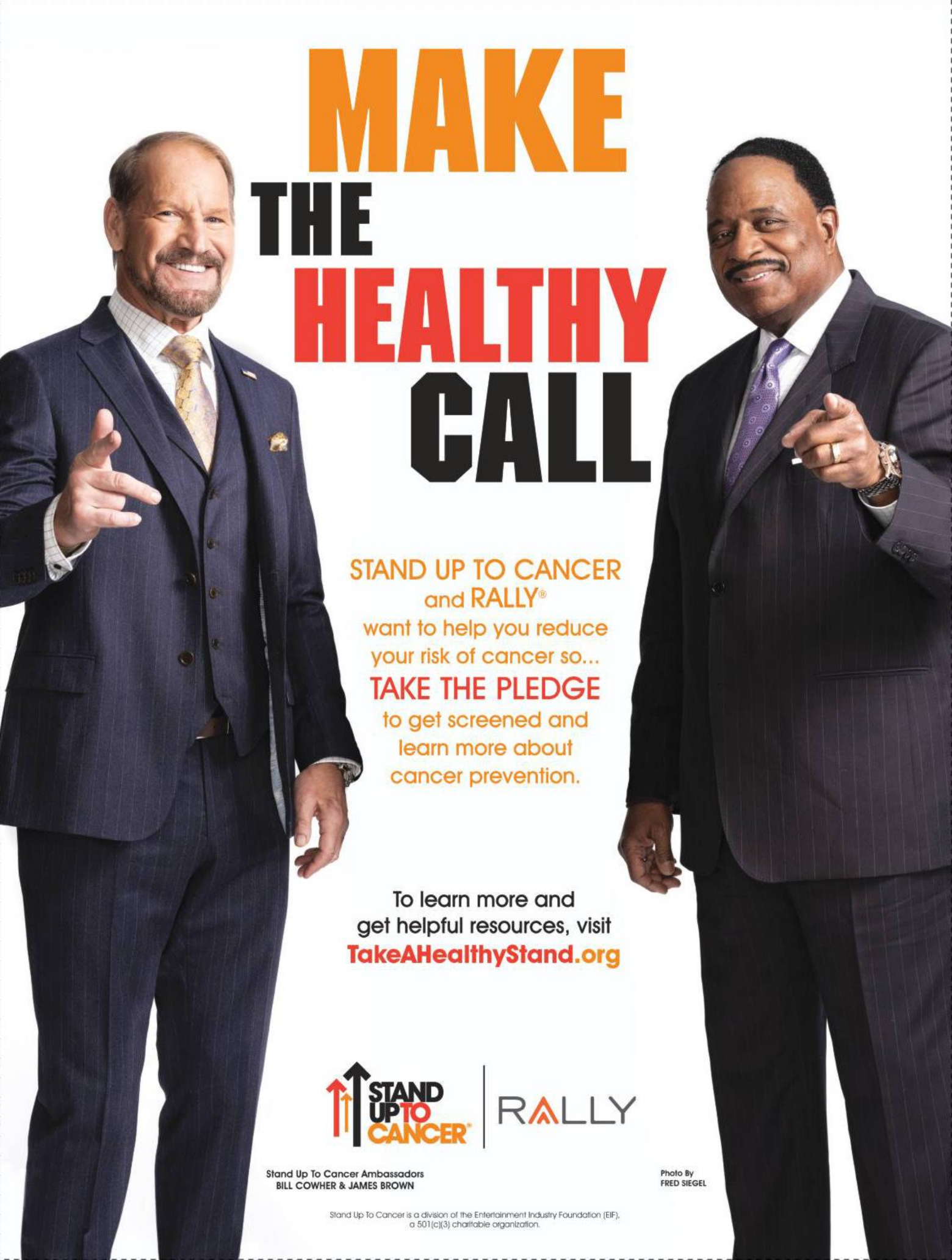
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