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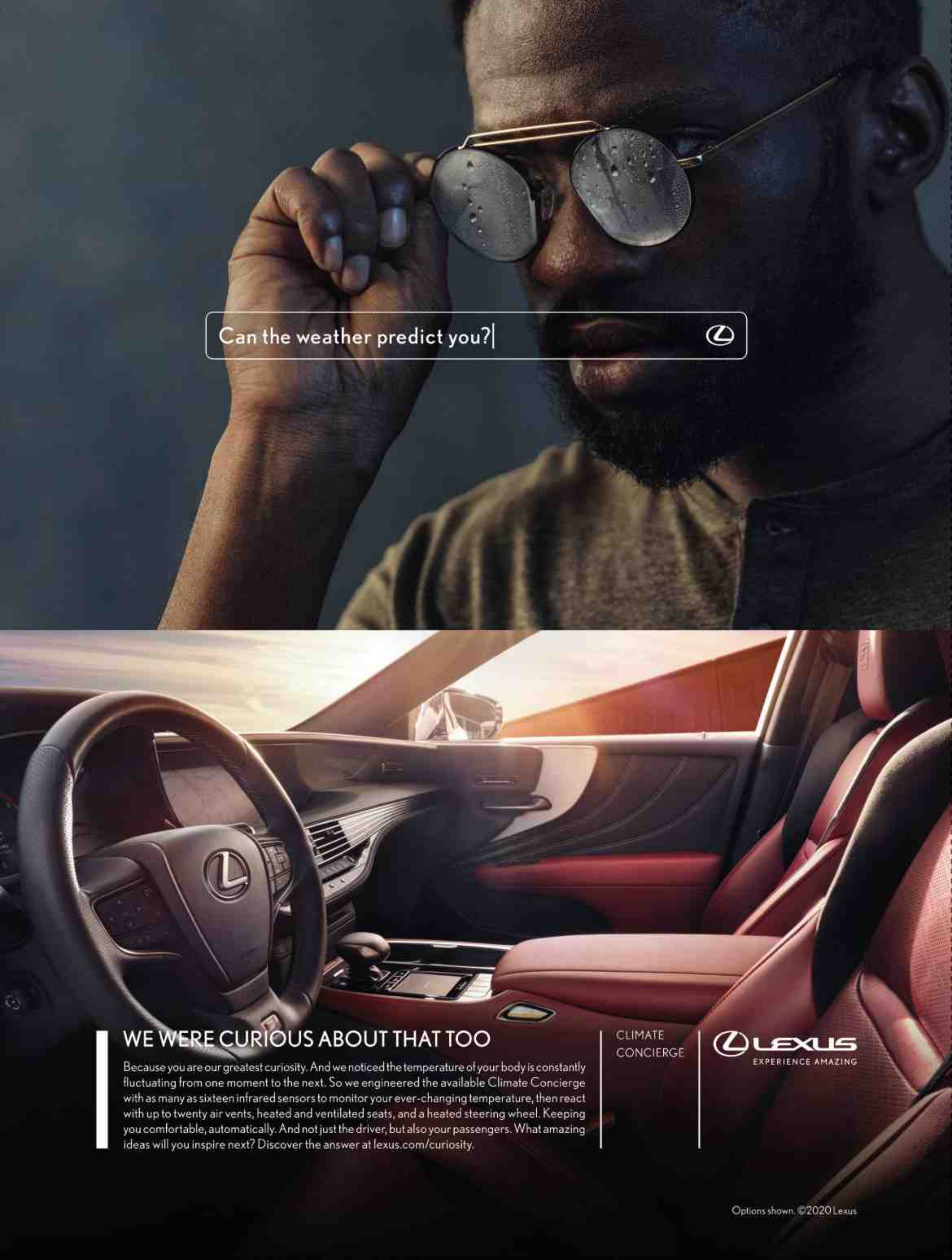
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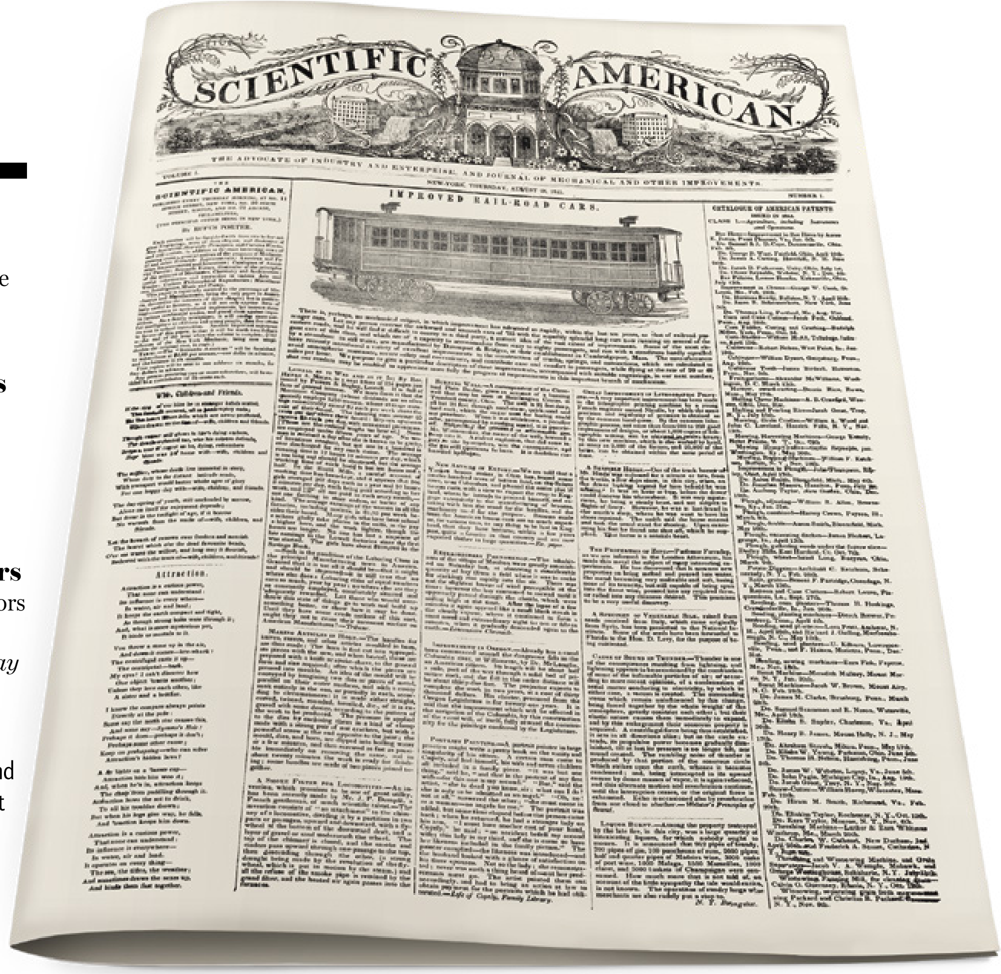
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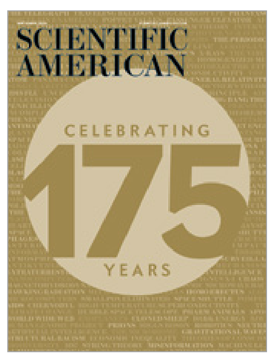
SCIENTIFIC AMERICAN, VOLUME 1, NUMBER 1: THURSDAY, AUGUST 28, 1845



**ON THE COVER**
From the telegraph to COVID-19, a chronological selection of inventions, discoveries, scientific breakthroughs and historical events that have helped determine the course of the past 175 years, for this magazine and the world at large.



# BIG QUESTIONS FROM... ANDREW FABIAN

A pioneering X-ray astronomer, Andrew Fabian is best known for revealing how supermassive black holes steer the fate of galaxy clusters. Here, he discusses some of the biggest mysteries in high-energy astrophysics, including the galactic life cycle, the belly of a black hole, and the secrets of dark matter.

Andrew Fabian knows what's hot. By examining the energetic X-rays produced by heated gases and celestial objects, the astronomer from the University of Cambridge has probed the hottest corners of the universe, including the blazing-hot gas in vast galaxy clusters.

"When you have maybe 100,000 galaxies clustered together, the gas between them gets squeezed by their large gravitational pull and becomes very hot, about 10 million degrees. That makes the gas emit lots of X-rays, which is how we can see it," says Fabian.

Emitting this radiation should ultimately cause this intergalactic gas to cool. "The gas has cooled some, but it hasn't cooled all the way—which was puzzling," says Fabian. "Something had to be stopping it." Fabian's quest to find what that something was led to a dramatic discovery. It turned out that the heating is caused by the supermassive black hole that sits at the center of the brightest galaxy in the cluster.

Through decades of observations—particularly of the Perseus cluster, the brightest X-ray emitting galaxy cluster in the sky—Fabian has unraveled how this heating mechanism works. As a black hole spins and matter circles and tumbles into it, particles that make up that matter collide, shooting out energetic jets of radiation and other particles. Those jets generate cosmos-shaking sound waves that ripple outward like bass notes from a loudspeaker, delivering enough energy to keep gas hot throughout the galaxy cluster. Further, by tracking the distortions in the X-rays bouncing off the material that swirls around a black hole's edge, Fabian has come up with a method for measuring the black hole's spin, which helps power its galaxy-changing jets.

Although Fabian insists that "we're only beginning to sort out how all these processes work," he was awarded the 2020 Kavli Prize in Astrophysics for advancing our understanding of the role black holes play in shaping the evolution of galaxies and galactic clusters.

In this interview, Fabian contemplates what lurks inside supermassive black holes, outlines the next steps in our investigation of galactic evolution, and explains how quasars could shed light on the mysteries of dark matter.

**What happens when matter falls into a black hole?**

"Don't know" is the answer. Matter, as it's falling in, passes through what we call the event horizon. We on the outside can't see within the event horizon because of the way that spacetime itself is warped around the black hole. If you were to fall to the center of the black hole, you would reach what we call the singularity. This is just a polite word for the bit we don't understand because it has all the mass of the black hole in an infinitely small size. At such extreme densities, you run into quantum mechanics, and because we don't have a solution for quantum gravity, we don't know what's going on. There's talk about how, if you have a spinning black hole, then the singularity is not a point but a ring, which could act as a wormhole if connected to a similar ring in another universe. These are interesting questions, but I'm very much grounded in observation, and I can see no way at the moment to observe any of this. But somebody may crack the problem of quantum gravity at some point.

**How did black holes end up at the center of galaxies?**

All massive galaxies have black holes at the center, as far as we can tell. We don't know when, in the process of galaxy formation, they arose. In the early universe, galaxy formation began with dark matter. Because dark matter doesn't collide with ordinary matter, it was able to form clumps, and then cold gas fell into these clumps, forming the galaxies. But we don't know how the first black holes formed or where they formed. That's something that will probably be sorted out in the next couple of decades by telescopes which can actually start to see the first stars and also the first black holes. After they formed, these black holes would then have a profound effect on the evolution of the surrounding galaxies. They can stop the formation of new stars by pushing gas away, or they can provoke the formation of new stars by compressing gases within their outflow. These cycles in which star formation starts and stops may happen many times during the evolution of a galaxy. To see how these galaxy clusters grow and at what point these cycles get set up, we'll have to look out at very, very distant clusters [to observe events that took place] when the clusters were very young. We will have to use much larger X-ray telescopes, like the Athena satellite we've been designing with the European Space Agency, which should be launched in the early 2030s.

**What exactly is dark matter?**

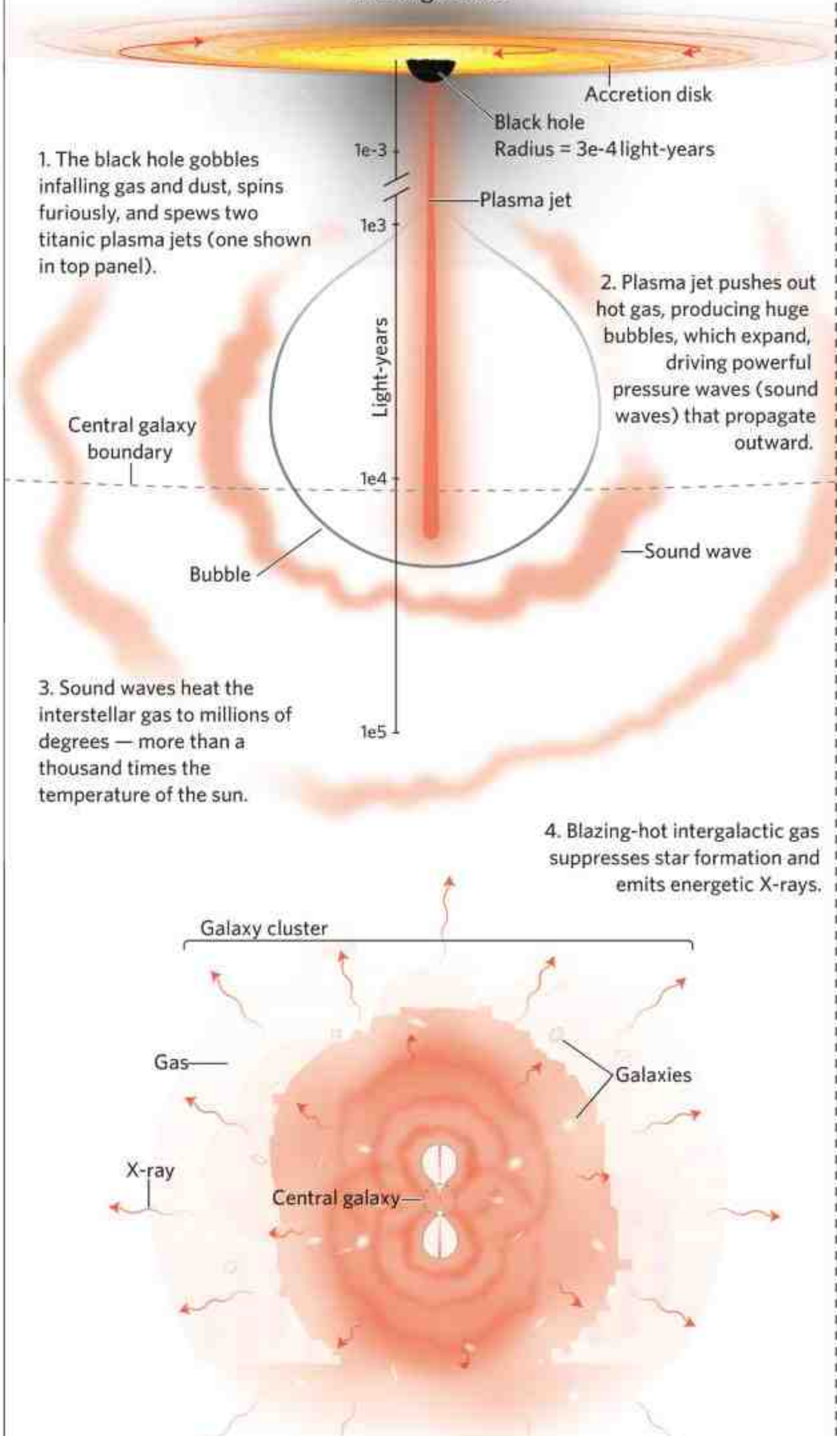
There's much more dark matter in the universe than there is ordinary matter, of which we're composed.

I think it's some kind of particle, but it's not a particle that we know of. I've been working with a colleague, Chris Reynolds, who has been looking at the center of the Perseus cluster to see if he can see signs of axions. An axion is a hypothetical particle that's got a very weak interaction with ordinary matter. It was introduced decades ago to solve a problem in physics, and at the time, there was a detergent called Axion. So, this particle was called an axion because it cleaned away a problem in physics. Axions may or may not exist, but if they do, they have a property similar to photons—they are both bosons. In the presence of a strong magnetic field, photons can turn into axions, and vice versa. What we're doing is using the quasar at the center of the galaxy NGC 1275 as a backlight to see any signs of this interchange as its light goes through the magnetic fields in the Perseus cluster. So far, we have not seen any effects that we can attribute to axions. It's nice that there are fundamental things out there that we know exist, yet we don't understand them. I find that exciting.

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

## ENGINES OF THE GALAXIES

The supermassive black hole in the central galaxy of a cluster is smaller than our solar system, yet as massive as a billion suns. X-ray, visible, and radio telescope observations reveal how it shapes the fate of galaxies.




5. Without this heating, infalling intergalactic gas would cool enough to form trillions of stars. It doesn't, showing the galaxy-shaping power of a supermassive black hole.

THE KAVLI PRIZE

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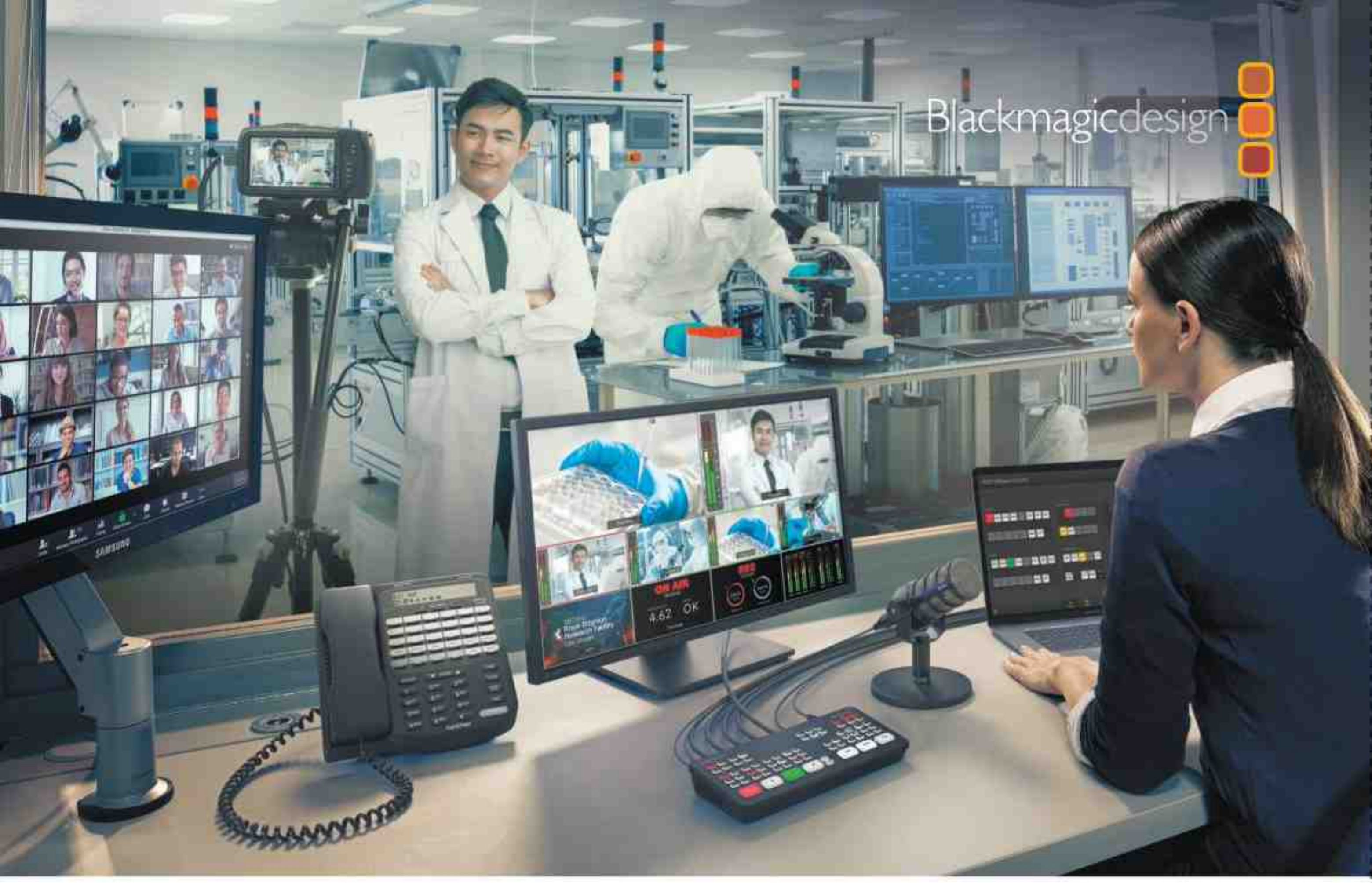
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**Laura Helmuth** is editor in chief of *Scientific American.*
Follow her on Twitter @laurahelmuth

# Celebrating Our Demisemiseptcentennial

**Welcome** to *Scientific American*'s 175th anniversary issue! We've had a blast putting it together and hope you enjoy it. *Scientific American* is the oldest continuously published magazine in the U.S. For our demisemiseptcentennial (also known as, no kidding, a quartoseptcentennial), we are presenting a mix of surprising history stories (featuring Harry Houdini, M. C. Escher and federal censors burning copies of our magazine) and deeper looks at some of the most transformative, thrilling, dizzying discoveries of the past 175 years.

When the magazine began, the universe didn't seem as big as it is today. Astronomers thought our Milky Way galaxy was the extent of the universe. Now we know we inhabit just one of over 100 billion galaxies. The universe isn't just mind-bendingly big, it's getting bigger, and—as if that weren't enough—the rate of expansion is faster all the time. Astrophysicist Martin Rees shows what we've learned and what the biggest questions are for the next 175 years (*page 58*).

One of the most disturbing discoveries of the past 175 years is that, on at least five occasions, most of the species on Earth have abruptly died off. The mass extinctions were triggered by massive volcanic activity or an asteroid impact, causing a cascade of catastrophe that disrupted the atmosphere and wiped out plants and animals that had ruled the planet for hundreds of millions of years. Now we are in danger of causing a sixth mass extinction. Starting on page 74, author Peter Brannen guides us through the absolute worst times on Earth and shows what was lost.

Charles Darwin published *On the Origin of Species* 14 years after *Scientific American* was established, transforming our understanding of life on Earth and of our own history as a species. Senior editor Kate Wong introduces our evolutionary ancestors from the past seven million years and reveals that our family tree is impressively tangled. Turn to page 66.

In the midst of a global pandemic, it's startling to read about how confident we once were that medicine could conquer infectious disease, as journalist Maryn McKenna recounts, starting on page 50. Our best long-term hope for conquering the new coronavirus is research into vaccines and antivirals, but in the meantime, public health measures that have been used for more than 175 years are the best way to stay safe. That, and staying informed by trustworthy sources of scientific information.

The most visible differences between life in 1845 and 2020 are technological. Historians Naomi Oreskes and Erik M. Conway (*page 42*) explore how science and technology have developed in parallel, each boosting the other, and how advances in information sharing are some of the main drivers of innovation.

To understand the information *Scientific American* has presented over the years, senior graphics editor Jen Christiansen and data designer Moritz Stefaner visualized the most commonly used words for each year of our existence. The visualization project begins on page 26 and continues throughout the issue with a time line and pairs of words that peaked in different years, showing ways the language of science has evolved.

The most shameful episodes in our history are when we used scientific language to promote bigotry. Senior editor Jen Schwartz and senior copy editor Dan Schlenoff on page 36 reckon with the sexism and racism in our archives and show how science can be twisted to make bias seem like objectivity. We are committed to making *Scientific American*'s future more inclusive and just.

Join us online at ScientificAmerican.com for more anniversary highlights, including an interactive featuring some of the greatest hits of science history. Search our database of most often used words to find your own patterns. Science has shaped our rich past, and we look forward to covering how it shapes the future. SA





*Illustration by Nick Higgins*


*May 2020*

**LIVING WITH ALZHEIMER'S**

An important through line in the special report on "A New Era for Alzheimer's" [The Future of Medicine] is the potential impact of lifestyle in modulating the risk of cognitive decline and dementia.

Three European countries—Finland, France and the Netherlands—have completed pioneering dementia-prevention trials in community-dwelling seniors. They show it is possible to reduce the risk of cognitive decline in older adults using a multidomain lifestyle intervention. And in 2018 the SPRINT MIND study reported significant reductions in the risk of mild cognitive impairment and of the combination of such impairment and dementia through aggressive lowering of systolic blood pressure.

Also, the Alzheimer's Association U.S. Study to Protect Brain Health through Lifestyle Intervention to Reduce Risk (U.S. POINTER) is recruiting participants now. Over two years this clinical trial will evaluate whether lifestyle interventions that target many risk factors simultaneously can protect cognitive function in older adults who are at increased risk for cognitive decline.

This line of research has exciting possibilities for Alzheimer's and all other dementias—as is apparent from its inclusion in heart disease treatment and prevention. The Alzheimer's Association and its collaborators appreciate your coverage on developments in Alzheimer's, as we continue to drive science forward.

MARIA C. CARRILLO *Chief Science Officer, Alzheimer's Association*

**"People with dementia lose capabilities they once had but never lose their personhood."**

JIM MANGI *DEMENTIA FRIENDLY SALINE*

**DEMENTIA AND PERSONHOOD**

In "The Human Toll of Alzheimer's" [The Future of Medicine], Joel Shurkin describes the loss of his wife to the disease. For 13 years and counting, I have accompanied my wife on her "unwelcome journey" with early-onset Alzheimer's, so I have great empathy with Shurkin. But my perspective is just a little different. Kathleen, my sweetheart of 45 years, has forgotten how to walk, use a fork or string a sentence together. She is living as an eight-year-old, so she cannot process her relationship to our daughter, grandkids or me. But Kathleen is still Kathleen. She has lost much, but she *is* the person I married. None of us is the same person as we were years ago, as Kathleen often reminded me. Fifty years ago I was young and stupid; now I'm not young.

People with dementia are exactly that: people, albeit changed. They lose capabilities they once had but never lose their personhood. A year ago a physician told me, "They're gone. There's no point in visiting them." Seldom expressed so bluntly, this terrible notion is common and underlies much of the care for people in the late stages of Alzheimer's or other dementias. We should never stop respecting these individuals for who they still are. And we should lovingly be with them as their unwelcome journeys conclude. We have no cure, but we must never stop caring.

JIM MANGI
*Dementia Friendly Saline, Michigan*

**ASSISTED DYING**

Claudia Wallis's otherwise thoughtful and informative article, "Euthanasia and a Final Gift" [The Science of Health], conflates euthanasia and MAID (medical assistance in dying). Doing so is likely to add confusion to an already fraught policy issue for people in the U.S. and possibly also in Canada.

There are immense legal, psychological and ethical differences between the two practices: Euthanasia refers to an action taken to end a patient's life that is *carried out by someone other than the patient* (typically a physician). It is usually performed by intravenous injection. MAID involves an action *taken by a patient* who has requested and obtained lethal medication from a physician under a carefully controlled, legally mandated protocol. The patient maintains full control over when to ingest the medication or whether to take it at all.

Wallis states that organ donation "works well after MAID because patients die quickly from the intravenous euthanasia drugs." Yet whereas euthanasia is legal in Canada, it is illegal in all U.S. jurisdictions and is thus never an element of MAID in our country.

PETER ROGATZ *Vice President, End of Life Choices New York*

*WALLIS REPLIES: Certainly there are differences between euthanasia and MAID, as Rogatz notes. But in Canada, which was the context of this column, the distinction is not so clear-cut, and the term "euthanasia" is sometimes used for MAID. As of January 31, the province of Ontario had processed 4,521 cases of MAID. In all but two of them, medical personnel administered an intravenous cocktail to end life. Self-administration, I learned, is rare in Canada.*

**FIRE AND ICELAND**

In "Massif Redo," William H. Sager describes his epiphany on realizing that the Tamu Massif volcano resulted from spreading tectonic plates, not from the "layer cake" buildup of eruptions that typically create such shield volcanoes on land. But isn't the process he describes the same as the one that formed Iceland?

VAN SNYDER *La Crescenta, Calif.*

*SAGER REPLIES: That inference seems reasonable up to a point. Iceland was formed by a hotspot centered on the Mid-Atlantic Ridge, and many scientists attribute this hotspot to a deep plume of molten material rising from the mantle. There are indeed*

# A culture of communication

For Dominique Chen, a robot interface that helps to create **JAPANESE PICKLES** is an exercise in using technology to provide greater connection.

**Dominique Chen, a researcher at Waseda University in Tokyo,** asks his pickling bacteria how they are every day — and then waits for an answer. Chen's not imagining things. His bacteria will answer through NukaBot, an IoT robot he invented to help people who make fermented Japanese pickles.

NukaBot is a robotic container for *nukadoko*, a rice bran paste used for pickling. Sensors inside the paste measure parameters such as pH and the release of different types of gases, which allows the robot to give status updates on behalf of the microorganisms breaking down the mix. An integrated speaker responds to questions like "How are you fermenting today?" or "What do you need?", and gives Chen advice on pickling stages or when the microorganisms need more contact with air.

**CHEN SAYS THAT THE POINT IS TO FORGE AN EMOTIONAL CONNECTION BETWEEN HUMANS AND MICROBES**

"The goal is to establish a model for human-microbe interaction that fosters affection for these invisible living beings," explains Chen, who has been fermenting pickles for more than a decade. While it's possible to automate this pickling process, Chen says that the point is to forge an emotional connection between humans and microbes, so that tasks like mixing *nukadoko* become more fulfilling.

His passion for technology and communication stems from Chen's international upbringing, which brought a fascination with cultural phenomena and personal experiences of living with mild disfluency. "Both of these led me to believe, as [science-fiction] author Ken Liu once wrote, that every act of communication is a miracle of translation in some way," he says.

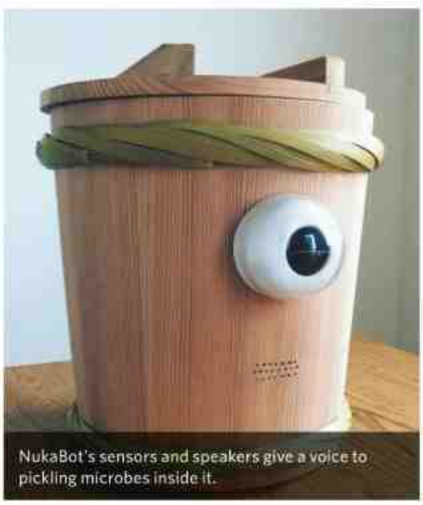
Before becoming an academic, Chen spearheaded an open copyright system known as the Creative Commons in Japan. After launching, running, and eventually selling a communication technology startup and working extensively on digital communication as art, Chen turned his interest toward research. Chen says he chose Waseda because its culture and multidisciplinary philosophy allowed him to join the humanities faculty, despite an information technology Ph.D.

"Engineers should be working with liberal-arts researchers more often to design better technologies," explains Chen. "I've become good friends with a psychology professor at Waseda. Now we regularly have lunch together and exchange research ideas. I really enjoy the diversity and open-mindedness of the other staff."

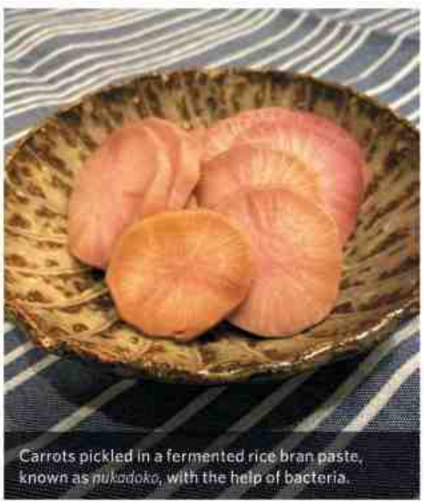
Waseda also has the largest international student cohort in Japan, and it offers the greatest number of courses and degree programs taught in English. As a result, its students are already experts in highly complex communication, notes Chen. Drawn from more than 110 countries and regions, they communicate as a diverse group within a foreign culture, as well as maintain connections at home, he points out. Currently, Chen and his students are pursuing many projects linked to digital well-being, and better ways to communicate through technology — be it with fellow classmates or with microbes. ■

WASEDA University

www.waseda.jp/top/en/



NukaBot's sensors and speakers give a voice to pickling microbes inside it.



Carrots pickled in a fermented rice bran paste, known as *nukadoko*, with the help of bacteria.

Dominique Chen (pictured) and his students study how technology can aid connection.

© Takashi Mochizuki

*magnetic anomaly stripes that go through Iceland, although the activity of the island's volcanoes perturbs those stripes, so they are hard to follow. Tamu Massif may be similar. But it formed within a much shorter time frame, and its stripes show it did so during a reorientation of the spreading direction (which is not so much the case for Iceland). Further, the stripes are more clearly expressed for Tamu Massif, and that volcano was never an island, whereas Iceland is a massive one.*

*For now we can't say whether Iceland and Tamu Massif are siblings, cousins or unrelated. Few undersea volcanoes are as well mapped as Tamu Massif, and our data set is a long way from being as good as we would like.*

## FACING PRIVACY LOSS

The editorial "Get Out of Our Faces" [Science Agenda] identifies many of the problems with facial-recognition technology and the need for regulation. What it fails to highlight is the unwitting forfeiture of privacy we commonly enable with our use of technology. It is quite possible for a corporation or government to, say, correlate pictures and names from Facebook and other social accounts into a facial-recognition database.

There is no real privacy anymore with the current social standard of posting photographs of everything you and your friends do. Along with the proliferation of ATM, traffic-control and security cameras, the futuristic films that deal with tracking a person's movements with these images are not far off. As the editors say, much of this is here already, and we are lacking both regulation and public enlightenment.

Mathieu Federspiel *via e-mail*

## POETRY APPRECIATION

I commend Dava Sobel for her selection of Janet MacFadyen's "The Boulders of Lyell Canyon" for the Meter column. I appreciate the introduction to a new major poet. I am a retired teacher of poetry, and if I have any strengths, they are in the analysis of rhythm and of figurative language, the two most essential elements of excellent complex poetry. This poem is an outstanding, astounding example.

William H. Moore *Professor of Humanities emeritus, Austin College*



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# How to Reinvent Policing

## Departments have turned into enemies of communities they are sworn to protect

*By the Editors*

**It was not just a knee pinned** to George Floyd's neck that killed him. Or gunshots that killed Breonna Taylor. Or a chokehold that killed Eric Garner. It was also centuries of systemic racism that have festered in U.S. society and institutions, including our overly punitive, adversarial system of policing. And videos of the recent police-involved killings do not show the broader toll that stop and frisk, arbitrary arrests and other aggressive law-enforcement actions have taken on Black and other minority communities. Nationwide and fundamental police reform is long overdue.

Since the advent of government-led "wars" on crime and drugs in the past decades, policing has taken a decisively violent turn, and police departments often see themselves as adversaries of the very communities they are meant to safeguard, according to policing researcher Peter Kraska of Eastern Kentucky University. In addition to this antagonistic culture, several studies show that police are more likely to stop, arrest and use force against Black and Latinx people than white people. Research by Yale University sociologist Monica Bell documents that individuals subject to such overpolicing do not see police as protecting them, even when they are concerned about violence in their communities. They report unease even after an encounter where officers acted appropriately.

Incremental reforms will not fix this perverse system: Chokeholds have been banned in New York City for decades, and the Minneapolis Police Department requires officers to intervene when a fellow officer uses excessive force, but neither rule prevented the death of Garner or Floyd. Nor will technology turn the tide. Body cameras have made the problem of police brutality against minority communities harder to ignore but have not reined it in.

Instead we need to rethink how we conceive of and support public safety so that it encompasses all communities. One way to do this would be to create policies that use social workers to tackle issues that have been dropped at the feet of police who are ill trained to handle them, such as homelessness, mental illness and working with young people to prevent violence. Law-enforcement professionals themselves have highlighted this problem, and some alternative programs point toward solutions. For example, community-based violence-prevention groups such as Cure Violence have lowered shootings and killings in cities such as Baltimore and Philadelphia where they have operated, according to policing researcher Alex Vitale of Brooklyn College. And programs such as CAHOOTS in Eugene, Ore.—which routes emergency calls about mental illness to social workers instead of the police—and the Denver Alliance for Street Health Response offer models for other cities to explore. Taking responsibility for dealing with these noncrime issues out of the hands of police removes officers from situations beyond their training and reduces the chances of encounters escalating to violence. Fewer than 1 percent of the thousands of calls CAHOOTS responded to last year necessitated police backup, the group reports. In designing these policies, officials must engage communities—particularly those who have suffered most from overpolicing—to understand what issues are most important to them in ensuring safety.

A necessary step will be to address the militarization of policing. The use of SWAT teams and tactics has ballooned well beyond the threatening hostage or active-shooter situations they were intended to confront. Studies by Kraska, the American Civil Liberties Union and others show SWAT teams are overwhelmingly used for serving search warrants and that communities of color are disproportionately targeted. Returning SWAT to its proper use—and restricting the access of wider police departments to military-style weapons or dogs trained to bite people—would reduce the chances for unnecessary violence and harm.

Accountability is another key element. Federal and local officials need the political will to create truly independent oversight mechanisms. But accountability also depends on police departments making data on killings, use of force, disciplinary records, budget allocations and other areas publicly available. Departments have resisted releasing such information, so Congress needs to pass laws that mandate that they do so.

Major police reform will take perseverance and money. (Some of the financing can come from reducing police budgets.) These approaches are a starting point as we confront the way dangerous biases, especially racism, have become embedded in police and other powerful institutions. We must work to root them out.

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*Illustration by Alexandra Bowman*


EVERYONE NEEDS SCIENCE.
SCIENCE NEEDS EVERYONE.

**Nora D. Volkow** is director of the National Institute on Drug Abuse at the National Institutes of Health.

# The Stigma of Addiction

## Despite what the science says, many think addiction shows moral weakness

*By Nora D. Volkow*

**Untreated drug and alcohol use** contributes to tens of thousands of deaths every year and affects the lives of many more people. We have effective treatments, including medications for opioid and alcohol use disorders, that could prevent a significant number of these deaths, but they are not being utilized widely enough, and people who could benefit often do not even seek them out. One important reason is the stigma around those with addiction.

Stigma is a problem for people with health conditions ranging from cancer and HIV to a variety of mental illnesses, but it is especially powerful in the context of substance use disorders. Even though medicine long ago reached the consensus that addiction is a complex brain disorder, those with addiction continue to be blamed for their condition. The public, as well as many people working in health care and in the justice system, continues to view addiction as a result of moral weakness and flawed character.

Stigma on the part of health care providers who see patients' drug or alcohol problems as their own fault can lead to substandard care or even to the rejection of individuals seeking treatment. Staff in emergency departments, for instance, may be dismissive of addicted people because they do not view treating drug problems as part of their job. As a result, those showing signs of acute intoxication or withdrawal symptoms are sometimes expelled from the ER by staff who are fearful of their behavior or who assume they are only seeking drugs. People with addiction can internalize this stigma, feeling shame and refusing to seek treatment.

During a visit to Puerto Rico several years ago, I visited a "shooting gallery"—a makeshift injection site—in San Juan, where I met a man who was injecting heroin into his leg. It was severely infected, and I urged him to visit an ER, but he had been treated horribly on previous occasions and preferred risking his life, or probable amputation, to the prospect of repeating his humiliation.

Beyond just impeding the provision or seeking of care, stigma may actually drive addicted people to continue using drugs. Research by Marco Venniro of the National Institute on Drug Abuse has shown that drug-dependent rodents choose social interaction over the drug when given the choice, but when the social choice is punished, the animals revert to drug use. Humans, too, are social beings, and some of us respond to both social and physical punishments by turning to substances to alleviate our pain. The humiliating rejection experienced by those who are stigmatized for their drug use acts as a powerful social punishment, driving them to continue and perhaps intensify their drug taking.

The stigmatization of people with substance use disorders may be even more problematic in the current COVID-19 crisis. In addition to the greater risk associated with homelessness and with drug use itself, the legitimate fear around contagion may mean that bystanders or even first responders will be reluctant to administer lifesaving naloxone to people who have overdosed. And there is a danger that overtaxed hospitals will pass over those with obvious drug problems when making difficult decisions about where to direct limited personnel and resources.

Alleviating stigma is not easy, in part because the rejection of people with addiction or mental illness arises from unease over their violations of social norms. Even health care workers may be at a loss as to how to interact with someone acting threateningly because of withdrawal or because of the effects of certain drugs (for example, PCP) if they have not received training in caring for people with substance use disorders. It is crucial that health care personnel, from staff in emergency departments to physicians, nurses and physician assistants, be trained in caring competently for people with substance use disorders. Treating patients with dignity and compassion is the first step.

There must be wider recognition that susceptibility to the brain changes in addiction is substantially influenced by factors outside an individual's control, such as genetics and the environment in which one is born and raised, and that medical care is often necessary to facilitate recovery as well as to avert the worst outcomes, such as overdose. When people with addiction are stigmatized and rejected, especially by those in health care, it only contributes to the vicious cycle that makes their disease so entrenched. SA

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*Illustration by María Hergueta*

# ADVANCES


New data on radiocarbon dating draws largely from single-year tree rings in ancient wood.

STEFAN DINSE *Alamy*

**INSIDE**



ARCHAEOLOGY

# Change the Date

## A long-awaited adjustment to radiocarbon dating could shed new light on old discoveries

**More than 3,500 years ago** a catastrophic volcanic eruption struck ancient Thera, known today as the Greek island of Santorini. Ash and pumice rained across the Mediterranean, and tsunami waves rolled onto faraway shores in Crete. In the 1960s archaeologists on Santorini uncovered a Minoan settlement frozen in time, with vibrant wall frescoes decorating multistory houses, all buried by volcanic debris.

The eruption was one of the most powerful volcanic explosions of the past 10,000 years and a crucial time point of the Mediterranean Bronze Age. It is also a major area of controversy in archaeology; researchers have argued for decades over the date of this cataclysm.

Although it does not settle the debate, a recent adjustment to the radiocarbon-dating process narrows down the possibilities. This much anticipated new calibration curve, a set of data points used to convert radiocarbon-dating results into calendar years, is highlighted in a special August issue of *Radiocarbon.* Called IntCal20, it draws from nearly twice the data of the previous curve, from 2013—and may prompt scientists to reevaluate the age of sites, artifacts and events around the world.

"It's a really massive increase in the data set, and with each revision our ability to confidently date the past improves," says Thomas Higham, a radiocarbon-dating specialist at the University of Oxford, who was not involved in the calibration effort. "A lot of people are excited about this new curve because it is going to give us the opportunity to sharpen our chronologies and understand more about the way the earth works and the way the earth has changed through time."

All living things absorb carbon 14, a radioactive carbon isotope that decays at a regular rate over time. This means that shells, bone, charcoal and other organic materials that archaeologists find contain a chemical timestamp. Discovered in the late 1940s, radiocarbon dating transformed the study of prehistory and became the gold standard for establishing chronologies in archaeology. A second revolution came when scientists realized atmospheric carbon 14 levels vary over time as the result of fluctuations in solar activity—and, more recently, atomic bombs and fossil-fuel burning. Thus, radiocarbon dates need to be calibrated against independent measurements, primarily from chunks of ancient wood. These have annual growth rings that scientists can directly tie to calendar years and can also analyze for radiocarbon.

For the earliest internationally accepted calibration curves, developed in the 1980s, tree-ring measurements were available only for the past few thousand years. In contrast, IntCal20 draws from nearly 14,000 years' worth. It also includes far more single-year tree-ring measurements than previous versions, accounting for shorter-lived spikes from phenomena such as bursts of solar radiation. Other absolute measurements from natural archives, including ice cores, seasonal lake sediments and cave stalagmites, extend the new curve back to 55,000 years, close to the earliest age radiocarbon dating can track.

The International Calibration Working Group, formed in 2002, crowdsources data to produce new versions of the widely used curve. And besides IntCal20, which is intended for samples from the Northern Hemisphere, the group has created separate curves for objects from the Southern Hemisphere and the ocean, which have slightly different radiocarbon levels.

Of the 12,904 raw measurements included in IntCal20, more than 800 come from 1700 to 1500 B.C.—the best-dated prehistoric section of the curve. Scientists know Thera's cataclysmic eruption happened during that span, but they want to pinpoint when.

"If you had a really good, firm calendar date for this event … it would mean that at any archaeological site in that region where you hit the ash, you would have an exact dated layer," says Charlotte Pearson, a tree-ring scientist at the University of Arizona, who was part of the IntCal20 effort and studies Thera. "That would pull together all the time lines for all these incredible cultures in this region," including the Minoans, the Hittites, the Hyksos and the ancient Egyptians.

But the date is elusive. Some pottery and ancient records point to the late 16th century B.C.; radiocarbon results have suggested a century or more earlier. Measurements that went into IntCal20 tighten the focus, but because the curve plateaus in this range, the data offer probabilities for a few windows of time rather than a definitive answer.

"The major difference is that the possible ranges are now substantially narrower," says Sturt W. Manning, a Cornell University archaeologist, who led early Thera-related radiocarbon work and was involved in IntCal20. The calibration suggests a late-17th-century B.C. date is most likely, with another window in the earlier to mid-16th century B.C., he says. With these new data, the estimate "has become greatly more precise—but it's the same debate, ironically." Nevertheless, Pearson thinks scientists are getting closer to a cal-

MATHEMATICS

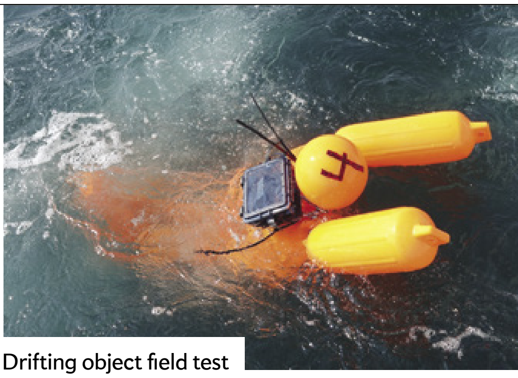
# Catching Your Drift

## Algorithm pinpoints "attractors" in the water to find people lost at sea

**When a craft sinks** or goes missing at sea, search-and-rescue teams often rely on computer models to determine where to scour for survivors. Currently used models incorporate data from satellites and offshore sensors to predict a drifting object's path, producing maps of the areas where it is most likely to be found. If the initial search is unsuccessful, the models incorporate that information to update their predictions.

Now a team of researchers has developed a new algorithm to anticipate the location of drifting objects during the first three hours of a search. Instead of modeling the trajectory of a missing person, the tool identifies zones in the water called transient attracting profiles (TRAPs), where currents and waves conspire to pull in nearby objects. In the early hours of future search-and-rescue operations, factoring in these previously hidden "attractors" could prove crucial in saving lives.

The movement of ocean water can be represented mathematically as a velocity field, which in this case describes the speed and direction of water at each point on the surface. The new algorithm, described in May in *Nature Communications,* uses ocean wave data and forecast models of this field to find zones with the strongest pull. Though invisible in the water, each TRAP can be drawn on a map as a curve of about 100 to 1,000 meters long. As surface conditions change, TRAPs move slowly enough to drag objects along with


Drifting object field test

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

them—similar to how a magnet moving under a table can pull an iron item along the tabletop.

Study lead author Mattia Serra of Harvard University and his colleagues field-tested the method by throwing GPS-tagged manikins in the turbulent waters just south of Martha's Vineyard in Massachusetts. Each manikin followed a different trajectory, but "they all clustered on the endar year for the event. "I do think it is dateable," she says. "It's just [a question of] which of the records is going to produce the clinching evidence."

With IntCal20's release, scientists and archaeologists expect a rush of new studies that recalibrate data—and not just from the Bronze Age. The new curve bumps the transition period at the end of the last ice age to 50 years earlier. This may influence how archaeologists interpret data connected to the mass extinction of megafauna and the arrival of humans into the Americas—other contentious dates. IntCal20 also suggests the oldest *Homo sapiens* fossil known in Eurasia, the Ust'-Ishim man found in Siberia, may be 1,000 years younger than previously believed. Higham is particularly excited about new measurements in the range of 50,000 to 55,000 years ago; he hopes these will show more about how anatomically modern humans, migrating out of Africa, interacted and exchanged genes with archaic humans, including Neandertals and Denisovans.

Manning says the next IntCal will incorporate more regional variations in radiocarbon measurements, possibly explaining discrepancies from the period around the Thera eruption. "We've moved to a new generation of accuracy and precision," he says. "With that will come a new focus on exactly what has been dated and how that radiocarbon age has been created." —*Megan I. Gannon*

same TRAP," just as the algorithm predicted, Serra says. These initial tests were carried out close to shore, but the same mathematics predicts the presence of TRAPs in the open ocean.

Lawrence Stone, chief scientist at the scientific consulting company Metron and chief designer of the U.S. Coast Guard's standard search-and-rescue protocol, welcomes these "absolutely fascinating, impressive results." The study "fits right in with the sort of thing that we like to do, and it's good scientific research that holds up," says Stone, who was not involved in the new study. "Let's put it in."

Stone emphasizes that the TRAPs tool would supplement, not replace, existing models. A spokesperson confirms that the Coast Guard is working to incorporate TRAP curves into its prediction maps. As research continues, Serra and his colleagues hope to factor in the effects of wind and buoyancy, thus increasing the predictions' accuracy.

—*Scott Hershberger*


Collared polar bear and her cubs

ENVIRONMENT

# Trackers on Ice

## Polar bears' dropped GPS collars can still help science

**Just because a scientist** puts a GPS tracking collar on a wild polar bear does not mean the animal will obligingly keep it on. In fact, these humongous neckbands are purposefully girthy so that if one becomes irritating, a bear can remove it. But scientists have now found a way to use signals from the discarded devices.

"These dropped collars potentially would have been considered garbage data," says Natasha Klappstein, a polar bear researcher at the University of Alberta. She and her collaborators (including researchers at the University of British Columbia and Environment and Climate Change Canada) instead used measurements from such collars, left on sea ice in Canada's Hudson Bay, to track the ice itself.

For their study, published in June in *The Cryosphere,* the researchers identified 20 collars that transmitted movement data consistent with ice drift rather than polar bear motion between 2005 and 2015. The resulting records of how melting ice typically drifts in Hudson Bay are unique; there are no easily accessible on-the-ground sensors, and satellite observations often cannot accurately capture the motion of small ice sheets.

The team compared the discarded collars' movements to widely used ice-drift modeling data from the U.S. National Snow and Ice Data Center (NSIDC). Collar data indicated that the NSIDC model underestimates the speed at which ice moves around in Hudson Bay—as well as the overall extent of drift. Over the course of several months the model could diverge from an ice sheet's location by a few hundred kilometers, the researchers say.

This means the bears may be working harder, when moving against the direction of the ice, than scientists had assumed: "Since we're underestimating the speed of drift, we're likely underestimating the energetic [effort] of polar bears," says University of British Columbia's Ron Togunov, lead author of the study.

The research reveals timely insight into how highly mobile ice moves. As melting increases in coming years, such ice will likely become more common farther north, in the central Arctic, says Andy Mahoney, a geophysicist at the University of Alaska, Fairbanks, who was not involved in the study. Scientists had known NSIDC data could underestimate drift speeds, Mahoney says, but "any time we can find a data gap and plug it is a good thing."

Plus, such data could improve predictions about how oil spills or other pollutants may spread in seas littered with drifting ice, says Walt Meier, a senior NSIDC research scientist, who was also not involved in the study. The findings may even influence future NSIDC models: "It's a really nice data set," Meier says. "And certainly one we'll take under consideration."

—*Chris Baraniuk*

ANDREW DEROCHER *University of Alberta*

TECH

# Fighting Fire with Paper

## A cheap, printed sensor could transmit wildfire warnings

**Wildfires have recently devastated** regions across the world, and their severity is increasing. Hoping to reduce harm, researchers led by Yapei Wang, a chemist at Renmin University of China, say they have developed an inexpensive sensor to detect such blazes earlier and with less effort.

Current detection methods rely heavily on human watchfulness, which can delay an effective response. Most wildfires are reported by the general public, and other alerts come from routine foot patrols and watchtower observers. Passing planes and satellites also occasionally spot something, but "the fire [first] appears on the ground," Wang says. "When [you see] the fire from the sky … it is too late."

The team says its new sensor can be placed near tree trunks' bases and send a wireless signal to a nearby receiver if there is a dramatic temperature increase. That heat also powers the sensor itself, eliminating the need to replace batteries. The key is molten salts called ionic liquids: an abrupt temperature change causes electrons to migrate within the liquids, creating electrical energy that triggers electrodes to send the signal. The team printed the substances onto ordinary paper to create a sensor for just $0.40, as described in June in *ACS Applied Materials & Interfaces.*

Jessica McCarty, a geographer at Miami University in Ohio, who was not involved in the study, says places such as San Diego—where wildland and city meet—could potentially benefit from sensors like this. When a fire breaks out in a canyon that extends to someone's property, she says, with such a device, "you know that as a homeowner before the fire agency may have detected it."

But improving coordination among the different agencies involved in firefighting is even more crucial to address, says Graham Kent, a seismologist at the University of Nevada, Reno, who was also not part of the study. Kent is director of ALERTWildfire, a network that uses cameras and crowdsourcing to watch for fires in California, Nevada and Oregon. "The whole way that you respond to a fire until it's put out is like a ballet," he says. "You'd have to choreograph it just so," with resources allocated at precisely the right time and place from detection to confirmation to dispatch to extinguishing. "Fire detection is just step one; if you blow steps two through 98, all that technology … just doesn't matter."

Wang says his team's next steps are to extend the device's signal range beyond the current 100 meters, which can limit practical use, and to develop a protective shield for it. The transmitter's effectiveness, McCarty notes, will also need to be tested in the field. *—Karen Kwon*

Fire raging in Colorado's Pike National Forest

MILE HIGH TRAVELER *Getty Images*


Guppies can darken their eyes.

ZOONAR GMBH *Alamy*

ANIMAL BEHAVIOR

# Matador Fish

## A guppy's bold evasion strategy

**Guppies make unassuming pets,** but in the wild they adopt a daring and counterintuitive tactic to avoid becoming dinner. When they spot a predator, they suddenly darken their eyes from silver to jet black—enticing the attacker to go straight for the guppy's head.

In a paper published in July in *Current Biology,* researchers report that this seemingly bizarre behavior may be a diversion that helps guppies dodge would-be hunters.

Robert Heathcote, a behavioral ecologist at the University of Exeter in England, says he came up with this hypothesis while eating a blueberry muffin on a train. He had noticed in high-speed videos that ambush predator fish called pike cichlids seemed to aim their attacks at the heads of the guppies with black eyes. "The guppy would wait right until the last minute and then kind of reverse itself and dodge out of the way," says Heathcote, the study's lead author.

To test how pike cichlids respond to black- versus silver-eyed guppies, Heathcote first tried using colored contact lenses, iPad videos and even tattooing the eye of a dead fish—but found the needle could not pierce the surprisingly tough eye surface. Eventually Heathcote and his colleagues built robotic guppies, pulled by fishing line, to test their hypothesis. The cichlids targeted the heads of black-eyed fakes but the bodies of silver-eyed ones.

Another experiment, with live guppies protected by a transparent barrier, revealed how the guppies rapidly swung their heads away to flee from oncoming predators' maws with an innate "fast-start" escape reflex. Pike cichlid attacks are ballistic and do not deviate from their course once launched, so the researchers could "simulate" whether a guppy would have escaped without the barrier's intervention.

Larger guppies, which are typically less agile and easier to catch, benefited the most from this matadorlike strategy. "It's this misdirection," says senior author Darren Croft, also at Exeter. "By doing that, they can pivot the head away and escape."

These guppies may not be the only prey animals using such a strategy. Other fish also change their eyes' tint, and species including epaulette sharks and rock doves have attention-grabbing color patterns on their backs.

"This [study] opens a whole new area of research, and it might explain cases where eyes or eyespots are very conspicuous," says Karin Kjernsmo, a behavioral and evolutionary ecologist at the University of Bristol in England, who was not involved in the study. "Maybe together with an evasive strategy, [these results] could explain why that is so."

In an eat-or-be-eaten world, there is always more than meets the eye.

*—Richard Sima*

MATERIALS SCIENCE

# Color Coded

## A changing, silk-based ink could lead to new wearables

**A new color-changing ink** could aid in health and environment monitoring—for example, allowing clothing that switches hues when exposed to sweat or a tapestry that shifts colors if a dangerous gas enters the room. The formulation could be printed on anything from a T-shirt to a tent.

Wearable sensing devices such as smart watches and patches use electronics to monitor heart rate, blood glucose, and more. Now researchers at Tufts University's Silklab say their new silk-based inks can respond to, and quantify, the presence of chemicals on or around the body. Silk's ability to "act like a protective 'cocoon' for biological materials" means the necessary sensing and color-changing compounds can be added to the ink without losing their function, says Fiorenzo Omenetto, a biomedical engineer at Silklab and senior author of a new paper on the technology published in July in *Advanced Materials*.

The researchers improved on an earlier iteration that worked with inkjet printers, thickening the ink with the chemical sodium alginate to make it viable for screen printing, and then added various reactive substances. With the new ink, they can now "easily print a large number of reactive elements onto large surfaces," Omenetto says.

The team made the ink by breaking down raw silk fibers into constituent proteins, which the researchers suspended in water. Next they mixed in various reactive molecules and analyzed how the resulting products changed color when exposed to alterations in their environment. When printed on fabric and worn, pH indicators, for example, could convey information about skin health or dehydration; lactate oxidase could measure a wearer's fatigue levels. The changes are visible to the naked eye, but the researchers also used a camera-imaging analysis to continuously monitor the color variations and create a database of values.

"In the case of a T-shirt, the wearer 'paints' the shirt [through] exercise—with colors correlating to the acidity distribution of their sweat," Omenetto says. The ink could also be adapted to track environmental changes in a room, he says, or to respond to bacteria and follow disease progression.

Mechanical engineer Tyler Ray of the University of Hawaii at Mānoa, who was not involved with the study, notes that most of today's wearable monitors are rigid and fairly bulky. The new ink technology has "the potential to transform consumer wearables from recreational novelty devices into body-worn, clinical-grade physiological measurement tools that yield physician-actionable information," he says. But "one of the challenges with any colorimetric approach is the effect various environmental conditions have on accuracy, such as lighting … or the camera used." Future work needs to address these issues.

*—Jillian Kramer*



*Illustrations by Thomas Fuchs*

IN THE NEWS

# Quick Hits

*By Scott Hershberger*

**ENGLAND**
Archaeologists found that 20 deep shafts, previously thought to be natural sinkholes and ponds, were dug by Neolithic humans. The shafts form a circle two kilometers in diameter, with the Durrington Walls monument at its center, just three kilometers from Stonehenge.

**ISRAEL**
Researchers sequenced DNA samples from the Dead Sea Scrolls, identifying fragments made from sheep skin and others made from cow hide. The technique could help match fragments together and unravel the artifacts' geographic origins.

**ARGENTINA**
The earliest dinosaurs laid soft-shelled eggs, paleontologists say. A new chemical analysis of a more than 200-million-year-old fossilized egg from Patagonia—and a clutch of more recent eggs from Mongolia, found in the Gobi Desert—revealed a thin film matching the characteristics of modern soft-shelled eggs.

**INDONESIA**
Scientists identified an elusive nose-horned dragon lizard in the forests of North Sumatra. Despite appearing in the mythology of the indigenous Bataks, the visually striking species had been spotted by scientists only once before—almost 130 years ago.

**BRAZIL**
In a new paper, researchers documented the largest lightning bolt ever recorded. The "mega-flash," which extended for more than 700 kilometers in southern Brazil in 2018, was detected by a new advanced weather satellite in geostationary orbit.

**AUSTRALIA**
Submarine drones uncovered an extensive system of underwater "rivers" of dense, salty water along Australia's continental shelf. These flows carry organic matter from the coast into the deep ocean, and their volume varies seasonally, peaking in winter.

For more details, visit www.ScientificAmerican.com/sep2020/advances

GENETICS

# Tomato Surprise

## New research catalogues tomatoes' genetic variation

**Tomatoes** come in a dizzying array of shapes, sizes and flavors—and a new study uses state-of-the-art DNA-sequencing technology to finally trace the genetic underpinnings of these differences. The comparison of 100 tomato varieties' genetic sequences reveals more than 230,000 variations within their DNA.

Understanding how these mutations modify tomatoes will give breeders and scientists new tools to refine this crop and others, says Zachary Lippman, a plant biologist at Cold Spring Harbor Laboratory and a senior author on the study, published in July in *Cell.* The scientists sequenced and compared the genomes of a wide range of tomatoes, including wild and vintage heirloom varieties as well as more modern ones. They used a technique called long-read sequencing to track down large stretches of tomato DNA that had been copied, deleted or moved. These structural variations, which significantly change the genome, were impossible to pinpoint using previous technologies that allowed scientists to read only small snippets at a time.

Scientists had known the DNA of a given species can have significant structural variations, but this is the first comprehensive determination of their extent and nature, says Boyce Thompson Institute plant biologist Jim Giovannoni, who was not involved in the study.

Once the researchers identified the numerous mutations, they examined how these variations influence tomato characteristics. They focused on three particular traits—flavor, size and ease of harvesting. In one test, the team identified a gene that infuses a smoky flavor, presenting breeders with a target attribute to enhance or eliminate at will. In another experiment, the scientists used the gene-editing tool CRISPR to modify the DNA structure and changed fruit size by making more copies of a particular gene. Finally, they investigated how variations influence a trait that makes tomatoes grow in an easier-to-harvest formation but results in lowered fruit production. The researchers showed how four structural variations together can tune relevant genes that maintain the trait without reducing fruit productivity, establishing a protocol to breed for that balance.

The study "reveals thousands of other gene-associated structural variations that may explain many important tomato traits—disease response, stress tolerance, yield, performance and quality—that can now be accessed," Giovannoni says. Knowing which gene to mutate for tuning a particular trait is a "holy grail" for agricultural plant breeders and geneticists, Lippman says, noting that studies like these can set the stage to improve crops using predictable, accurate breeding.

*—Harini Barath*

GETTY IMAGES

BIOLOGY

# Egg Hitchhikers

## Fish eggs still hatched after passing through a duck

**For centuries** scientists speculated that fish eggs reached isolated lakes and ponds by hitching rides on water birds' feathers or feet. But according to findings published in July in the *Proceedings of the National Academy of Sciences USA,* the mode of transport for at least some eggs could be much more intimate: the new research provides the first evidence that soft-membraned fish eggs, eaten and pooped out by birds, can still hatch into viable young.

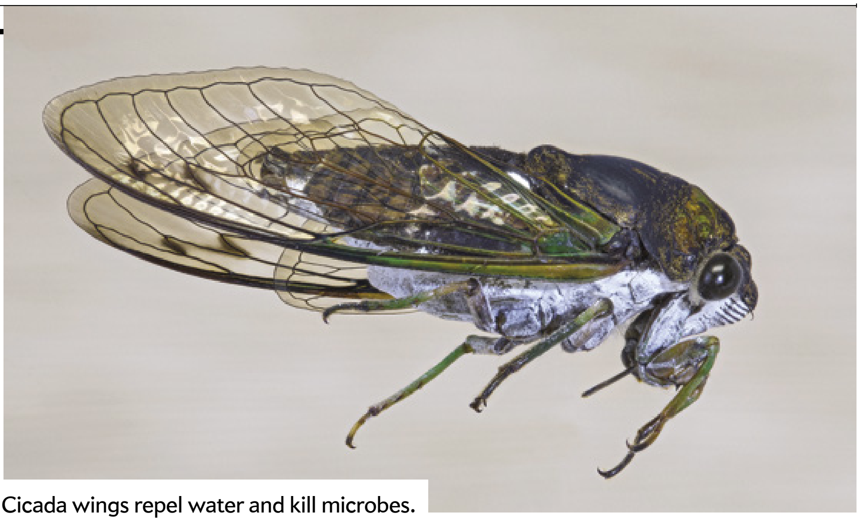
"No one ever really thought of bird guts before because I think it's quite an absurd thing," says co-author Orsolya Vincze, an ecologist at the Danube Research Institute in Debrecen, Hungary. "We were hopeful we'd find something, but we still thought it was pretty unlikely." Researchers did hatch a killifish egg from swan excrement in 2019—but killifish eggs are unusually hardy, able to withstand extended periods of dehydration.

Vincze and her colleagues hypothesized that ordinary fish eggs might be able to survive being eaten after the study's first author, Ádám Lovas-Kiss, observed that soft plant material stayed alive in bird feces.

To test their hunch, the researchers acquired eight captive-bred mallard ducks from a local breeder and the eggs of two carp species from an aquaculture institute. They force-fed each duck three grams of fertilized eggs (about 500 eggs per serving) from each fish species over two separate experiments. Examination of the birds' feces revealed 18 whole eggs, which the investigators placed in an aquarium. Twelve had viable living embryos, and three hatched into normal baby fish.

"For me, this research shows that there are scientific questions that can yield insightful results, while being implemented within simple, easy-to-understand and [easy-to-]reproduce experimental setups," says Tibor Hartel, an ecologist at Babeş-Bolyai University in Romania, who was not involved in the study.

Vincze and her colleagues suspect the success rate would be higher in the wild, where conditions are more favorable for keeping eggs healthy; they hope to test this idea in future experiments. They also plan to conduct follow-up studies on a more diverse set of fish species. *—Rachel Nuwer*



Cicada wings repel water and kill microbes.

CHARLES FLOYD *Alamy*

BIOLOGY

# Winging It

## Chemistry and structure unite to give cicada wings special properties

**Nature often inspires** engineering. Cicada wings, for example, have long tantalized researchers with their water-repellent and antimicrobial properties, which would be useful to replicate in manufactured products. But previous studies involved totally removing the wings' surface chemicals, sometimes damaging the wings and giving an incomplete picture of how those chemicals work together with the wings' structure. New research investigates substances coating cicada wings layer by layer, revealing a complex interplay between topography and chemistry.

Researchers analyzed two cicada species that each have a highly ordered pattern of tiny, conelike structures called nanopillars on their wings. Previous work suggested nanopillars contribute to the insects' ability to shed water and help kill microbes.

To avoid wing damage, the team tested a method called microwave-assisted extraction that had not been used on intact insect wings before, says Jessica Román-Kustas, an analytical chemist at Sandia National Laboratories. Román-Kustas is lead author on the new study, which appeared in May in *Advanced Materials Interfaces.* The method involved heating and cooling wings immersed in chloroform and methanol, analyzing layers of chemicals as they came off. "It [was] days of sitting at the microwave with a timer and a computer," she says.

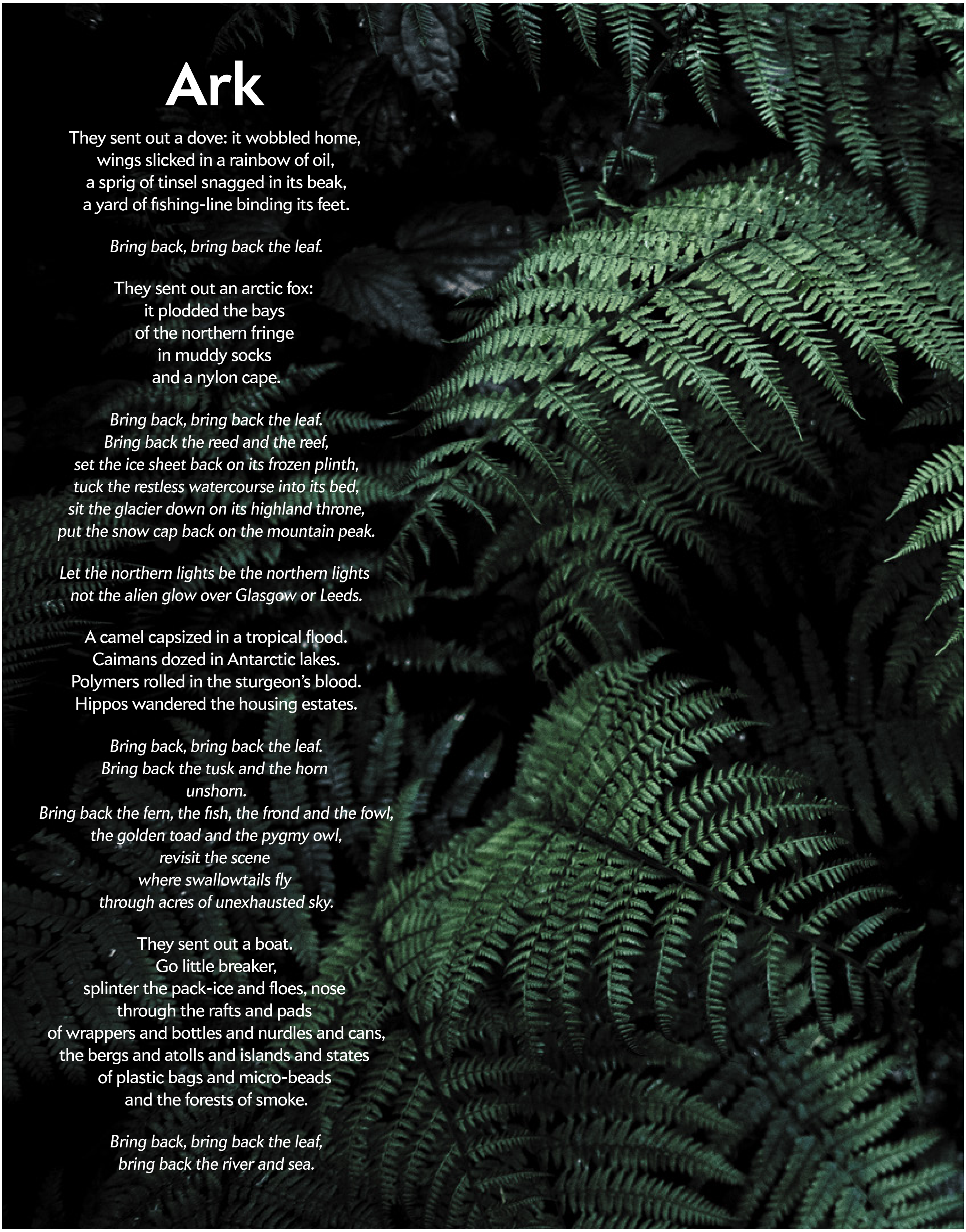
In both cicada species, the researchers found that the nanopillars' chemical makeup is important for maintaining structural integrity. "When you remove the outer [chemical] layers from the nanopillar, the pillars become shorter and bend toward each other," says Marianne Alleyne, a biologist at the University of Illinois at Urbana-Champaign and a senior author on the study.

In the annual cicada *Neotibicen pruinosus,* this wilting effect was more extreme and made the wings less water-repellent at first (although they recovered some of that ability as more chemicals were removed). Bacteria-killing activity actually increased as the first layers were removed but then decreased again as more compounds were stripped. The team found that the cicada *Magicicada cassinii,* which emerges every 17 years and has shorter nanopillars, has surface chemicals that by themselves seem to have bactericidal properties—suggesting these cicadas rely more on their chemical components than structure to kill microbes.

"It is clear … that different layers serve different purposes," says Terry Gullion, a physical chemist at West Virginia University, who was not involved in the study, "and the ability to probe only specific layers is very important [to obtain] a much better understanding of the overall physical properties' dependence on chemical makeup."

Understanding how chemicals do (or do not) affect structure may help scientists engineer better products. "By having this fundamental knowledge about how structure and chemistry relate to each other," Alleyne says, "we can design new materials more rationally, making choices about the structure and chemistry … based on what we have observed in nature." *—Jillian Kramer*

**Simon Armitage,** Professor of Poetry at the University of Leeds and the current U.K. national Poet Laureate, wrote “Ark” to commemorate the September 2019 naming of a new polar research ship, the RSS *Sir David Attenborough*.



# Ark

They sent out a dove: it wobbled home,
wings slicked in a rainbow of oil,
a sprig of tinsel snagged in its beak,
a yard of fishing-line binding its feet.

*Bring back, bring back the leaf.*

They sent out an arctic fox:
it plodded the bays
of the northern fringe
in muddy socks
and a nylon cape.

*Bring back, bring back the leaf.*
*Bring back the reed and the reef,*
*set the ice sheet back on its frozen plinth,*
*tuck the restless watercourse into its bed,*
*sit the glacier down on its highland throne,*
*put the snow cap back on the mountain peak.*

*Let the northern lights be the northern lights*
*not the alien glow over Glasgow or Leeds.*

A camel capsized in a tropical flood.
Caimans dozed in Antarctic lakes.
Polymers rolled in the sturgeon’s blood.
Hippos wandered the housing estates.

*Bring back, bring back the leaf.*
*Bring back the tusk and the horn*
*unshorn.*
*Bring back the fern, the fish, the frond and the fowl,*
*the golden toad and the pygmy owl,*
*revisit the scene*
*where swallowtails fly*
*through acres of unexhausted sky.*

They sent out a boat.
Go little breaker,
splinter the pack-ice and floes, nose
through the rafts and pads
of wrappers and bottles and nurdles and cans,
the bergs and atolls and islands and states
of plastic bags and micro-beads
and the forests of smoke.

*Bring back, bring back the leaf,*
*bring back the river and sea.*

SZABO ERVIN-EDWARD *Getty Images*

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

# Feast and Famine

## Intermittent fasting is the diet du jour, but many of its health claims remain unproven

*By Claudia Wallis*

**Healthy weight management** comes with many perks. Among the proven benefits: a reduced risk of diabetes, less joint pain, lower chances of certain cancers and an overall fitter cardiovascular system. Some regimens, particularly the Mediterranean diet, seem especially well suited to delivering these advantages, though, as with all diets, only to the degree that people can stick with them and avoid overeating. Now research hints that another trendy diet may offer even more extensive health benefits. At least that is the claim by some who study an approach to eating—and not eating—called intermittent fasting.

Intermittent fasting (IF) has its roots in decades of studies showing that if you feed rodents only every other day, they not only remain lean but develop fewer aging-related diseases and live 30 to 40 percent longer. In a 2019 review article in the *New England Journal of Medicine,* gerontologist Rafael de Cabo of the National Institute on Aging and neuroscientist Mark Mattson of Johns Hopkins University summarized a wealth of findings in animals and a more limited number in people. In rodents and to some degree in monkeys, IF is a veritable fountain of youth, lowering body weight, blood pressure and cholesterol levels, improving glucose control, reducing systemic inflammation, maintaining brain health, and even boosting endurance and coordination. In humans, studies have shown that various forms of IF can be effective ways to lose weight, control blood sugar and lower blood pressure. There are hints that the more stringent forms—those with longer or stricter fasts—offer additional benefits. "But to be honest, a lot of the benefits that we see in animals are not really translating to humans," says Krista Varady, a professor of nutrition at the University of Illinois at Chicago. "It's not a magic diet."

IF comes in three main flavors: alternate-day fasting, when people alternate between feast days (eating normally or a little extra) and fast days with one meager meal of about 500 calories; the 5:2 plan, which means eating normally five days a week but only one scant meal the other two days; and time-restricted eating, when daily dining is confined to a window of eight hours (or, in some versions, six or 10 hours).

Scientists attribute many of the positive effects of IF to something called metabolic switching—after 10 or 12 hours of fasting, the body depletes its supply of glycogen (a stored form of glucose) and starts burning ketones (a fuel made from fat by the liver). This switch affects growth factors, immune signals and other chemicals. "But ketones are not the whole story," Mattson says. "These periods of fasting-eating-fasting-eating activate genes and signaling pathways that make neurons more

resilient," he says, mainly based on animal research. "It stimulates a process called autophagy: the cells go into a stress-resistance and recycling mode where they get rid of damaged proteins." Mattson likens cycles of fasting and eating to exercise and rest: "Your muscles don't get bigger during exercise; they get bigger during the recovery."

There is good evidence that IF helps people shed pounds. For example, two studies, each with about 100 overweight women, compared the 5:2 regimen with a diet that cut daily calories by 25 percent; both found that the two diets led to the same amount of weight loss over three to six months. The intermittent fasters, however, wound up with better blood sugar control and a greater reduction in body fat. In addition, a 2019 study by Varady's team with 43 overweight people showed that alternate-day fasting improved the body's response to insulin by more than twice as much as a typical calorie-cutting diet.

IF may also have an edge in reducing blood pressure, says Courtney Peterson, assistant professor of nutrition at the University of Alabama at Birmingham. In a small but rigorous study with prediabetic men, Peterson's laboratory showed that restricting meals to a six-hour window that ended at 3 P.M. led to better insulin sensitivity and blood pressure even without weight loss. As for other benefits, dozens of human trials are underway to test IF as a way to slow cancer growth and reduce symptoms of multiple sclerosis, stroke, Crohn's disease and other illnesses.

In the end, the only successful diets—whatever the goal—involve permanent changes in eating habits. IF can work well over the long haul for meal skippers and people who hate to count calories. But Varady saw a high dropout rate in a yearlong study of alternate-day fasting and is skeptical of time-restriction windows that shut too early: "Nobody wants to skip dinner." SA

*Illustration by Fatinha Ramos*


175

SCIENTIFIC AMERICAN

# 175 YEARS of DISCOVERY

A few years after the first issue of this magazine was published, a New Jersey carpenter found traces of gold in California's American River, setting in motion a Gold Rush in which some 100,000 prospectors flooded the Sierra Nevada seeking their fortune. Rufus Porter, inventor, muralist and founder of this magazine, saw a different opportunity than the average 49er. He wanted to ferry paying passengers from the East Coast to California via hydrogen airship, a huge craft that would make the trip in three days. That scheme never took off. *Scientific American,* however, is still going strong.

*SciAm* has endured in part because of continual self-evaluation and reinvention. In that spirit, we decided to use this anniversary issue to take a hard look at our past, by analyzing the shifting ways we've talked about science ("The Language of Science," on page 26) and by excavating and owning up to some of the most egregious material we've printed ("Reckoning with Our Mistakes," on page 36). We chose to tell a few of the more entertaining stories from our history—like the time Hans Bethe wrote an article for us on the hydrogen bomb, leading the feds to raid our offices, burn 3,000 copies of the magazine, and eventually find our editor in chief "subversive and disloyal" ("Nuclear Reaction," on page 73).

But we are most interested in the sweep of scientific progress that *Scientific American* has spent nearly 18 decades covering. After all, when our first issue came out in 1845, the planet Neptune had yet to be discovered; today cosmologists soberly debate the existence of parallel universes. In the articles that follow, some of the smartest writers and scientists around describe how we—as in we inquisitive humans—got from there to here and where we're headed next. *—The Editors*

# THE LANGU


This influx of fresh words is the result of a pivotal redesign that debuted in May 1948. It marks the point at which the magazine's editorial vision shifted away from covering inventions and industry toward explaining applied and theoretical science in clear language to the interested layperson.
A dramatic vocabulary shift is made apparent here in the form of a gray cliff, with gold, orange and purple words spilling down to fill the void. Some of the "older" words that were severely pinched at this transition point include "set," "purpose," "describe" and "claim."
water
invention
patent
1850
1860
1870
1880
1890
1900
1910
1920
1930
1940
1950

# 175TH ★ANNIVERSARY★ ISSUE

HISTORY OF SCIENCE

# AGE OF SCIENCE

## HOW THE WORDS WE USE HAVE EVOLVED OVER THE PAST 175 YEARS

*Graphics by Moritz Stefaner*
*Captions by Jen Christiansen*

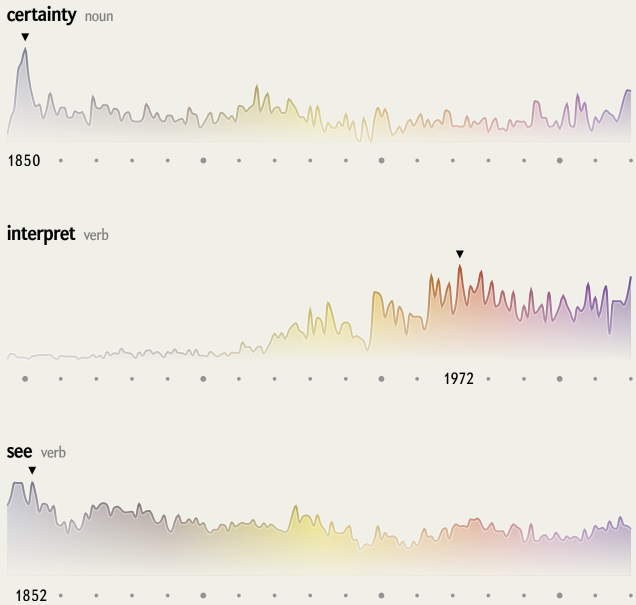

The most popular words used in the pages of *Scientific American* are displayed here by frequency, from 1845 (*left*) through 2020 (*right*). Before visualizing the full corpus of our archives, we culled words shorter than three letters, numbers and so-called stop words such as "then" and "or." The remaining top 1,000 words were gathered for each of the 175 years and merged across the years for a total of 4,420 prevailing words. Each layer represents one word, and the thickness of the layer corresponds to the fraction of text occupied by that word, by year. The color and vertical position of each layer are based on the year in which the respective word's relative frequency peaked: Words routinely used in the early days of the magazine (*gray*) slowly give way to words used more often in recent years (*purple*). (The range of brightness of neighboring layers alternates for improved legibility.) The jarring visual effect of those vertical stripes signals sudden changes in vocabulary. The three annotation bubbles here offer some historical context for both rapid shifts and consistent periods. —*J.C.*

SINCE AT LEAST THE 17TH CENTURY, science has struggled with words. Francis Bacon, visionary of a new, experimental natural philosophy, called language an “idol of the marketplace”: a counterfeit currency we trade in so habitually that we no longer notice the gap between words and the world. True to its Baconian ideology, the Royal Society of London, one of the world’s oldest scientific societies, made *nullius in verba* (roughly, “on no one’s word”) its motto soon after it was established in 1660. Satirist Jonathan Swift parodied the Royal Society’s suspicion of language in *Gulliver’s Travels,* published in 1726: instead of conversing, some members of the Academy of Lagado carry around a sack of things that they exchange instead of words. Science aspired to show, not tell.

Yet science has never been speechless. Scientific journals also began in the 17th century, and since then, science has been all about communication—first and foremost between scientists and other scientists, but also with a broader public fascinated by the latest discoveries, inventions and speculations about fossils, electricity, atoms, computers, genes and galaxies. How to communicate about the world in words? Into the crack between words and things sprang images: woodcuts, engravings, lithographs, photographs, diagrams, graphics of all kinds. Modern science is ingeniously, intrinsically and extravagantly visual. No wonder “see” is a word whose popularity spans all 175 years of writing about science and technology in *Scientific American*.

It is entirely in keeping with the visual spirit of scientific communication that the very words used in all 5,107 issues of *Scientific American* since 1845 should be turned into an image. Like the patterns in marbled paper, the word frequencies undulate, soaring and plunging as a function of time to track the way science talked about itself to itself. Epistemic virtues (which are to knowledge what moral virtues are to goodness) such as “certainty,” flanked by its boon companions “universal,” “rational” and “truth,” spiked in the middle decades of the 19th century, whereas clusters such as “imagination,” “intuition,” “conjecture” and “interpret” peaked suggestively between the 1950s and the 1970s. After World War II, when the most prominent scientists of the day—Albert Einstein, J. Robert Oppenheimer, Linus Pauling—reflected on the wider significance of their science for a nonspecialist audience, values and assumptions taken for granted in research journals came out into the open in the pages of *Scientific American*.

Just as revealing as the jagged peaks and troughs are the trajectories of words that have persisted over time: “average,” “exception,” “cause,” “experiment,” “observation,” “standard,” “skill” and, yes, “see.” Instead of the Alps, these word landscapes resemble gently rolling hills: they have their ups and downs, but for the most part they are as steady as the horizon. They represent the enduring practices of science that survive revolutions in theories and even shifts in epistemic virtues.



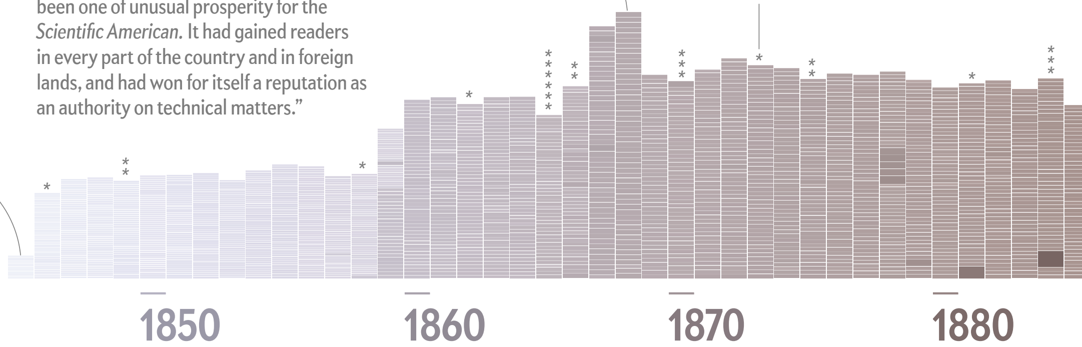

Scientific images are multipurpose tools: they represent things, relationships, even arguments. But just as a map does not duplicate the territory it represents, words do not mirror the world in every detail. Although the relative frequencies of words used are highly suggestive, they cannot convey the texture of the magazine issue by issue. A reader nowadays might wonder: Where are the women? Why are some fields of research missing? Who paid for science back then? No image can tell the whole story, if only because the story that interests us changes over time. When images do succeed, they enlist sight in the cause of insight—in this case, a rippling physiognomy of 175 years of science for the curious public.

**Lorraine Daston** is a director emerita at the Max Planck Institute for the History of Science in Berlin. Her current projects include work on the meaning of modernity in the history of science and on the relation between moral and natural orders. She is author of several books, including *Objectivity* (Zone Books, 2007), co-written with Peter Galison, which is about how objectivity became the cardinal epistemic virtue in science.

*Scientific American* was founded by Rufus Porter as a weekly publication. Its tagline proclaimed it to be "The Advocate of Industry and Enterprise, and Journal of Mechanical and Other Improvements." Although early issues maintained a sharp focus on inventions, they also included poetry, Porter's musings on religion, and painting instructions. The very first issue—dated August 28, 1845—holds 97,621 characters and seven images.

1868 was an ambitious year, with 16.89 million characters spread more or less evenly across 52 issues. As noted by the editors in 1915, "The period from 1859 to 1882 had been one of unusual prosperity for the *Scientific American*. It had gained readers in every part of the country and in foreign lands, and had won for itself a reputation as an authority on technical matters."

**Each asterisk represents one corrupt issue file. Data from these editions are not included in the quantitative analysis.*

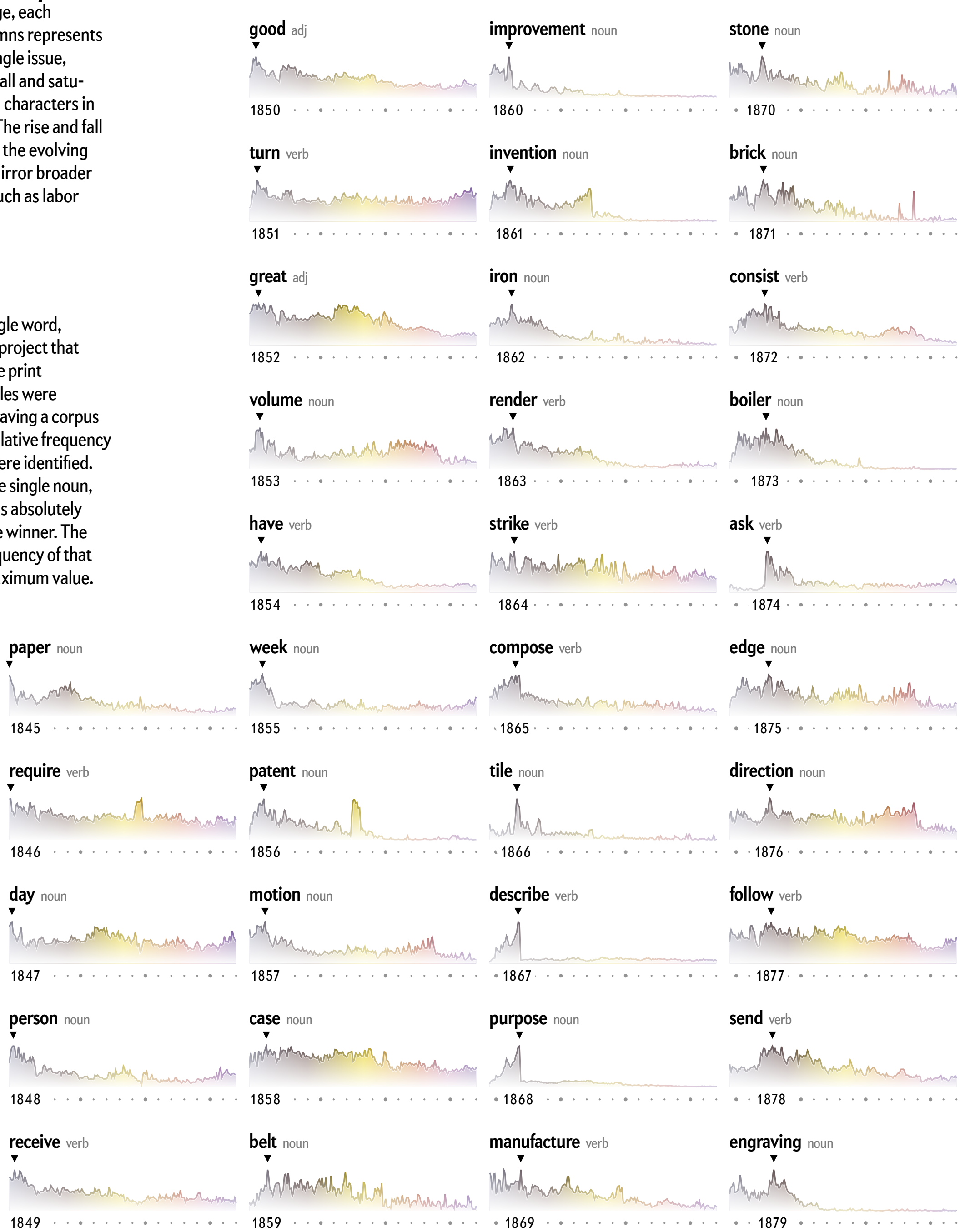



## *Character-Count Landscape*

Running along the top of the page, each segment within the annual columns represents the number of characters in a single issue, ranging from short and light to tall and saturated, maxing out at 1.04 million characters in the December 6, 1884, edition. The rise and fall of annual character counts echo the evolving mission of the publication and mirror broader trends in society and industry, such as labor strikes and fluctuating budgets.

## *Word of the Year*

Each year is represented by a single word, selected through a text-analysis project that started with all 5,107 issues of the print magazine. (Thirty-seven of the files were corrupt and could not be read, leaving a corpus of 5,070 issues.) Words whose relative frequency peaked in each individual year were identified. Among those top contenders, the single noun, verb, adjective or adverb that was absolutely used most often was deemed the winner. The line charts, which reflect the frequency of that word over time, are scaled by maximum value.




*Graphics by Moritz Stefaner and Christian Lässer*

Most issues in 1884 were 16 pages. An exception: the December 6 edition, which also incorporated a 24-page mail-order catalog of article collections indexed by topic, including carbuncle and boil remedies and practical uses of electricity.

With a redesign unveiled in 1911, the editors aimed to appeal to a broader readership by injecting more personality-driven content, in part by printing more "signed articles, written by men of special knowledge and world-wide reputation in the particular fields of which they write."

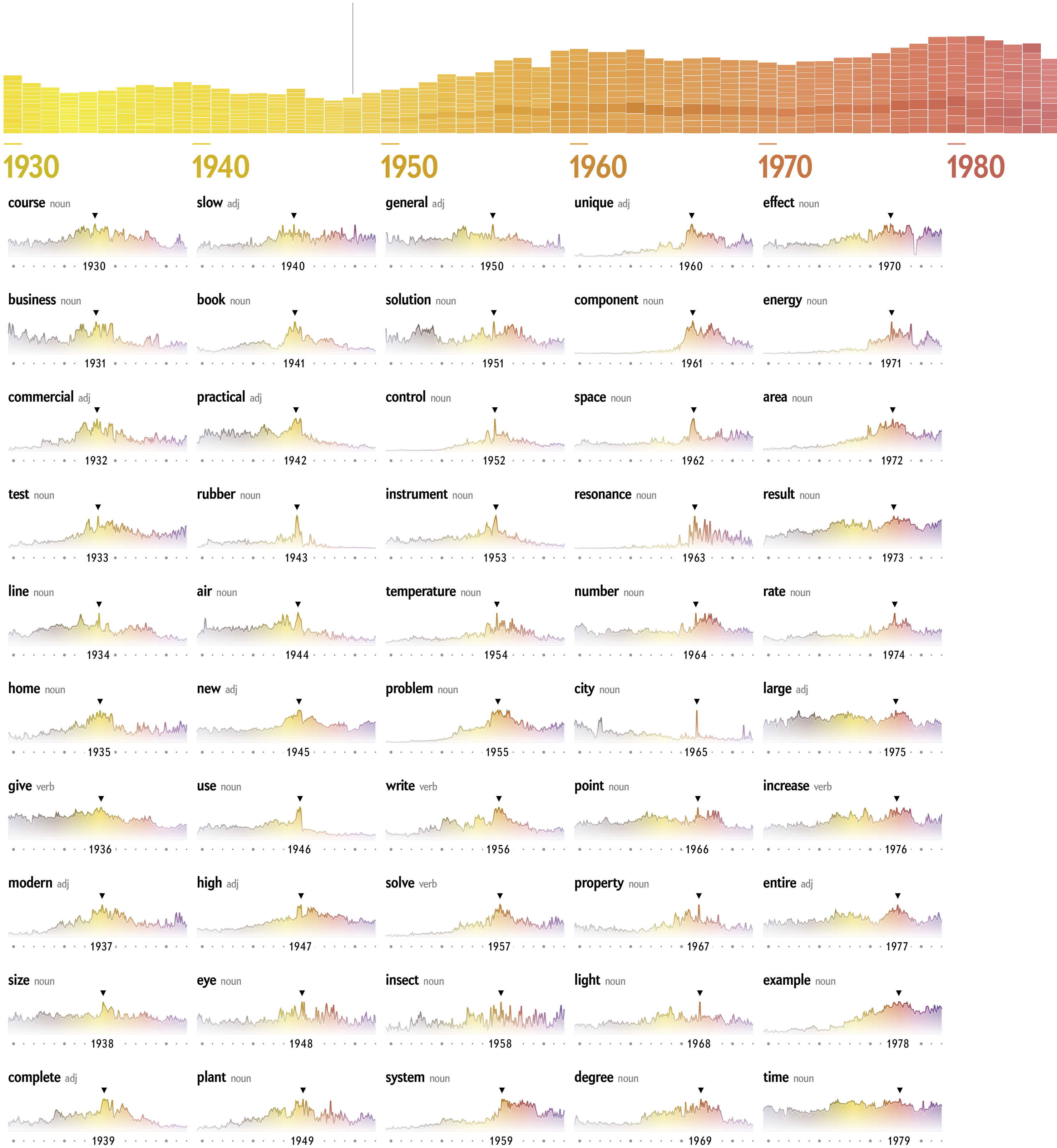
Traces of the Printers Strike of 1919 are visible as light bands in this column. Without the aid of professional typesetters, typed pages were transferred directly to lithographic stone. Large letters and widely spaced lines necessitated succinct articles.

The magazine went from a weekly publication to a monthly publication in November 1921.

Average issue page and character counts were reduced between 1929 and 1933, most likely to cut costs during the Great Depression.

As the editors wrote leading up to the May 1948 redesign: “The new *Scientific American* will report the development of all branches of science: the physical, biological and social sciences, as well as their more significant applications in medicine, engineering and industry.… The new *Scientific American* will solicit articles by scientists. Recognizing, however, that the main business of scientists is science, it will obtain most of its articles from its own staff, journalists whose life work is the reporting of science.… The finished product will be the result of a joint effort, the scientist providing the substance of what is reported and the journalist the art of clear communication.”

Larger single-topic issues, which are traditionally printed in September, leave a visible imprint across many decades. Topics included fundamental questions in science (1953), the universe (1956), technology and economic development (1963), materials (1967), life and death and medicine (1973), microelectronics (1977) and the brain (1979).

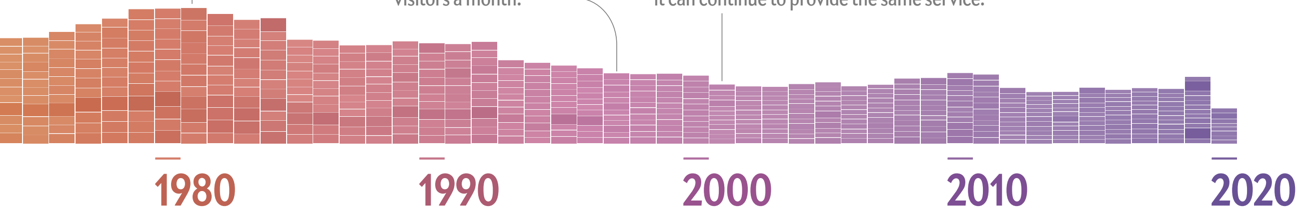


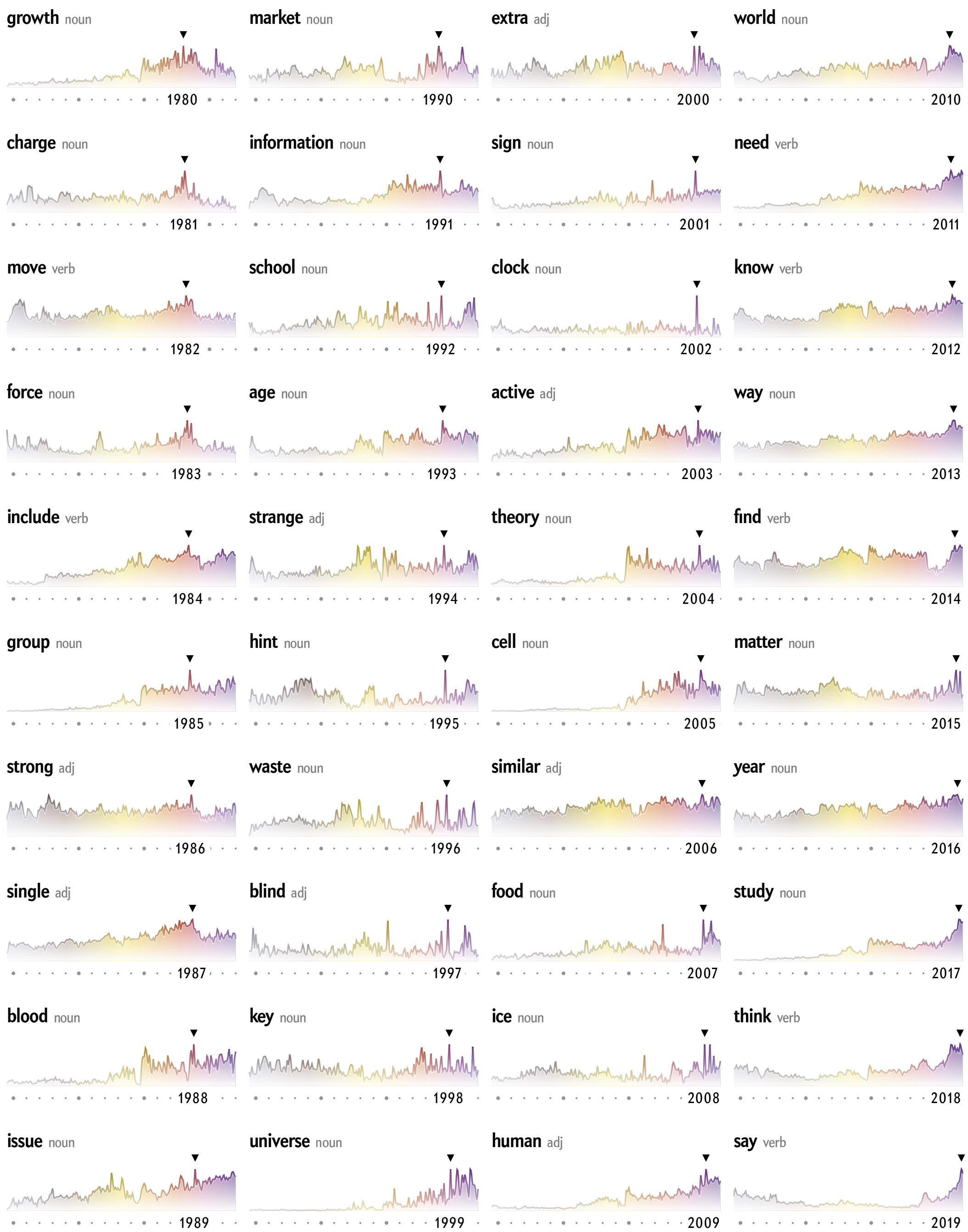
1981 marks peak average character count per issue and an average length of 200 pages per issue. Issues remained thick for several years, despite a recession in the U.S. during the early 1980s.

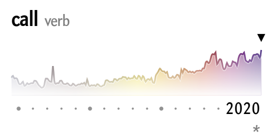
The ScientificAmerican.com domain is created in 1997, replacing earlier versions of the magazine's Web site dating from 1996. (Words published exclusively online are not included in this text analysis.) Today the Web site receives nearly 10 million visitors a month.

After the April 2001 issue redesign, page count held fairly steady, but there is an obvious drop in character count. The shift happened in part because additional space was afforded to photography and dynamic typography. From the editor's letter: "Why rethink the look and content of a magazine that is the best at what it does? Precisely because the magazine's mission hasn't changed but the readers' world has.… Time for reading has become more precious. This magazine's methods and coverage therefore need to shift just so that it can continue to provide the same service."

Today *Scientific American* continues the print tradition—including 14 local-language international editions—even as our content continues to expand online. In 2019 more than 2,000 articles were published on our digital platform.



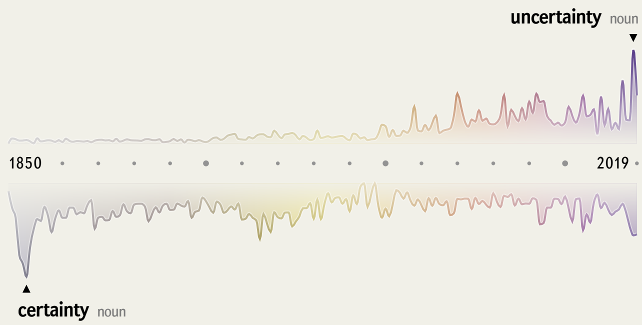



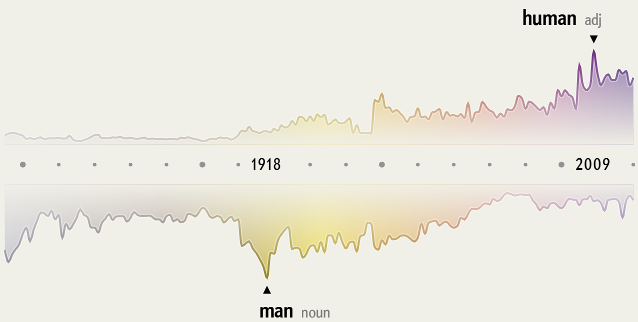



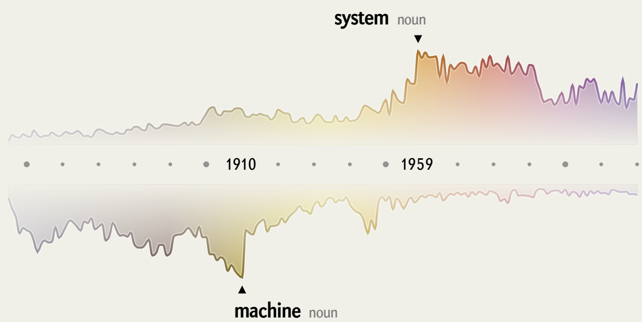

**2020 includes data available by press date (January through August issues).*

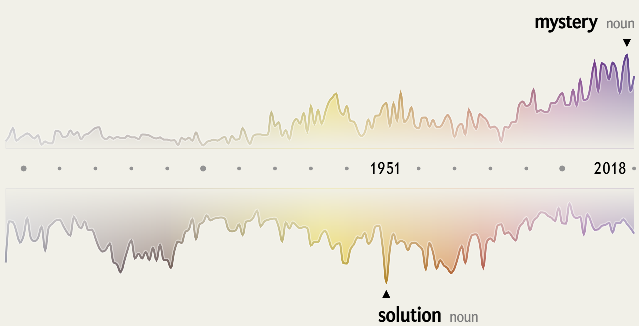
Perhaps just as telling as the words that we've printed are the words that our readers are looking for on ScientificAmerican.com. Some of the most popular search terms in 2020 include "coronavirus," "climate change," "genetics" and "cancer."

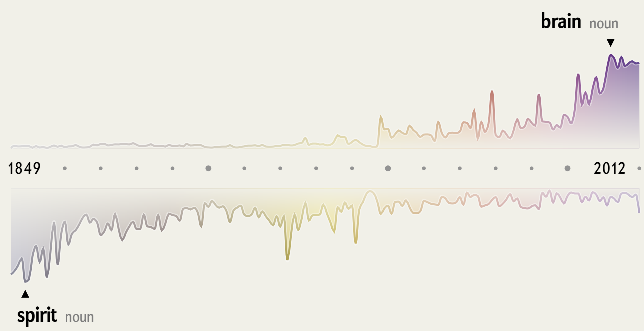
**Wordplay** Tracking the popularity of single words is fun, but word pairings offer more context for how science was portrayed in the magazine. First, editors suggested word pairs that might uncover intriguing relationships. The resulting line charts compare the relative frequency of word occurrence in print issues of *Scientific American* each year, scaled by maximum value. The patterns revealed by these combinations run the gamut from somewhat predictable (weather/climate) to validating (certainty/uncertainty) to socially progressive (man/human). Many more pairings can be found in the articles that follow. To search for your own favorite words and to explore other juxtapositions, visit the interactive portal at www.scientificamerican.com/interactive/science-words

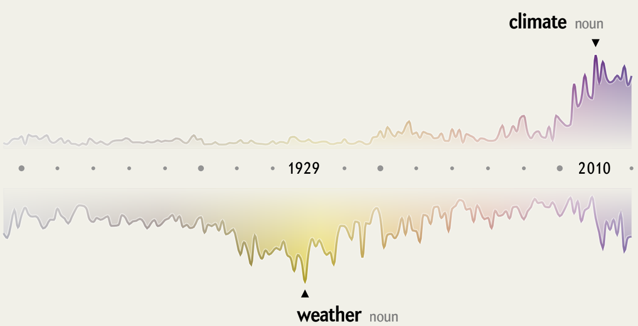


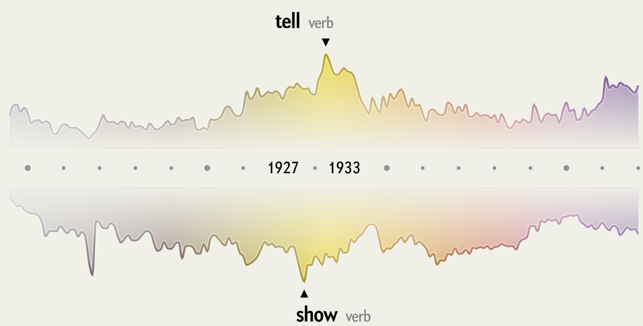



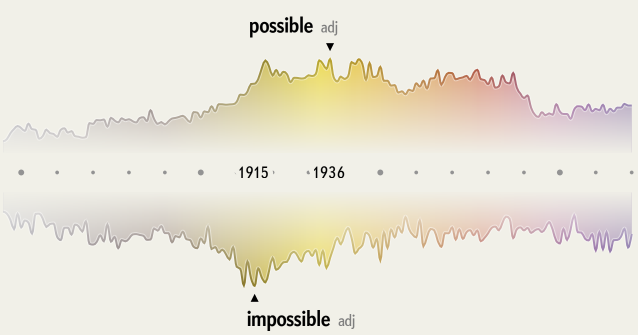



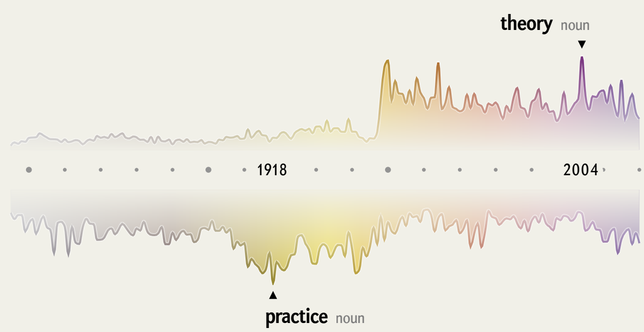



# How to Process History

## A data designer explains the art and science behind this visualization project

*By Moritz Stefaner*

Summarizing the history of a 175-year-old magazine—that's 5,107 editions with 199,694 pages containing 110,292,327 words!—into a series of graphics was a daunting assignment. When the hard drive with 64 gigabytes of .pdf files arrived at my home in Germany, I was curious to dig in but also a bit scared: as a data-visualization consultant with a background in cognitive science, I am well aware that the nuance of language and its semantic contents can only be approximated with computational methods.

I like to start by brainstorming concept ideas and data-discovery questions and immersing myself in the available materials. To get inspired, I read samples of the magazine across the decades, marveling at the old illustrations and typefaces. I set up a data-preprocessing pipeline early on to extract the text from the .pdf files and run the first analyses. I used Jupyter Notebooks (a flexible programming environment for data exploration) with the spaCy Python library (which uses computational linguistics to turn mere character sequences into a structured representation of language) as well as the pandas package (a tool kit for processing large amounts of numeric data easily and quickly).

A central question in any data-science project is how wide a net one casts on the data set. If the net is too coarse, all the interesting little fish might escape. Yet if it is too fine, one can end up with a lot of debris, and too much detail can obscure the big picture. Can we find a simple but interesting and truthful way to distill a wealth of data into a digestible form? The editors and I explored many concept ideas: looking at sentence lengths, the first occurrences of specific words, changes in interpunctuation styles (would there be a rise of question marks?), and mentions of persons and places. Would any of these approaches be supported by the available data?

It soon became apparent that any texts from the predigital era of *Scientific American* (before 1993) are to some degree affected by optical character-recognition (OCR) errors. Reconstructing the original text from images is an inherently noisy process where letters can be mixed up (for instance, "substantially" was often parsed as "snbstantlally"), words might be combined or split at the wrong places, or multicolumn layouts might be read in the wrong order. Accordingly, zooming out on the data-analysis lens to a yearly perspective (rather than working on the level of individual editions) and analyzing the count of single words (rather than looking for compound terms or doing sentence-level analyses) became our sweet spot in the trade-off space between accuracy and robustness against noise.

My first intuition was to focus on "what" has been written about, but working with the data, I became especially intrigued by looking at the "how": the evolution of verbs, adjectives and adverbs. These word types can tell so much about how the tone and attitude of the original magazine have changed from the engineering-driven, mechanistic language to the multifaceted science magazine we know today.

Another key insight was learning that there is actually very little variety in the vocabulary used in the English language. Given that the frequency of words in a language (and in the corpus of *Scientific American*'s text archives) is so skewed, rather than comparing raw numbers of how often words occur, it became far more compelling to look at how the proportion of text a word occupies each year (its relative frequency) evolves over time.

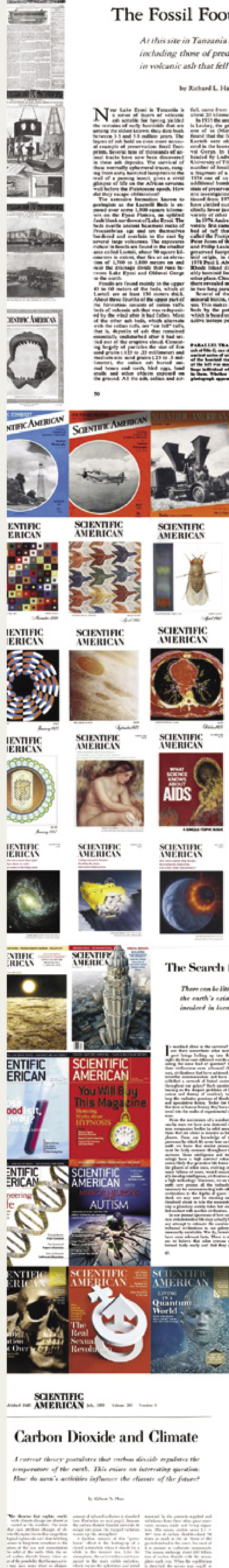
Based on this central idea, we explored many different visual forms—word clouds, stack area graphs, line charts, animations, spatial maps of semantic spaces—before settling on the layered stacked area chart for the opening spread (*pages 26–27*) as the overview visualization. This high-level view of the major shifts in vocabulary, shown as "sediment layers," is complemented by the individual miniature line charts showing the evolution of each top peaking word per year.

Making dense chart arrangements effortlessly scannable requires conscious visual design choices. Reinforcing the shape of the line chart with a continuous color scale may seem like a redundant decoration, but it is perceptually quite effective because it allows us to quickly see if a word is "old" or "new" without studying the line shape in detail. In addition, the color associations (gray/brown representing the mechanistic, vintage past, compared to a fresh, modern purple for the present) help to tie data semantics and visual form together.

Doing data science means having to live with imperfections. No model can be a 1:1 reproduction of reality, and some of the data still remains mysterious to me. For instance: Why does the use of "substantially" drop so substantially after 1868? (I suspect some OCR errors in connection with new typefaces.) Others are launching points for investigation: Why did "tomato" peak so heavily in 1978? Each new discovery instigates curiosity, and I encourage others to view this data set not as an objective and final measurement but as inspiration for new questions.

Explore the data yourself at www.scientificamerican.com/interactive/science-words SA

**Moritz Stefaner,** based in Germany, is an independent designer and consultant with a background in cognitive science and interface design. His work balances analytical and aesthetic aspects in mapping complex phenomena to support data-driven decision-making.




Footprints of Laetoli
The Inflationary Universe
SCIENTIFIC AMERICAN
APRIL 1950
VOL. 182, NO. 4
On the Generalized Theory of Gravitation
An account of the newly published extension of the general theory of relativity against its historical and philosophical background
by Albert Einstein
The Hydrogen Bomb: II
A Chat with Madame Curie
What the Discoverer of Radium Thinks of Us and What We Think of Her
By Austin C. Lescarboura
The Quantum Universe
A Crisis in Physics?
Habits
Sleep
World Changing Ideas
Stone Age Brains
Planet X
Tiny Killers
Secret Life of the Sun
Sleep Learning
Evolved to Exercise
Inconceivable
Humans
Black Hole Mystery
Cyber Cells
A Fire Within
Dinosaur Feathers
Computer, Heal Thyself
Artificial Muscles
Loop Quantum Gravity
Fly by Wire
Suspended Animation
Memory Code
New Nukes?
Cosmology
Climate Change
Privacy
Grassoline
Multiverse
Food
Our Unconscious Mind
The Proton Problem
To Seek Out New Life
Europa's Ocean
Tsunami
A Last Look at Laetoli

# RECKONING *with* OUR MISTAKES

SOME OF THE CRINGIEST ARTICLES IN THE MAGAZINE'S HISTORY REVEAL BIGGER QUESTIONS ABOUT SCIENTIFIC AUTHORITY

*By Jen Schwartz and Dan Schlenoff*

*Illustration by Ellen Weinstein*

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

**Dan Schlenoff** is a senior copy editor at *Scientific American* and has edited the 50, 100 and 150 Years Ago column for one seventh of the magazine's history.

AN ARTICLE ABOUT WOMEN ENGINEERS, PUBLISHED IN 1908, HAS A PROMISING start: If women are attending technical schools and are not legally blocked from working in a forge or firm, why do they face so many obstacles to employment? A reader in 2020 who discovers such a socially progressive question in the archives of *Scientific American* anticipates a discussion of sex discrimination. Perhaps women such as Emily Warren Roebling, who took over her husband's role as chief engineer on construction of the Brooklyn Bridge after he became bedridden, will be held up for their contributions to the field. Surely the article will feature the voice of Nora Stanton Barney, who had recently fought to become the first woman accepted as a junior member in the American Society of Civil Engineers and was active in the suffrage movement.

Alas, no. Author Karl Drews explains it simply: the obstacles "are inherent in the nature of the case and are due to women's comparative weakness, both bodily and mental." He elaborates: "The work of the engineer is creative in the highest sense of the word. From his brain spring the marvels of modern industry," in contrast to women, "whose notable performances have hitherto been confined to the reproductive arts." The path to the workshop takes "blistered hands, not dilettante pottering and observation." Drews declares that even "the most resolute and indefatigable of women" cannot overcome these difficulties. His rationale is sound, he says, because there has been "no great woman composer, painter, or sculptor." Even "the best of woman novelists are surpassed by men."

After making these conclusions in the first few paragraphs, Drews does something more insidious: he invokes data to support his case. The writer sent an inquiry letter to dozens of engineering firms and technical societies to "obtain some definite information on the subject." But he manipulates the cherry-picked survey results to uphold his thesis. Drews denigrates the few women who do come up by baselessly attacking their skills; the sole engineer he deems worthy is uniquely "masculine." When Drews discovers that some women in the U.S. Census identify themselves as boilermakers, he asks an electrical engineering institute if

## WORDPLAY

**THE RELATIVE FREQUENCY OF REVEALING AND INTERESTING TERMS IN THIS MAGAZINE, FROM 1845 TO THE PRESENT.**

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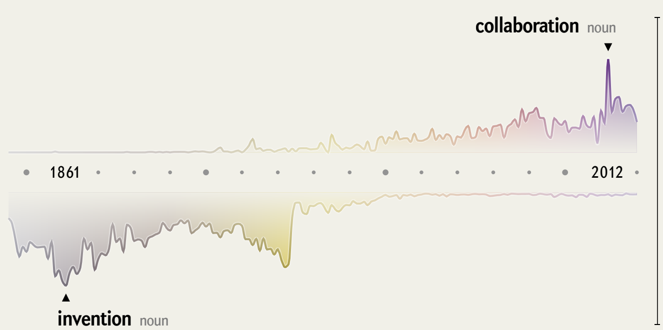





*Graphics by Moritz Stefaner and Christian Lässer*

this can possibly be true. They reply that they are "too chivalrous" to permit such a thing. And poof! Those women's careers cease to exist.

In today's terms, we would say the author is gaslighting the experiences of women engineers when he is not erasing them outright. While the article is outrageous in tone, it is even more instructive as a case study in how the trappings of science have sometimes been misused in these pages to uphold systemic oppression. Under the cloak of empirical evidence, Drews and other writers entrenched discrimination by framing it as unimpeachable truth.

**It is impossible** to make an exhaustive assessment of the magazine's mistakes, but we scoured our archives for some of the most illustrative. Our identity has changed significantly over the decades—from a compendium of inventions to industrial boosterism to reporting on scientific events to experts explaining their research to today, where a journalistic approach guides coverage. One thing that remained fairly consistent, however, is the magazine's position that science could spread prosperity and solve the world's problems.

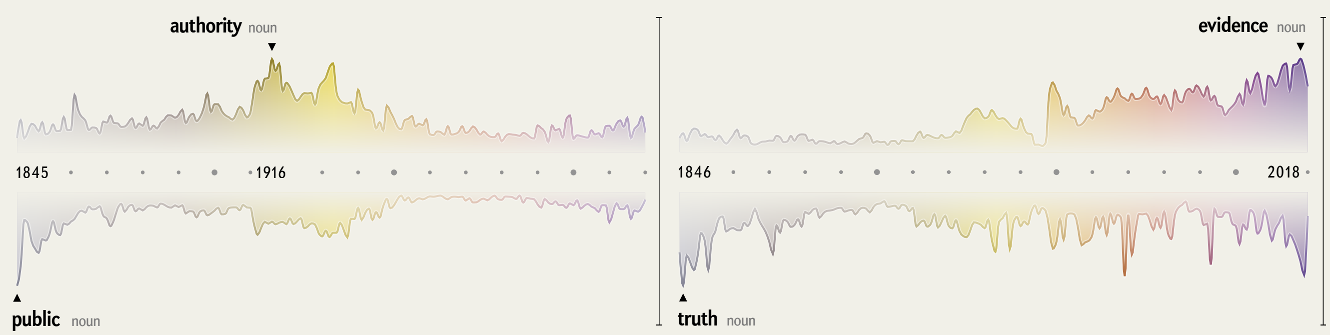
In 1856 the editors, who were criticizing the annual meeting of the American Association for the Advancement of Science (AAAS) as "impractical" (too many papers about the solar system, not enough on construction safety codes), wrote: "What is science but well-arranged facts derived from study and observation? It is not merely speculation—hypothesis—it is positive truth." How quaintly arrogant. If it were that simple to establish and convey a shared reality, we would not have needed to devote an entire issue in 2019 to the warping of truth, the breakdown of trust, the chaos of misinformation. Wearing masks and cutting greenhouse gases would not be political issues. Today we would be more inclined to say science can *explain* the world's problems, including the ones it helped to create.

These days when we deliberate story proposals and editorial strategy, we reassess the status quo and ask one another deeper questions: What makes someone an expert? Who is interrogating the data? What are our responsibilities as gatekeepers? Who is missing from our pages? Because when we look back, it is easier to identify the voices and ideas we published that caused harm; it is harder to assess how much was lost by overlooking or excluding people and perspectives who could have shaped knowledge for a better, safer, fairer world.

Science is done by fallible humans, and the job of editors (also fallible humans) is to evaluate it with skepticism while respecting expertise. For much of its history, *Scientific American* carved out a niche between journalism and peer-reviewed journals. That hybrid model, however, also gave us a wide berth without clear boundaries. We could operate in both spaces without having to adhere to the rules of either one. As long as an article could be classified as scientific in its approach, was not too fringe-y, and, more important, was contributed by a person of appropriate reputation (that is, mostly elite, white, older men), there was an editorial attitude of "anything goes." And too often anything did.

For more than 100 years we revered inventor-entrepreneur types with a tone that undermined the collaborative spirit of science while ignoring the contributions of women and nonwhite scholars. In doing so, we perpetuated the myth of the eccentric male genius whose discoveries arise though his brilliance alone. We cannot help but wonder if generations of men who absorbed through our coverage that the highest "scientific" aspiration was to get rich by inventing some practical technology helped to breed the tech titans of today, who take all the credit for (and control over) their products while shirking responsibility for any consequences those products have wrought on society.

In the name of progress (and manifest destiny), we often disparaged knowledge that threatened the expansion of Western civilization. In one column from 1868, the editors opine on a report from General William Tecumseh Sherman on how "Indian affairs" were hampering railroad construction. Sherman, as you might remember, is infamous for his "scorched earth" style of warfare against both the Confederate Army and Native Americans. But *Scientific American*'s editors didn't think Sherman was being aggressive *enough:* "The Indians must be summarily and thoroughly squelched.... They are the most treacherous, as well as the most inhuman, of all barbarous races." Later that year Sherman launched an appalling campaign to obliterate one of the most important resources for many Great Plains tribes by slaughtering millions of bison and nearly wip-



ing out the species. Starved and traumatized, the tribes were forced onto reservations.

Fast-forward to the present, when we face flooding cities, overfished oceans and depleted soils. Imagine if back in the 19th century, *Scientific American* editors dispatched correspondents to write open-minded reports on Indigenous peoples' resource management and foodways. Perhaps they would have learned how grazing bison help to sustain fertile soils, an "ecosystem service" that cattle do not provide. In a belated reversal, scientists are turning to Indigenous communities to learn how to live sustainably and encourage biodiversity. The Intergovernmental Panel on Climate Change is increasingly drawing on Indigenous knowledge and voices to assess how humanity can best adapt to a changing world.

## The trappings of science have been misused in these pages to uphold systemic oppression. Under the cloak of empirical evidence, some writers entrenched discrimination by framing it as unimpeachable truth.

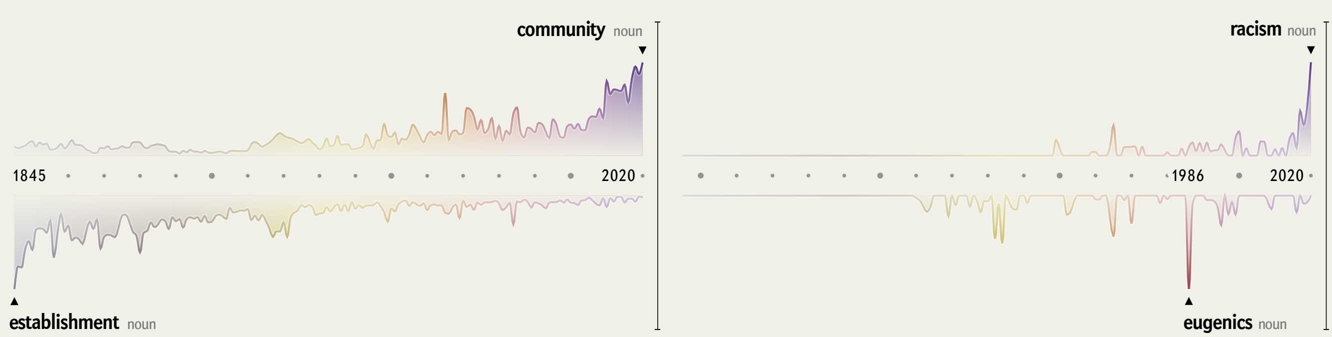
**During the 19th century,** *Scientific American* published articles that legitimized racism. The magazine vigorously advocated for the patent system and its route to wealth—but only for white people. In 1861 the editors wrote that even free Black Americans could not be granted patents, because they were "not regarded as citizens" and could not defend against infringement in court.

By 1871 Charles Darwin had concluded that all living humans were descended from the same ancestral stock. Leading German anthropologists were promoting the "psychic unity" of all people. But none of that stopped the rise of scientific racism, including false ideas about biological determinism. On October 5, 1895, the magazine published a speech by AAAS president Daniel G. Brinton, in which he argues "the black, the brown, and the red races differentiate anatomically so much from the white … they never could rival its results by equal efforts." Right from the womb, he says (offering only his opinion as evidence), a person's race determines "his tastes and ambitions, his fears and hopes, his failure or success."

Brinton and his cohort were not hapless scientists whose research was perverted for nefarious policy. The highest goal of anthropology, Brinton wrote, is to measure the "peculiarities" of "races, nations, tribes" so that people can be governed according to their "sub-species." These differences "supply the only sure foundation for legislation; not a priori notions of the rights of man." In 1896, less than a year after we published Brinton's speech, the U.S. Supreme Court ruled in *Plessy v. Ferguson* that "separate but equal" schools and other facilities were legal. As California Supreme Court Justice Loren Miller explained in a 1966 book, the ruling "smuggled Social Darwinism into the Constitution."

*Scientific American* also covered eugenics extensively. The intellectual roots of eugenics sought to improve the human species through breeding. Long before it became the obsession of the Nazi regime, the bias along racial and class lines had become apparent—yet we continued covering eugenics neutrally rather than critically. With the proliferation of both-sides-ism, we allowed contributors to hide racist political agendas under the guise of science. Articles written against eugenics were often labeled "the opposition."

Even after a staff writer argued, in 1932, that a lack of knowledge in genetics and environmental influences and unreliable intelligence tests meant that eugenicists were misleading "the fallacy-ridden human race," articles promoting eugenics as scientific consensus continued to appear in the magazine. In 1933 a neo-Malthusian promoted birth control but only to prevent the reproduction of "defectives." (The two accompanying photographs are a crowd of people in what looks like a bread line next to a cluster of caged guinea pigs.) The



following year the president of the Human Betterment Foundation wrote that the "trend toward race degeneracy is evident in statistics so well known that they need not here be rehearsed." (A pull quote from the article features "the famous Viennese surgeon" Adolf Lorenz asserting that eugenic sterilization "eventually will come to all civilized countries as a means of getting rid of the scum of humanity.") In 1935 an article was ominously entitled "The Oddest Thing about the Jews."

We are not saying the magazine should have ignored the topic of "human betterment"—it was part of the zeitgeist and its false ideas about genetic inferiority attached to race, ethnicity and class needed to be debunked. But the same editors who recognized that eugenics was a dangerous pseudoscience should not have given eugenicists a platform at all.

The Second World War years were a period of low editorial quality in general; the brand was rescued and reimagined by different owners in 1948. New editor in chief Dennis Flanagan later told Mary Carol Zuegner (who wrote her Ph.D. thesis on *Scientific American*) that he was "a great believer in the importance of context." This principle ushered in work of greater integrity, some of which has become even more relevant over time. In the 1960s articles investigating racism placed the need for change on the institutional level. One uses survey data to show that riots are not attributable to individual behavior but to the "blocked-opportunity theory." In April 1967 psychological studies show that racial unrest will continue until the Black community gets "genuine political and economic power."

But articles such as these do not negate that our coverage promoted systemic racism, and it is chilling to experience the effects of that legacy on our current pandemic crisis. Americans who are willing to sacrifice the lives of people who are disabled, poor, elderly or from historically oppressed groups so that the U.S. economy can "go back to normal" sound like modern-day eugenicists. How else to explain the acceptance that some of us are inherently more worthy of life than others? Advocating for "going back to normal" in 2020 is not all that different from protecting "the sane social structure" of 1933. *Scientific American* contributed to the programming that "normal" and "sane" for some means oppression and death for others.

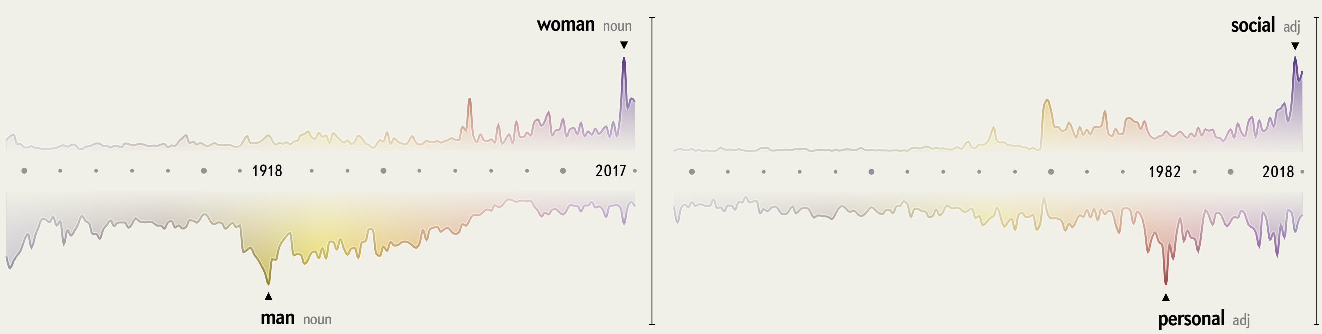
**In her dissertation,** Zuegner analyzed how *Scientific American* covered the 1925 trial of a Tennessee schoolteacher, John T. Scopes, whose crime was teaching evolution. She writes: "The magazine's editorial stance, played out in small notes in its opinion pages, was one of nonchalance because editors were so sure of the outcome, that science would prevail."

This bedrock faith is now our most dangerous delusion. You, too, dear reader, might lean on it during these cataclysmic times. It may be easy to laugh at the popularity of the flat-earth movement, to dismiss conspiracy as silly. It is less amusing to learn that only half of Americans in a 2020 poll said they would get a coronavirus vaccine when it becomes available. It would be an egregious error if we editors fail to understand how these "antiscience" stances are rooted in similar forces, including a rise in institutional distrust, pervasive disinformation, the legacy of scientific racism, and a stubborn belief that we can beat back chaos if we just publish more "well-arranged facts."

After all, *Scientific American* no longer luxuriates as the preeminent delivery system of science to the public. No one does. We are one node in a dizzying information ecosystem where attention goes to the loudest noise.

Reckoning with this "science as authority" attitude means that we can better serve a deeply confused public. We feel just as overwhelmed by the problems of our world as you do, and we think this humility is a good thing. It means that we are awake to the challenges we face, that we are examining our assumptions. Confronting our history gives us the courage to understand the limitations of our own age and reach beyond them.

With coronavirus infections surging across much of the U.S., the stakes could not be higher. If *Scientific American* is to help shape a more just and hopeful future, we must learn from the arrogance and exclusions of our past. Not just because it is right, but because the power of scientific knowledge is stronger for it. And if you are an Indigenous scientist who studies bison grazing and would consider writing an article for us about grasslands restoration, we'd be honored to hear from you. We sincerely regret that the recognition is 175 years late. SA



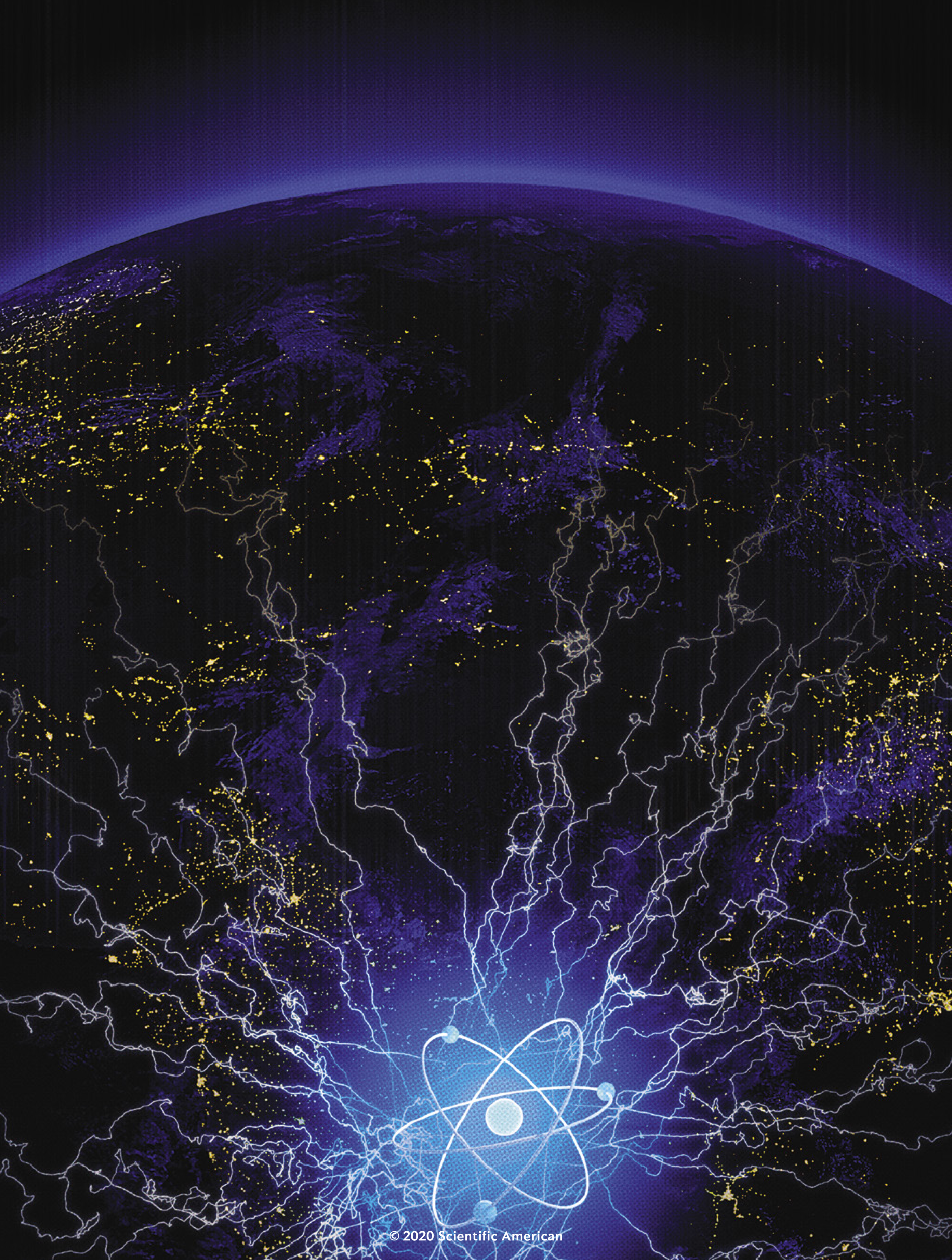
TECHNOLOGY

# THE INFORMATION MANIPULATORS

## BY MOVING MATTER AND ENERGY, INNOVATORS HAVE DEMOCRATIZED INFORMATION

*By Naomi Oreskes and Erik M. Conway*

*Illustration by Tavis Coburn*



**Naomi Oreskes** is a professor of the history of science and an affiliated professor of Earth and planetary sciences at Harvard University. She is author of *Why Trust Science?* (Princeton University Press, 2019) and *Science on a Mission: How Military Funding Shaped What We Do and Don't Know about the Ocean* (University of Chicago Press, 2020). She also writes the Observatory column for *Scientific American.*

**Erik M. Conway** is a visiting associate professor of history at the California Institute of Technology and author of *Exploration and Engineering: The Jet Propulsion Laboratory and the Quest for Mars* (Johns Hopkins University Press, 2015).

IT IS A TRUISM AMONG SCIENTISTS THAT OUR ENTERPRISE BENEFITS HUMANITY BECAUSE OF THE technological breakthroughs that follow in discovery's wake. And it is a truism among historians that the relation between science and technology is far more complex and much less linear than people often assume. Before the 19th century, invention and innovation emerged primarily from craft traditions among people who were not scientists and who were typically unaware of pertinent scientific developments. The magnetic compass, gunpowder, the printing press, the chronometer, the cotton gin, the steam engine and the water wheel are among the many examples. In the late 1800s matters changed: craft traditions were reconstructed as "technology" that bore an important relation to science, and scientists began to take a deeper interest in applying theories to practical problems. A good example of the latter is the steam boiler explosion commission, appointed by Congress to investigate such accidents and discussed in *Scientific American*'s issue of March 23, 1878.

Still, technologists frequently worked more in parallel with contemporary science than in sequence. Technologists—soon to be known as engineers—were a different community of people with different goals, values, expectations and methodologies. Their accomplishments could not be understood simply as applied science. Even in the early 20th century the often loose link between scientific knowledge and technological advance was surprising; for example, aviation took off before scientists had a working theory of lift. Scientists said that flight by machines "heavier than air" was impossible, but nonetheless airplanes flew.

When we look back on the past 175 years, the manipulation of matter and energy stands out as a central domain of both scientific and technical advances. Techno-scientific innovations have sometimes delivered on their promises and sometimes not. Of the biggest advances, three really did change our lives—probably for the better—whereas two were far less consequential than people thought they would be. And one of the overarching impacts we now recognize in hindsight was only weakly anticipated: that by moving matter and energy, we would end up moving information and ideas.

**One strong example** of science-based technology that changed our lives is electricity. Benjamin Franklin is famous for recognizing that lightning is an atmospheric electrical discharge and for demonstrating in the 1700s that lightning rods can protect people and property. But

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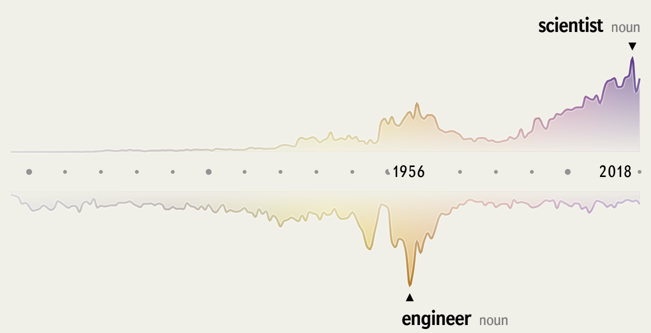
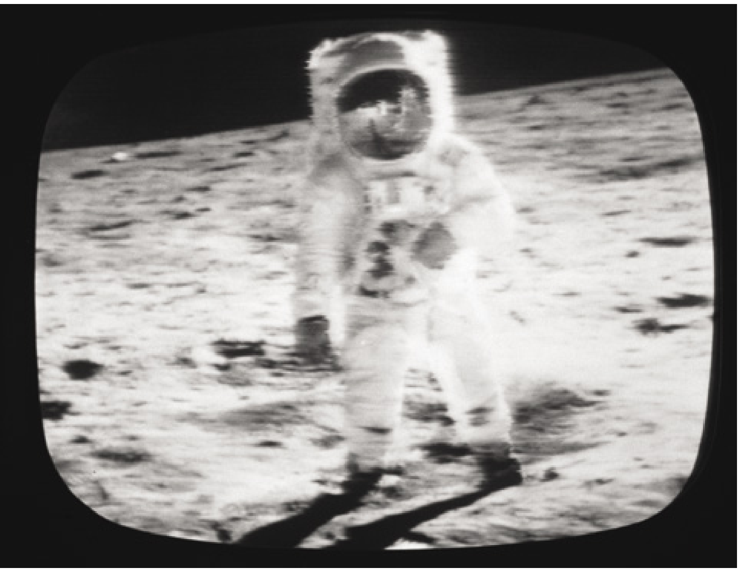





*Graphics by Moritz Stefaner and Christian Lässer*



TELEVISION became widespread in time to deliver the moon landing.

GETTY IMAGES

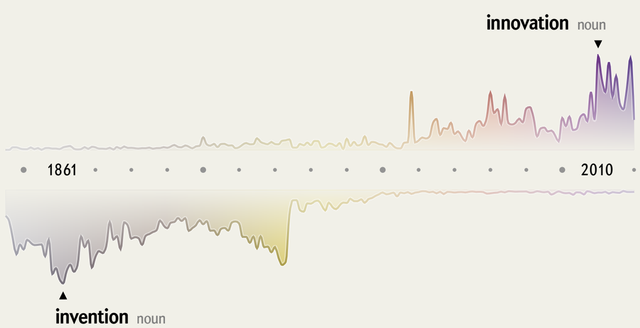
the major scientific advances in understanding electricity came later when Michael Faraday and James Clerk Maxwell established that it was the flow of electrons—matter—and that it could be understood in the broader context of electromagnetism. Faraday showed that electricity and magnetism are two sides of the same coin: moving electrons creates a magnetic field, and moving a magnet induces electric current in a conductor. This understanding, quantified in Maxwell's equations—a mathematical model for electricity, magnetism and light—laid the foundation for the invention of the dynamo, electricity generation for industries and households, and telecommunications: telegraph, telephone, radio and television.

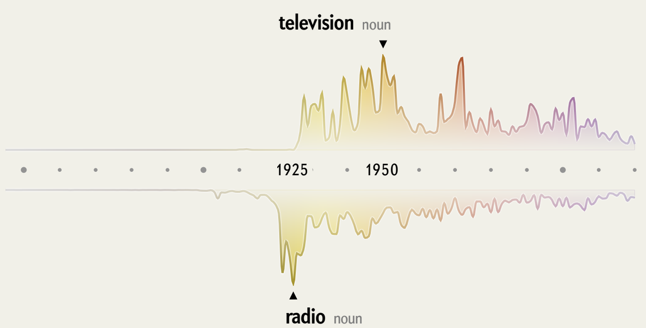
Electricity dramatically expanded the size of factories. Most factories had been powered by water, which meant they had to be located close to streams, typically in narrow river valleys where space was tight. But with electricity, a factory could be erected anywhere and could take on any size, complete with lighting so it could run around the clock. This innovation broadened mass production and, with it, the growth of consumer society. Electricity also transformed daily life, powering the subways, streetcars and commuter rail that let workers stream in and cities sprawl out and creating the possibility of suburban living. Home lighting extended the time available for reading, sewing and other activities. Entertainment blossomed in a variety of forms, from the "electrifying" lighting displays of the 1904 St. Louis World's Fair to cinema and radio. Home electricity was soon also powering refrigerators, toasters, water heaters, washing machines and irons. In her 1983 prizewinning book *More Work for Mother,* Ruth Schwartz Cowan argues that these "labor-saving" appliances did more to raise expectations for household order and cleanliness than to save women labor, yet there is no question that they changed the way Americans lived.

One of the most significant and durable changes involved information and ideas. Electricity made the movie camera possible, which prompted the rise of cinema. The first public movie screening was in Paris, in 1895, using a device inspired by Thomas Edison's electric Kinetoscope. (The film showed factory workers leaving after a shift.) Within a few years a commercial film industry had developed in Europe and America. Today we think of movies primarily as entertainment—especially given the emergence of the entertainment industry and the centrality of Hollywood in American life—but in the early 20th century many (possibly most) films were documentaries and newsreels. The newsreels, a standard feature in cinemas, became a major source of information about world and national events. They were also a source of propaganda and disinformation, such as a late-1890s "fake news" film about the Dreyfus affair (a French political scandal in which a Jewish army officer was framed on spy charges laced with anti-Semitism) and fake film footage of the 1898 charge up San Juan Hill in the Spanish-American War.

Information drove the rise of radio and television. In the 1880s Heinrich Hertz demonstrated that radio waves were a form of electromagnetic radiation—as predicted by Maxwell's theory—and in the 1890s Indian physicist Jagadish Chandra Bose conducted an experiment in which he used microwaves to ignite gunpowder and ring a bell, proving that electromagnetic radiation could travel without wires. These scientific insights laid the foundations for modern telecommunications, and in 1899 Guglielmo Marconi sent the first wireless signals across the English Channel. Techno-fideists—people who place faith in technology—proclaimed that radio would lead to world peace because it enabled people across the globe to communicate. But it was a relatively long road from Marconi's signals to radio as we know it: the first programs were not developed until the 1920s. Meanwhile radio did nothing to prevent the 1914–1918 Great War, later renamed World War I.

In the early 20th century there was little demand for radio beyond the military and enthusiasts. To persuade people to buy radios, broadcasters had to create content, which required sponsors, which in turn contributed to the growth of advertising, mass marketing and consumer culture. Between the 1920s and the 1940s radios became a fixture in American homes as programs



competed with and often replaced newspapers as people's primary source of information. Radio did not bring us world peace, but it did bring news, music, drama and presidential speeches into our lives.

Television's story was similar: content had to be created to move the technology into American homes. Commercial sponsors produced many early programs such as Texaco Star Theater and General Electric Theater. Networks also broadcast events such as baseball games, and in time they began to produce original content, particularly newscasts. Despite (or maybe because of) the mediocre quality of much of this programming, television became massively popular. Although its scientific foundation involved the movement of matter and energy, its technological expression was in the movement of information, entertainment and ideas.


WORLD WIDE WEB blurred the line between producers and consumers of media, a shift with cultural and political consequences that are still unfolding.

GETTY IMAGES

World War II tore the world apart again, and science-based technologies were integral. Historians are nearly unanimous in the belief that operations research, code breaking, radar, sonar and the proximity fuse played larger roles in the Allied victory than the atomic bomb, but it was the bomb that got all the attention. U.S. Secretary of War Henry Stimson promoted the idea that the bomb had brought Japan to its knees, enabling the U.S. to avoid a costly land invasion and saving millions of American lives. We know now that this story was a postwar invention intended to stave off criticism of the bomb's use, which killed 200,000 civilians. U.S. leaders duly declared that the second half of the 20th century would be the Atomic Age. We would have atomic airplanes, trains, ships, even atomic cars. In 1958 Ford Motor Company built a model chassis for the Nucleon, which would be powered by steam from a microreactor. (Needless to say, it was never completed, but the model can be seen at the Henry Ford Museum in Dearborn, Mich.) Under President Dwight Eisenhower's Atoms for Peace plan, the U.S. would develop civilian nuclear power both for its own use and for helping developing nations around the globe. American homes would be powered by free nuclear power "too cheap to meter."

The promise of nuclear power was never fulfilled. The U.S. Navy built a fleet of nuclear-powered submarines and switched its aircraft carriers to nuclear power (though not the rest of the surface fleet), and the government assembled a nuclear-powered freighter as a demonstration. But even small reactors proved too expensive or too risky for nearly any civilian purpose. Encouraged by the U.S. government, electrical utilities in the 1950s and 1960s began to develop nuclear generating capacity. By 1979 some 72 reactors were operating across the country, mostly in the East and the Midwest. But even before the infamous accident at the Three Mile Island nuclear power plant that year, demand for new reactors was weakening because capital and construction costs were not falling and public opposition was rising. In the five years after the accident, more than 50 reactors planned in the U.S. were canceled and others required costly retrofits. Nuclear anxieties worsened after the 1986 Chernobyl disaster in the former Soviet Union. Today the U.S. generates about 20 percent of its electricity from nuclear plants, which, though significant, is hardly what nuclear energy's 1950s boosters had predicted.

**While some pundits** claimed the 20th century was the Atomic Age, others insisted it was the Space Age. American children in midcentury grew up watching science-fiction TV programs centered on the dream of interplanetary and intergalactic journeys, reading comic books starring superheroes from other planets and

listening to vinyl records with songs about the miracle of space travel. Their heroes were Alan Shepard, the first American in space, and John Glenn, the first American to orbit Earth. Some of their parents even made reservations for a flight to the moon promised by Pan American World Airways, and Stanley Kubrick featured airplane space flight in his 1968 film, *2001: A Space Odyssey*. The message was clear: by 2001 we would be routinely flying in outer space.

The essential physics required for space travel had been known since the days of Galileo and Newton, and history is replete with visionaries who saw the potential in the laws of motion. What made the prospect real in the 20th century was the advent of rocketry. Robert Goddard is often called the "father of modern rocketry," but it was Germans, led by Nazi scientist Wernher von Braun, who built the world's first usable rocket: the V-2 missile. A parallel U.S. Army–funded rocket program at the Jet Propulsion Laboratory demonstrated its own large ballistic missile shortly after the war. The U.S. government's Operation Paperclip discreetly brought von Braun and his team to the states to accelerate the work, which, among other things, eventually led to NASA's Marshall Space Flight Center.

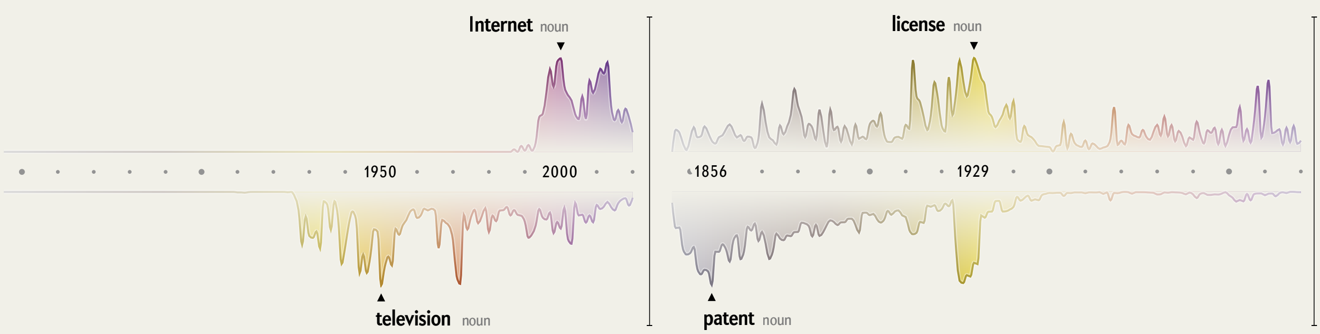
This expensive scientific and engineering effort, pushed by nationalism and federal funding, led to Americans' landing on the moon and returning home. But the work did not result in routine crewed missions, much less vacations. Despite continued enthusiasm and, recently, substantial private investment, space travel has been pretty much a bust. Yet the same rockets that could launch crewed vessels could propel artificial satellites into Earth orbit, which allowed huge changes in our ability to collect and move information. Satellite telecommunications now let us send information around the globe pretty much instantaneously and at extremely low cost. We can also study our planet from above, leading to significant advances in weather forecasts, understanding the climate, quantifying changes in ecosystems and human populations, analyzing water resources and—through GPS—letting us precisely locate and track people. The irony of space science is that its greatest payoff has been our ability to know in real time what is happening here on Earth. Like radio and TV, space has become a medium for moving information.

**A similar evolution** occurred with computational technology. Computers were originally designed to replace people (typically women) who did laborious calculations, but today they are mainly a means to store, access and create "content." Computers appeared as a stealth technology that had far more impact than many of its pioneers envisaged. IBM president Thomas J. Watson is often cited as saying, in 1943, that "I think there is a world market for maybe five computers."

Mechanical and electromechanical calculation devices had been around for a long time, but during World War II, U.S. defense officials sought to make computation much faster through the use of electronics—at the time, thermionic valves, or vacuum tubes. One outcome was Whirlwind, a real-time tube-based computer developed at the Massachusetts Institute of Technology as a flight simulator for the U.S. Navy. During the cold war, the U.S. Air Force turned Whirlwind into the basis of an air-defense system. The Semi-Automatic Ground Environment system (SAGE) was a continent-scale network of computers, radars, wired and wireless telecommunications systems, and interceptors (piloted and not) that operated into the 1980s. SAGE was the key to IBM's abandoning mechanical tabulating machines for mainframe digital computers, and it revealed the potential of very large-scale, automated, networked management systems. Its domain, of course, was information—about a potential military attack.

Early mainframe computers were so huge they filled the better part of a room. They were expensive and ran very hot, requiring cooling. They seemed to be the kind of technology that only a government, or a very large business with deep pockets, could ever justify. In the 1980s the personal computer changed that outlook dramatically. Suddenly a computer was something any business and many individuals could buy and use not just for intense computation but also for managing information.

That potential exploded with the commercialization of the Internet. When the U.S. Defense Advanced Research Projects Agency set out to develop a secure, failure-tolerant digital communications network, it already had SAGE as a model. But SAGE, built on a telephone system using mechanical switching, was also a model of what the military did not want, because centralized switching centers were highly vulnerable to attack. For a communications system to be "survivable," it would have to have a set of centers, or nodes, interconnected in a network. The solution—ARPANET—was developed in the 1960s by a diverse group of scientists and engineers funded by the U.S. government. In the 1980s it spawned what we know as the Internet. The Internet, and its killer app the World Wide Web, brought the massive amount of information now at our fingertips, information that has changed the way we live and work and that has powered entirely new industries such as social media, downloadable entertainment, virtual meetings, online shopping and dating, ride sharing, and more. In one sense, the history of the Internet is the opposite of electricity's: the private sector developed electrical gener-



ation, but it took the government to distribute the product widely. In contrast, the government developed the Internet, but the private sector delivered it into our homes—a reminder that casual generalizations about technology development are prone to be false. It is also well to remember that around a quarter of American adults still do not have high-speed Internet service.

**Why is it that electricity,** telecommunications and computing were so successful, but nuclear power and human space travel have been a letdown? It is clear today that the latter involved heavy doses of wishful thinking. Space travel was imbricated with science fiction, with dreams of heroic courage that continue to fuel unscientific fantasies. Although it turned out to be fairly manageable to launch rockets and send satellites into orbit, putting humans in space—particularly for an extended period—has remained dangerous and expensive.

NASA's space shuttle was supposed to usher in an era of cheap, even profitable, human space flight. It did not. So far no one has created a gainful business based on the concept. The late May launch of two astronauts to the International Space Station by SpaceX may have changed the possibilities, but it is too soon to tell. Most space entrepreneurs see tourism as the route to profitability, with suborbital flights or perhaps floating space hotels for zero-*g* recreation. Maybe one day we will have them, but it is worth noting that in the past tourism has followed commercial development and settlement, not the other way around.

Nuclear power also turned out to be extremely expensive, for the same reason: it costs a lot to keep people safe. The idea of electricity too cheap to meter never really made sense; that statement was based on the idea that tiny amounts of cheap uranium fuel could yield a large amount of power, but the fuel is the least of nuclear power's expenses. The main costs are construction, materials and labor, which for nuclear plants have remained far higher than for other power sources, mainly because of all the extra effort that has to go into ensuring safety.

Risk is often a controlling factor for technology. Space travel and nuclear power involve risk levels that have proved acceptable in military contexts but mostly not in civilian ones. And despite the claims of some folks in Silicon Valley, venture capitalists generally do not care much for risk. Governments, especially when defending themselves from actual or anticipated enemies, have been more entrepreneurial than most entrepreneurs. Also, neither human space travel nor nuclear power was a response to market demand. Both were the babies of governments that wanted these technologies for military, political or ideological reasons. We might be tempted to conclude, therefore, that the government should stay out of the technology business, but the Internet was not devised in response to market demand either. It was financed and developed by the U.S. government for military purposes. Once it was opened to civilian use, it grew, metamorphosed and, in time, changed our lives.

In fact, government played a role in the success of all the technologies we have considered here. Although the private sector brought electricity to the big cities—New York, Chicago, St. Louis—the federal government's Rural Electrification Administration brought electricity to much of America, helping to make radio, electric appliances, television and telecommunications part of everyone's daily lives. A good deal of private investment created these technologies, but the transformations that they wrought were enabled by the "hidden hand" of government, and citizens often experienced their value in unanticipated ways.

**These unexpected benefits** seem to confirm the famous saying—variously attributed to Niels Bohr, Mark Twain and Yogi Berra—that prediction is very difficult, especially about the future. Historians are loath to make prognostications because in our work we see how generalizations often do not stand up to scrutiny, how no two situations are ever quite the same and how people's past expectations have so often been confounded.

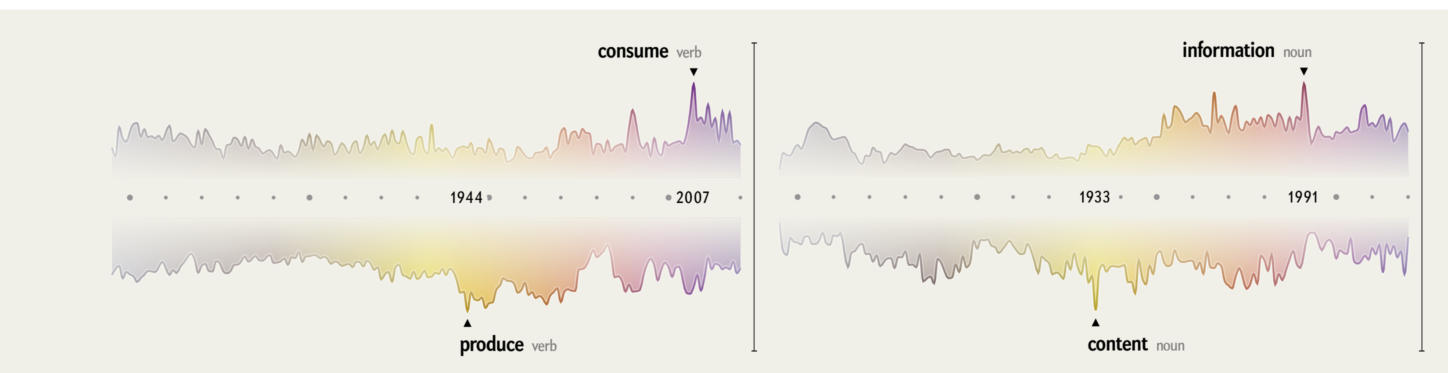
That said, one change that is already underway in the movement of information is the blurring of boundaries between consumers and producers. In the past the flow of information was almost entirely one-way, from the newspaper, radio or television to the reader, listener or viewer. Today that flow is increasingly two-way—which was one of Tim Berners-Lee's primary goals when he created the World Wide Web in 1990. We "consumers" can reach one another via Skype, Zoom and FaceTime; post information through Instagram, Facebook and Snapchat; and use software to publish our own books, music and videos—without leaving our couches.

For better or worse, we can expect further blurring of many conventional boundaries—between work and home, between "amateurs" and professionals, and between public and private. We will not vacation on Mars anytime soon, but we might have Webcams there showing us Martian sunsets. SA

FROM OUR ARCHIVES

Long Live the Web: A Call for Continued Open Standards and Neutrality. Tim Berners-Lee; December 2010.

scientificamerican.com/magazine/sa



# Subway to Nowhere

*SCIENTIFIC AMERICAN*'S EDITOR SECRETLY BUILT NEW YORK CITY'S FIRST UNDERGROUND TRAIN—POWERED BY AIR—ONLY TO HAVE IT CRUSHED BY POLITICAL OPPOSITION

*BY KATHERINE HARMON COURAGE*

**IN DOWNTOWN NEW YORK,** mysterious deliveries of heavy equipment were arriving at the Devlin & Co. clothing store on Warren Street and Broadway. In the middle of the night, metal rods would periodically poke up through the roadbed from somewhere below. A grand and secret project was underway, which its mastermind thought would revolutionize urban life.

Horse-drawn cart traffic was choking the city, which in 1869 housed nearly a million people. Getting around plagued residents with "filthy, health-destroying, patience-killing street dust," as a *Scientific American* writer put it—much of it probably dried horse manure. Alfred Ely Beach, who almost 25 years earlier, at the age of 20, acquired *Scientific American* with a partner, had a plan that would clean up traffic and clean the air.

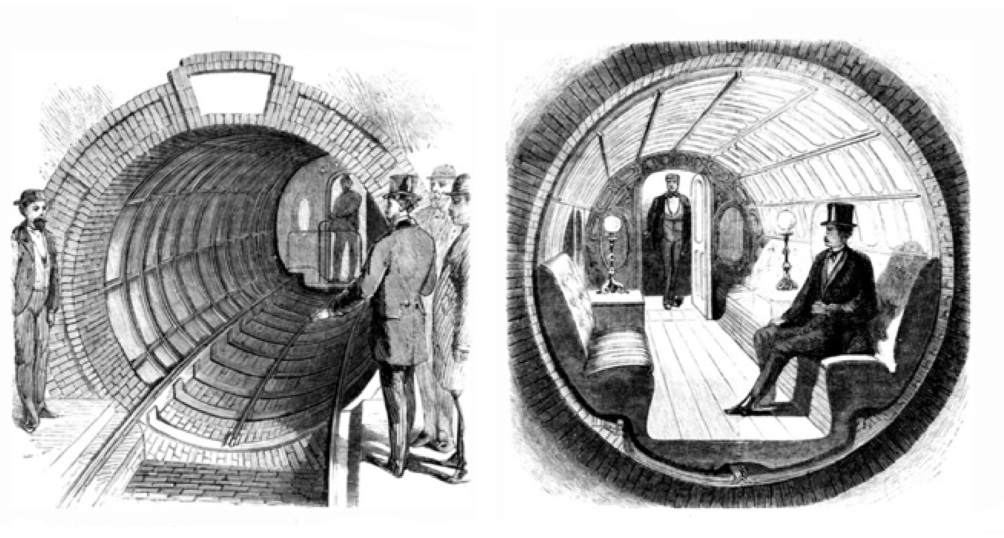
In 1867 Beach, who was a prodigious inventor, demonstrated an aboveground, pneumatically powered train inside a tube at the American Institute Fair in New York City. It was a visitor favorite. Forced-air tubes were being used to transport mail in London, and as a later *Scientific American* article mused, "If a package of letters could be blown through a tube, why not a package of human beings in a car?"

Beach, a chief editor at the magazine, had also published a design for a short, cylindrical tunneling machine, or shield, nine feet in diameter, made of iron and timber, that could dig a round tunnel underground by ramming forward, driven by hydraulic power. He had everything he needed to create a clean, modern transportation system for Manhattan—except for permission to build it.

The city was ruled by the notoriously corrupt William "Boss" Tweed, who among many illegal doings was getting kickbacks from the city's steam-powered train and horse-pulled bus lines. Hiding his true vision, Beach managed to gain city permits to build small pneumatic tubes belowground to carry mail and later snuck through an amendment that allowed a single, large tube that ostensibly would hold the smaller tubes.

Having made money through a very successful patent agency, which he oversaw while working at the magazine, Beach put up $350,000, and the project quietly got underway 21 feet below bustling Broadway. Using the shield, workers dug the tunnel two feet at a time, reinforcing the newly exposed walls. Periodically, the crew would force a metal rod up through the soil to the road above to check that they were on course.

It is hard to keep a secret in New York City, though, and word of the project began to leak. On February 26, 1870, less than two months after it was begun, Beach revealed the finished sample section of Beach Pneumatic Transit. Lawmakers, scholars and members of the press descended to the basement of an adjacent store and stepped into a new subterranean rail station. The visitors did not find "damp and dimly lighted cellars, but commodious, airy, and comfortable apartments," as *Scientific American* noted soon after. There was even a fountain. The tunnel itself, as if to highlight its cleanliness, was lined in white brick.



FIRST SUBWAY in New York City was secretly built by *Scientific American* editor Alfred Ely Beach; the magazine revealed these engravings in its March 5, 1870, issue.

*SCIENTIFIC AMERICAN*, VOL. XXII, NO. 10; MARCH 5, 1870

The day after the opening the *New York Times* wrote: "It must be said that every one of [the visitors] came away surprised and gratified.... And those who entered to pick out some scientific flaw in the project were silenced by the completeness of the machinery, the solidity of the work and the safety of the running apparatus."

On March 1 the pneumatic train opened to public patrons, who paid $0.25 for a ride on the curiosity. A gigantic, 100-horsepower fan installed at the back of the station pushed an enclosed train car, rolling on tracks, about 300 feet that included a bend, to the next and only stop. Engineers then reversed the fan to create negative pressure that pulled the train back to its starting point. The one cylindrical car slowly whooshed along with just 1.5 inches of clearance between it and the tunnel walls. The car's interior was lavishly outfitted with upholstery, bright zirconia lamps and seats for 18 people. Thousands of patrons would take the joy ride in the ensuing months.

Beach planned to eventually run the pneumatic wonder the full length of Manhattan, boasting luxury cars 100 feet long. Tweed, however—infuriated at being fooled and upstaged—blocked the project and directed his administration to allocate funds for an elevated railway on the west side of the island instead. Beach also took a hit in the 1873 financial crisis and closed Beach Pneumatic Transit. He continued to work diligently at the magazine until, on January 1, 1896, perhaps in cruel irony, he died from a lack of air, perishing from pneumonia at age 69.

Three years later, after a building on Broadway burned down, workers who were clearing rubble happened on the tunnel, which had been closed off for a quarter of a century. A *Scientific American* article reported that the tunnel was "still in a good state of preservation, demonstrating beyond a doubt its utility for rapid transit purposes."

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**Katherine Harmon Courage** is a contributing editor to *Scientific American.*

★ 175TH ANNIVERSARY ISSUE ★

MEDICINE

# RETURN *of the* GERMS

FOR MORE THAN A CENTURY DRUGS AND VACCINES MADE ASTOUNDING PROGRESS AGAINST INFECTIOUS DISEASES. NOW OUR BEST DEFENSES MAY BE SOCIAL CHANGES

*By Maryn McKenna*

*Illustration by Maria Corte*

**Maryn McKenna** is a journalist specializing in public health, global health and food policy and a senior fellow of the Center for the Study of Human Health at Emory University. She is the author most recently of *Big Chicken: The Incredible Story of How Antibiotics Created Modern Agriculture and Changed the Way the World Eats* (National Geographic Books, 2017).

IN 1972 THE DISTINGUISHED VIROLOGIST FRANK MACFARLANE BURNET LOOKED BACK OVER MEDICAL progress made in the 20th century with considerable satisfaction, surveying it for the fourth edition of the book *Natural History of Infectious Disease.* That very year routine vaccination against smallpox had ceased in the U.S., no longer needed because the disease had been eliminated from the country. During the previous year the combined vaccine against measles, mumps and rubella had been licensed, and four years before, in 1968, a pandemic of influenza had been quelled by a new vaccine formula. In 1960 Albert Sabin had delivered an oral vaccine against polio, and five years before that Jonas Salk had produced the first polio shot, preventing the dreaded paralysis that crippled children every summer. Since the time of World War II, drug development had delivered 12 separate classes of antibiotics, beginning with natural penicillin and ending seemingly forever the threat of deadly infections from childhood diseases, injuries, medical procedures and childbirth.

A few pages from the end of his book (co-authored with David O. White), Burnet made a bold prediction: "The most likely forecast about the future of infectious disease," he wrote, "is that it will be very dull."

Burnet was an experienced scientist who had shared the Nobel Prize in Physiology or Medicine in 1960 for pioneering ideas about the way people developed immune reactions. And at 73 he had lived through devastating epidemics, including the planet-spanning flu pandemic of 1918 while he was a university student in Australia. So he had seen a lot of advances and had played a role in some of them. "From the beginnings of agriculture and urbanization till well into the present century infectious disease was the major overall cause of human mortality," he wrote on the book's first page. "Now the whole pattern of human ecology has, temporarily at least, been changed."

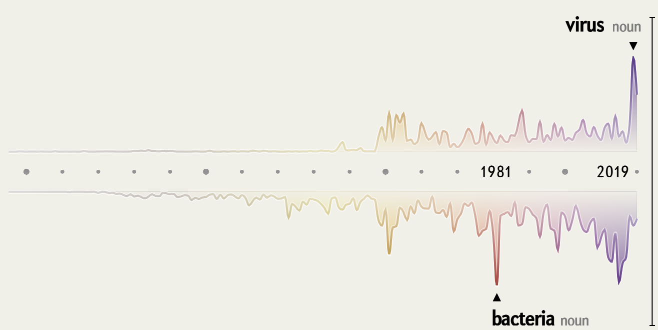
Four years after Burnet made his optimistic prediction, the headmaster of a village school in what is now the Democratic Republic of the Congo collapsed with an unexplained bleeding disorder and died, the first recognized victim of Ebola virus. Nine years after his forecast, in 1981, physicians in Los Angeles and an epidemiologist at the U.S. Centers for Disease Control and Prevention diagnosed five young men in Los Angeles with an opportunistic pneumonia, the first signal of the worldwide pandemic of HIV/AIDS. In 1988 the gut bacterium *Enterococcus,* a common source of hospital infections, developed resistance to the last-resort antibiotic vancomycin, turning into a virulent superbug. And in 1997 a strain of influenza designated H5N1 jumped from chickens to humans in a market in Hong Kong, killing one third of the people it infected and igniting the first of multiple global waves of avian flu.

Those epidemics represent only a few of the infectious disease eruptions that now occur among humans every year, and efforts to stem them have taken on a renewed and urgent role in modern medicine. Some of these contagions are new to our species; others are resurgent old enemies. Sometimes their arrival sparks

# WORDPLAY

**THE RELATIVE FREQUENCY OF REVEALING AND INTERESTING TERMS IN THIS MAGAZINE, FROM 1845 TO THE PRESENT.**

See "The Language of Science" on page 26 for more detail and page 33 for more word pairings.






*Graphics by Moritz Stefaner and Christian Lässer*

JONAS SALK injects a child with the polio vaccine in the 1950s, a victory over a terrifying disease.

GETTY IMAGES

small outbreaks, such as an eruption of H7N7 avian flu in 2003 among 86 poultry-farm workers in the Netherlands. Now a never-before-seen illness, COVID-19, has caused a global pandemic that has sickened millions and killed hundreds of thousands.

None of these scenarios matches what Burnet envisioned. He thought of our engagement with infectious diseases simply as one mountain that we could climb and conquer. It might be more accurate to understand our struggle with microbes as a voyage across a choppy sea. At times we crest the waves successfully. In other moments, as in the current pandemic, they threaten to sink us.

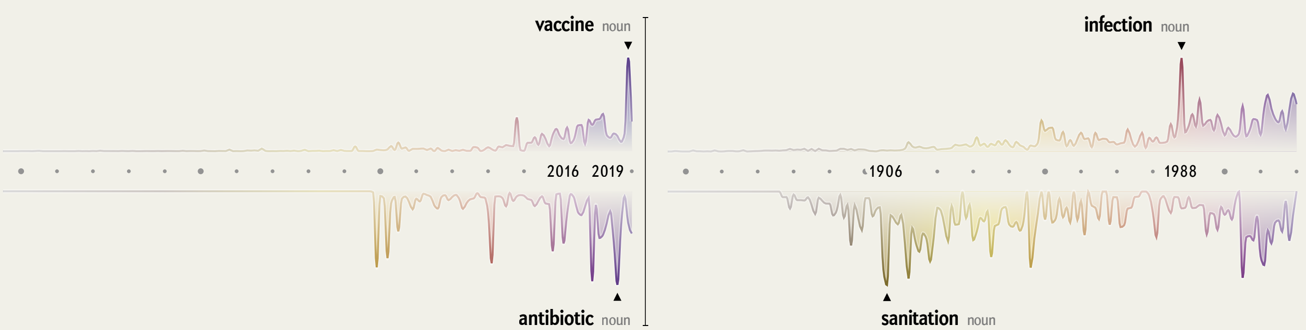
**It is difficult,** under the weight of the novel coronavirus, to look far enough back in American history to perceive that—surprisingly—freedom from infectious disease was a part of the early New England colonists' experience. Beginning in the 1600s, these people fled English and European towns drenched in sewage and riven with epidemics where they might be lucky to live to their 40th birthday. They found themselves in a place that felt blessed by God or good fortune where a man—or a woman who survived childbearing—could, remarkably, double that life span.

This was true, of course, only for the colonizers and not for the Indigenous Americans whom they displaced. The Spanish who arrived in Central and South America about a century earlier, and other European colonists who followed to the North, brought diseases so devastating to the precontact population that researchers have estimated 90 percent of the existing inhabitants were killed. Nor was it true for enslaved people brought to American shores, whose lives were cut short by abuse in the South's plantation system.

New Englanders before the 19th century, however, "had a very strange and unusual experience with infectious diseases," says David K. Rosner, a historian and co-director of the Center for the History and Ethics of Public Health at Columbia University. "When infections hit, and they did hit—smallpox, yellow fever—they were largely very localized and of relatively short duration."

At the time and through the early 1800s, disease was understood as a sign of moral transgression, a visitation meant to guide an erring population back to righteousness. In 1832 the edge of a worldwide pandemic of cholera washed up on the East Coast of the U.S., carried into port cities by ships plying trade routes. The governors of a dozen states declared a mandatory day of prayer and fasting. In New York the well-off fled the city for the socially distanced countryside, blaming the poor left behind for their own misfortune. A letter preserved by the New-York Historical Society, written by its founder, captures the callousness of some wealthy people: "Those sickened … being chiefly of the very scum of the city, the quicker [their] dispatch the sooner the malady will cease."

Cholera was a global devastation, but it was also a doorway to our modern understanding of disease. Dogma held that its source was miasmas, bad air rising from rotting garbage and stagnant water. As late as 1874—20 years after physician John



Snow traced the source of a London cholera outbreak to a neighborhood's well and halted it by removing the pump handle—an international conference on the disease declared that "the ambient air is the principal vehicle of the generative agent of cholera." It was not until 10 years later, when bacteriologist Robert Koch found identical bacteria in the feces of multiple cholera victims in India and reproduced the bacterium in a culture medium, that a microbe was proved to be the cause. (Koch was not aware that Italian bacteriologist Filippo Pacini had made the same observations in the year when Snow took the handle off the pump.)

This explanation for the source of cholera became one of the foundations of germ theory. The concept that disease could be transmitted and that the agents of transmission could be identified—and possibly blocked—transformed medicine and public health. The idea ignited a burst of innovation and civic commitment, a drive to clean up the cities whose filthy byways allowed disease-causing microbes to fester. Towns and states established municipal health departments and bureaus of sanitation, built sewer systems and long-distance water supplies, regulated food safety and ordered housing reform.

These improvements tipped industrial nations toward what would later be called the epidemiological transition, a concept coined by Abdel Omran in 1971 to describe the moment when deadly infections would retreat and slow-growing chronic diseases could become society's priority. Science started a seemingly unstoppable climb up the mountain of 20th-century achievement: viral identification, vaccine refinement, the development of antibiotics, the achievement of immunotherapies, the parsing of the human genome. Life expectancy in the U.S. rose from an average of 47 years in 1900 to 76 years toward the end of the century. The last case of smallpox, the only human disease ever eradicated, was recorded in 1978. The Pan American Health Organization declared its intention to eliminate polio from the Americas in 1985. The future seemed secure.

TENTS OUTSIDE Los Angeles County–U.S.C. Medical Center were set up to screen a large surge of COVID-19 patients.

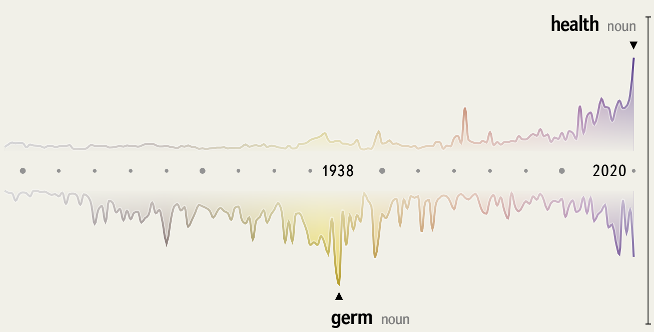
VALERIE MACON *Getty Images*

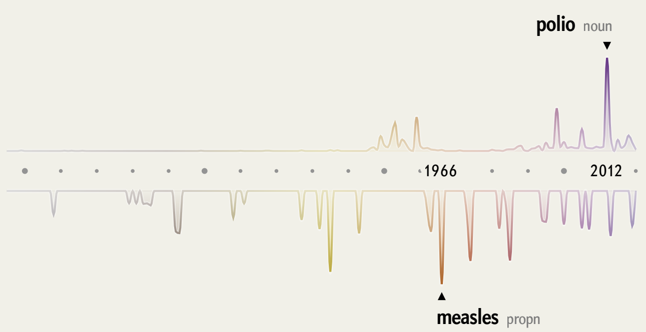
**It was not, of course.** In October 1988, in this magazine, Robert Gallo and Luc Montagnier wrote: "As recently as a decade ago it was widely believed that infectious disease was no longer much of a threat in the developed world. The remaining challenges to public health there, it was thought, stemmed from noninfectious conditions such as cancer, heart disease and degenerative diseases. That confidence was shattered in the early 1980's by the advent of AIDS."

Gallo and Montagnier were co-discoverers of the HIV virus, working on separate teams in different countries. When they wrote their article, there were more than 77,000 known cases of AIDS on the planet. (There are almost 75 million now.) As the researchers noted, recognition of the new illness punctured the sense of soaring assurance that infectious diseases had been conquered. Four years after Gallo and Montagnier wrote, 19 eminent scientists gathered by the Institute of Medicine (now part of the National Academies of Sciences, Engineering and Medicine) broadened the point in a sober book-length assessment of what they termed "emerging infections." Scientists and politicians had become complacent, they said, confident in the protection offered by antibiotics and vaccines and inattentive to the communicable-disease threats posed by population growth, climate warming, rapid international travel, and the destruction of wild lands for settlements and mega-farms.

"There is nowhere in the world from which we are remote," the group warned, "and no one from whom we are disconnected." They recommended urgent improvements in disease detection and reporting, data sharing, lab capacity, antibiotics and vaccines. Without those investments, they said, the planet would be perpetually behind when new diseases leaped into humans and catastrophically late in applying any cures or preventions to keep them from spreading.

Their warning was prescient. At the time of their writing, the U.S. was recovering from its first major resurgence of measles since



vaccination began in the 1960s. More than 50,000 cases occurred across three years when epidemiological models predicted that there should have been fewer than 9,000. The year after the Institute of Medicine's report was published, five healthy young people collapsed and died in the Southwestern U.S. from a hantavirus passed to them by deer mice. In 1996 researchers in Chicago discovered that antibiotic-resistant *Staphylococcus* bacteria had leapfrogged from their previous appearances in hospitals into everyday life, causing devastating illnesses in children who had no known risks for infection. Across health care, in urban life and in nature, decades of progress seemed to be breaking down.

"We forgot what rampant infectious disease looked like," says Katherine Hirschfeld, an associate professor of anthropology at the University of Oklahoma, who studies public health in failing states. "Science built us a better world, and then we got cocky and overconfident and decided we didn't have to invest in it anymore."

But unlike illnesses in the past—cholera epidemics in which the rich fled the cities, outbreaks of tuberculosis and plague blamed on immigrants, HIV cases for which gay men were stigmatized—infections of today do not arrive via easy scapegoats (although jingoistic politicians still try to create them). There is no type of place or person we can completely avoid; the globalization of trade, travel and population movement has made us all vulnerable. "We cannot divide the world anymore into countries that have dealt with infectious disease successfully and those that are still struggling," Hirschfeld says. "Countries have enclaves of great wealth and enclaves of poverty. Poor people work for rich people, doing their landscaping, making things in their factories. You cannot wall off risk."

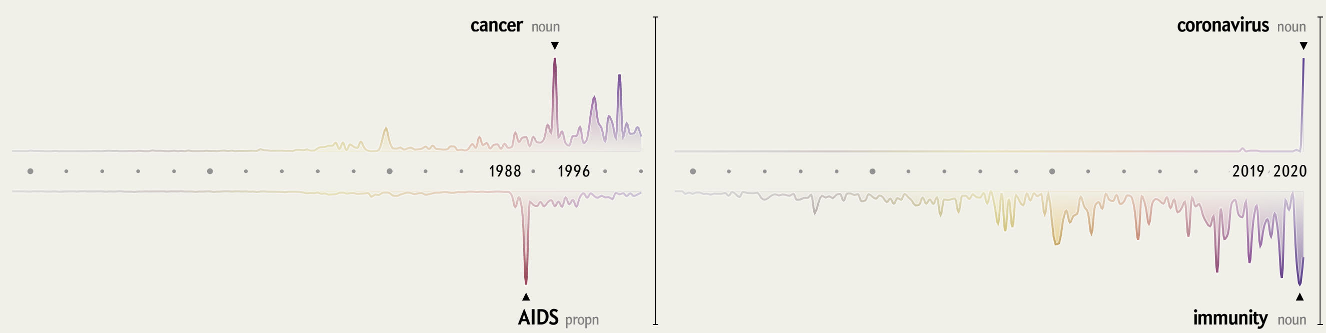
**The planet that slid down** the far side of the 20th century's wave of confidence is the planet that enabled the spread of COVID-19. In the five years before its viral agent, SARS-CoV-2, began its wide travels, there were at least that many warnings that a globally emergent disease was due: the alerts appeared in academic papers, federal reports, think-tank war games and portfolios prepared at the White House to be handed off to incoming teams. The novel coronavirus slipped through known gaps in our defenses: it is a wildlife disease that was transmitted to humans by proximity and predation, spread by rapid travel, eased by insufficient surveillance, and amplified by nationalist politics and mutual distrust.

We were unprepared, with no vaccine or antiviral. In past epidemics of coronaviruses, such as SARS in 2003 and MERS in 2012, scientists had begun work on vaccines, but funding and interest dried up as the outbreaks waned. If research had continued, the current emergency might be shortened. Preventions and pharmaceuticals were the stellar achievements of the 20th century, but among scientists and physicians who deal with emerging diseases, there is a sense that attempts to repeat such successes will not be sufficient to save us. What is equally urgent, they argue, is attending to and repairing the conditions in which new diseases arise.

"Poverty has more impact than any of our technical interventions," says Peter J. Hotez, a physician and vaccine developer and founding dean of the Baylor University National School of Tropical Medicine. "Political collapse, climate change, urbanization, deforestation: these are what's holding us back. We can develop all the vaccines and drugs we want, but unless we figure out a way to deal with these other issues, we'll always be behind."

Evidence for Hotez's statement is abundant in the toll of those who have suffered disproportionately in the current pandemic—people who rely on urban transit, live in public housing or nursing homes, or are subject to the persistent effects of structural racism. What has made them vulnerable is not primarily a lack of drugs or vaccines. "My hospital is buried in COVID-19 patients," says infectious disease physician Brad Spellberg, chief medical officer at Los Angeles County–University of Southern California Medical Center, one of the largest public hospitals in the U.S. "We serve a community of people who cannot physically distance. They are homeless, they are incarcerated, they are working poor living with a family of four in one room."

The term often used to denote what Hotez and Spellberg are describing is "social determinants of health." It is an unsatisfying phrase that lacks the muscular directness of "shot" and "drug," but it is a crucial and also measurable concept: that social and economic factors, not just medical or innate immunological ones, strongly influence disease risk. Negative social determinants include unsafe housing, inadequate health care, uncertain employment and even a lack of political representation. They are the root cause of why the U.S., the richest country on Earth, has rapidly rising rates of hepatitis, sexually transmitted diseases, and parasitic and waterborne infections, as reported in *Scientific American* in 2018—infections that first arise among the poor and unhoused but then migrate to the wealthy and socially secure. As research by British epidemiologists Richard Wilkinson and Kate Pickett has shown, unequal societies are unhealthy ones: the larger the gap in income between a country's wealthiest and poorest, the more likely that country is to experience lower life expectancy and high-



er rates of chronic disease, teen births and infant mortality. That phenomenon goes a long way toward explaining why COVID-19 wreaked such devastation in New York City, one of the most financially unequal cities in the country, before the city government applied the brute-force tool of lockdown and regained control.

Lockdowns are effective, but they cannot be sustained indefinitely, and they carry their own costs of severe mental health burdens and of keeping people from health care not related to the virus. And although quarantines may keep a pathogen from spreading for a while, they cannot stop a virus from emerging and finding a favorable human host. What might prevent or lessen that possibility is more prosperity more equally distributed—enough that villagers in South Asia need not trap and sell bats to supplement their incomes and that low-wage workers in the U.S. need not go to work while ill because they have no sick leave. An equity transition, if not an epidemiological one.

**It is difficult to enumerate** features of this more protected world without them sounding like a vague wish list: better housing, better income, better health care, better opportunities. Still, changes that some places around the globe are already enacting as defenses against current infection might make future infections less likely. Closing streets to encourage biking as Lisbon has done, turning parking spaces into café spaces as has happened in Paris, and creating broadband for remote working and shifting health care to telemedicine, both proposed in the U.S.—these adaptations sound like technological optimism, but they could help us construct a society in which people need not crowd into unsafe urban spaces and in which income can be detached from geography.

It is certainly also necessary to re-up the investments in preparedness that the Institute of Medicine rebuked the U.S. for dropping almost 30 years ago. "We need to think about this with an insurance mindset," says Harvey Fineberg, a physician and president of the Gordon and Betty Moore Foundation, who was president of the institute when it prepared a 2003 follow-up to its warning. "If your house doesn't burn down, you don't bang your head on the wall on December 31 and say, Why did I buy that fire insurance? We buy insurance proactively to prevent the consequences of bad things that happen. That is the mindset we need to adopt when it comes to pandemics."

The U.S. has responded to the coronavirus with an extraordinary federally backed effort to find and test a vaccine in time to deliver 300 million doses by early 2021. This is a tremendous aspiration given that the shortest time in which a vaccine has ever been produced from scratch is four years (that vaccine was against mumps). There is no question that medical science is much better equipped than it was when Burnet was writing in the 1970s; *Natural History of Infectious Disease* came out before monoclonal antibody drugs, before gene therapy, before vaccines that could target cancers rather than microbes. The apotheosis of such work may be the development of chimeric antigen receptor T cell, or CAR-T, therapies, which debuted in 2017 and reengineer the body's own specialized immune system cells to combat cancers.

But CAR-T is also a sign of how concern for infectious diseases has slid into a trough of disregard. CAR-T therapies help a rare few patients at an extraordinary cost—their price before any insurance markup hovers around $500,000—whereas antibiotics, which have saved millions from death by infection, have slipped into peril. Most of the major companies that were making antibiotics in the 1970s—Eli Lilly, AstraZeneca, Bristol-Myers Squibb and Novartis, among others—have left the sector, unable to make adequate profits on their products. In the past year four small biotechnology companies with new antibiotic compounds went bankrupt. This happened even though antibiotics are a crucial component of medicine—and now it is becoming clear that they will be needed for some COVID-19 patients to cure severe pneumonias that follow the initial viral infection.

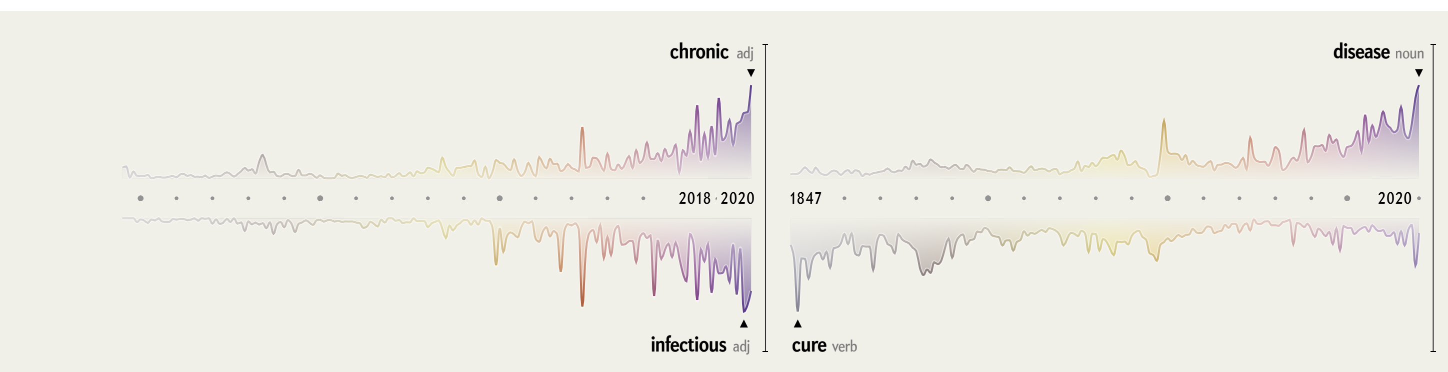
Better structures for preparedness—disease surveillance, financial support for new drugs and vaccines, rapid testing, comprehensive reporting—will not by themselves get us to a planet safer from pandemics any more than car-free streets and inexpensive health care will. But they could give us a place from which to start, a position in which we are relatively more secure as a society, relatively more safe from known diseases, and more likely to detect previously unknown threats and to innovate in response to them.

Rosner, the historian, looks back to the explosive energy of the Progressive Era and wonders what a post-COVID equivalent might be. "In the 19th century we built entire water systems, we cleaned every street in cities," he says. "We have so constricted our vision of the world that it seems we can't address these issues. But there are moments in past crises when we have let the better angels in our society come to the fore: after the Great Depression, in the New Deal. It's not impossible." SA

FROM OUR ARCHIVES

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

scientificamerican.com/magazine/sa



# Science vs. the Supernatural

THIS MAGAZINE LAUNCHED A CONTEST TO PROVE, OR DISPROVE, THE EXISTENCE OF GHOSTS *BY KATHERINE HARMON COURAGE*

**IN 1922 *SCIENTIFIC AMERICAN*** announced a high-stakes international contest to find scientific proof of ghosts. The competition offered $5,000, and it pitted top scientists of the day against wildly popular psychic mediums. The contest also escalated a growing feud between two famous friends: renowned magician and escape artist Harry Houdini and Sherlock Holmes creator Arthur Conan Doyle.

The magazine's interest in the afterlife was not so much an anomaly but a product of the time. The U.S. and Europe were reeling from enormous numbers of deaths in the Great War and the 1918 influenza pandemic. To their families and friends, the spirits of the newly departed seemed to be appearing everywhere—in parlor séances with mediums and at kitchen tables through store-bought Ouija boards. "There was this desperation, this collective yearning to know if there was existence after death," says David Jaher, whose book *The Witch of Lime Street* chronicles the period.

In parallel to this supernatural fascination, these years were filled with breakneck technological innovation. Electricity and radio were making what was previously unimaginable possible: instant illumination and voices from afar appearing out of thin air. "The science and technology of the time all seemed very magical to people," Jaher says. "There was such a thin line between what is a scientific miracle and what is a supernatural miracle." So cross-Styx communication, or spiritualism, did not seem entirely unreasonable.

In an unlikely turn, Conan Doyle, a trained medical doctor as well as the author behind a famously rational detective, had become one of the highest-profile proponents of spiritualism on either side of the Atlantic. He was convinced that, among other things, he had been able to communicate with his dead son. He even toured the U.S. in the early 1920s to lecture on the topic.

On the debunking side was Houdini. The magician and Conan Doyle had briefly been friends, but then the writer tried to arrange for Houdini to receive a message from his dead mother via a medium. The illusionist saw that the act was a ruse, however, and he easily spotted trickery by other mediums as well, such as the use of a wire to move a distant object. He was unhappy with Conan Doyle and condemned the work of mediums as a "racket," Jaher says, "defrauding the bereaved."

ON OPPOSITE SIDES about spiritualism, Arthur Conan Doyle (*left*) believed it, and Harry Houdini (*right*) found fakes.

ALAMY

*Scientific American* regularly covered spiritualism as an interest of science. Many well-respected scientists, including renowned physicist Oliver Lodge—a magazine contributor—were vocal defenders of the practice's legitimacy. While in the U.S., Conan Doyle contacted *Scientific American*'s publisher, Orson Munn, and suggested that instead of covering psychic work as an ongoing debate, the magazine ought to take an official stance on it. Munn agreed.

Munn and the magazine's editors decided that the best way to determine their stance would be to hold the aforementioned contest, which was refereed by a committee consisting of two scientists, two psychic experts and the skeptical Houdini. The contest promised to use the latest scientific tools to ascertain once and for all whether there were true conduits to the spirit world. This equipment included "induction coils, galvanometers, electroscopes, etc., some with the purpose of testing the electrical condition of the medium at the moment when phenomena are produced, others to prove the presence or absence of material objects," the magazine explained in the March 1923 issue.

The psychic tests, initially performed in the magazine's library, got off to a slow and rocky start. Many of Conan Doyle's most revered mediums refused to appear in a public competition. Contestants who did show were quickly dismissed by the judges as tricksters. "I never saw such awkward work in my life," Houdini noted after one of the early sessions.

And so it went, in fits and false-apparition starts, for more than a year. Then news began to emerge about a medium in Boston who did not take money for her séances and who seemed to have no particular motive for being a conduit. The woman, Mina Crandon, was married to a respected surgeon and so loathed publicity—unlike other mediums the magazine had encountered—that she received a pseudonym: Margery. So an editor and some of the contest judges set off to the Crandons' residence on Lime Street in Boston for preliminary visits. Bells rang in the dark, a Victrola played without explanation and the voice of the medium's dead brother conversed with observers.

But Margery could not convince Houdini, who called her "all fraud." The *Scientific American* committee eventually reached the same conclusion after observing nearly 100 séances. In 1925 the magazine announced, "The famous Margery case is over so far as the *Scientific American* Psychic Investigation is concerned."

Notably, however, the publication did not call humbug on the entire field and kept its committee going. As late as 1941, it upped the prize to $15,000. But it seemed unconvinced that conclusive evidence would surface on either side. In a 1942 article, a writer for the magazine mused that "it is, perhaps, too much to hope that it may ever be permanently settled."

**Katherine Harmon Courage** is a contributing editor to *Scientific American.*

ASTRONOMY

# OUR PLACE *in the* UNIVERSE

HOW ASTRONOMERS REVEALED A MUCH BIGGER AND STRANGER COSMOS THAN ANYONE SUSPECTED

*By Martin Rees*

*Illustration by Maria Corte*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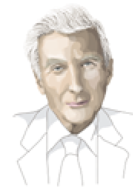


**Martin Rees** is an astrophysicist who has been the U.K.'s Astronomer Royal since 1995. He has served as master of Trinity College, Cambridge, and president of the Royal Society. Rees is author of nine books, including *On the Future: Prospects for Humanity* (Princeton University Press, 2018).

IN 1835 FRENCH PHILOSOPHER AUGUSTE COMTE ASSERTED THAT NOBODY WOULD EVER KNOW WHAT the stars were made of. "We understand the possibility of determining their shapes, their distances, their sizes and their movements," he wrote, "whereas we would never know how to study by any means their chemical composition, or their mineralogical structure, and, even more so, the nature of any organized beings that might live on their surface."

Comte would be stunned by the discoveries made since then. Today we know that the universe is far bigger and stranger than anyone suspected. Not only does it extend beyond the Milky Way to untold numbers of other galaxies—this would come as a surprise to astronomers of the 19th and early 20th century to whom our galaxy was "the universe"—but it is expanding faster every day. Now we can confidently trace cosmic history back 13.8 billion years to a moment only a billionth of a second after the big bang. Astronomers have pinned down our universe's expansion rate, the mean density of its main constituents, and other key numbers to a precision of 1 or 2 percent. They have also worked out new laws of physics governing space—general relativity and quantum mechanics—that turn out to be much more outlandish than the classical laws people understood before. These laws in turn predicted cosmic oddities such as black holes, neutron stars and gravitational waves. The story of how we gained this knowledge is full of accidental discoveries, stunning surprises and dogged scientists pursuing goals others thought unreachable.

**Our first hint** of the true nature of stars came in 1860, when Gustav Kirchhoff recognized that the dark lines in the spectrum of light coming from the sun were caused by different elements absorbing specific wavelengths. Astronomers analyzed similar features in the light of other bright stars and discovered that they were made of the same materials found on Earth—not of some mysterious "fifth essence" as the ancients had believed.

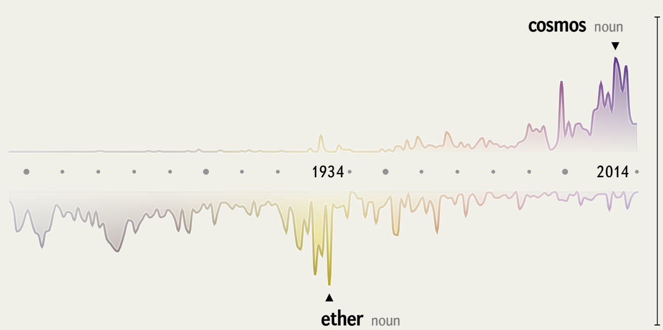
But it took longer to understand what fuel made the stars shine. Lord Kelvin (William Thomson) calculated that if stars derived their power just from gravity, slowly deflating as their radiation leaked out, then the sun's age was 20 million to 40 million years—far less time than Charles Darwin or the geologists of the time inferred had elapsed on Earth. In his last paper on the subject, in 1908, Kelvin inserted an escape clause stating that he would stick by his estimate "unless there were some other energy source laid up in the storehouse of creation."

That source, it turned out, is nuclear fusion—the process by which atomic nuclei join to create a larger nucleus and release energy. In 1925 astrophysicist Cecilia Payne-Gaposchkin used the light spectra of stars to calculate their chemical abundances and found that, unlike Earth, they were made mainly of hydrogen and helium. She revealed her conclusions in what astronomer Otto Struve described as "the most brilliant Ph.D. thesis ever written in astronomy." A decade later physicist Hans Bethe showed that the fusion of hydrogen nuclei into helium was the main power source in ordinary stars.

## WORDPLAY

**THE RELATIVE FREQUENCY OF REVEALING AND INTERESTING TERMS IN THIS MAGAZINE, FROM 1845 TO THE PRESENT.**

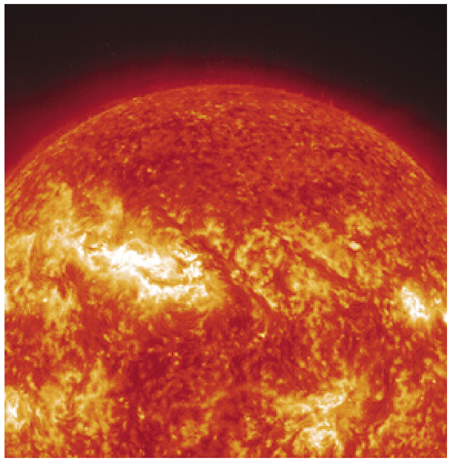
See "The Language of Science" on page 26 for more detail and page 33 for more word pairings.






*Graphics by Moritz Stefaner and Christian Lässer*

At the same time stars were becoming less mysterious, so, too, was the nature of fuzzy "nebulae" becoming clearer. In a "great debate" held before the National Academy of Sciences in Washington, D.C., on April 26, 1920, Harlow Shapley maintained that our Milky Way was preeminent and that all the nebulae were part of it. In contrast, Heber Curtis argued that some of the fuzzy objects in the sky were separate galaxies—"island universes"—fully the equal of our Milky Way. The conflict was settled not that night but just a few years later, in 1924, when Edwin Hubble measured the distances to many nebulae and proved they were beyond the reaches of the Milky Way. His evidence came from Cepheids, variable stars in the nebulae that reveal their true brightness, and thus their distance, by their pulsation period—a relation discovered by Henrietta Swan Leavitt.



WHAT IS the source of the sun's power? The answer—fusion—came in 1938.

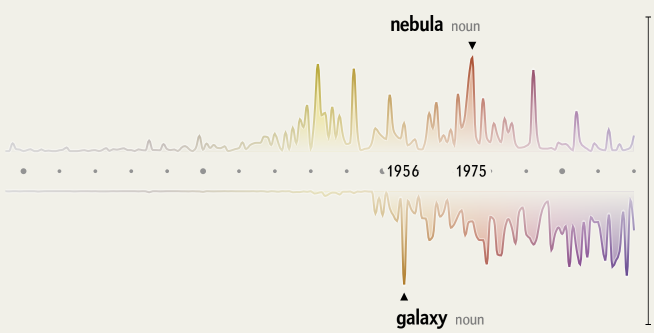
SOHO (ESA AND NASA)

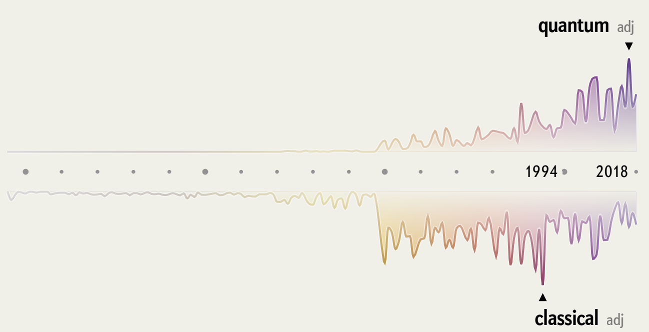
Soon after Hubble realized that the universe was bigger than many had thought, he found that it was still growing. In 1929 he discovered that spectral features in the starlight from distant galaxies appeared redder—that is, they had longer wavelengths—than the same features in nearby stars. If this effect was interpreted as a Doppler shift—the natural spreading of waves as they recede—it would imply that other galaxies were moving away from one another and from us. Indeed, the farther away they were, the faster their recession seemed to be. This was the first clue that our cosmos was not static but was expanding all the time.

The universe also appeared to contain much that we could not see. In 1933 Fritz Zwicky estimated the mass of all the stars in the Coma cluster of galaxies and found that they make up only about 1 percent of the mass necessary to keep the cluster from flying apart. The discrepancy was dubbed "the missing mass problem," but many scientists at the time doubted Zwicky's suggestion that hidden matter might be to blame. The question remained divisive until the 1970s, when work by Vera Rubin and W. Kent Ford (observing stars) and by Morton Roberts and Robert Whitehurst (making radio observations) showed that the outer parts of galactic disks would also fly apart unless they were subject to a stronger gravitational pull than stars and gas alone could provide. Finally, most astronomers were compelled to accept that some kind of "dark matter" must be present. "We have peered into a new world," Rubin wrote, "and have seen that it is more mysterious and more complex than we had imagined." Scientists now believe that dark matter outnumbers visible matter by about a factor of five, yet we are hardly closer than we were in the 1930s to figuring out what it is.

Gravity, the force that revealed all that dark matter, has proved to be nearly as baffling. A pivotal moment came in 1915 when Albert Einstein published his general theory of relativity, which transcended Isaac Newton's mechanics and revealed that gravity is actually the deformation of the fabric of space and time. This new theory was slow to take hold. Even after it was shown to be correct by observations of a 1919 solar eclipse, many dismissed the theory as an interesting quirk—after all, Newton's laws were still good enough for calculating most things. "The discoveries, while very important, did not, however, affect anything on this earth," astronomer W.J.S. Lockyer told the *New York Times* after the eclipse. For almost half a century after it was proposed, general relativity was sidelined from the mainstream of physics. Then, beginning in the 1960s, astronomers started discovering new and extreme phenomena that only Einstein's ideas could explain.

One example lurks in the Crab Nebula, one of the best-known objects in the sky, which is composed of the expanding debris from a supernova witnessed by Chinese astronomers in A.D. 1054. Since it appeared, the nebula has kept on shining blue and bright—but how? Its light source was a longtime puzzle, but the answer came in 1968, when the dim star at its center was revealed to be anything but normal. It was actually an ultracompact neutron star, heavier than the sun but only a few miles in radius and spinning at 30 revolutions per second. "This was a totally unexpected, totally new kind of object behaving in a way that astronomers had never expected, never dreamt of," said Jocelyn Bell Burnell, one of the discoverers of the phenomenon. The star's excessive spin sends out a wind of fast electrons that generate the blue light. The gravitational force at the surface of such an incredibly dense object falls way outside of Newton's purview—a rocket would need to be fired at half the speed of light to escape its pull. Here the relativistic effects predicted by Einstein must be taken into account. Thousands of such spinning neutron stars—called pulsars—have been



discovered. All are believed to be remnants of the cores of stars that exploded as supernovae, offering an ideal laboratory for studying the laws of nature under extreme conditions.

The most exotic result of Einstein's theory was the concept of black holes—objects that have collapsed so far that not even light can escape their gravitational pull. For decades these were only conjecture, and Einstein wrote in 1939 that they "do not exist in physical reality." But in 1963 astronomers discovered quasars: mysterious, hyperluminous beacons in the centers of some galaxies. More than a decade passed before a consensus emerged that this intense brightness was generated by gas swirling into huge black holes lurking in the galaxies' cores. It was the strongest evidence yet that these bizarre predictions of general relativity actually exist.

**When did the universe begin?** Did it even have a beginning? Astronomers had long debated these questions when, in the middle of the 20th century, two competing theories proposed very different answers. The "hot big bang" model said the cosmos began extremely small, hot and dense and then cooled and spread out over time. The "steady state" hypothesis held that the universe had essentially existed in the same form forever.

The contest was settled by a serendipitous discovery. In 1965 radio astronomers Arno Penzias and Robert Wilson were trying to calibrate a new antenna at Bell Labs in New Jersey. They had a problem: no matter what they did to reduce background interference, they measured a consistent level of noise in every direction. They even evicted a family of pigeons that had been nesting in the antenna in the hope that they were the source of the problem. But the signal persisted. They had discovered that intergalactic space is not completely cold. Instead it is warmed to nearly three kelvins (just above absolute zero) by weak microwaves. Penzias and Wilson had accidentally uncovered the "afterglow of creation"—the cooled and diluted relic of an era when everything in the universe was squeezed until it was hot and dense.

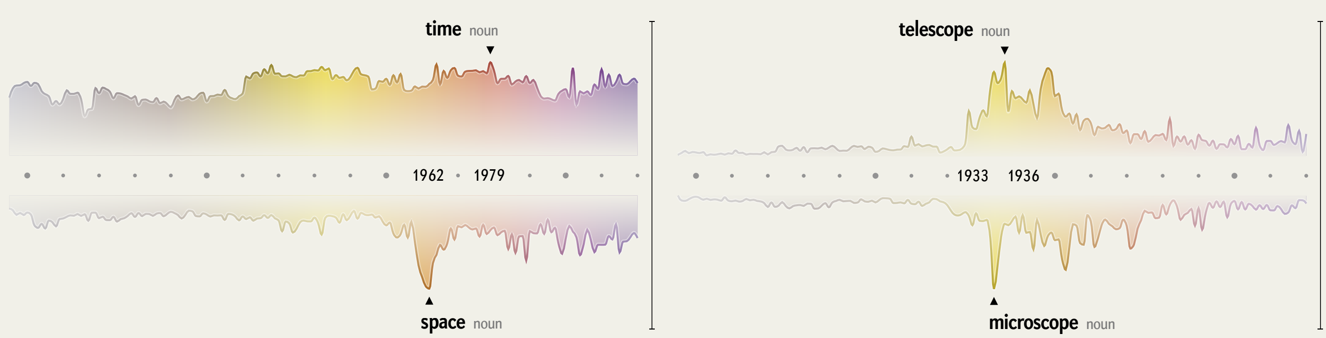
The finding tipped the balance firmly in favor of the big bang picture of cosmology. According to the model, during the earliest, hottest epochs of time, the universe was opaque, rather like the inside of a star, and light was repeatedly scattered by electrons. When the temperature fell to 3,000 kelvins, however, the electrons slowed down enough to be captured by protons and created neutral atoms. Thereafter light could travel freely. The Bell Labs signal was this ancient light, first released about 300,000 years after the birth of the universe and still pervading the cosmos—what we call the cosmic microwave background. It took a while for the magnitude of the discovery to sink in for the scientists who made it. "We were very pleased to have a possible explanation [for the antenna noise], but I don't think either of us really took the cosmology very seriously at first," Wilson says. "Walter Sullivan wrote a first-page article in the *New York Times* about it, and I began to think at that point that, you know, maybe I better start taking this cosmology seriously."

Measurements of this radiation have since enabled scientists to understand how galaxies emerged. Precise observations of the microwaves reveal that they are not completely uniform over the sky. Some patches are slightly hotter, others slightly cooler. The amplitude of these fluctuations is only one part in 100,000, but they are the seeds of today's cosmic structure. Any region of the expanding universe that started off slightly denser than average expanded less because it was subjected to extra gravity; its growth lagged further and further, the contrast between its density and that of its surroundings becoming greater and greater. Eventually these clumps were dense enough that gas was pulled in and compressed into stars, forming galaxies. The crucial point is this: Computer models that simulate this process are fed the initial fluctuations measured in the cosmic microwave background, which represent the universe when it was 300,000 years old. The output after 13.8 billion years of virtual time have elapsed is a cosmos where galaxies resemble those we see, clustered as they are in the actual universe. This is a real triumph: we understand, at least in outline, 99.998 percent of cosmic history.

**It is not only the big cosmic picture** that we have come to understand. A series of discoveries has also revealed the history of the elemental building blocks that make up stars, planets and even our own bodies.

Starting in the 1950s, progress in atomic physics led to accurate modeling of stars' surface layers. Simultaneously, detailed knowledge of the nuclei not just of hydrogen and helium atoms but also of the rest of the elements allowed scientists to calculate which nuclear reactions dominate at different stages in a star's life. Astronomers came to understand how nuclear fusion creates an onion-skin structure in massive stars as atoms successively fuse to build heavier and heavier elements, ending with iron in the innermost, hottest layer.

Astronomers also learned how stars die when they exhaust their hydrogen fuel and blow off their outer gaseous layers. Lighter stars then settle down to a quiet demise as dense, dim objects called white dwarfs, but heavier stars shed more of their mass, either in winds during their lives or in an explosive death via supernova. This expelled mass turns out to be crucial to our own existence: it mixes into the interstellar medium and recondenses into new stars



orbited by planets such as Earth. The concept was conceived by Fred Hoyle, who developed it during the 1950s along with two other British astronomers, Margaret Burbidge and Geoffrey Burbidge, and American nuclear physicist William Fowler. In their classic 1957 paper in *Reviews of Modern Physics* (known by the initials of its authors as BBFH), they analyzed the networks of the nuclear reactions involved and discovered how most atoms in the periodic table came to exist. They calculated why oxygen and carbon, for instance, are common, whereas gold and uranium are rare. Our galaxy, it turns out, is a huge ecological system where gas is being recycled through successive generations of stars. Each of us contains atoms forged in dozens of different stars spread across the Milky Way that lived and died more than 4.5 billion years ago.


INSIDE the Crab Nebula is a neutron star: classical physics fails, and relativity applies.

NASA, ESA AND HUBBLE HERITAGE TEAM (STScI AND AURA)

Scientists long assumed this process was seeding planets—and possibly even life—around stars other than our own sun. But we did not know for sure whether planets existed outside our solar system until the 1990s, when astronomers developed clever methods for identifying worlds that are too dim for us to see directly. One technique looks for tiny periodic changes in a star's movement caused by the gravitational pull of a planet orbiting it. In 1995 Michel Mayor and Didier Queloz used this strategy to detect 51 Pegasi b, the first known exoplanet orbiting a sunlike star. The technique can reveal a planet's mass, the length of its "year" and the shape of its orbit. So far more than 800 exoplanets have been found this way. A second technique works better for smaller planets. A star dims slightly when a planet transits in front of it. An Earth-like planet passing a sunlike star can cause a dimming of about one part in 10,000 once per orbit. The Kepler spacecraft launched in 2009 found more than 2,000 planets this way, many no bigger than Earth. A big surprise to come from astronomers' success in planet hunting was the variety of different planets out there—many much larger and closer to their stars than the bodies in our solar system—suggesting that our cosmic neighborhood may be somewhat special.

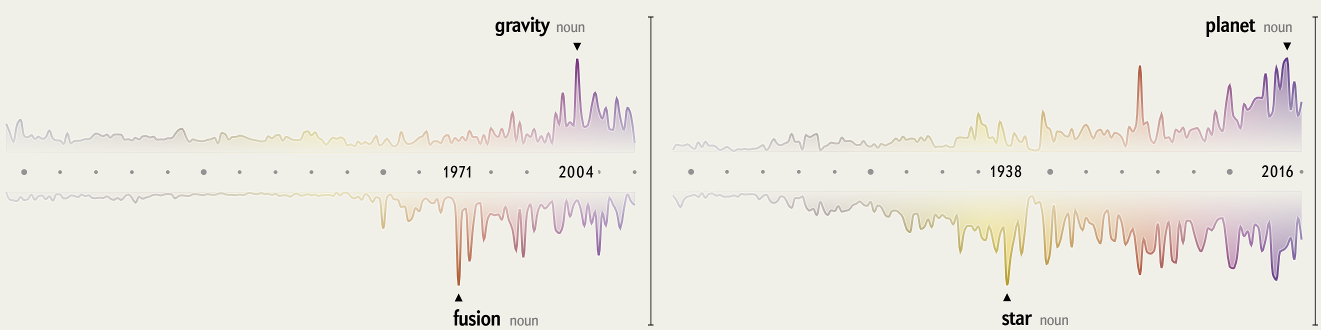
By this point scientists understood where almost all the elements that form planets, stars and galaxies originated. The final piece in this puzzle, however, arrived very recently and from a seemingly unrelated inquiry.

General relativity had predicted a phenomenon called gravitational waves—ripples in spacetime produced by the movement of massive objects. Despite decades of searching for them, however, no waves were seen—until September 2015. That was when the Laser Interferometer Gravitational-wave Observatory (LIGO) detected the first evidence of gravitational waves in the form of a "chirp"—a minute shaking of spacetime that speeds up and then dies away. In this case, it was caused by two black holes in a binary system that had started out orbiting each other but gradually spiraled together and eventually converged into a single massive hole. The crash occurred more than a billion light-years away. LIGO's detectors consist of mirrors four kilometers apart whose separation is measured by laser beams that reflect light back and forth between them. A passing gravitational wave causes the space between the two mirrors to jitter by an amount millions of times as small as the diameter of a single atom—LIGO is indeed an amazing feat of precision engineering and perseverance.

Since that first find, more than a dozen similar events have been detected, opening up a new field that probes the dynamics of space itself. One event was of special astrophysical interest because it signaled the merger of two pulsars. Unlike black hole mergers, this kind of collision, a splat between two ultradense stars, yields a pulse of optical light, x-rays and gamma rays. The discovery filled a gap in the classic work of BBFH: the authors had explained the genesis of many of the elements in space but were flummoxed by the forging of gold. In the 1970s David N. Schramm and his colleagues had speculated that the exotic nuclear processes involved in hypothetical mergers of pulsar stars might do the job—a theory that has since been validated.

**Despite the incredible progress** in astronomy over the past 175 years, we have perhaps more questions now than we did back then.

Take dark matter. I am on record as having said more than 20 years ago that we would know dark matter's nature long before today. Although that prediction has proved wrong, I have not given up hope. Dark energy, however, is a different story. Dark energy entered the picture in 1998, when researchers measuring the dis-



tances and speeds of supernovae found that the expansion of the universe was actually accelerating. Gravitational attraction pulling galaxies toward one another seemed to be overwhelmed by a mysterious new force latent in empty space that pushes galaxies apart—a force that came to be known as dark energy. The mystery of dark energy has lingered—we still do not know what causes it or why it has the particular strength it does—and we probably will not understand it until we have a model for the graininess of space on a scale a billion billion times smaller than an atomic nucleus. Theorists working on string theory or loop quantum gravity are tackling this challenge, but the phenomenon seems so far from being accessible by any experiment that I am not expecting answers anytime soon. The upside, however, is that a theory that could account for the energy in the vacuum of space might also yield insights into the very beginning of our universe, when everything was so compressed and dense that quantum fluctuations could shake the entire cosmos.

Which brings us to another major question facing us now: How did it all begin? What exactly set off the big bang that started our universe? Did space undergo a period of extremely rapid early expansion called inflation, as many theorists believe? And there is something else: some models, such as eternal inflation, suggest that "our" big bang could be just one island of spacetime in a vast archipelago—one big bang among many. If this hypothesis is true, different big bangs may cool down differently, leading to unique laws of physics in each case—a "multiverse" rather than a universe. Some physicists hate the multiverse concept because it means that we will never have neat explanations for the fundamental numbers that govern our physical laws, which may in this grander perspective be just environmental accidents. But our preferences are irrelevant to nature.

About 10 years ago I was on a panel at Stanford University where we were asked by someone in the audience how much we would bet on the multiverse concept. I said that on a scale of betting my goldfish, my dog or my life, I was nearly at the dog level. Andrei Linde, who had spent 25 years promoting eternal inflation, said he would almost bet his life. Later, on being told this, physicist Steven Weinberg said he would happily bet my dog and Linde's life. Linde, my dog and I will all be dead before the question is settled. But none of this should be dismissed as metaphysics. It is speculative science—exciting science. And it may be true.

And what will happen to this universe—or multiverse—of ours? Long-range forecasts are seldom reliable, but the best and most conservative bet is that we have almost an eternity ahead with an ever colder and ever emptier cosmos. Galaxies will accelerate away and disappear. All that will be left from our vantage point will be the remnants of the Milky Way, Andromeda and smaller neighbors. Protons may decay, dark matter particles may be annihilated, there may be occasional flashes when black holes evaporate—and then silence.

This possible future is based on the assumption that the dark energy stays constant. If it decays, however, there could be a "big crunch" with the universe contracting in on itself. Or if dark energy strengthens, there would be a "big rip" when galaxies, stars and even atoms are torn apart.

Other questions closer to home tantalize us. Could there be life on any of these new planets we are discovering? Here we are still in the realm of speculation. But unless the origin of life on Earth involved a rare fluke, I expect evidence of a biosphere on an exoplanet within 20 years. I will not hold my breath for the discovery of aliens, but I think the search for extraterrestrial intelligence is a worthwhile gamble. Success in the search would carry the momentous message that concepts of logic and physics are not limited to the hardware in human skulls.

Until now, progress in cosmology and astrophysics has owed 95 percent to advancing instruments and technology and less than 5 percent to armchair theory. I expect that balance to persist. What Hubble wrote in the 1930s remains a good maxim today: "Not until the empirical resources are exhausted, need we pass on to the dreamy realms of speculation."

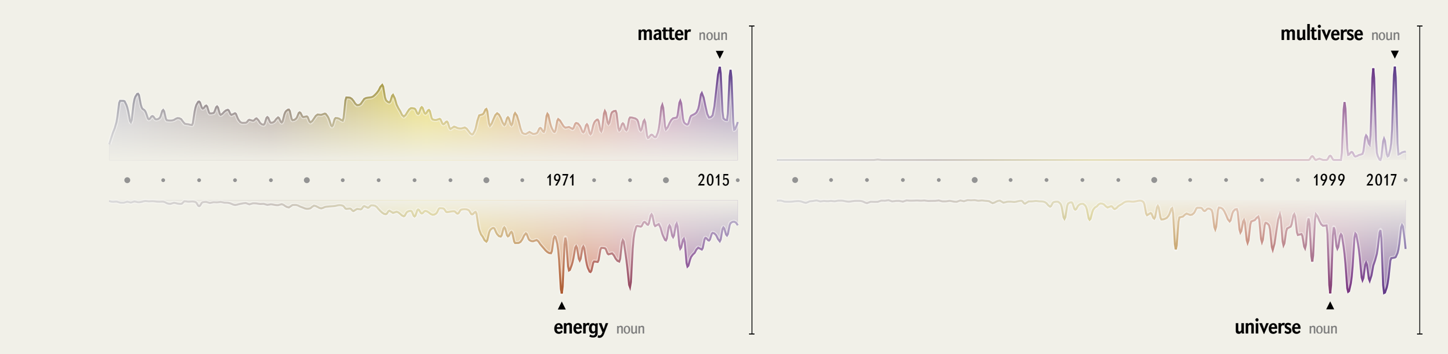
There have been many particularly exhilarating eras in the past 175 years—the 1920s and 1930s, when we realized the universe was not limited to the Milky Way, and the 1960s and 1970s, when we discovered objects that defy classical physics, such as neutron stars and quasars, and clues about the beginning of time from the cosmic microwave background. Since then, the pace of advancement has crescendoed rather than slackened.

When the history of science gets written, this amazing progress will be acclaimed as one of its greatest triumphs—up there with plate tectonics, the genome and the Standard Model of particle physics. And some major fields in astronomy are just getting going. Exoplanet research is only 25 years old, and serious work in astrobiology is really only starting. Some exoplanets may have life—they may even harbor aliens who know all the answers already. I find that encouraging. SA

**FROM OUR ARCHIVES**

Five Historic Photographs from Palomar. Edwin P. Hubble; November 1949.
On the Generalized Theory of Gravitation. Albert Einstein; April 1950.
Astronomy. Harlow Shapley; September 1950.

scientificamerican.com/magazine/sa



# The Symmetry Pair

**IN THE 1960S MARTIN GARDNER HELPED TO TURN THE ARTIST M. C. ESCHER INTO A SENSATION** *BY STEPHEN ORNES*

**BETWEEN 1957 AND 1986** Martin Gardner wrote the Mathematical Games column for this magazine, with a total of 297 installments. During that time he became the world's most prolific and best-known popularizer of recreational mathematics. His fans still revere him as a kind of sorcerer who conjured up an endless feast of puzzles, games and riddles built on mathematical ideas that often turned on counterintuitive twists. He may have lived as he wrote: after visiting Gardner's office, in the attic of the writer's home, the late mathematician John Horton Conway remarked that "it was filled with puzzles, games, mechanical toys, scientific curiosities, and a host of other intriguing objects, exactly like a wizard's den."

In his April 1961 column, Gardner introduced U.S. audiences to Dutch artist M. C. Escher, a meticulous craftsman who took great delight in defying expectations and breaking rules. He created mind-bending worlds where impossible things happen: Animals crawl out of the page, staircases rise to meet themselves and form infinite closed loops where one can climb forever, gravity pulls in multiple directions, and waterfalls cascade into the same pools that produced them.

Gardner's column was not directly about Escher. It was a rave review of *Introduction to Geometry* by University of Toronto geometer H.S.M. Coxeter, which explored areas where older textbooks had feared to tread, such as non-Euclidean geometries. Coxeter had used Escher's works to illustrate the book.

It was a natural pairing: For all of his blatant disregard for convention and authority, Escher embraced the laws of symmetry in geometry. In math-speak, "symmetry groups" refers to the collection of ways one can slide, reflect or rotate an object so that its final appearance is the same as its starting one. Escher often invoked translations, mirror reflections and repetition of forms.

The cover of *Scientific American*'s April 1961 issue shows a flock of flying geese drawn by Escher with half facing to the left and the other half facing right. Closer inspection reveals that the birds are similar—the left-facing half look like, but are not quite, mirror images of the right-facing half. After a few seconds of staring at the picture, a viewer realizes that the birds interlock like puzzle pieces. Mathematicians describe one or more geometric shapes arranged to interlock and completely cover a flat surface as "tiling the plane." Squares, hexagons and equilateral triangles can do it. Escher's birds can, too, apparently.

ONE VERSION OF M. C. ESCHER'S IMAGE of knights appeared in a 1961 *Scientific American* column by Martin Gardner.



Mathematician Doris Schattschneider, the world's foremost expert on symmetry in Escher's works, says that 1961 column likely served to "whet the appetites" of mathematicians and scientists. Five years later Gardner devoted an entire column to Escher's work and included a wide variety of examples.

And that is when things took off. "Escher was overwhelmed" by a deluge of letters from collectors and admirers who wanted to own their own Escher, Schattschneider says. "After Mr. Gardner's article, my customers, especially in America, give me no peace," Escher wrote to his friend Cornelius Roosevelt, a former CIA agent (and grandson of Theodore Roosevelt), who by that time had become the world's foremost collector of all things Escher. Gardner, in the wake of his column, became a kind of Escher broker, redirecting would-be buyers who (through letters to this magazine) requested a print of their own.

The Escher craze had begun, and his popularity exploded in the late 1960s and the 1970s. Escher's work challenged long-held ideas about certainty and truth, coinciding with the countercultural wave of the period. "I cannot help mocking all our unwavering certainties," he said in 1965. "Are you sure that a floor cannot also be a ceiling? Are you absolutely certain that you go up when you walk up a staircase? Can you be definite that it is impossible to have your cake and eat it?" Escher died in 1972, but his work lives on in large (often pirated) posters on dormitory-room walls and in wildly popular museum exhibitions around the world.

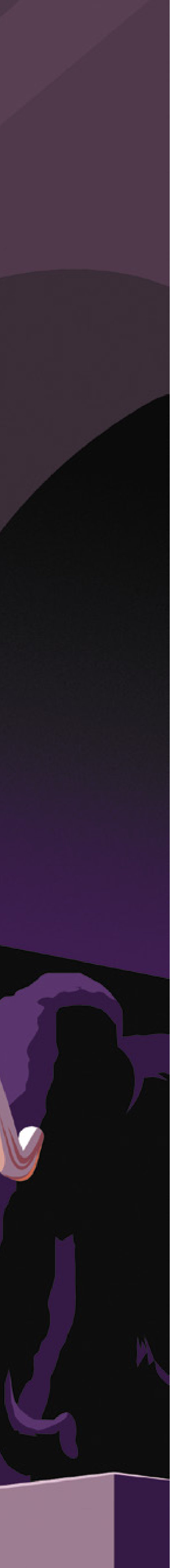
Despite this popularity, the artist never felt at home—or even welcome—in the worlds of math and art. The art world often seemed hostile to his work, and Escher once said he was "embarrassed" by the term "artist." In a review of a 1998 retrospective, a *New York Times* art critic dismissed Escher as the "nonartist's nonartist."

"I'm starting to speak a language which is understood by very few people. It makes me feel increasingly lonely," he wrote to his son George in 1959, two years before Gardner's first column. "Mathematicians may be friendly and interested and give me a fatherly pat on the back, but in the end I am only a bungler to them. 'Artistic' people mainly become irritated."

But in the playful world of Gardner's Mathematical Games, Escher had found a home. "I think your article is excellent indeed," he wrote to Gardner after seeing a 1966 column. Today he would likely recognize his community as the growing group of artists who find aesthetic inspiration in mathematical ideas.

One key attribute Escher shares with those artists, as well as with mathematicians and with anyone who finds themselves unable to resist a puzzle, is a certain kind of perseverance. "What can I do," he once wrote to his son Arthur, "when this sort of problem fascinates me so much that I cannot leave it alone?"

**Stephen Ornes** lives in Nashville, Tenn., and is author of *Math Art: Truth, Beauty, and Equations* (Sterling, 2019).





EVOLUTION

# THE ORIGIN *of* US

FOSSILS AND DNA HAVE REVEALED THE COMPLEXITY OF HUMAN EVOLUTION. DARWIN WOULD BE DELIGHTED

*By Kate Wong*

*Illustration by Pascal Blanchet*

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IN 1859, 14 YEARS AFTER THE FOUNDING OF THIS MAGAZINE, CHARLES DARWIN PUBLISHED THE MOST important scientific book ever written. *On the Origin of Species* revolutionized society's understanding of the natural world. Challenging Victorian dogma, Darwin argued that species were not immutable, each one specially created by God. Rather life on earth, in all its dazzling variety, had evolved through descent from a common ancestor with modification by means of natural selection. But for all of Darwin's brilliant insights into the origins of ants and armadillos, bats and barnacles, one species is conspicuously neglected in the great book: his own. Of *Homo sapiens*, Darwin made only a passing mention on the third-to-last page of the tome, noting coyly that "light will be thrown on the origin of man and his history." That's it. That is all he wrote about the dawning of the single most consequential species on the planet.

It was not because Darwin thought humans were somehow exempt from evolution. Twelve years later he published a book devoted to that very subject, *The Descent of Man*. In it, he explained that discussing humans in his earlier treatise would have served only to further prejudice readers against his radical idea. Yet even in this later work, he had little to say about human origins per se, instead focusing on making the case from comparative anatomy, embryology and behavior that, like all species, humans had evolved. The problem was that there was hardly any fossil record of humans at that time to provide evidence of earlier stages of human existence. Back then, "the only thing you knew was what you could reason," says paleoanthropologist Bernard Wood of George Washington University.

To his credit, Darwin made astute observations about our kind and predictions about our ancient past based on the information that was available to him. He argued that all living humans belong to one species and that its "races" all descended from a single ancestral stock. And pointing to the anatomical similarities between humans and African apes, he concluded that chimpanzees and gorillas were the closest living relatives of humans. Given that relationship, he figured, early human ancestors probably lived in Africa.

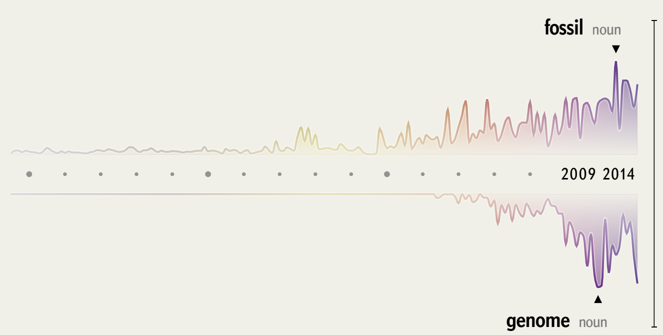
Since then, Wood says, "the evidence has come in." In the past century and a half, science has confirmed Darwin's prediction and pieced together a detailed account of our origins. Paleoanthropologists have recovered fossil hominins (the group that comprises *H. sapiens* and its extinct relatives) spanning the past seven million years. This extraordinary record shows that hominins indeed got their start in Africa, where they evolved from quadrupedal apes into the upright-walking, nimble-fingered, large-brained creatures we are today.

And the archaeological record of hominin creations, which encompasses roughly half that time, charts their cultural evolution—from early experiments with simple stone tools to the invention of symbols, songs and stories—and maps our ancestors' spread across the globe. The fossils and artifacts demonstrate that for most of the period over which our lineage has been evolving, multiple hominin species walked the earth. Studies of modern and ancient DNA have generated startling

## WORDPLAY

**THE RELATIVE FREQUENCY OF REVEALING AND INTERESTING TERMS IN THIS MAGAZINE, FROM 1845 TO THE PRESENT.**

See "The Language of Science" on page 26 for more detail and page 33 for more word pairings.






*Graphics by Moritz Stefaner and Christian Lässer*

NEANDERTALS were the first extinct hominin species to be recognized in the fossil record and the first to yield ancient DNA.

JAVIER TRUEBA *Science Source*

insights into what happened when they encountered one another.

The human saga, we now understand, is far more intricate than scholars of yore envisioned. The tidy tropes of our prehistory have collapsed under the weight of evidence: there is no single missing link that bridges apes and humankind, no drumbeat march of progress toward a predestined goal. Our story is complicated, messy and random. Yet it still can be accommodated under Darwin's theory of evolution and in fact further validates that framework.

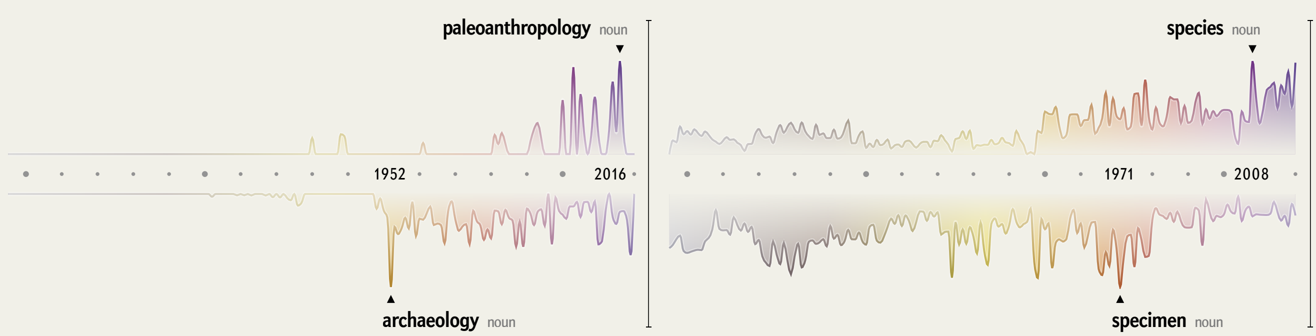
This is not to say scientists have it all figured out. Many questions remain. But whereas the origin of humans was once an uncomfortable speculation in Darwin's big idea, it is now among the best-documented examples of evolution's transformative power.

**We humans are strange creatures.** We walk upright on two legs and possess supersized brains, we invent tools to meet our every need and express ourselves using symbols, and we have conquered every corner of the planet. For centuries scientists have sought to explain how we came to be, our place in the natural world.

This quest was often distorted by racist ideologies. Consider the era leading up to the birth of Darwin's bombshell theory. In the 1830s, while a young Darwin was making his momentous voyage onboard the *Beagle,* a movement was underway to promote the idea that the various modern human groups around the globe—races—had separate origins. To build the case for polygenism, as the theory is known, scientists such as Samuel Morton in Philadelphia collected skulls from people across the world and measured their sizes and shapes, falsely believing those attributes to be proxies for intelligence. When they ranked the specimens from superior to inferior, Europeans would conveniently come out on top and Africans on the bottom. "There was a desire to provide scientific justification for political and power structures," says anthropological geneticist Jennifer Raff of the University of Kansas. "It was science in the service of slavery and colonialism."

Although Darwin's work came down firmly on the side of monogenism—the idea that all humans share a common ancestor—it was nonetheless co-opted to support notions about racial superiority. Social Darwinism, for one, misapplied Darwin's ideas about the struggle for existence in natural selection to human society, providing a pseudoscientific rationalization for social injustice and oppression. Darwin himself did not subscribe to such views. In fact, his opposition to slavery may have been a driving force in his research agenda, according to his biographers Adrian Desmond and James Moore.

By the time Darwin published *The Descent of Man,* in 1871, the idea that humans had evolved from a common ancestor with apes was already gaining traction in the scientific community thanks to books published in the 1860s by English biologist Thomas Henry Huxley and Scottish geologist Charles Lyell. Still, the fossil evidence to support this claim was scant. The only hominin fossils known to science were a handful of remains a few tens of thousands of years old that had been recovered from sites in Europe. Some were *H. sapiens;* others would eventually be recognized as a separate but very closely related species, *Homo neanderthalensis*. The implication was that fossils of more apelike human ancestors were out there somewhere in the world, awaiting discovery. But the suggestion by Darwin, like Huxley before him, that those ancestors would be found in Africa met with resistance from scholars who saw Asia



as a more civilized birthplace for humankind and emphasized similarities between humans and Asia's gibbons.

Perhaps it should come as no surprise, then, that when the first hominin fossil significantly older and more primitive than those from Europe turned up, it came not from Africa but from Asia. In 1891 Dutch anatomist Eugène Dubois discovered remains on the Indonesian island of Java that he thought belonged to the long-sought missing link between apes and humans. The find, which he named *Pithecanthropus erectus,* spurred further efforts to root humankind in Asia. (We now know that Dubois's fossil was between 700,000 and one million years old and belonged to a hominin that was much more humanlike than apelike, *Homo erectus.*)

Two decades later the search turned to Europe. In 1912 amateur archaeologist Charles Dawson reported that he had found a skull with a humanlike cranium and an apelike jaw in an ancient gravel pit near the site of Piltdown in East Sussex, England. Piltdown Man, as the specimen was nicknamed, was a leading contender for the missing link until it was exposed in 1953 as a fraudulent pairing of a modern human skull with an orangutan's lower jaw.

Piltdown so seduced scholars with the prospect of making Europe the seat of human origins that they all but ignored an actual ancient hominin that turned up in Africa, one even older and more apelike than the one Dubois discovered. In 1925, 43 years after Darwin's death, anatomist Raymond Dart published a paper describing a fossil from Taung, South Africa, with an apelike braincase and humanlike teeth. Dart named that fossil—a youngster's skull now known to be around 2.8 million years old—*Australopithecus africanus,* "the southern ape from Africa." But it would take nearly 20 years for the scientific establishment to accept Dart's argument that the so-called Taung Child was of immense significance: the fossil linked humans to African apes.

Evidence of humanity's African origins has accumulated ever since. Every hominin trace older than 2.1 million years—and there are now quite a few of them—has come from that continent.

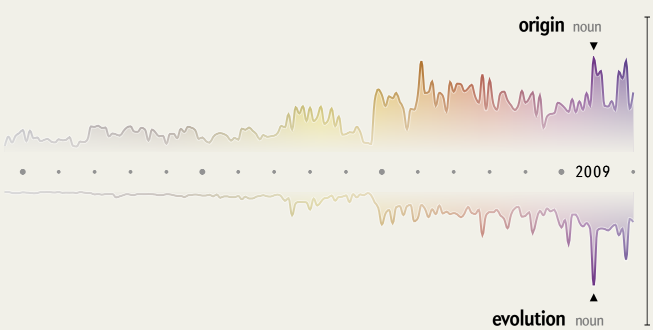
**Even as fossil discoveries** proved Darwin right about the birthplace of humanity, the pattern of our emergence remained elusive. Darwin himself depicted evolution as a branching process in which ancestral species divide into two or more descendant species. But a long-standing tradition of organizing nature hierarchically—one that dates back to Plato and Aristotle's Great Chain of Being—held sway, giving rise to the notion that our evolution unfolded in linear fashion from simple to complex, primitive to modern. Popular imagery reflected and reinforced this idea, from a caricature in *Punch's Almanack* for 1882 showing a progression from earthworm to Darwin, to the iconic monkey-to-man illustration that appeared in the 1965 Time-Life book *Early Man* and became known as the March of Progress.

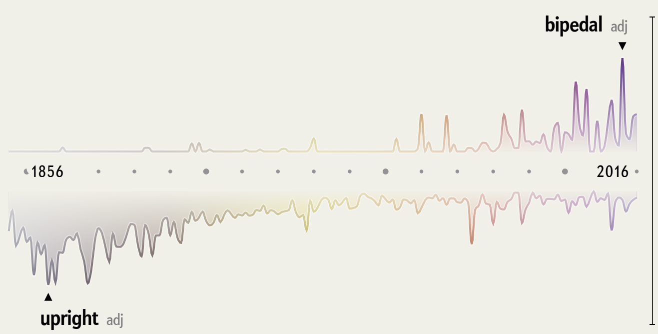
From the rich assortment of fossils and artifacts recovered from around the world in the past century, however, paleoanthropologists can now reconstruct something of the timing and pattern of human evolution. The finds clearly show that this single-file scheme is no longer tenable. Evolution does not march steadily toward predetermined goals. And many hominin specimens belong not in our direct line of ancestry but on side branches of humankind—evolutionary experiments that ended in extinction.

From the outset, our defining traits evolved not in lockstep but piecemeal. Take our mode of locomotion, for example. *H. sapiens* is what anthropologists call an obligate biped—our bodies are built for walking on two legs on the ground. We can climb trees if we need to, but we have lost the physical adaptations that other primates have to arboreal life. Fragmentary fossils of the oldest known hominins—*Sahelanthropus tchadensis* from Chad, *Orrorin tugenensis* from Kenya and *Ardipithecus kadabba* from Ethiopia—show that our earliest ancestors emerged by around seven million to 5.5 million years ago. Although they are apelike in many respects. all of them exhibit characteristics associated with walking on two legs instead of four. In *Sahelanthropus,* for example, the hole in the base of the skull through which the spinal cord passes has a forward position suggestive of an upright posture. A bipedal gait may thus have been one of the very first traits that distinguished hominins from ancestral apes.

Yet our forebears appear to have retained traits needed for arboreal locomotion for millions of years after they first evolved the ability to walk on two legs. *Australopithecus afarensis,* which lived in eastern Africa from 3.85 million to 2.95 million years ago and is famously represented by the skeleton known as Lucy, discovered in 1974, was a capable biped. But it had long, strong arms and curved fingers—features associated with tree climbing. It would be another million years before modern limb proportions evolved and committed hominins to life on the ground, starting with early *H. erectus* in Africa (sometimes called *Homo ergaster*).

The brain evolved on quite a different schedule. Over the course of human evolution, brain size has more than tripled. A comparison of the braincase of *A. afarensis* with that of the much older *Sahelanthropus,* however, shows that hardly any of that growth occurred in the first few million years of human evolution. In fact, most of the expansion took place in the past two million years, perhaps enabled by a feedback loop in which advances in technology—stone tools and the like—gave hominins access to more nutri-



tious foods such as meat, which could fuel a larger and thus more energetically demanding brain, which in turn could dream up even better technology, and so on. Shifts in the shape and structure of the brain accompanied these gains, with more real estate allocated to regions involved in language and long-range planning, among other advanced cognitive functions.

This mosaic pattern of hominin evolution in which different body parts evolved at different rates produced some surprising creatures. For instance, *Australopithecus sediba* from South Africa, dated to 1.98 million years ago, had a humanlike hand attached to an apelike arm, a big birth canal but a small brain, and an advanced ankle bone connected to a primitive heel bone.

Sometimes evolution even doubled back on itself. When one examines a hominin fossil, it can be difficult to discern whether the species retained a primitive trait such as small brain size from an earlier ancestor or whether it lost the characteristic and then re-evolved it. But the strange case of *Homo floresiensis* may well be an example of the latter. This member of the human family lived on the island of Flores in Indonesia as recently as 50,000 years ago yet looked in many ways like some of the founding members of our genus who lived more than two million years earlier. Not only did *H. floresiensis* have a small body, but it also possessed a remarkably tiny brain for *Homo,* about the size of a chimp's. Scientists' best guess is that this species descended from a brawnier, brainer *Homo* species that got marooned on Flores and evolved its diminutive size as an adaptation to the limited food resources available on its island home. In so doing, *H. floresiensis* seems to have reversed what researchers once considered a defining trend of *Homo*'s evolution: the inexorable expansion of the brain. Yet despite its small brain, *H. floresiensis* still managed to make stone tools, hunt animals for food and cook over fires.

Adding to the complexity of our story, it is now clear that for most of the time over which humans have been evolving, multiple hominin species walked the earth. Between 3.6 million and 3.3 million years ago, for example, at least four varieties of hominins lived in Africa. Paleoanthropologist Yohannes Haile-Selassie of the Cleveland Museum of Natural History and his team have recovered remains of two of them, *A. afarensis* and *Australopithecus deyiremeda,* as well as a possible third creature known only from a distinctive fossil foot, in a single area called Woranso-Mille in Ethiopia's Afar region. How they managed to share the landscape is a subject of current investigation. "Competing species could co-exist if there were plenty of resources or if they were exploiting different parts of the ecosystem," Haile-Selassie says.

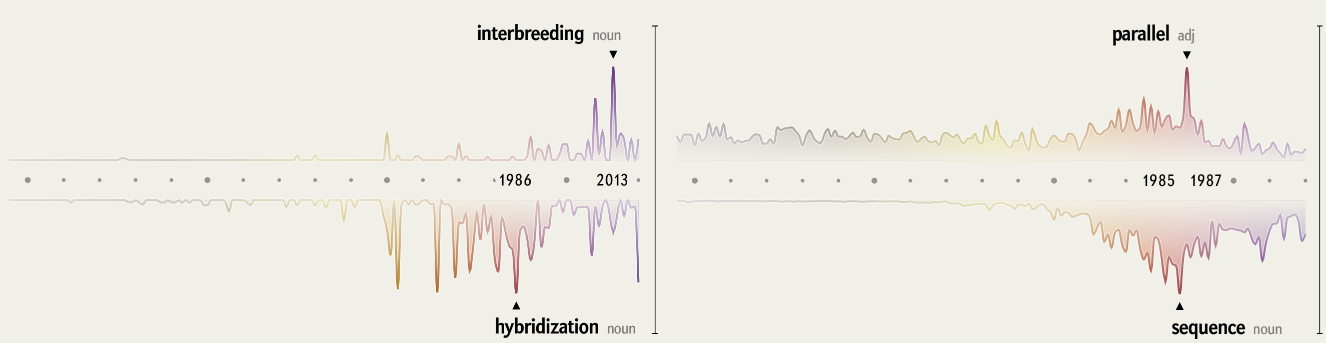
Later, between roughly 2.7 million and 1.2 million years ago, representatives of our genus, *Homo*—large-brained tool users with dainty jaws and teeth—shared the grasslands of southern and eastern Africa with a radically different branch of humanity. Members of the genus *Paranthropus,* these hominins had massive teeth and jaws, flaring cheek bones and crests atop their heads that anchored powerful chewing muscles. Here the co-existence is somewhat better understood: whereas *Homo* seems to have evolved to exploit a wide variety of plants and animals for food, *Paranthropus* specialized in processing tough, fibrous plant foods.

## Evolution does not march steadily toward predetermined goals.

*H. sapiens* overlapped with other kinds of humans, too. When our species was evolving in Africa 300,000 years ago, several other kinds of hominins also roamed the planet. Some, such as the stocky Neandertals in Eurasia, were very close relatives. Others, including *Homo naledi* in South Africa and *H. erectus* in Indonesia, belonged to lineages that diverged from ours in the deep past. Even as recently as 50,000 years ago, hominin diversity was the rule, with the Neandertals, the mysterious Denisovans from Asia, tiny *H. floresiensis* and another small hominin—the recently discovered *Homo luzonensis* from the Philippines—all at large.

**Such discoveries make for a much** more interesting picture of human evolution than the linear account that has dominated our view of life. But they raise a nagging question: How did *H. sapiens* end up being the sole surviving twig on what was once a luxuriant evolutionary bush?

Here are the facts of the case. We know from fossils found at the site of Jebel Irhoud in Morocco that our species originated in Africa by at least 315,000 years ago. By around 200,000 years ago it began making forays out of Africa, and by 40,000 years ago it had established itself throughout Eurasia. Some of the places *H. sapiens* colonized were occupied by other hominin species. Eventually the other folks all disappeared. By around 30,000 to 15,000 years ago, with the end of the Neandertals in Europe and the Denisovans in Asia, *H. sapiens* was alone in the world.



Researchers have often attributed the success of our species to superior cognition. Although the Neandertals actually had slightly larger brains than ours, the archaeological record seemed to indicate that only *H. sapiens* crafted specialized tools and used symbols, suggesting a capacity for language. Perhaps, the thinking went, *H. sapiens* won out by virtue of sharper foresight, better technology, more flexible foraging strategies and bigger social networks for support against hard times. Alternatively, some investigators have proposed, maybe *H. sapiens* waged war on its rivals, exterminating them directly.

But recent discoveries have challenged these scenarios. Neandertal technology, archaeologists have learned, was far more varied and sophisticated than previously thought. Neandertals, too, made jewelry and art, crafting pendants from shells and animal teeth and painting abstract symbols on cave walls. Moreover, they may not have been our only enlightened kin: a 500,000-year-old engraved shell from Java suggests that *H. erectus* also possessed symbolic thought. If archaic hominins had many of the same mental faculties as *H. sapiens,* why did the latter prevail?

The conditions under which *H. sapiens* got its start may have played a role. Fossil and archaeological data suggest that our species mostly stayed in Africa for the first couple of hundred thousand years of its existence. There, some experts argue, it evolved as a population of interconnected subgroups spread across the continent that split up and reunited again and again over millennia, allowing for periods of evolution in isolation followed by opportunities for interbreeding and cultural exchange. This evolutionary upbringing may have honed *H. sapiens* into an especially adaptable hominin. But that is not the whole story, as we now know from genetics.

Analyses of DNA have revolutionized the study of human evolution. Comparing the human genome with the genomes of the living great apes has shown conclusively that we are most closely related to chimpanzees and bonobos, sharing nearly 99 percent of their DNA. And large-scale studies of DNA from modern-day human populations across the globe have illuminated the origins of modern human variation, overturning the centuries-old notion that races are biologically discrete groups with separate origins. “There have never been pure populations or races,” Raff says. Modern human variation is continuous, and most variation actually exists within populations rather than between them—the product of our demographic history as a species that originated in Africa with populations that mixed continuously as they migrated around the world.

More recently, studies of ancient DNA have cast new light on the world of early *H. sapiens* as it was when other hominin species were still running around. In the late 1990s geneticists began recovering small amounts of DNA from Neandertal and early *H. sapiens* fossils. Eventually they succeeded in getting entire genomes not only from Neandertals and early *H. sapiens* but also from Denisovans, who are known from just a few fragmentary fossils from Siberia and Tibet. By comparing these ancient genomes with modern ones, researchers have found evidence that our own species interbred with these other species. People today carry DNA from Neandertals and Denisovans as a result of these long-ago encounters. Other studies have found evidence of interbreeding between *H. sapiens* and unknown extinct hominins from Africa and Asia for whom we have no fossils but whose distinctive DNA persists.

Mating with other human species may have aided *H. sapiens’* success. Studies of organisms ranging from finches to oak trees have shown that hybridization with local species can help colonizing species flourish in novel environments by giving them useful genes. Although scientists have yet to figure out the functions of most of the genes people today carry from extinct hominins, they have pinpointed a few, and the results are intriguing. For instance, Neandertals gave *H. sapiens* immunity genes that may have helped our species fend off novel pathogens it encountered in Eurasia, and Denisovans contributed a gene that helped people adapt to high altitudes. *H. sapiens* may be the last hominin standing, but it got a leg up from its extinct cousins.

**Scientists have many more pieces** of the human-origins puzzle than they once did, but the puzzle is now vastly bigger than it was previously understood to be. Many gaps remain, and some may never close. Take the question of why we evolved such massive brains. At around 1,400 grams, the modern human brain is considerably larger than expected for a primate of our body size. “The singularity is why it’s interesting—and why it’s impossible to answer scientifically,” Wood observes. Some experts have suggested that hominin brains ballooned as they adapted to climate fluctuations between wet and dry conditions, among other explanations. But the problem with trying to answer “why” questions about the evolution of our unique traits, Wood says, is that there is no way to evaluate the proposed explanations empirically. “There isn’t a counterfactual. We can’t go back to three million years ago and not change the climate.”

Other mysteries may yield to further investigation, however. For example, we do not yet know what the last common ancestor of humans and the *Pan* genus that includes chimps and bonobos looked like. Genomic and fossil data suggest that the two lineages diverged between eight million and 10 million years ago—up to three million years before the oldest known hominin walked the earth—which means that paleoanthropologists may be missing a substantial chunk of our prehistory. And they have hardly any fossils at all of *Pan,* which has been evolving along its own path just as long as we have. Insights may come from a project currently underway in central Mozambique, where Susana Carvalho and René Bobe of the University of Oxford and their colleagues are hunting for fossil primates, including hominins, in sediments older than the ones that yielded *Sahelanthropus, Orrorin* and *Ardipithecus.*

Later stages of the human story are riddled with unknowns, too. If *H. sapiens* was interbreeding with the other hominin species it encountered, as we now know it was, were these groups also exchanging culture? Might *H. sapiens* have introduced Neandertals to novel hunting technology and artistic traditions—or vice versa? New techniques for retrieving ancient DNA and proteins from otherwise unidentifiable fossils and even cave sediments are helping researchers determine which hominin species were active and when at key archaeological sites.

One wonders where the next 175 years will take us in the quest to understand who we are and where we come from. We may have found our place in nature, located our twig on the shrub, but we are still searching for ourselves. We’re only human, after all.

FROM OUR ARCHIVES

Last Hominin Standing. Kate Wong; September 2018.

scientificamerican.com/magazine/sa

# Nuclear Reaction

HOW AN ARTICLE ABOUT THE H-BOMB LANDED *SCIENTIFIC AMERICAN* IN THE MIDDLE OF THE RED SCARE *BY ALFRED W. McCOY*

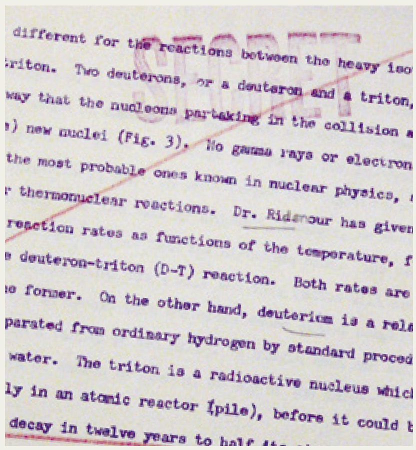
**ON APRIL 1, 1950,** the *New York Times* carried a sensational front-page headline, "U.S. Censors H-Bomb Data; 3,000 Magazine Copies Burnt." The story's lead sentence read: "Gerard Piel, editor of the *Scientific American,* attacked the censorship policies of the Atomic Energy Commission yesterday when he disclosed ...." The article went on to report that the government had destroyed every trace of the original text by physicist Hans Bethe, melting down the "objectionable linotype slugs" at the printing plant and then incinerating the "complete file of proofs" along with those 3,000 printed copies.

Piel, a scion of the family that brewed Piels Beer, was one of the first journalists to recognize the implications of nuclear research for weapon making, and he faced censorship, blacklisting and surveillance. Reporting for *Life* from 1943 to 1944, Piel was shown a telegram from the wartime Office of Censorship warning the magazine that certain topics, such as "atomic energy" and "uranium," were now classified. "I took that telegram as a reading list," Piel recalled. During an interview with Piel, Robert W. Wood of Johns Hopkins University fumed about a secret Manhattan Project that was placing heavy orders for his spectroscopic research equipment. The physicist, however, figured out the purpose of the classified endeavor. "They're engaged in making the most frightful weapon," Wood told Piel.

Realizing the "Age of the Atom" was dawning, Piel spoke with close colleagues at *Life* about a new publication with the editorial independence for an informed discussion about the uses of science. With *Life* buddy Dennis Flanagan and New York friend Donald H. Miller, Jr., Piel relaunched the moribund *Scientific American* in 1948 with a simple editorial approach. Leading scientists would explain developments in their fields to intelligent readers, and *Scientific American*'s editors would translate their convoluted texts into readable prose. This editorial formula captivated its educated audience, eventually attracting essays by more than 150 Nobel Prize winners, including Albert Einstein, Niels Bohr and Francis Crick.

After Piel recruited colleagues from *Life,* famed informer Whitaker Chambers, then a senior editor at *Time,* told the FBI "that a group of three or four people left *Time* and became editors of *Scientific American.*" He also reported they were "probably Communist sympathizers," adding erroneously that "a mysterious subsidy" became available to buy *Scientific American.*

In 1950 *Scientific American* joined the nuclear debate with a four-part inquiry into the hydrogen bomb. In the first installment, scientist Louis Ridenour criticized the decision to build this destructive weapon and condemned the "bankruptcy of our secrecy policy" that stifled public debate. A month later, in the April 1950 issue, physicist Hans Bethe pleaded for finding ways to "save humanity from this ultimate disaster" by reconsidering the president's decision to build the new super bomb. Because he had circulated his draft among colleagues, the Atomic Energy Commission (AEC) had seen the manuscript, and it telegrammed the magazine to bar publication of Bethe's article, which had already gone through part of its press run. When Piel asked for specific objections, the AEC replied that any details could compromise national security. In a closed-door confrontation, the AEC finally agreed to permit publication with some "ritual deletions."


different for the reactions between the heavy iso
triton. Two deuterons, or a deuteron and a triton,
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s) new nuclei (Fig. 3). No gamma rays or electron
the most probable ones known in nuclear physics,
r thermonuclear reactions. Dr. Ridenour has given
reaction rates as functions of the temperature, f
e deuteron-triton (D-T) reaction. Both rates are
he former. On the other hand, deuterium is a rel
parated from ordinary hydrogen by standard proced
water. The triton is a radioactive nucleus which
ly in an atomic reactor (pile), before it could b
decay in twelve years to half

REDACTED: Hans Bethe's H-bomb article.

Piel recalled that at this sensitive juncture, Miller asked the AEC security officers: "Well, what do we do with the 3,000 copies already printed of the magazine?" Miller then suggested: "There are good shredders up there. But then, you know, someone could take the shredded pieces and put them back together again. Maybe it's better to burn it, don't you think?" Oblivious to the symbolism after a war against Nazis who had staged book burnings, the tone-deaf AEC security men agreed. All those 3,000 copies were incinerated—an act almost without precedent in America. Adding gravity to the act, the issue featured an essay by Einstein that propounded a comprehensive field theory that would hold physics together.

Piel's mind was still not at rest, though. His magazine was "a very fragile little institution," with just over 100,000 circulation. "The Atomic Energy Commission or somebody in it at any time can leak this to the House Un-American Activities Committee or Joe McCarthy," he thought, "and we'll be cooked. So I called up the *New York Times* and said I have a story."

The incident became what Piel called "a nationwide overnight sensation" that protected him from accusations of breaching national security. A *Times* editorial supported *Scientific American,* warning that "censors ... run the risk of doing great harm."

Piel's stance won him public admiration and closer FBI surveillance. Agents reported that Piel and his first wife, then living in Greenwich Village, "were active in the '12th Street Neighbors for Peace,' which was connected with the Stockholm Peace Petition," an advocacy group for a nuclear weapons ban.

At the peak of the McCarthy-era's witch hunt for Communists in May 1953, a Senate subcommittee summoned *Scientific American* managing editor Leon Svirsky. Although suspecting that Svirsky had been a member of a secret Communist cell at *Time* magazine, Piel provided skilled counsel that let him emerge from the Senate hearing unscathed.

While investigating alleged Communists inside the U.S. Army in July 1954, the Senate's Internal Security Subcommittee subpoenaed *Scientific American*'s promotions director, Stephen M. Fischer, who had been press secretary for Henry Wallace's 1948 Progressive presidential campaign. With the adept lawyer Piel provided, Fischer evaded prosecution by confessing his Communist Party membership while refusing to name names. But the most challenging security case was Piel's own. When Piel was asked to become an adviser for a journal published by the U.S. Public Health Service, his acceptance required an FBI security check. The bureau determined, Piel said, "I was a subversive and disloyal to the United States."

At an appeal to the Loyalty Board, the FBI reported that *Scientific American* had "derided" the evidence in the Rosenberg atomic espionage case, which, Piel said, "it certainly had." Another demerit was his friendship with Harvard University astronomer Harlow Shapley, a contributor to the magazine and a peace activist who had dismissed Senator Joseph McCarthy's accusations of his disloyalty as "untrue and vague." Finally, the FBI report accused Piel of membership in the American Labor Party, a Progressive group allied with Mayor Fiorello LaGuardia of New York, to which Piel said, "I certainly was." Even so, his name was cleared from the taint of disloyalty.

All this dissent established the magazine's reputation for editorial independence, winning subscribers and advertisers. By deftly manipulating the historical forces at play—press freedom versus national security—Gerard Piel had made his publication an important forum for critical analysis of U.S. science policy during the coldest years of the cold war.

**Alfred W. McCoy** is a professor of history at the University of Wisconsin–Madison. He is author of *Beer of Broadway Fame: The Piel Family and Their Brooklyn Brewery* (State University of New York Press, 2016), from which this article is adapted.

NATIONAL ARCHIVES AND RECORDS ADMINISTRATION, ARCHIVES II, RECORD GROUP 326, RECORDS OF THE ATOMIC ENERGY COMMISSION, OFFICE OF THE SECRETARY, GENERAL CORRESPONDENCE RELATING TO WEAPONS, 1946–1951, BOX 107, FOLDER 380.01, "PUBLICATION OF INFORMATION REGARDING THE THERMONUCLEAR BOMB (SECRET)." IMAGE PROVIDED BY ALEX WELLERSTEIN

GEOLOGY

# THE WORST TIMES on EARTH

MASS EXTINCTIONS SEND US A WARNING ABOUT THE FUTURE OF LIFE ON THIS PLANET

*By Peter Brannen*

*Illustration by Pascal Blanchet*

**Peter Brannen** is a science journalist whose book *The Ends of the World* is about the five major mass extinctions (Ecco, 2017). Brannen was a 2018–2019 Scripps Fellow at the University of Colorado Boulder.

PANGAEA, 252 MILLION YEARS AGO—THE WORLD IS OVER. SIBERIA HAS BEEN ERUPTING FOR 300,000 years, is still erupting and won't stop. Not a volcano, mind you, but Siberia—two million square miles of it. A suppurating, billowing, continent-scaled wasteland of glowing rock and steam. The seas, once resplendent with horn corals and sponge reefs, are now sour and laden with mercury. Hot as soup, they bubble deathly swamp gas that feeds vile, hurricane-churned slicks of slime. The seabed is vacant, as scuttling trilobites die out after a quarter of a billion years. Beside this rancid ocean, on the shores of a blasted supercontinent, the forests are gone. Instead hot rivers now spill over the dead land in wide braids. Fungus blooms where vanished groves of ferns once held contests full of fangs and armor—gorgonopsids battling pareiasaurs. Their final bones are now scoured by hot winds and bleached by a searing sunlight, unfiltered by ozone. Night falls and brings odd constellations that light the dead waves, lapping at dead shores, tossing old bits of a dead reef from a dead sea. It smells awful. The planet is ruin and slime and heat. The ocean suffocates. Bacterial mounds spread. A hundred thousand suns rise and fall on a hopeless world. A hundred thousand springtimes arrive with no respite. It's still all but barren. A million years of misery pass. Ten million.

At long last, the planet is finally reborn—this time with dinosaurs and ichthyosaurs and pterosaurs and mammals and turtles and sturgeon—almost as if a new story entirely has begun, exuberant, confident, vital: the Mesozoic era. The old story, too dark to retell, has long been filed away somewhere deep in the great cabinets of Earth, along with an epitaph in the rocks, written in geochemistry: carbon dioxide destroyed this world.

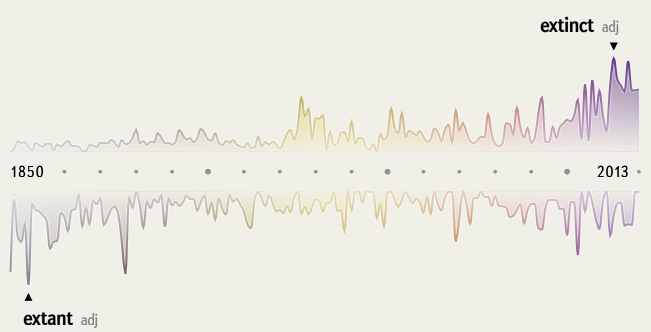
**Mass extinctions** are not merely bad days in Earth history. They are not even very bad days. They are the very, very worst days in the entire half-billion-year history of complex life. They are supremely horrifying, astronomically rare, global Ragnaroks that end the lineages of most living creatures on the planet. They are terrible, surreal things: 20,000 years of suffocating greenhouse heat punctuated by volcanic winter blasts or an afternoon of celestial terror and tsunamis. And until around 1980, they were mostly thought to be disreputable speculation.

Over the past two centuries the field of geology, like the fossil record itself, has been characterized by long periods of stasis punctuated by exhilarating moments of upheaval and innovation. It would be arbitrary to identify *one* founding figure for the modern study of geology, but one could do worse than Scottish geologist James Hutton, who did much to reveal the "abyss of time" underneath us. At a salt-sprayed Siccar Point on the eastern coast of Scotland in 1788, he spied an outcrop made of two kinds of rock, one stacked on top of

## WORDPLAY

**THE RELATIVE FREQUENCY OF REVEALING AND INTERESTING TERMS IN THIS MAGAZINE, FROM 1845 TO THE PRESENT.**

See "The Language of Science" on page 26 for more detail and page 33 for more word pairings.





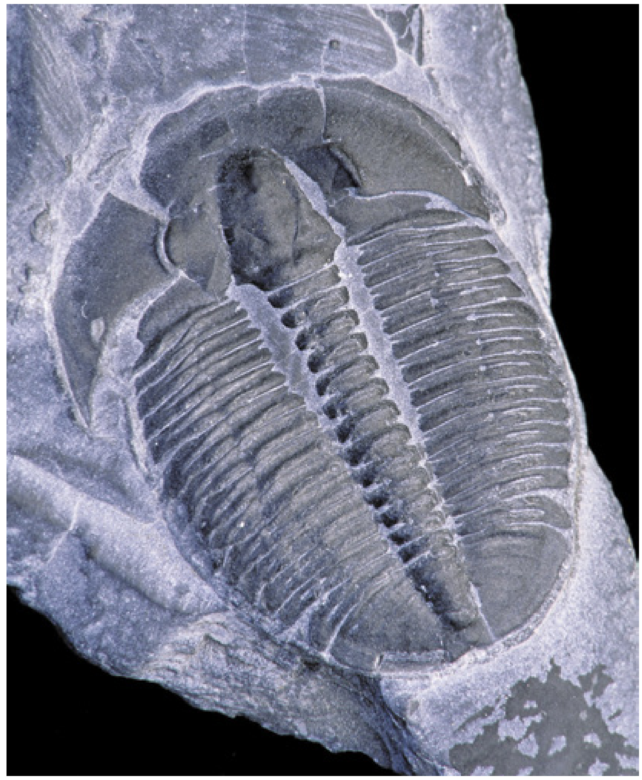

*Graphics by Moritz Stefaner and Christian Lässer*

the other, meeting abruptly in the middle. But the rock on the bottom—laminations of deep-sea muck—had been formed at the bottom of the ocean, tilted sideways, thrust up into the air and planed off by wind and erosion. And the rock on the top had been formed by tropical rivers on dry land. The missing time implied between the two rocks, now conjoined but separated by an unthinkable gap, shattered Hutton. The body of his writing is notoriously obtuse and unimpressive; he apparently saved all his eloquence for one haunting observation that, in the confusion of Earth beneath our feet, "we find no vestige of a beginning, no prospect of an end." Although the history of humanity has played out in the shallows so far, time, it turns out, is *deep*.

Geologists cast off the strictures of biblical time and Noah's flood, and their new field matured over the decades, spurred by a significant material reward for finding coal and minerals in a strange new industrial age. The story of life on Earth, however fragmentary and tantalizing, slowly revealed itself.

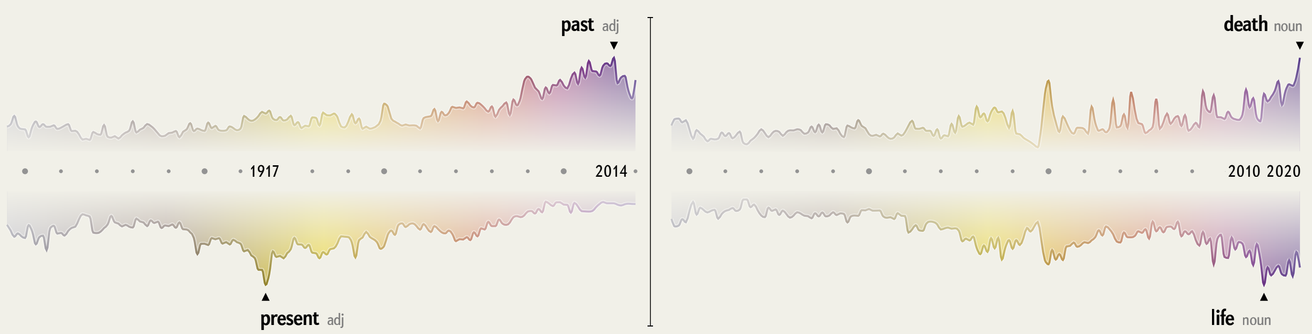
At this magazine's founding, the field was in its adolescence. It was still dominated by men of means—the kind of ascotted dilettantes rendered humorlessly in oil and lithograph portraits. The contributions of women such as Mary Anning, the unmatched fossil hunter who scoured the English shoreline unearthing the local "snakestones" and "stone crocodiles" that littered the wave-battered Jurassic Coast, were acknowledged only sheepishly. Although *Scientific American* headlines from the time still hint at a somewhat rudimentary state of affairs ("Experts Doubt the Sun Is Actually Burning Coal"), by midcentury geology had nonetheless been established as an empirical, systematized field of inquiry with roots in antiquity—one of the many such intellectual eddies that swirled out of Enlightenment-era "natural philosophy." That is, it now had rules. The rules were deceptively simple and powerful. Layers of ocean rock now propped up at unusual angles on land must have once laid flat on a seafloor in some distant age. Dikes of old magma that pierced this stony tiramisu must have worked their shoots into the layered rock sometime after. The fossils entombed in these rock layers could be correlated to those fossils and those rocks with the same layers, way over there.

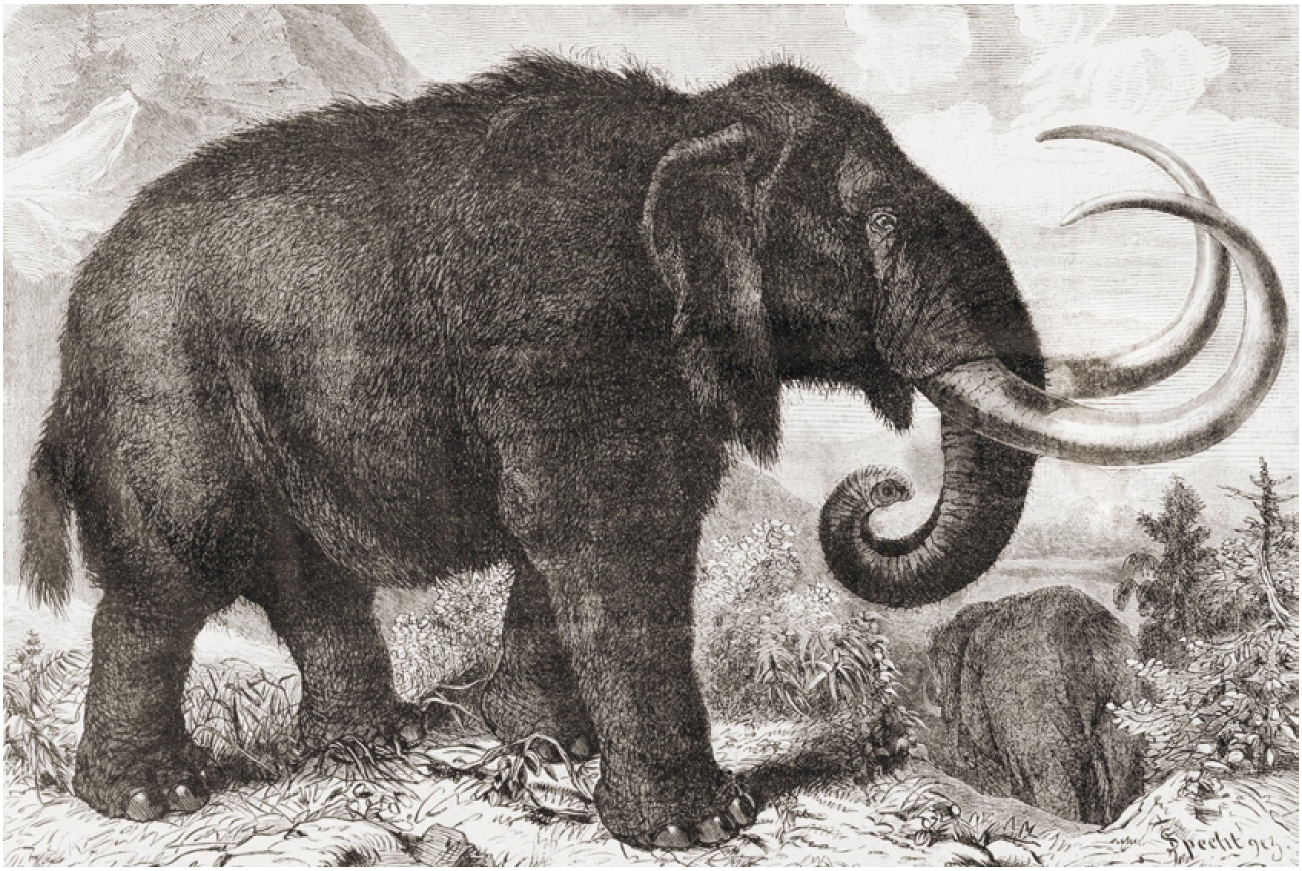
In 1860 English geologist John Phillips drew on the fossil-collecting labor of decades prior, and a growing body of paleontology literature scattered across elegant monographs, to plot a surprisingly modern curve of the richness of life over Earth history, the first ever such diagram. The graph ominously included two profound dips in life: one crash that separated the trilobite-spangled Paleozoic era from the dinosaur-haunted Mesozoic era and another plunge that separated the Mesozoic from our own Cenozoic time (all terms of Phillips's invention). The dramatic breaks in fossil life hinted at some kind of ancient calamity that divided the great ages and supported the blasphemous idea that species—that is, God's very Creation—might go extinct, which had been proposed half a century earlier by the renowned French naturalist Georges Cuvier. On considering the odd elephant bones that littered the New World, of mammoths and mastodons ("*animal de l'Ohio*"), Cuvier had proposed that life on Earth, like French rule, could be swept away in "revolutions." Phillips's graph provided something close to quantitative proof, and Phillips himself thought that each recovery consisted of separate acts of divine creation. Yet it would take more than a century for



TRILOBITES swam the seas for a quarter of a billion years before being annihilated in history's worst mass extinction.

ED RESCHKE *Getty Images*





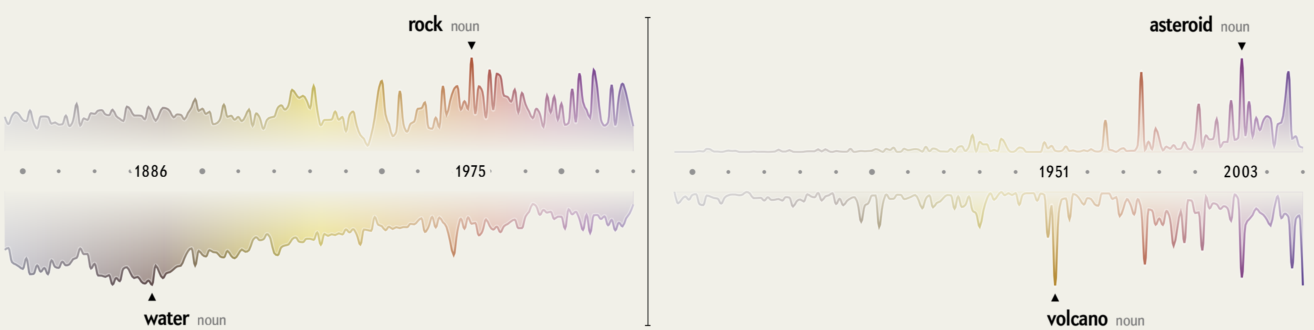
1867 RENDERING of a woolly mammoth, whose bones led Georges Cuvier to propose that life could be extinguished in "revolutions."

anyone to take the idea of mass extinctions seriously again.

This is because, by the end of the 19th century, the field was still dominated, and would continue to be dominated for decades, by the enduring framework of "uniformitarianism." This concept, popularized by Charles Lyell, is summarized in a catchphrase still taught to geology students: "The present is the key to the past." That is, the unhurried processes at work on the face of Earth today—the relentless if unimpressive work of rain on rock, the inexorable incision of rivers into highlands or the piling of sand into desert dunes—have always been plying the planet in the same tedious fashion and could account for everything we find in the rock record. Painting on this vast new canvas of time, Charles Darwin would propose that similarly small but steady biological changes over generations, filtered by the relentless tournament of life and death, and given Hutton's eons to ramify, could produce the "endless forms" of life "most beautiful" on Earth today. Pointedly absent from this measured account of planetary history were the gauche cataclysms of Cuvier and Phillips.

**Geology was upended** in the middle of the 20th century by the plate tectonic revolution—the validation of the once fringe idea that continents drifted across the world like rudderless ships. Even so, the idea of sudden apocalyptic global mass

ALAMY



extinctions remained suspect at best. Catastrophism was spooky, reminiscent of a benighted prescientific world where capricious gods subjected the world to cleansing acts of global destruction. Worse, speculation about why the dinosaurs had disappeared had become something of a cottage industry among cranks, and serious scientists were nervous about associating with a crowd who proposed, among dozens of other incoherent ideas for their demise, "dwindling brain and consequent stupidity," development of heads that became "too heavy to lift," "psychotic suicidal factors," "competition with caterpillars," "terminal hay fever" and "methane poisoning from dinosaur flatulence." And yet the orthodoxy began to crack.

"*Neokatastrophismus?*" the iconoclastic German scientist Otto Schindewolf asked of his fellow paleontologists in 1963, attempting to revive Cuvier's catastrophism for the 20th century. Because his question was posed in German, few English-speaking scientists felt the need to reply. But Schindewolf could no longer overlook the ominous interruption of life he saw—among other places—exposed in the ancient rocks of the Salt Range in Pakistan. There appeared to be a dreadful global collapse of the ocean ecosystem at the end of the Permian period a quarter of a billion years ago (in fact, the greatest mass extinction in Earth history), just as Phillips had plotted more than a century prior. Schindewolf conscripted a supernova for his vision of the apocalypse, proposing that it might have irradiated Earth and seeded the biosphere with ruinous mutations.

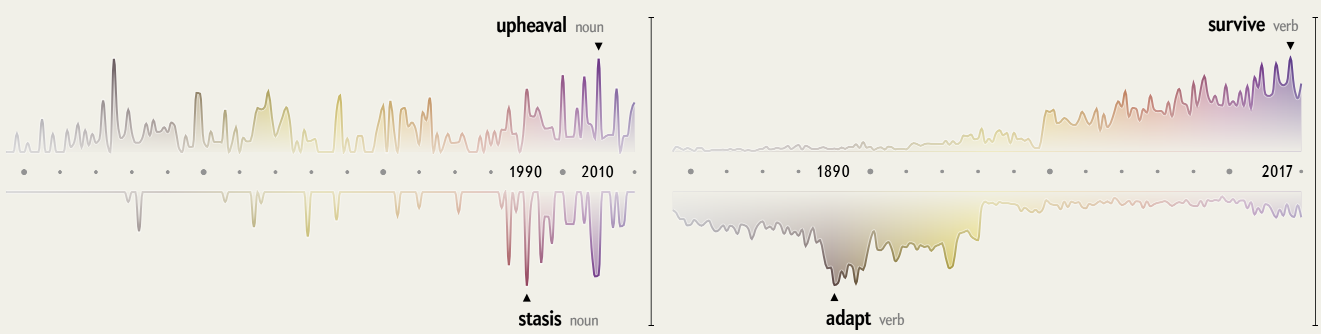
In that same year American Norman Newell, plotting the fates of 2,500 animal families over Earth history, noted six intervals when extinction seemed to cut a broad swath through all of life, instead proposing dramatic sea-level changes as his preferred Grim Reaper. And at the end of the decade Digby McLaren, director of the Canadian Geological Survey's Institute of Sedimentary and Petroleum Geology, insisted in his 1969 presidential address to the Paleontological Society that his fellow paleontologists were trying to "define out of existence" the obvious breaks in the fossil record, such as a devastating wave of death 375 million years ago that wiped out the largest global reef system in the history of life. "I cannot accept a uniformitarian explanation," he said of the catastrophe, glaringly apparent in ancient rocks from Iran to Alberta. McLaren had an idea for what could cause such a discontinuity.

"I shall, therefore, land a large or very large meteorite in the Paleozoic Pacific," he announced, capable of generating "a wave twenty thousand feet high. This will do." McLaren's address, it is reported, was "met with embarrassed silence," and many paleontologists in the audience, still under Lyell's spell, assumed he must have been joking.

Then, in 1980, an asteroid landed in the field. Walter Alvarez, then a young University of California, Berkeley, professor, was traipsing the Apennines above the medieval Italian town of Gubbio. In this mountainous pile of ancient limestone seafloor, pushed up by the grinding advance of Africa into Europe, there was a sharp break—a lifeless clay layer—between the placid sea life of dinosaur times and the impoverished life of the early age of mammals. Perhaps this transformative interval took place over millions of years, validating the uniformitarian view. Or perhaps Cuvier and Phillips had it right all along, and the turnover was devastatingly short. Curious, Alvarez recruited his father, Luis, a Nobel-winning physicist, to help tackle the question. It was quite the second act for the elder Alvarez, a pioneer of military radar technology and Manhattan Project alum who helped to develop the atomic bomb and even watched "Little Boy" explode over Hiroshima from an attending B-29. His wartime work became unexpectedly relevant to the catastrophe they were investigating, which throttled the planet some 66 million years earlier.

The Alvarezes knew that unusual elements like iridium were delivered to Earth from above by an eternal drizzle of space dust, at a steady rate. Measure the iridium in the ominous clay layer, they reasoned, and if there's just a little bit, the dramatic turnover in life couldn't have taken very long. Conversely, if there's a lot of iridium, it took a very long time indeed. But what if, as they discovered, there was 100 times more iridium than they ever expected? After bombarding the clay samples with neutrons from a nuclear reactor and analyzing them, the Alvarezes were astonished. The only vehicle large enough for this much exotic material was not a light drizzle of space dust but one truly gigantic space

## For decades the idea of sudden global mass extinctions remained suspect at best.



rock. (Often omitted in this account, though not by the Alvarezes themselves, is the fact that Dutch geologist Jan Smit and Belgian geologist Jan Hertogen made the very same discovery among ancient ocean rocks in Spain at the very same time and even published their results in the journal *Nature* two weeks earlier than the Alvarezes' landmark *Science* paper.)

The resulting chaos from such an impact would be like all-out nuclear warfare, only worse. There would be the unimaginable heat from the initial explosion, which would have been thousands of times more powerful than the detonation of all the nuclear weapons on Earth at the height of the cold war, all in one place, all at once. "Certainly enough," as one impact modeler put it to me, "to lift a mountain back into space at escape velocity." It has been proposed that as this spacebound ejecta encircled the globe, it might have turned the atmosphere into a pizza oven for 20 minutes (with dinosaurs playing the role of pepperoni). Then there might have been the decades of darkness and cold from the nuclear winter to follow, starving any lingering creature lucky enough to have avoided being evaporated outright by the asteroid, swept up in its tsunamis, or turned to charcoal by the ballistic reentry of its debris into the atmosphere.

In 1991 whatever lingering skepticism about the impact that remained among uniformitarian hardliners was wiped away by the discovery of a 110-mile crater buried under tens of millions of years of limestone on Mexico's Yucatán peninsula. In fact, the crater had already been discovered in 1978 by geophysicists working for the Mexican national oil company Pemex, but they had announced their findings at a geophysics conference that had escaped notice of paleontologists for more than a decade. And the structure had been found some 1,000 years earlier by the Maya, who built settlements around limestone sinkholes that pock the Yucatán and that provided freshwater. The pattern of these sinkholes reflects the deeply disturbed rock far below and maps almost exactly onto the crater's edge, in a 110-mile ring.

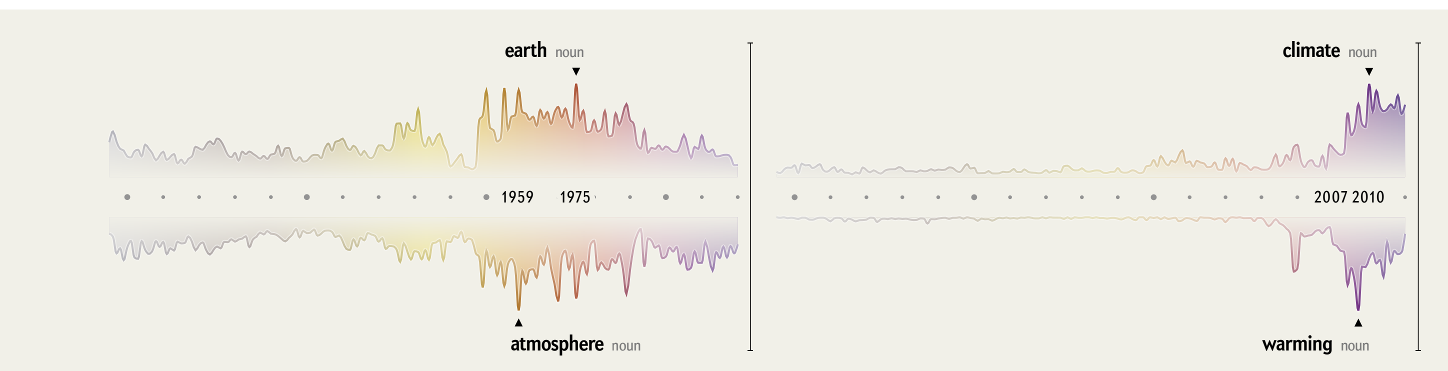
Popular culture took note. The 1990s saw a rash of impact-inspired cable specials and movies strewn with bad CGI, which—along with the astounding, apocalypse-scaled collision of the comet Shoemaker-Levy 9 with Jupiter in 1994—were sufficient to convince the public of the dangers of space rocks. This is typically where the story ends. As far as most people are concerned, mass extinctions are what happen when big things fall out of the sky.

**But something funny happened** over the next 30 years as geologists fanned out across the globe to look for convincing evidence of impacts—such as layers of iridium, shocked quartz or giant craters—at the ominous rock boundaries that mark the four other major mass extinctions in Earth history. They didn't find any. And all but one of the so-called Big Five mass extinctions were *even more severe* than the catastrophe that wiped out the nonbird dinosaurs.

In fact, there even existed major impact structures, such as the Triassic-age 62-mile-wide Manicouagan Crater in Quebec (now a circular system of lakes amid a boreal paradise of blackflies) or the massive crater that created the Chesapeake Bay 36 million years ago, that did not seem to bother life much at all. Given the remarkable correlation of the Yucatán impact with the disappearance of the large dinosaurs (and much of the rest of life on Earth at the end of the Cretaceous period), this came as a surprise. Stranger still, the stunning finale of the age of dinosaurs was also accompanied not only by an envoy from outer space but by one of the largest volcanic events in the history of animal life: a swath of eruptions that drowned much of India *miles* deep in lava. While the consensus is that the asteroid did most of the damage, this was the same class of world-changing eruptions responsible not only for dozens of minor mass extinctions and climate misadventures throughout Earth history but several of the other major mass extinctions as well, including the worst ever at the end of the Permian 252 million years ago.

In the past few decades a subtler story about mass extinctions has emerged. Geologists are now armed with powerful techniques Hutton couldn't have dreamed of. Scattering to remote rock outcrops around the world or to archives of muck hoisted from the bottom of the ocean by drill ships, they wring secrets out of old seashells with mass spectrometers, and from age-battered hunks of granite with radioisotope geochronology, and from fossil and geochemical databases with neural networks underwritten by blistering processing power. And in this diffuse project to understand Earth history, geologists have in recent years revealed a roster of existential threats to life far more intimate than simply death from above. The most frequent mass killer of life on Earth, it turns out, is Earth itself. And the most reliable murder weapon is carbon dioxide.

One hundred and thirty-five million years before a mindless hunk of space garbage intercepted Earth's orbit and ruined a perfectly good dinosaur world, the planet was gripped by a mass extinction that was even worse. A world of bizarre crocodilians, giant amphibians, stony corals, a ubiquity of strange but venerable eel-like creatures, and 80 percent of the rest of complex life



EXPOSED SEAM in Colorado of the K-T boundary, which marks the mass extinction that ended the reign of the dinosaurs.

on Earth was destroyed. As the supercontinent Pangaea pulled apart at the seams, stretching like taffy, an open sore of oozing, incandescent rock erupted at the surface, covering three million square miles in lava in pulses over 600,000 years. While the eruptions would have caused all sorts of chaos, perhaps most important they injected thousands of gigatons of carbon dioxide into the atmosphere, and the oceans overdosed on this volcanic $CO_2$. The seawater acidified as a simple matter of chemistry, and the temperature of the planet soared as a simple matter of physics. This is what $CO_2$ does. Today the New Jersey Palisades across the Hudson River from New York City are the volcanic plumbing that remains from these titanic eruptions of the Triassic end times, old magma that is matched by the same volcanic rock, of the same age, as far afield as Morocco, Brazil, Nova Scotia and Spain.

Hundreds of millions of years earlier the two oldest major mass extinctions destroyed planets we wouldn't recognize, their continents misshapen and scattered about unfamiliar oceans. The oceans of these alien planets were patrolled by gigantic cephalopods and, later, even more gigantic fish, guillotine-mawed and fortified by helmets of bone. Our planet endlessly cycles carbon—the stuff of life—through rocks, air, water and life in a balance that keeps the climate habitable and ocean chemistry hospitable. But these archaic worlds saw this carbon cycle suddenly derailed—unraveled by $CO_2$-sucking episodes of tropical mountain building, accelerated rock weathering and the novel global geoengineering project of land plants. These kill mechanisms are somewhat more convoluted, and admittedly less dramatic, than an asteroid, but they did the trick. These bygone planets spun out of control, alternately freezing and broiling as Earth struggled to regain its composure and wrangle a global carbon cycle gone haywire.

But it was 252 million years ago, on the forsaken planet that opened this tour of ancient apocalypses—that sun-bleached world, with oceans almost absent of animals—when the story of life on Earth nearly came to its premature conclusion. This was Pangaea, a world before dinosaurs or mammals or flowers. But it was still a rich world, one with conifers and lithe, vaguely leonine predators and lumbering, warty, reptile prey. And then, it was over. It ended in a continent-scaled flood of glowing rock, brief volcanic winters issuing from the eruptions and a roster of billowing volcanic gases, many of which would be banned on a battlefield—such as chlorine gas and mercury.

As the magma incinerated underground seams of salt and gypsum, eruptions of halocarbons would have obliterated the ozone layer—and indeed, plant fossils bear the mutations wrought by this ancient atmospheric destruction. But it wasn't until the seams of magma feeding these eruptions hit huge deposits of natural gas, coal and carbon-rich rocks underground that the greatest mass extinction ever hit its appalling crescendo. Methane and carbon dioxide exploded out of the ground by the tens of thousands of gigatons. Temperatures spiked by almost 22 degrees Fahrenheit. And in the oceans, where spreading anoxia and acidification wiped out 96 percent of life, it was as hot as a jacuzzi. And then, in the fossil record, silence.

**At the start** of the industrial revolution, long slumbering forests of carbon were resurrected from the ancient Earth and pressed into service in the furnaces of modernity. We know that this artificial fire can't go on forever without immiserating our world. At 416 parts per million, carbon dioxide is already higher than it has been in millions of years and is perhaps rising even faster than in these greatest calamities of all time. Meanwhile centuries—millennia even—of hunting, land clearing and pollution have impoverished the natural world. By one estimate, at the rate at which we are currently driving species extinct, we could match the biological devastation of those towering mass extinctions of the ancient past within 300 to 12,000 years. This might sound like a long time frame, but from a geologic perspective, it is downright subliminal. More worryingly, there may yet exist unseen ecological cliff edges along the way, beyond which the biosphere does not simply suffer the onslaught of attrition but collapses suddenly in cascading failures. In other words, there may be tipping points—points of no return.

We know what we have to do to avoid being inducted into the wretched Pantheon of the worst things that have ever happened in Earth history. We must set aside swaths of the planet—in the form of marine protected areas, natural reserves and corridors for migration—to allow the living world to recover from the uppercut we have already delivered it. Then, we must simply stop digging up old life from deep in Earth's crust and lighting it on fire at the surface. As humanity leans on the very same levers pulled in the very worst things that have ever happened in history, we must consult the ages and listen to the counsel of broken worlds past. SA

**FROM OUR ARCHIVES**

The Mass Extinctions of the Late Mesozoic. Dale A. Russell; January 1982.

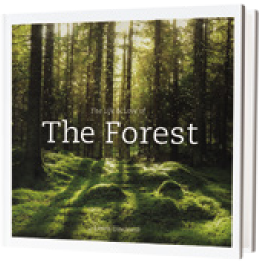
scientificamerican.com/magazine/sa

JULIE MOWBRAY *Alamy*

*By Andrea Gawrylewski*

# The Life & Love of the Forest

by Lewis Blackwell. Abrams, 2020 ($50)

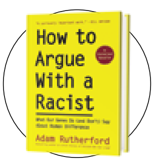



AUTUMN TREES in the forest of Bøkeskogen in Larvik, Norway

**For those who have spent months indoors** during the pandemic, walks in the woods have been a rare source of relief. This artful book is a captivating tribute to all forests that, even if we can't travel to them, soothe the mind. Author Blackwell goes well beyond the standard coffee-table book fare and explores the value of forests as ecosystems, the products that they provide, and their symbolic role in pop culture and human emotional well-being. The collection of images from global photographers captures the many moods of the woods, from fragile stillness to riotous color and lively habitat. Forests are the engines of our livable environment, Blackwell writes, and we must fight to protect and rebuild them.

## How to Argue with a Racist: What Our Genes Do (and Don't) Say about Human Difference

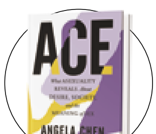
by Adam Rutherford. The Experiment, 2020 ($21.95)




**Racists often cite** pseudoscientific arguments for their bigotry. But when properly understood, biology is antiracist, geneticist Rutherford shows. His timely crash course on the science of human variety focuses in turn on skin color, genealogy, athleticism and intelligence. From the physiological factors that influence sprinting ability to the surprisingly interconnected family tree of humanity, research reveals that our differences depend on environmental factors and genetic quirks of local communities, not a biological notion of race. Rutherford equips readers with the tools to discredit the prejudices of both racists and well-intentioned people. Despite its fraught history, scientists' understanding of genes has long since converged on one truth: race, while very real as a social construct, has no foundation in science. *—Scott Hershberger*

## Ace: What Asexuality Reveals about Desire, Society, and the Meaning of Sex

by Angela Chen. Beacon Press, 2020 ($26.95)




**Asexual people** have always existed, but they have long gone unacknowledged. Even Alfred Kinsey, when developing his scale for sexual orientation, called asexual people Group X and excluded them from the spectrum. Journalist Chen interviewed nearly 100 asexual people—or "aces"—to fill in this historical gap and present various aspects of the asexual experience in scientific and cultural context. For example, Chen points to how the definition of hypoactive sexual desire disorder in the *Diagnostic and Statistical Manual of Mental Disorders* (*DSM-5*), the American Psychiatric Association's current compendium of psychological conditions, reinforces the idea that low sexual desire is something that needs to be cured. Although asexuality is often described as a lack of sexual attraction, Chen argues that "we must consider that negative space can be more than an absent image." *—Karen Kwon*

## Crime Dot Com: From Viruses to Vote Rigging, How Hacking Went Global

by Geoff White. Reaktion Books, 2020 ($27.50)


**Journalist** White uses the stories of different hacks, dating from the 1980s to the 2016 election, to connect illicit activity on the earliest Internet forums to today's cyberattacks by hacktivists and state-sanctioned hacking teams. He humanizes this history by highlighting the people behind the tech: the Filipino student who unleashed the Love Bug, one of the first global cyberattacks to rely on psychological manipulation; the former cybercriminal who worked with the FBI to bring down Silk Road, a dark Web black market for illegal drugs (a scheme that involved him faking his own death); and the audio producer who lost thousands of dollars in a scam that exploited personal information stolen from telecommunications company TalkTalk. To secure, or "harden," systems against cybercrime, White writes, "it's humans, not necessarily computers, that we need to harden up." *—Sophie Bushwick*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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).

# Tainted Money Taints Research

## How sex offender Jeffrey Epstein bought influence at Harvard University

*By Naomi Oreskes*

**This past May, Harvard University** (where I teach) issued a report on its relationship with the convicted sex offender Jeffrey Epstein. It was an admirably forthright mea culpa highlighting three areas of concern. The first was the contradiction of addressing sexual assault and harassment on campus while accepting money from a man who had promoted sexual abuse of minors. The second was the mockery made of academic standards when, after donating $200,000 to the psychology department, Epstein was appointed as a visiting fellow there despite a complete lack of appropriate academic qualifications. The third was his close connection to Harvard's Program for Evolutionary Dynamics (PED). Even after his release from prison, Epstein continued to be a frequent visitor: between 2010 and 2018 Epstein (at that point a registered sex offender) went to the PED offices more than 40 times. During that period he had an on-campus office and a key card and pass code with which he could enter buildings during off-hours.

It is not just that an awful person was able to buy a halo of respectability. The Epstein affair brings to light a much larger problem: it undermines the integrity of the research enterprise when individuals can pick and choose lines of inquiry that appeal to them simply because they can pay for them.

Academic life is tough in part because researchers with good ideas have to compete for funding. When peer review operates properly, it identifies the best ideas to support, usually by using panels—not individuals—to see to it that a range of views is represented. The process is imperfect, but women, people of color, young scholars, investigators at nonelite universities and individuals promoting ideas that challenge conventional wisdom at least have a chance. But more than two thirds of Epstein's donations—$6.5 million—went to PED director Martin Nowak. Epstein encouraged others to give another $2 million to geneticist George Church. Both were already extremely well established and well funded; Epstein was helping the flush get flusher. (Church notes that Epstein's funding supported not just him but also his large and diverse team; Nowak did not reply to a request for comment.)

What made it even worse was that Epstein was a latter-day eugenicist whose interests were tied to a delusional notion of seeding the human race with his own DNA. Given this stance, it is particularly disturbing that he focused his largesse on research on the genetic basis of human behavior. Human genetics is an ethically sensitive and intellectually contested domain where it behooves us to ensure that the highest standards of scientific rigor are in place and that nongenetic explanations for behavior are given a fair chance to compete.

Scientists might claim that Epstein's money in no way caused them to lower their standards, but we have broad evidence that the interests of funders often influence the work done. The *New York Times* concluded that in this case it led researchers "to give credence to some of Mr. Epstein's half-baked scientific musings." True or not, it should trouble us that a corrupt man was making decisions affecting research at a major U.S. university. He had no academic competence—yet he effectively made choices about which research initiatives were interesting and promising.

Moreover, when Epstein got into trouble, several faculty members defended him and even visited him in jail. When Epstein's lawyer, Harvard professor Alan Dershowitz, needed help to argue (on semantic grounds) that Epstein was not guilty as charged, he reached out to Harvard psychologist and linguist Steven Pinker. Pinker (who never took funds from Epstein) says he did not know to what use his advice was being put and aided Dershowitz only as "a favor to a friend and colleague." But that is precisely the point: Epstein had purchased friends in high places, and those friends had friends who helped him, even if inadvertently.

These matters have come to light because Epstein was a criminal, but Harvard is not alone in accepting tainted money. Universities need to develop policies to ensure that research funding is based on merit, not cronyism, and researchers who are seeking public trust must be able to show that their own ethical compasses are not deflected by the magnetism of money. SA

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*Illustration by Jay Bendt*

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


# Home Un-Alone

## What you live in can shape how you live

*By Steve Mirsky*

**When COVID-19 hit** the U.S., most of us became homebodies. Journalist Emily Anthes was thus propitious in the timing of her new book, *The Great Indoors: The Surprising Science of How Buildings Shape Our Behavior, Health, and Happiness* (Scientific American/Farrar, Straus and Giroux). You may distract yourself from cabin fever by learning about the cabin.

Actually, the work covers a wide variety of indoor situations. One chapter looks at architectural design that encourages exercise. For example, apartment building planners stumbled on this shocking strategy: to get people to use the stairs more, make the stairwells wider and well lit. You know, nicer to use.

Another entry analyzes ways to contend with flooding, namely, throw in the towel: build homes with "buoyancy blocks" that absorb $H_2O$. The blocks then—get this—expand and lift the house. Just be careful walking out the front door.

Other parts of the book deal with prisons, hospitals, offices, smart homes, housing for neurodiverse people, and even living spaces in space. For instance, the Russian part of the International Space Station has a greenhouse for testing off-planet agronomy. Gardening in orbit seems to be a mood enhancer and could lead to asteroid belt borscht.

All fascinating stuff, but it was the material in the chapter "The Indoor Jungle" about dwellings, the walls of which we've been staring at for months, that really grabbed me by the throat. Or maybe the armpit. A study found that homes with more women than men had a lot of *Lactobacillus* bacteria, "a major component of the vaginal microbiome." The same study revealed that where men were in the majority, homes had bacteria that thrive in the gut, on the skin and in armpits. I just felt a great disturbance in the force, as if thousands of readers suddenly cried out in terror and ran to open up a window.

Living indoors inevitably means sharing our habitats with such human-associated microbial communities. Anthes mentions a 2016 study in the Amazon basin that sampled homes in communities ranging from a remote village to Manaus, with a population of more than two million. The open-air thatched huts of the village contained mostly bacteria found on and in soil, water and insects. Bacteria in the city residences were mostly those found on, and in, us.

In a footnote, Anthes also notes that wild animals, notorious for their lack of constructed walls and ceilings, leave barely a trace of themselves in their homes, microscopically speaking. She quotes North Carolina State University ecologist Rob Dunn, who took part in the surveys already mentioned and who also studied what you would expect to be a particularly ripe *objet d'ooh ooh ah ah:* "Chimp nests are all environmental microbes. You can't tell a chimp has ever been there." Well, not by the bacteria, anyway.

Anthes rounds up a lot of research demonstrating that the right home microbe mix can promote health. For example, kids who grow up on farms or with dogs have some protection against asthma, probably because the animals' microbes train the young immune systems. Homes without such microbes leave us less prepared for the challenges that arise when a tiny troublemaker does find our warm, moist bodies.

Big bacterial differences exist even among farming communities. A 2016 *New England Journal of Medicine* study found that the Hutterites, who use modern agricultural methods, have more than four times the childhood asthma rates of the Amish, who still plow with horses. Amish kids have more infection-fighting white blood cells than do young Hutterites, whereas the latter group outpaced the former in cells involved with allergic reactions. The root cause can be found all over the root cellar: the dust in Amish homes contained more bacterial molecules than did the Hutterites'.

Anthes includes a prescription for a healthful home microbiome: "Keep things dry. Forgo cleansers, textiles, and materials that contain added antimicrobials. Open a window. Get a dog. (Or, if you can swing it, a cow.)" That's no bum steer. SA

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*Illustration by Matt Collins*

# 50, 100 & 150 YEARS AGO

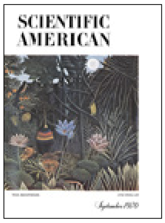
INNOVATION AND DISCOVERY AS CHRONICLED IN *SCIENTIFIC AMERICAN*

*Compiled by Dan Schlenoff*

SEPTEMBER

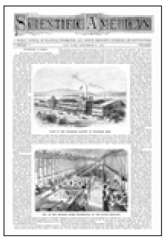
## 1970 Pacific Junction

"A four-week Pacific cruise this spring by the U.S. Navy research vessel *DeSteiguer* has produced further evidence that the earth's crust consists of discrete drifting plates. The voyage provides an example of theory successfully predicting fact: if three oceanic plates should drift apart, a wedge-shaped area would appear on the seafloor with its apex at the triple juncture. The McKenzie-Morgan hypothesis was published jointly in 1968; it led one of W. Jason Morgan's Princeton colleagues, Kenneth S. Deffeyes, to calculate the size and shape of the triple-juncture wedge to be expected in the Galápagos area. Deffeyes then led the *DeSteiguer* expedition and collected the data that proved the correctness of the hypothesis."



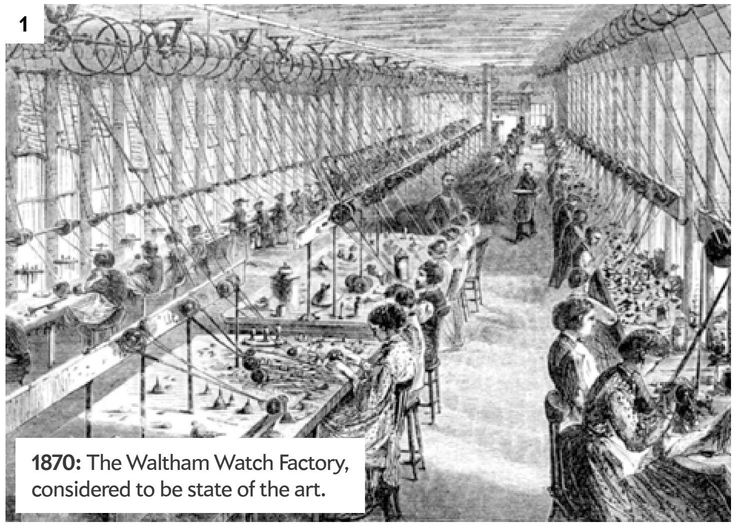
1970

1920


1870

## 1920 Malaria Control

"Among the unusual control methods adopted in the prevention of the hatching of mosquito larvae is the spraying of streams with kerosene or a heavy black oil, classified by dealers as a grade immediately below fuel oil. The application is made with knapsack pump sprayers or by means of automatic drip cans. Of course, the expensiveness of the oil is a factor to reckon with, but one small Southern lumbering town made effective its control operations at a per capita cost of $1.23. Moreover, the visits of the physicians for the purpose of treating malaria were reduced 70 percent compared with the previous year."


1

**1870:** The Waltham Watch Factory, considered to be state of the art.

## 1870 Modern Timepieces

"In the Waltham Watch Factory, simple hand machines, with which a few of the parts of the watch had been produced, were here brought together, and hundreds of new ones, at many hundreds of thousands of dollars' cost, were created, and all interwoven, as it were, into one vast mechanical organism. A single steam engine distributes its power by means of driving shafts through a whole colony of similar working rooms, and the result is the production of watches at the rate of one every three minutes, and with a uniformity and perfection which have at once and forever antiquated all previous methods of their production."

## Inventive Talent

"In our practice as patent solicitors we have frequently been called upon to prepare applications for female inventors; and we can say to those who are unbelievers in regard to the power of women to achieve, as a class, anything higher than a pound-cake or a piece of embroidery, that the inventions made by women, and for which they solicit patents through our agency, are generally found to be in their practical character, and in their adaptation and selection of means to effect a definite purpose, fully equal to the inventions made by men."

*SCIENTIFIC AMERICAN*, VOL. XXIII, NO. 11; SEPTEMBER 10, 1870 (1); *SCIENTIFIC AMERICAN*, VOL. 247, NO. 3; SEPTEMBER 1982 (2)

EPIC TALES

CELEBRATING 175 YEARS

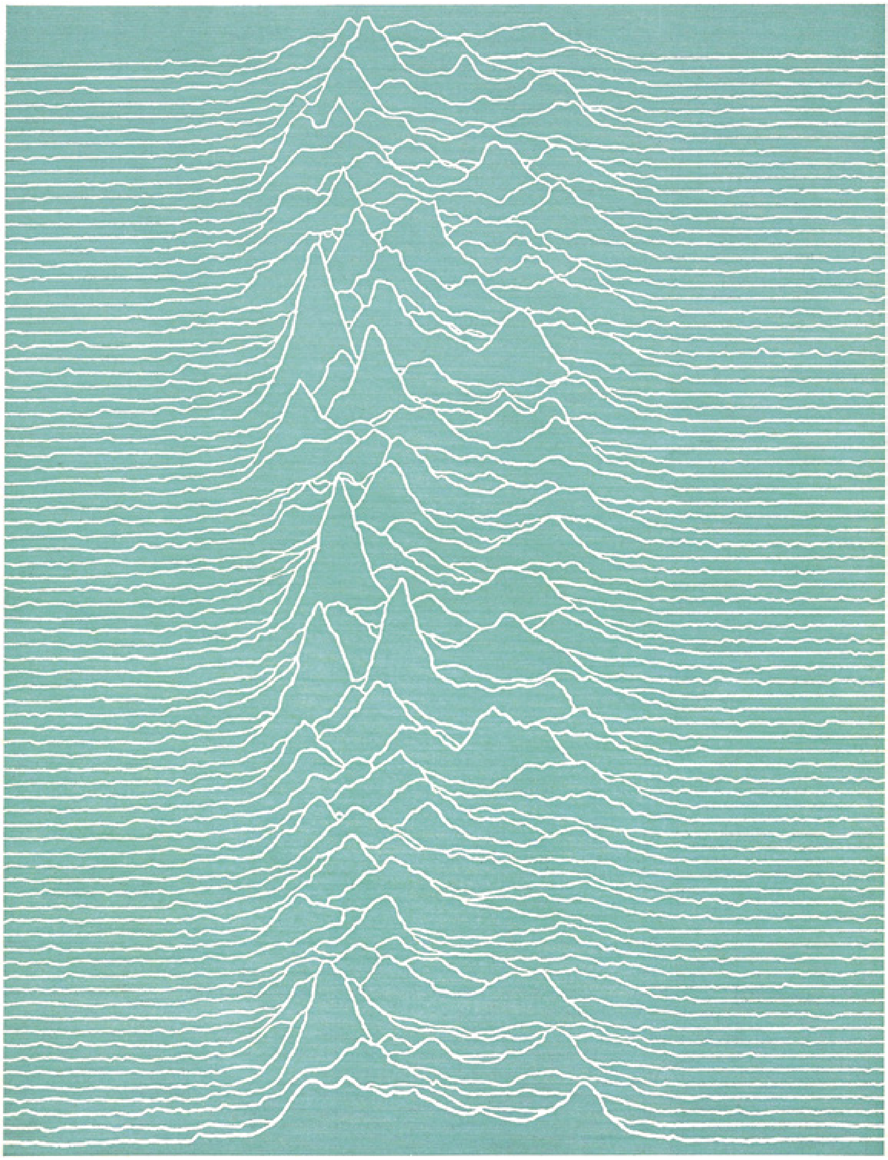
## How We Make Things

Humans, for a long time, have been planning for future needs by making things. The industrial revolution, starting in about 1760, replaced traditional energy sources with the power of steam. From the founding of this magazine in 1845 and for the next century, the efforts of physics and chemistry—with help from the new management sciences—created more and better machines and energy sources, increased the amount of goods made and the appetite for raw materials. Electronic computers appeared in the 1940s and by the 1980s were coming into widespread use for guiding machines. Perhaps someday we will harness the power of nature and use chemical bonds and biological materials to do our labor for us. —*D.S.*

2

**1982:** By the time this September issue was published, computers, which emerged in the 1940s, were common in most workplaces.

*Text by Jen Christiansen, Graphic by Harold D. Craft, Jr.*

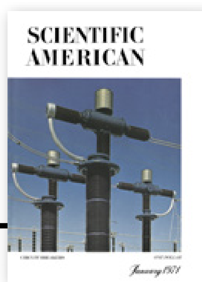


# Pulsar as Pop Icon

## A classic data visualization brought an astronomical curiosity to music lovers

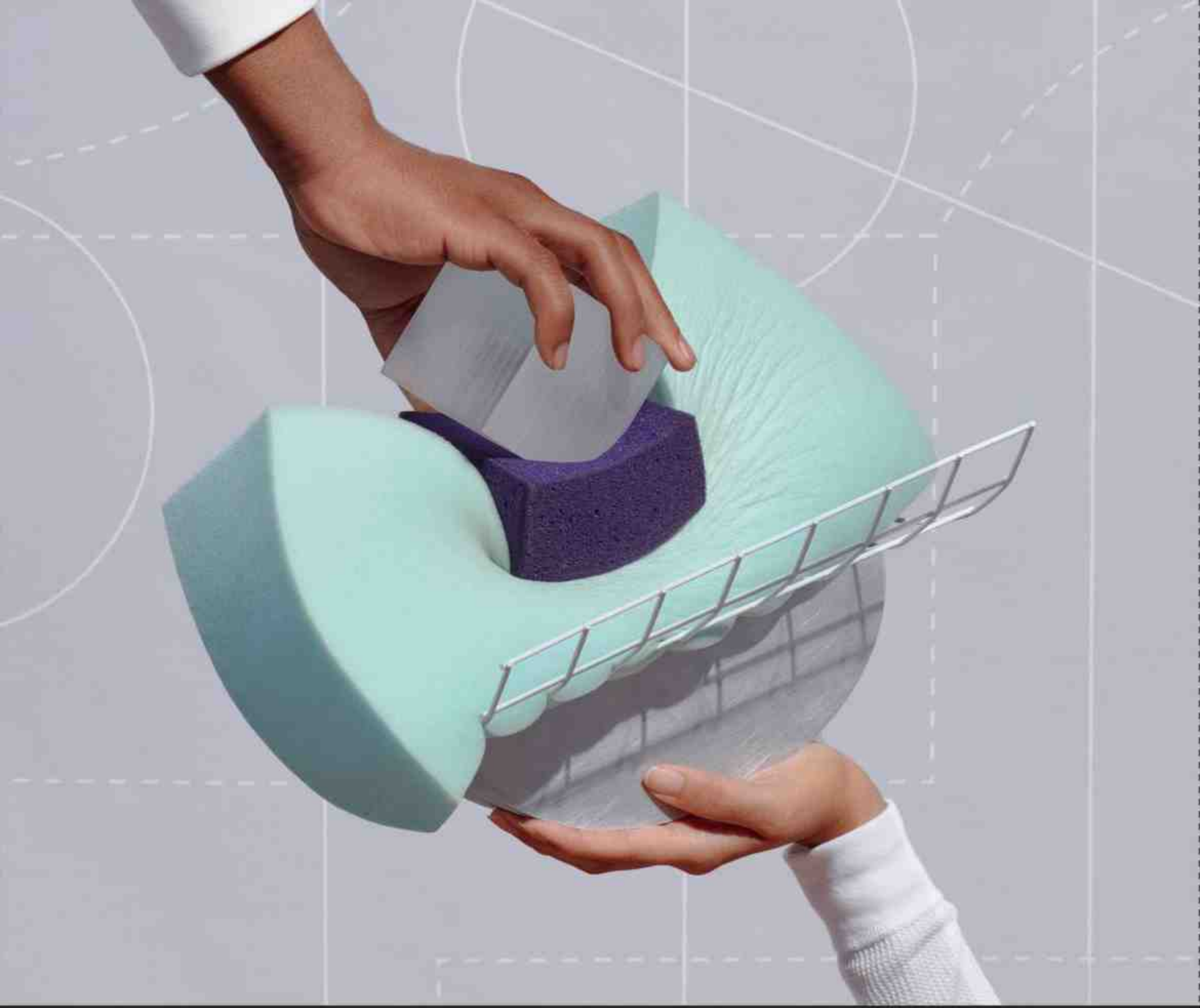
**Fifty years ago this month** Harold D. Craft, Jr., published a remarkable black-on-white plot in his Ph.D. dissertation at Cornell University. A stacked series of jagged lines displayed incoming radio waves from pulsar CP1919, as detected at Arecibo Observatory in Puerto Rico. Several months later the chart appeared as a full-page visualization in *Scientific American,* this time with white lines on a field of cyan.

A pulsar is a rapidly rotating neutron star that emits a radio-frequency beam that sweeps through space like a lighthouse beacon. In the graphic, 80 consecutive pulses—recorded at a frequency of 318 megahertz—are stacked. One pulse (*shown from left to right*) lasts about 0.04 second, with peak intensity near the center. Pulses occur every 1.337 seconds.




In 1979 the chart took a big step into public consciousness. Designer Peter Saville featured a white-on-black version as cover art for the English rock band Joy Division's *Unknown Pleasures* album, with no band name, album title or other identifiers—a bold move. On *Scientific American*'s 175th anniversary we honor Craft's work and a data visualization that made the leap from student research to pop culture icon. SA

SOURCE: "THE NATURE OF PULSARS," BY JEREMIAH P. OSTRIKER, IN *SCIENTIFIC AMERICAN*, VOL. 224; NO. 1; JANUARY 1971, MODIFIED FROM "RADIO OBSERVATIONS OF THE PULSE PROFILES AND DISPERSION MEASURES OF TWELVE PULSARS," BY HAROLD D. CRAFT, JR.; SEPTEMBER 1970




## THE MILGAUSS

Introduced in 1956, and tested at CERN where it was exposed to the strong magnetic forces created by their experiments, the Milgauss is capable of resisting interference up to 1,000 gauss, far exceeding any conditions encountered on Earth. Today, the Milgauss's lightning bolt seconds hand and unique green sapphire crystal remain symbols of innovation and ingenuity in the scientific community.

*#Perpetual*

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