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SCIENTIFIC AMERICAN

THE NEUTRINO PUZZLE

Could the largest ever probe of these particles lead to a new frontier in physics?

PLUS

SATURN UP CLOSE
Cassini's pathbreaking run PAGE 78

HOW THE PET TRADE HURTS WILDLIFE
It could be worse than habitat loss PAGE 40

GUNS AND VIOLENCE
What the data say vs. what people believe PAGE 54

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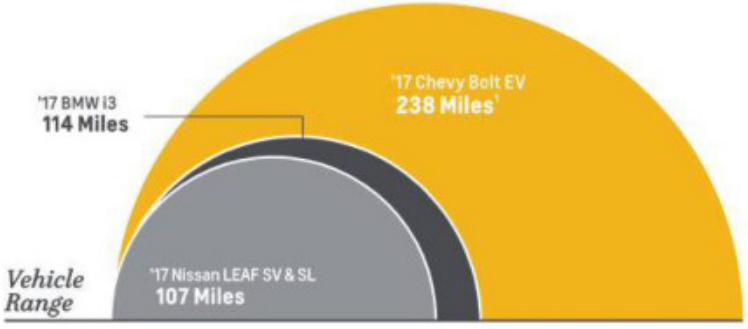

MORE DESIGN.

The all-electric Bolt EV offers a roomy interior and a range of technologies to help you along your journey. Its smart interior design features seating for five and up to 56.6 cubic feet[5] of cargo space. Bolt EV offers built-in 4G LTE Wi-Fi[86] that connects up to seven devices. It also offers Apple CarPlay™[7] and Android Auto™[8] compatibility, letting you easily connect to your phone to play music, get directions and more.

MORE RECOGNITION.

Bolt EV has been bringing home some pretty impressive industry awards lately. Its complete package of range, great technology and design earned it 2017 *Motor Trend* Car of the Year.® It turned heads by winning 2017 Green Car of the Year from *Green Car Journal*.[9] And Bolt EV was named 2017 North American Car of the Year™ at the North American International Auto Show. It goes to show when you make a great electric vehicle, people take notice.

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SCIENTIFIC AMERICAN

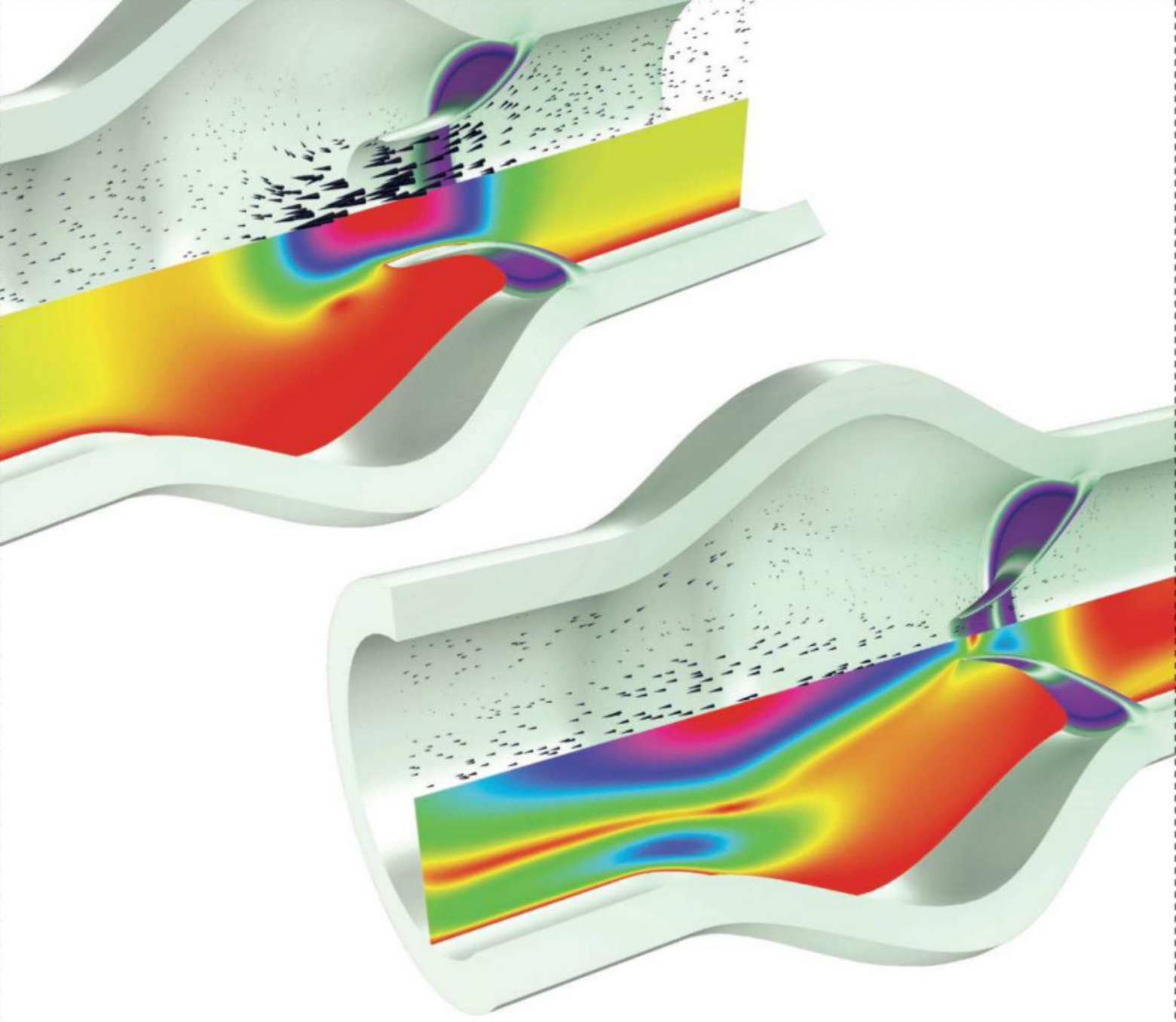
OCTOBER 2017

VOLUME 317, NUMBER 4

Photograph by Ben Rollins

ON THE COVER

Tiny particles called neutrinos fly through matter all the time. An ambitious experiment due to start in the U.S. in the 2020s aims to stop them in their tracks. The goal is to solve some long-standing mysteries, such as why neutrinos have mass when theory says that they should be massless.
Image by Mark Ross Studios.



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ON THE WEB

Mediterranean Migrant Mystery
An Italian forensic scientist is trying to identify the badly decomposed remains of 700 migrants drowned in the Mediterranean Sea.
Go to www.ScientificAmerican.com/oct2017/forensics

Scientific American (ISSN 0036-8733), Volume 317, Number 4, October 2017, published monthly by Scientific American, a division of Nature America, Inc., 1 New York Plaza, Suite 4500, New York, N.Y. 10004-1562. Periodicals postage paid at New York, N.Y., and at additional mailing offices. Canada Post International Publications Mail (Canadian Distribution) Sales Agreement No. 40012504. Canadian BN No. 127387652RT; TVQ1218059275 TQ0001. Publication Mail Agreement #40012504. Return undeliverable mail to Scientific American, P.O. Box 819, Stn Main, Markham, ON L3P 8A2. **Individual Subscription rates:** 1 year $49.99 (USD), Canada $59.99 (USD), International $69.99 (USD). **Institutional Subscription rates:** Schools and Public Libraries: 1 year $84 (USD), Canada $89 (USD), International $96 (USD). Businesses and Colleges/Universities: 1 year $399 (USD), Canada $405 (USD), International $411 (USD). Postmaster: Send address changes to Scientific American, Box 3187, Harlan, Iowa 51537. **Reprints available:** write Reprint Department, Scientific American, 1 New York Plaza, Suite 4500, New York, N.Y. 10004-1562; fax: 646-563-7138; reprints@SciAm.com. **Subscription inquiries: U.S. and Canada (800) 333-1199; other (515) 248-7684. Send e-mail to scacustserv@cdsfulfillment.com.** Printed in U.S.A.

Mariette DiChristina is editor in chief of *Scientific American*. Follow her on Twitter @mdichristina

What the World Needs Now

Whether they are advancing discovery or being applied to help address societal problems, the process and products of research offer tremendous human benefits. Maybe that is why I struggle to understand how the rise of populism, with the root of "popular," coincides with a seeming increase in antiscience sentiments. Changes in U.S. leadership after the 2016 election have brought budget cuts and even the outright redacting of scientific information related to topics such as climate change. The British exit, or "Brexit," from the European Union is similarly impinging on the work of scientists. Meanwhile China is strongly supporting clean energy, quantum satellites and genomics as an engine of economic growth and political strength. What are we to make of these changes, just when it seems the world needs science most?

Our annual special report on the "State of the World's Science," starting on page 64, provides an essential analysis. One key for science, I expect, is how we all talk about it. It's been troubling me for some time that I myself always, in my Pollyanna way, greet new developments with hope and excitement—whereas others may worry about the possibility of job losses or, as in the case of genetics research, may feel moral qualms. As journalist Brooke Borel writes in "Message Control," "researchers must be willing not only to hear the public's confusion and pushback but also to adapt."

This issue is a veritable feast of what science can do for us if we are willing to engage with it. Let me list the ways. Do guns really keep us safe? "Journey to Gunland," by journalist Melinda Wenner Moyer (*page 54*), compiles the evidence. Is the wild pet trade good for conservation? (Spoiler alert: no.) See "Loved to Death," by journalist Richard Conniff (*page 40*). How did surgery shift from the "butchering art" to modern healing? Medical historian Lindsey Fitzharris explains in "Dangerous Medicine" (*page 74*).

On the "awe and wonder" front, delights await. Planetary scientist Carolyn Porco provides a fantastic survey of what we have learned from the famous exploration mission in "Cassini at Saturn," starting on page 78. In our cover story, "The Neutrino Puzzle," beginning on page 32, senior editor Clara Moskowitz ventures underground, to a cave at the Fermi National Accelerator Laboratory outside Chicago, where "trillions of neutrinos are flying through every inch of my body each second." Most zip through the empty spaces within all matter on our planet, unimpeded. In Illinois, and at another detector 800 kilometers away in Minnesota, on occasion a neutrino collides with an earthbound atom, creating a tiny flash that is nonetheless visible to scientists. Not only are we made of "starstuff," as Carl Sagan put it, we also temporarily host bits of the universe within. SA

Illustration by Nick Higgins

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BY PRIVATE JET

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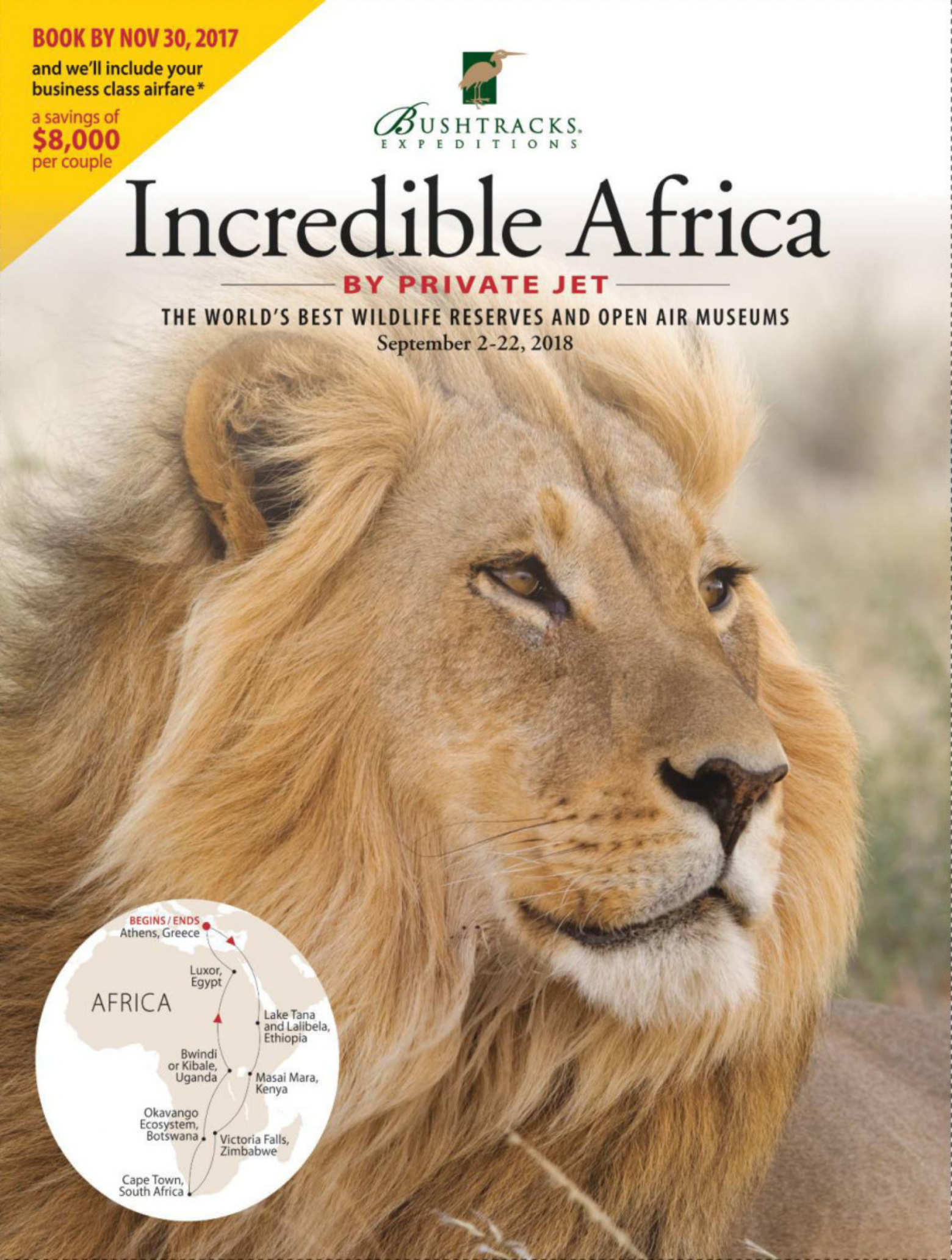

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Learn as You Explore

To understand Africa requires drawing on many perspectives – archaeology, biology, linguistics, botany, political science, history, and conservation among others. That's why Bushtracks has assembled a diverse team of experts from eight countries that are as passionate about their subject matter as they are eager to share it with travelers. Collectively, their insights form the backbone of a travel story that begins in Ethiopia at the source of the Blue Nile, sweeps south through savannas, waterfalls, vineyards, and montane forests, and then circles back to the Nile once more to the tombs of the Egyptian pharaohs. **Here are just a few of the experts you'll meet:**

Dr. Gladys Kalema-Zikusoka
Uganda

Veterinarian and social entrepreneur Gladys Kalema-Zikusoka is one of Africa's leading scientists working to protect endangered mountain gorillas from human diseases. She founded an NGO, Conservation Through Public Health, she launched a coffee brand to save gorillas, and she is the subject of the BBC documentary, *Gladys the African Vet*.

DINE WITH DR. KALEMA-ZIKUSOKA
Prior to your gorilla trekking experience, learn about the critical role public health plays in sustainable gorilla populations

Senator David Coltart
Zimbabwe

Senator Coltart is one of the most prominent political and human rights figures in Zimbabwe. A human rights lawyer, he has served three terms in Parliament, ending in the Senate. With a career in opposition to Robert Mugabe's government, Senator Coltart offers a firsthand view of Zimbabwe's political, social and economic struggles over three turbulent decades.

RIDE A CLASSIC STEAM TRAIN WITH SENATOR COLTART
Gain a greater appreciation of Southern Africa's past and present from a lifelong social activist

Chris Fallows
South Africa

Wildlife photographer Chris Fallows specializes in marine predators. He has been featured in more than 50 international documentaries, and hosted Discovery Channel's Shark Week series *Air Jaws*. Chris spends 200 days at sea each year operating Apex Shark Expeditions with his wife Monique and brings unparalleled insight into shark behaviors and habitat.

TAKE A MARINE SAFARI WITH CHRIS FALLOWS
View penguins, cetaceans, sharks, and the diverse marine ecosystem of False Bay, South Africa

Julius Ole Karia
Kenya

Maasai pastoralist, naturalist guide and conservationist Julius Ole Karia hails from Aitong in the northern Masai Mara. An engaging storyteller, Mr. Ole Karia will accompany the group on optional walking excursions identifying birds, insects, and beneficial plants. In this natural setting Mr. Ole Karia will share personal insights about the Maasai warrior culture and living among wildlife.

WALK IN THE MARA WITH JULIUS OLE KARIA
Learn about beneficial plants and their traditional uses in the daily lives of Kenya's Maasai pastoralists

June 2017

"I wonder why so much attention is spent trying to mimic the human brain. We make hundreds of thousands of brains every day; they are called babies."

BARRY MALETZKY *VIA E-MAIL*

LEARNING CODE

I appreciate "Making AI More Human," Alison Gopnik's article about the two ways that artificial intelligence is being configured to approach learning. In top-down methods, such as Bayesian models, abstract concepts are used to create a hypothesis and predict which patterns of data should be seen if it is true. Meanwhile in bottom-up methods, such as "deep learning," abstract concepts are derived by looking for patterns in concrete data.

Whereas the top-down approach makes lots of sense because that's how we learn most things in school, the bottom-up one remains quite mysterious, as mysterious as how a child learns his or her mother tongue. So a machine is shown thousands of pictures of, say, the letter A, and through brute repetition it starts to know that when the pixels are arranged just so, that's an A. But what is going on inside the machine? Is it postulating a series of guesses and thus creating its own rules? And if that is the case, then what logical tools does it have available to create and test the guesses?

JAMES LOEWEN *Oakland, Calif.*

Assumptions about fabricating an artificial brain ignore what little we know about how the human brain thinks, feels and acts, and we cannot view it as a slower version of a computer. The brain is a soft, squishy organ, which has evolved over millions of years, and its synaptic connections are not electronic but electrochemical (hence our sluggish ability to solve equations, compared with a computer's speed).

Scientists working on AI are aware of this disparity and are trying to build ever more humanlike central nervous systems, such as computers that "learn" through trial and error. But these machines can only duplicate certain brainlike functions.

I wonder why so much attention (and consequent funding) is spent trying to mimic the human brain instead of, for example, researching practical medical advances. We make hundreds of thousands of brains every day; they are called babies.

BARRY MALETZKY *via e-mail*

BUBBLE TROUBLE

In "The Quantum Multiverse," Yasunori Nomura discusses the classic idea of a multiverse in which cosmic inflation led to an infinite number of "bubble universes" and an alternative theory in which such universes do not coexist in real space but rather are potential outcomes of observations, or "probability space."

Nomura notes that we might be able to observe "a remnant from a 'collision' of bubble universes in the sky." Is it therefore implicit that our "bubble" could collide at any time with another one? And if so, would our bubble (and our existence) simply "burst" without any advance warning?

E. DENNIS KELL *Mays Landing, N.J.*

Nomura states that superdistant galaxies are moving away from Earth faster than the speed of light and therefore cannot be observed, a limit called the cosmological horizon. Yet Albert Einstein put a speed limit on everything in the universe: the speed of light. Thus, the theory of relativity would be violated if anything receded from Earth faster than that speed.

BRUCE BARNBAUM *Granite Falls, Wash.*

NOMURA REPLIES: Regarding Kell's question: Because of the eternally inflating nature of the space in which our bubble resides, the probability of our universe colliding with other universes is almost certain. It is very unlikely, however, that our bubble would "burst"—the effect would be diluted by the many things that have occurred within our universe. In fact, the dilution is expected to be so strong that the possibility of finding even faint evidence of a bubble collision is (unfortunately) low.

In response to Barnbaum: There is no contradiction here. If we define the velocity as the change of the physical distance divided by time, then distant objects do recede from us faster than the speed of light, but this is only because space is expanding. The objects are not actually propagating faster than light.

COSMOS CONSENSUS?

Nomura describes the concept of a multiverse as arising from the theory of inflation. But in the February issue ["Pop Goes the Universe"], Anna Ijjas, Paul J. Steinhardt (one of the originators of the theory) and Abraham Loeb described themselves as now questioning the inflation idea.

I realize that there are many opinions and competing theories at the fringe of our knowledge about the cosmos and our existence, but you could at least reference this conflict and give readers some context for this latest venture into the unknown. If inflation is passé among those at the forefront of the quest for understanding the nature of our ultimate environment, then does it not follow that theories built on that idea are equally suspect?

J. A. SCLATER *Aldergrove, British Columbia*

THE EDITORS REPLY: Ijjas, Steinhardt and Loeb did raise objections to the theory of inflation, but as the authors pointed out in their February article, their view is a minority opinion. In our July issue, we printed a letter responding to that article that was co-signed by 33 scientists who support inflation, including Nomura. Although the ultimate verdict on inflation is

still out, we believe both articles represent important and legitimate scientific viewpoints, so we invited the authors to present their ideas to readers directly.

ALTERNATIVE ARCHAEOLOGY

In "Romance of the Vanished Past" [Skeptic], Michael Shermer argues against my book *Magicians of the Gods,* which describes the possibility of a forgotten episode of civilization in prehistory. Shermer's article is a shallow and tendentious treatment of a complex subject that does not take proper account of rebuttals to critical attacks on the Younger Dryas impact hypothesis, in which a comet strike more than 12,000 years ago caused the megafaunal extinction in North America, and misrepresents the state of the argument around my theory that this event wiped out an advanced human society as well.

Please inform your readers that in May, Shermer held a live online debate with me on the *Joe Rogan Experience,* Episode 961, that covered these subjects in much greater depth and afforded me the possibility of presenting a proper rebuttal. It is available at http://bit.ly/2rr6ivF

GRAHAM HANCOCK *via e-mail*

SHERMER REPLIES: If I had to distill the hours of my debate with Hancock into one central point, it would be the importance of philosopher Karl Popper's idea of falsifiability in science: that scientific theories make predictions that observations can prove to be incorrect. What would it take to falsify Hancock's theory?

Further, outsider scientists in general, and alternative archaeologists such as Hancock in particular, can and do make important contributions but only if their paradigm-challenging ideas not only explain why an accepted theory is wrong but also why the evidence better fits their theory. In my opinion, Hancock's idea is based entirely on negative evidence—what he thinks is wrong with the accepted archaeological timeline—and he offers no positive evidence of this purported lost civilization: no metal, no writing, no tools and not even pottery.

CLARIFICATION

"Lost at Sea," by Danielle L. Dixson, refers to $GABA_A$ as a neurotransmitter. Technically, it is a neurotransmitter receptor.

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Put Science Back in Congress

A group of objective expert advisers should counsel the Senate and House science committees

By the Editors

The White House and Congress have lost their way when it comes to science. Notions unsupported by evidence are informing decisions about environmental policy and other areas of national interest, including public health, food safety, mental health and biomedical research. The president has not asked for much advice from his Office of Science and Technology Policy, evidently.

The congressional committees that craft legislation on these matters do not even have formal designated science advisers. That's a big problem. Take the House Committee on Science, Space, and Technology. Its leader, Republican Representative Lamar Smith of Texas, clearly misunderstands the scientific process, which includes assessment by independent peer reviewers prior to publication. The result has been a nakedly antiscience agenda. The committee has packed its hearings with industry members as witnesses instead of independent researchers. Democratic members have felt compelled to hold alternative hearings because they feel Smith has not allowed the real experts to speak. Smith's misinformed leadership has made it clear that congressional science committees need to be guided by genuinely objective experts.

So far this year, Smith and fellow committee member Representative Frank Lucas of Oklahoma have each introduced bills that would seriously weaken the Environmental Protection Agency. Lucas's bill would help stack the EPA's Science Advisory Board with industry representatives and supporters. Smith's—the Honest and Open New EPA Science Treatment (HONEST) Act—would make it harder for the EPA to create rules based on good research. As Rush Holt, CEO of the American Association for the Advancement of Science, a former representative and a nuclear physicist, said of an earlier version of the bill, this sort of legislation is nothing less than an attempt to "fundamentally substitut[e] a [political] process for the scientific process."

This is lunacy. We should not allow elected officials—especially the heads of congressional science committees—to interfere with the scientific process, bully researchers or deny facts that fit poorly with their political beliefs. Instead of seeing science as a threat, officials should recognize it as an invaluable tool for improving legislation.

To educate members about the best available research, both the House and Senate science committees should create independent groups of impartial researchers and policy specialists to advise them on science and technology issues, including those related to energy, genetically modified foods, and clean air and water. (Industry representatives would still have a voice, but they would counsel the committees separately.) The advisers could provide counsel without advocating specific courses of action. The scientific community—perhaps the heads of the National Academy of Sciences—could select the advisers, who would serve limited terms. Policy makers would still make the decisions, but with help from experts, those decisions would at least be based on facts.

Congress used to have a body of this kind—the widely respected Office of Technology Assessment (OTA). The OTA was an office of Congress: it served members and committees, and a bipartisan board of senators and representatives oversaw it. Until 1995, the OTA created reports on scientific issues ranging from alternative fuels to cancer and presented Congress with options it could pursue to reach different goals. Then the Republican-controlled Congress axed its funding during budget cuts. Many have advocated for the OTA's return, including *Scientific American*. Last year Representative Bill Foster of Illinois introduced a resolution calling for its revival.

Whether it comes from a resurrected OTA, a new, dedicated advisory panel or some other body, independent, evidence-based advice on scientific matters would provide a strong counterbalance to the opinions of special interests. Science would get a voice, no matter who was in power. This voice could not force members of Congress to accept scientific truth over alternative "facts." But at least it would give them the opportunity to do so. SA

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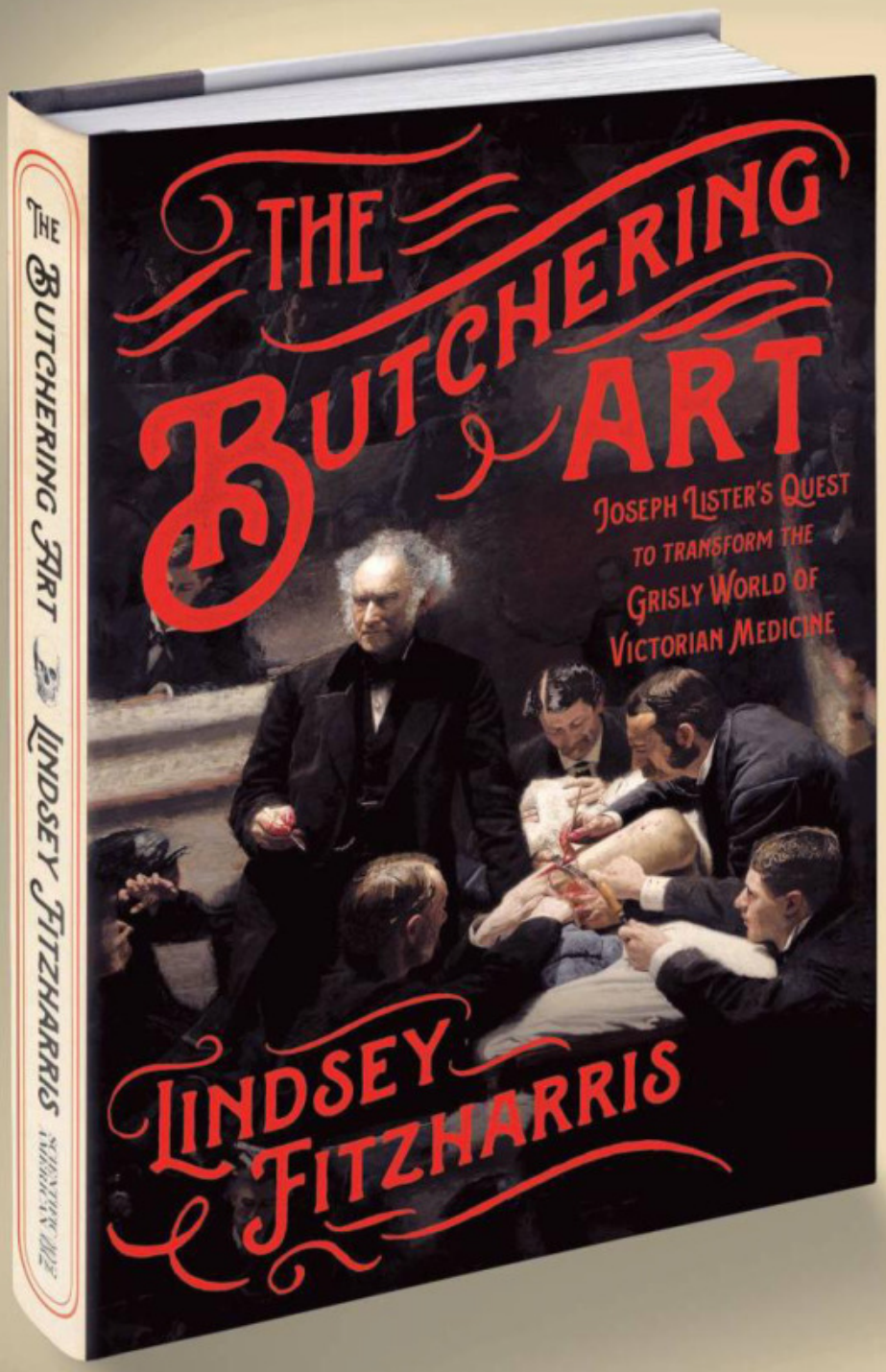
Illustration by Julia Yellow



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SCIENCE MATTERS

Sunita Sah is an assistant professor of management and organizations and John and Norma Balen Sesquicentennial Fellow at the Samuel Curtis Johnson Graduate School of Management at Cornell University. Her research focuses on institutional corruption, business ethics and advice.

Forensic Science Must Be Scientific

A body created to set national standards is now in danger

*By Sunita Sah and co-authors**

Keith Allen Harward served 33 years in jail after being convicted of rape and murder, largely on the strength of bite-mark evidence. He was subsequently found to be innocent on the basis of DNA and released. When he was incarcerated, the man considered the likely perpetrator remained free.

This miscarriage of justice was the result of bad science. Bite-mark evidence has been shown to lack any scientific credibility, yet it continues to be used in court. To a public accustomed to watching crimes being solved on television shows, where the results are always pristine and the guilty are always convicted, there is a perception that forensic science is flawless. The reality is that it is not, and we are in danger of halting and even reversing the considerable steps that have been taken to fix it.

In 2009 the National Research Council evaluated the state of forensic science and, shockingly, concluded that many of the techniques used in court actually have no scientific basis. In response, in 2013 the Department of Justice established the National Commission on Forensic Science (NCFS), which was directed to explore these issues and make recommendations for addressing them. Administered jointly by the DOJ and the National Institute of Standards and Technology, the commission—of which we are members—has worked diligently over the past four years to identify problems and propose changes to strengthen forensic science.

This work now may become undone. On April 10 the DOJ, under the new attorney general Jeff Sessions, refused to extend the term of the NCFS, which brought together diverse stakeholders, including forensic scientists, judges, lawyers, victims' advocates, law enforcement and practicing independent scientists. Its formal demise came a couple of weeks later. This is a tremendous missed opportunity for the progress of forensic science and criminal justice. During its four years of operation, the NCFS made strides in bridging the scientific and legal disciplines. For example, the NCFS found language such as "reasonable scientific certainty" to be meaningless and recommended that it not be used in court because it gives the false impression of scientific rigor.

Even more important, the NCFS recommended that all forensic techniques should be independently validated before being used in criminal investigations. Some of them have been, but too many have not. Bite-mark evidence is one example: despite lacking any scientific foundation, it is, incredibly, still being admitted into the courts. Last year the President's Council of Advisors on Science and Technology flagged firearms identification and latent fingerprint and footwear analyses as also unscientific.

Medical therapies, airplanes and electrical devices are tested by independent entities before they can be used routinely: the public demands that this be done and takes for granted that it has occurred. The public has the right to expect the same of forensic techniques, given the substantial consequences of the "evidence" produced in court. It must reflect "the truth, the whole truth and nothing but the truth."

The DOJ now proposes to improve forensic science by moving its oversight and development to an office within the department. This is precisely the opposite of what was recommended by the National Research Council report and the NCFS. The DOJ is home to many dedicated public servants, including scientists whose passion for justice is unquestioned. But the department is not a scientific body, and it is difficult to see how forensic science can become a true science in such an environment. Science flourishes when it is free and independent; only then can the tools and technology that it creates be truly reliable.

Proclaiming evidence to be scientific does not make it so. Given this state of affairs, we are bewildered by the decision to end the NCFS. Questions about the validity of forensic science will not go away, and failure to address them will lead to further convictions of innocent people. For our society, the stakes don't get much higher. SA

***Arturo Casadevall,** Johns Hopkins Bloomberg School of Public Health; **Suzanne Bell,** West Virginia University; **S. James Gates, Jr.,** University of Maryland; **Thomas D. Albright,** Salk Institute for Biological Studies; **M. Bonner Denton,** University of Arizona.

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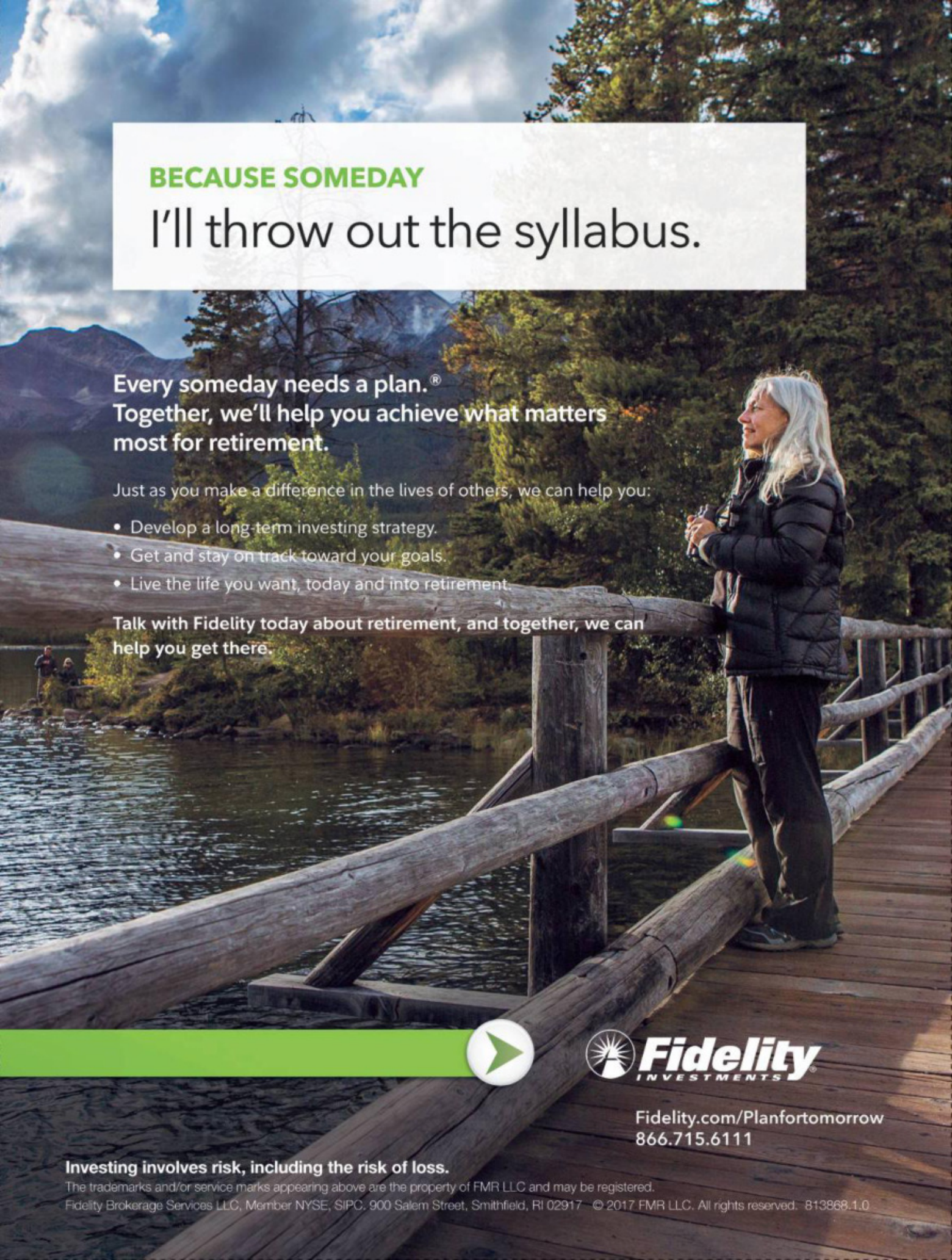
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ADVANCES

NASA's OSIRIS-REx spacecraft at the water-rich asteroid Bennu. The craft aims to return a sample of the space rock to Earth for further study.

INSIDE

POLICY

Space Prospecting

Asteroid mining tests the boundaries of international law

The Outer Space Treaty (OST) turns 50 this month. The foundational 1967 pact establishes space as "the province of all mankind" and forbids the nearly 100 states that have ratified or acceded to it from colonizing celestial bodies or using them for military operations. The agreement is taking on renewed relevance with the looming prospect of asteroid mining—a possibility that was barely imaginable when the treaty was forged but is now a near reality.

Two companies, California-based Deep Space Industries and Washington State–based Planetary Resources, are actively working toward extracting resources from asteroids. They aim to supply deep-space necessities such as water, rocket fuel and building materials, which are prohibitively expensive to transport from Earth. Both firms say they plan to launch prospecting spacecraft to asteroids by late 2020, with missions to test the technology in low Earth orbit slated for as early as this year. Their ambitious timeline has full-scale mining operations planned for the latter half of the 2020s.

The easiest resource to target is water, says Deep Space Industries chief scientist John Lewis. The life-supporting liquid can be electrically converted into hydrogen and oxygen for fuel. Water makes up as much

as 10 percent of the mass of some asteroids, locked up in minerals similar to the glittery mica found in many Earth rocks—but it can be baked out in a solar oven, along with other volatiles such as nitrogen or sulfur compounds. Modified terrestrial mining techniques could make it possible to harvest iron from asteroids as well.

To extract anything, though, companies will first need to gather raw materials from an asteroid—a process that some countries, including Russia, Brazil and Belgium, say runs afoul of the treaty. The OST makes no explicit mention of mining, but one of its key provisions is a ban on "national appropriation" of celestial bodies. That arguably applies to resource extraction, but the pact "doesn't provide you with much guidance" on that front, says Frans von der Dunk, a space law professor at the University of Nebraska–Lincoln.

Proponents of asteroid mining, von der Dunk says, view the ban similarly to the "global commons" status of the high seas: no state may colonize the Atlantic Ocean, yet anyone can harvest its fish. Planetary Resources chief counsel Brian Israel and others similarly argue that using materials harvested from an asteroid would not constitute appropriation.

Several governments have embraced this permissive interpretation. The U.S. Department of State has held for decades that the OST permits commercial exploitation. The federal government doubled down in 2015, when President Barack Obama signed a law recognizing American citizens' property rights to asteroid-derived resources and authorizing a licensing program for mining. Luxembourg, which is angling to become a world hub for space mining, recently passed a similar law. By establishing national licensing regimes, Brian Israel argues, such laws fulfill the OST's requirement that states ensure the compliance of their citizens.

Not everyone is so sanguine, however. For other global commons, such as Antarctica, the guidelines for permissible extraction were spelled out in far more detailed treaties, notes Joanne Gabrynowicz, editor in chief emerita of the *Journal of Space Law*. Without such clarification, opponents of unilateral space mining claim that "because outer space belongs to everyone, the resources belong to everyone," von der Dunk says. Therefore, countries must agree on an "international licensing body and some international sharing of benefits" before private entities can mine. This argument resonates especially with developing countries, which see echoes of rich colonialists' history of invading foreign territories and exploiting their resources, Gabrynowicz adds.

The United Launch Alliance Atlas V rocket, carrying NASA's OSIRIS-REx spacecraft, lifts off from Cape Canaveral, Fla., in 2016.

But the prospects for a new international framework appear grim. The Moon Agreement, an earlier attempt at spelling out the rules for resource use, remains unratified by any major spacefaring country specifically because of concerns about mandatory benefit sharing, and the global appetite for new treaties seems meager. Von der Dunk hopes that "the rest of the world more or less aligns with the U.S. approach" over the next few years. But Stanford University research engineer Nicolas Lee predicts that nothing will happen until "a company actually goes out there and does something."

That day may be closer than it seems. Lindy Elkins-Tanton, principal investigator for NASA's upcoming scientific mission to the metal asteroid Psyche, says previous missions have demonstrated all the technology needed to nestle against—if not land on—an asteroid. And NASA's OSIRIS-REx spacecraft is already en route to the water-rich asteroid Bennu, aiming to return a sample of the space rock for scientific study. OSIRIS-REx principal investigator Dante Lauretta, who also consults for Planetary Resources, believes almost all of the mission's technology will translate to commercial enterprise. Meanwhile the costs of space missions are plummeting thanks to the burgeoning private space industry.

There will still be a lag between the first missions and full-scale mining; Lauretta compares the current phase to "kicking over rocks to see where the gold nuggets are" and acknowledges that the technology for processing materials in space is not yet ready. But Lee is certain someone will pull off a mining operation sooner or later. When that happens, companies and regulators will have to find a healthy balance among many interests. "Exploration has not always been a positive thing in the past," Elkins-Tanton says. "We've got this opportunity right now to do better." —*Jesse Dunietz*

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ADVANCES

CONSERVATION

Scaredy-Cats

Pumas react like prey to the presence of people

Humans kill large carnivores—a category of animals that includes wolves, bears, lions, tigers and pumas—at more than nine times their mortality rate in the wild. Although they may not be our prey in the traditional sense, new research shows that some of the world's biggest carnivores are responding to humans in a way that resembles how prey animals react to predators. Biologists at the Santa Cruz Puma Project, an ongoing research effort in the mountains of California's central coast, report that even the formidable puma, or mountain lion, shows its fearful side when people are around.

In a recent study, the researchers followed 17 mountain lions outfitted with GPS collars to the animals' deer kill sites. Once the cats naturally left the scene between feedings, ecologist Justine A. Smith, now at the University of California, Berkeley, and her team trained motion-activated cameras on the prey carcasses. On the animals' return, the cameras triggered nearby speakers, which broadcast recordings of either frogs croaking or humans conversing.

The pumas almost always fled immediately on hearing the human voices, and many never returned to resume feeding or took a long time to do so. But they only rarely stopped eating or fled when they heard the frogs. They also spent less than half as much time feeding during the 24 hours after first hearing human chatter, compared with hearing the frogs, the team reported this year in the *Proceedings of the Royal Society B*.

The human presence in such a situation has far-reaching consequences. A previous study found that Santa Cruz pumas living near residential areas killed 36 percent more

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PLANETARY SCIENCE

Fossil Moon

Studying the lunar soil could yield clues to Earth's early atmosphere and life

A Japanese spacecraft orbiting the moon recently made a surprising find: oxygen that came from Earth. Scientists think this oxygen could provide a historical record of our planet's ancient atmosphere.

Few reliable clues exist as to the early history of Earth's atmosphere and rocky surface because geologic activity has erased detailed evidence over time. Also wiped out are snapshot details that could be gleaned from meteorites made of material that formed around the same time and from similar material as Earth.

The discovery of terrestrial oxygen on the moon now suggests another way to get at the atmospheric history of Earth's first two billion years. The moon is constantly bombarded by a stream of highly charged particles emanating from the sun, called the solar wind. But for five days about every month our lunar neighbor is shielded by Earth's magnetosphere—a bubblelike region where the planet's magnetic field dominates. During this time, a window opens for slower oxygen ions from Earth to arrive at the moon. Scientists believe that these ions, which the SELENE spacecraft (better known as Kaguya) detected, drifted over geologic time from the outer layers of Earth's atmosphere and became embedded in the moon's regolith, a loose top layer of soil and rock. A team led by planetary scientist Kentaro Terada of Osaka University in Japan reported the result earlier this year in *Nature Astronomy*. "Our new finding is a direct link that ions from Earth's atmosphere are transported to the moon," where they could remain in the lunar soils for billions of years, Terada says.

This result excites scientists interested in a transition coinciding with the beginnings of photosynthesis in simple microbes, the planet's primeval life-forms. Somewhere around 2.45 billion years ago Earth's atmosphere changed from oxygen-poor to oxygen-rich under still mysterious circumstances that scientists call the Great

deer than those in less populated places. The new finding could explain why: if the cats are scared away from their kills before they finish feeding, they may be taking more prey to compensate. And fewer deer could mean more plants go uneaten, according to Chris Darimont, a professor of conservation science at the University of Victoria in British Columbia, who was not involved in the study. Thus, fear of humans may alter the entire food chain.

"Humans are the most significant source of mortality for pumas in this population even though [the cats are] not [legally] hunted" for food or sport, Smith says. Many are hunted illegally, struck by vehicles or legally killed by governmental agencies as a means of protecting livestock. "So they have good reason to be fearful of us," she adds. Darimont predicts other large carnivores would show similar responses because humans have effectively become the planet's apex predators—even if we often do not eat what we kill. "I expect this to be common because the human predator preys on just about every medium-to-large vertebrate on the planet," he says. "And at very high rates."

—Jason G. Goldman

COURTESY OF NASA

Oxidation Event. Could some of the atmospheric oxygen produced at that time linger on the moon today? If scientists can collect and analyze samples of the terrestrial oxygen embedded in lunar soil, it could provide insights into how Earth's atmosphere has evolved over the eons.

In addition to trapped oxygen, the moon may harbor a trove of other evolutionary information about primordial Earth. "In principle, the moon has this remarkable collection of detritus from its sister planet," says astrobiologist Caleb Scharf of Columbia University, who was not involved in the new research. And that detritus might carry even more intriguing data. He adds: "It's not inconceivable that there are fossil organisms in Earth meteorites on the lunar surface." *—Saswato R. Das*

PALEONTOLOGY

Giant Shape-Shifters

"Rangeomorphs" could offer clues to the origins of animal life

An artist's depiction of the extinct giant, frond-shaped organisms known as rangeomorphs.

Paleontologists unearthed a strange sight in Newfoundland in the early 2000s: an ancient fossil bed of giant, frond-shaped marine organisms. Researchers had discovered these mysterious extinct creatures—called rangeomorphs—before, but they continue to defy categorization. Now scientists believe the Newfoundland fossils and their brethren could help answer key questions about life on Earth.

Rangeomorphs date back to the Ediacaran period, which lasted from about 635 million to 541 million years ago. They had stemlike bodies that sprouted fractal-like branches and were soft like jellyfish. Scientists think these creatures grew to sizes until then unseen among animals—up to two meters long. After they went extinct, the planet saw an explosion of diverse large animal life during the Cambrian. "Rangeomorphs are part of the broader context of what was going on at this time in Earth's history," says study co-author Jennifer Hoyal Cuthill, a paleobiology research fellow at the Tokyo Institute of Technology. Figuring out how rangeomorphs grew to such great sizes could help provide context for understanding how big, diverse animals originated and how conditions on Earth—which were shifting around this time—may have affected the evolution of life.

To better understand these connections, Hoyal Cuthill and University of Cambridge paleontologist Simon Conway Morris analyzed several rangeomorph fossils. The pair performed a micro CT scan on one well-preserved fossil of a species called *Avalofractus abaculus,* found in Newfoundland, to examine its 3-D structure in fine detail. They also took photographic measurements of two other specimens for comparison.

The researchers examined various aspects of the rangeomorphs' stems and branches, then used mathematical models to investigate the relation between the fossils' surface areas and volumes. Their models, combined with the fossil observations, revealed that the organisms' size and shape appeared to be governed by the amount of available nutrients, according to the study, published recently in *Nature Ecology & Evolution.* This may explain why they could reach such large sizes during a period when Earth's geochemistry was changing.

But other experts are hesitant to generalize in this way. "This is an interesting finding that supports the growing consensus among researchers that rangeomorphs had the potential to grow differently in response to their environment," says Jack Matthews, a research fellow at the Oxford University Museum of Natural History, who was not involved in the work. But "it is perhaps premature for this study to apply its finding to all rangeomorphs."

If the explanation turns out to be correct, though, Hoyal Cuthill says, it could provide an answer for "what links this amazing appearance of larger organisms in the fossil record with [what was] happening on Earth."

—*Annie Sneed*

Illustration by Reid Psaltis

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EVOLUTION

Genetic Compromises

Microbes face trade-offs when optimizing desirable traits

To survive hostile environments, an organism often has to acquire new traits. But the rules of evolution appear to restrict how many such characteristics it can optimize at once. In a new study, researchers say they found that some bacteria make a genetic trade-off: the microbes involved were able to develop only one of two new traits and selected the one that best helped them thrive in a given setting.

The results could provide a model for studying how infectious microbes become resistant to antibiotics. "We want to understand the rules, if there are rules, for how organisms adapt," says senior study author Seppe Kuehn, a biological physicist at the University of Illinois at Urbana-Champaign. "If we can, maybe there's a chance to make great breakthroughs in terms of treatment."

David Fraebel, a graduate student in Kuehn's laboratory, grew *Escherichia coli* in either a nutrient-rich or nutrient-poor growth medium and measured how quickly the microbes spread. A mathematical model predicted that the fastest-spreading microbes would be those that combined two traits: swimming speed and growth rate. But instead the microbes chose just one trait: in the nutrient-rich environment, those that migrated farthest had opted for speedy swimming. In contrast, in the nutrient-poor medium, the fastest reproducers won out.

By comparing the DNA sequences of the more evolved microbes with those of their ancestors, Fraebel found that the fastest movers had acquired one mutation, whereas the quickest reproducers had acquired a different one. None of the surviving organisms had both.

The finding, reported in eLife, suggests the fittest bacteria selected one "evolutionary path or the other," Kuehn says. Such compromises may be one of the many genetic tools organisms use to survive when confronting a challenge in their environment. —*Michael Waldholz*

IN THE NEWS

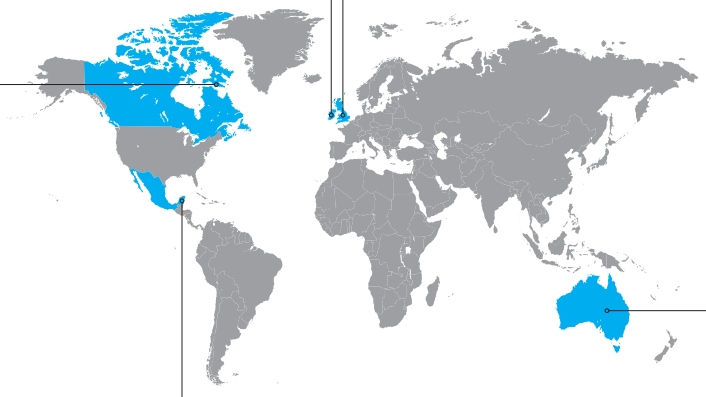
Quick Hits

IRELAND

A joint American and Irish research team has found that the best aid for people stung by a lion's mane jellyfish is a vinegar wash followed by a heat pack. These jellyfish swarm Ireland's coastlines from June to September, causing beach closures.

U.K.

A recent Royal Academy of Engineering report recommends that the U.K. start making more biofuel from waste, such as sawmill residue and whiskey dregs, rather than from food crops, such as wheat.



CANADA

Sapphires have been found in only one region of the Great White North, but a recent study reports that the gems can form under a wider range of pressures and temperatures, giving clues to where more may be hidden.

AUSTRALIA

Health care and government officials are planning to build a 90-resident community for people with dementia that is intended to resemble a small town. Afflicted inhabitants of a similar village in the Netherlands reportedly require fewer medications.

MEXICO

A Swiss reinsurance company has developed a new policy for hotels near a coastal reef off southern Mexico that would help cover the cost of rebuilding this Caribbean habitat following natural disasters.

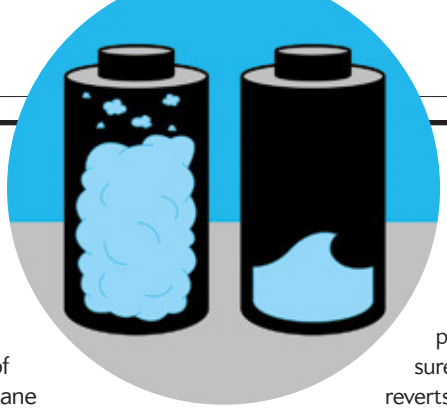
For more details, visit
www.ScientificAmerican.com/oct2017/advances

—Leslie Nemo

ENGINEERING

Better Batteries

Gas-based electrolytes could be safer and last longer than conventional liquid ones



Some owners of Samsung Galaxy Note7 smartphones learned the hard way last year that lithium-ion batteries, commonly used in many consumer electronics, can be flammable and even explosive. Such batteries typically rely on liquid electrolytes, which are made up of an organic solvent and dissolved salts. These liquids enable ions to flow between electrodes separated by a porous membrane, thus creating a current. But the fluid is prone to forming dendrites—microscopic lithium fibers that can cause batteries to short-circuit and heat up rapidly. Now research suggests that gas-based electrolytes could yield a more powerful and safer battery.

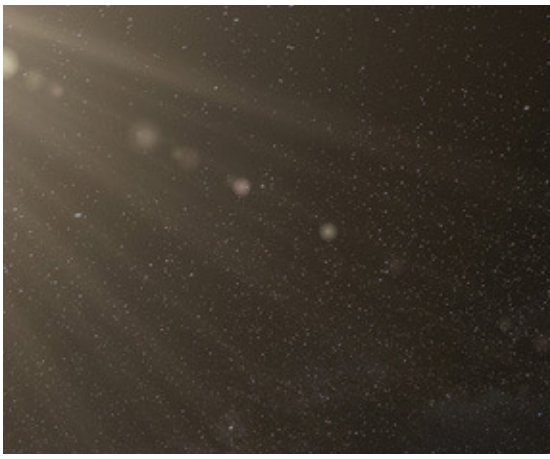
Cyrus Rustomji, a postdoctoral researcher at the University of California, San Diego, and his colleagues recently tested electrolytes composed of liquefied fluoromethane gas solvents, which can absorb lithium salts as well as their conventional liquid-based counterparts do. After the experimental battery was fully charged and drained 400 times, it held a charge nearly as long as it did when new; a conventional lithium-ion battery tends to last nearly 20 percent as long. The condensed-gas battery also generated no dendrites. The findings were published earlier this year in *Science*.

If a standard lithium-ion battery is punctured—and the membrane separating the electrodes is pierced—the electrodes can come into contact and short-circuit. This causes the battery to overheat in the presence of its reactive lithium electrolyte and possibly catch fire (which is exacerbated by oxygen entering from outside). But fluoromethane liquefies only under pressure, so if the new batteries are punctured, the pressure releases, the liquid reverts to a gas and the gas can escape, explains Rustomji, lead author of the *Science* paper. As a result, "there is no electrolyte to create a rush of ion movement" and therefore no fire, he says.

The batteries perform well in temperatures as low as −60 degrees Celsius, unlike standard lithium-ion batteries, so they could power instruments in high-altitude drones and long-range spacecraft, Rustomji says.

Donald Sadoway, a professor of materials chemistry at the Massachusetts Institute of Technology, who was not involved in the study, says the new concept "opens our eyes to a class of liquids that has been understudied." But, he adds, the researchers need to ensure that excessive heat does not cause the batteries' liquefied gas to expand rapidly and lead to a dangerous increase in pressure. —*Matthew Sedacca*

Illustration by Thomas Fuchs



SPACE TECH

Sailing on Sunshine

A spacecraft that harnesses the sun's rays may light the way for new missions

There are no gas stations in space. To send affordable, lightweight spacecraft on long-range missions, NASA and several aerospace companies are seeking ways to exploit the power of sunlight. Possibilities include reflective "sails" billowed by the sun's rays, as well as next-generation solar electric propulsion. In the coming months a privately backed project called LightSail 2 plans to launch a lunch box–size craft into orbit, where it will deploy a Mylar sail about as big as two parking spaces. If successful, these technologies could propel future NASA missions to Mars and beyond.

Solar sails are not science fiction—in 2010 Japan's IKAROS probe demonstrated a proof of concept during an interplanetary mission to Venus. Proponents say the technology used in

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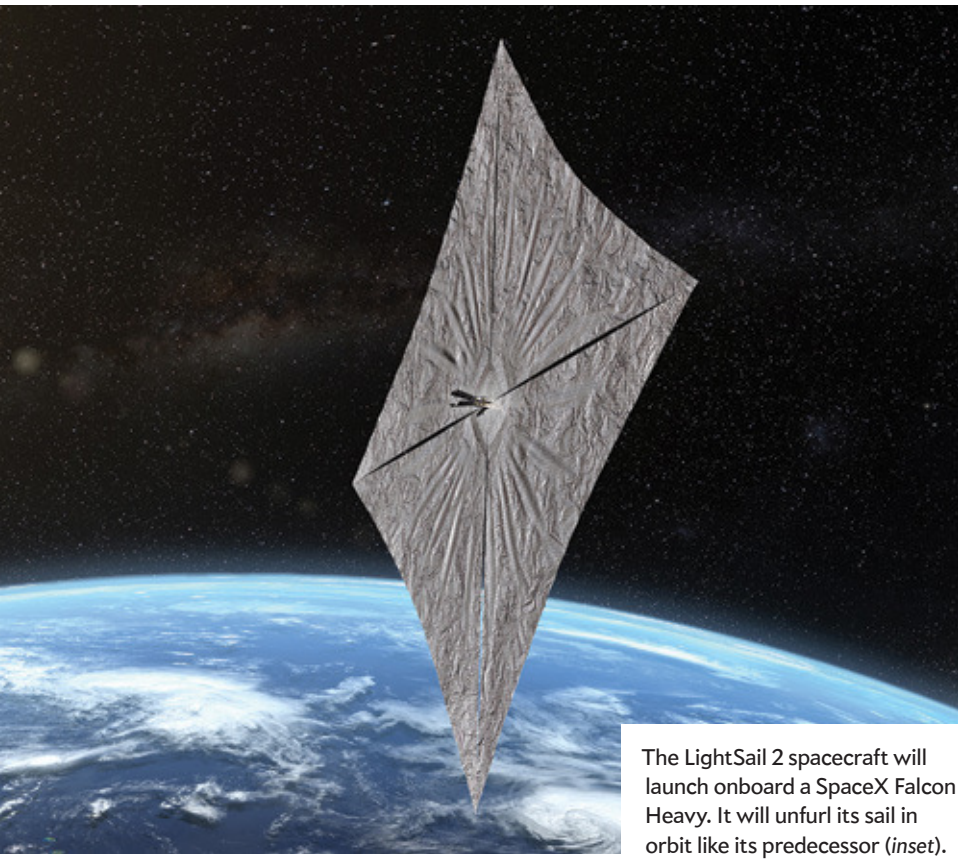


The LightSail 2 spacecraft will launch onboard a SpaceX Falcon Heavy. It will unfurl its sail in orbit like its predecessor (*inset*).

the planned $5.45-million LightSail 2 demonstration, funded by the nonprofit Planetary Society, could maneuver low-cost satellites called CubeSats in Earth orbit without fuel. LightSail 2's performance could also inform NASA's Near-Earth Asteroid (NEA) Scout solar sail mission, scheduled to launch in 2019.

"The real niche [for solar sails] is for very small payloads that have long duration [and] low thrust requirements," says Les Johnson, principal investigator for technology for the NEA Scout mission at NASA's Marshall Space Flight Center in Huntsville, Ala. Steady sunlight pressure—equivalent to less than one ounce of push per acre of sail—can gradually accelerate a small probe. And tilting the sail steers the spacecraft by changing the angle at which sunlight reflects off it, Johnson explains. The technology is ideal for relatively cheap missions with tiny payloads that can take their time, such as NEA Scout's planned reconnaissance of an asteroid.

By the time sunlight reaches the vicinity of Jupiter's orbit, it is too weak for most solar sail–powered missions. But Jeffrey Sheehy, chief engineer of NASA's Space Technology Mission Directorate in Washington, D.C., and Johnson agree that the technology could potentially pave the way for interstellar missions, in which powerful lasers could accelerate sail spacecraft to a tenth the speed of light or faster. One private effort, called Breakthrough Starshot, hopes to send such craft on a flyby mission to Alpha Centauri, the star system nearest Earth, within a generation.

Sunlight could also drive much larger robotic or crewed spacecraft indirectly via solar electric propulsion, Sheehy says. Solar panels can provide electrical power for fuel-efficient thrusters that convert gas into plumes of plasma that propel the spacecraft.

NASA has already recruited companies such as Aerojet Rocketdyne and Ad Astra Rocket Company to scale up the power output of these systems. "Right now we fly solar electric propulsion systems that are just a few kilowatts," Sheehy says. "What [we're] trying to do is [get] to a few tens of kilowatts as a stepping-stone to a few hundreds of kilowatts." —*Jeremy Hsu*

ENGINEERING

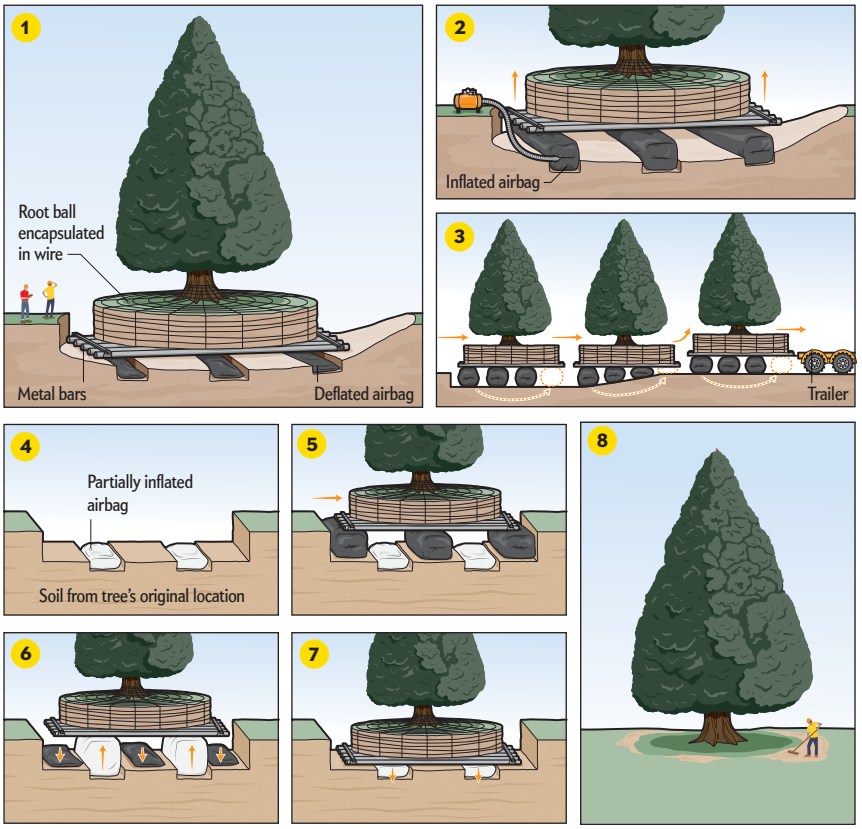
Moving a Giant

The logistics of excavating and relocating a town's century-old, living sequoia tree

Inhabitants of Boise, Idaho, watched with trepidation earlier this year as the city's oldest, tallest resident moved two blocks. The 105-year-old sequoia tree serves as a local landmark, not only for its longevity but also because renowned naturalist and Sierra Club co-founder John Muir provided the original seedling. So, when Saint Luke's Health System found that the 10-story-tall conifer stood in the way of its planned hospital expansion, officials called tree-moving firm Environmental Design.

The Texas-based company has developed and patented scooping and lifting technology to move massive trees. Weighing in at more than 800,000 pounds, the Boise sequoia is its largest undertaking yet. "I [had] lost enough sleep over this," says David Cox, the company's Western region vice president—and that was before the hospital mentioned the tree's distinguished origin.

Before the heavy lifting began, the team assessed the root system and dug a five-foot-deep cylinder, measuring 40 feet in diameter, around the trunk to protect all essential roots. After encapsulating the root ball in wire mesh, the movers allowed the tree to acclimate to its new situation for seven months before relocating it. The illustration details what followed. —*Leslie Nemo*



1. Mark A. Merit and his team at Environmental Design installed underneath the root ball a platform of seven-inch-diameter, 44-foot-long steel bars and, just below the rods, a first set of uninflated airbags (*shown in gray*). The team also dug a shallow ramp.
2. In roughly 15 minutes, the movers inflated the airbags to about three feet in diameter to raise the root ball to the surface of the hole.
3. By underinflating the front bags, the team allowed the platform carrying the tree to roll up the ramp and out of the hole while staying level. A trailer hauled the tree along as team members removed the airbags from the back of the platform and replaced them in the front. They repeated the process until the tree arrived at the edge of its new home.
4. There a second set of partially inflated bags (*shown in white*) waited inside the hole. Soil surrounding the sequoia in its original location was relocated as well, because trees are more likely to survive a transplant when they move with their original soil.
5. Using the first set of airbags, the movers rolled the platform into the new hole.
6. The bags waiting there were then inflated further to take the weight of the sequoia while the transportation bags were deflated and removed from under the tree.
7. The white bags were then deflated in about half an hour to lower the sequoia's root ball to the bottom of its hole. The bags were removed, but the metal bars were left with the tree because they rust and degrade over a number of years.
8. For the next five years the local park service will monitor and maintain the tree in its new home.

SOURCE: "TREE MOVER SYSTEM WITH AIRBAGS," BY MARK A. MERIT AND THOMAS P. COX. PATENT NO. US 8,844,449. PUBLISHED SEPTEMBER 30, 2014

> "I [had] lost enough sleep over this" before learning it was a John Muir tree.
> —*David Cox, Environmental Design*

Illustration by Brown Bird Design

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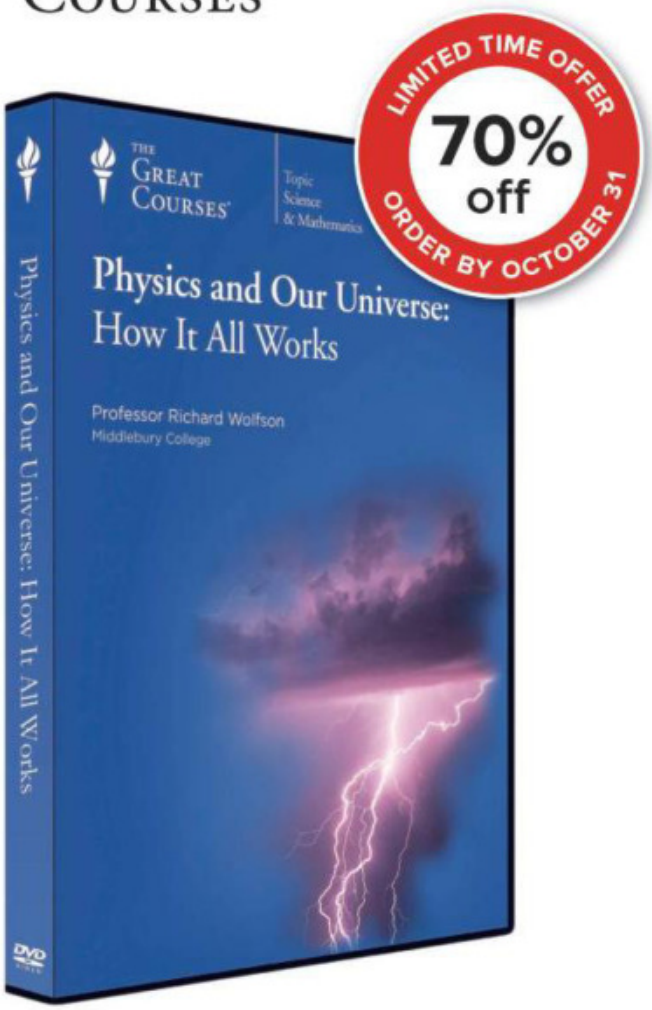

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Back to Basics

Many physicians are advocating a simpler approach to treating lower back pain: exercise

By Daisy Yuhas

It began like many other spring mornings on my leafy college campus. Birds were singing outside the dormitory windows, and the sun was shining. As I started to sit up, however, panic hit me: I couldn't get out of bed. Any effort to prop myself up on my elbows or shift my feet and legs met with waves of pain that rolled up my body.

I grabbed my nearby cell phone and called the campus nurse. After a brief chat, she declared that I had thrown out my lower back. The damage had probably been done the day before, when I foolishly lifted a number of large, heavy objects in an empty classroom, too stubborn to find help and too careless to properly bend my knees with each lift. I had nothing to worry about, the nurse informed me. My body would soon heal itself.

Although sudden pain in the lower back can be excruciating, it often feels more irrevocable than it truly is. Some 80 percent of people experience such distress at some point in their lifetime; the vast majority of cases pass without requiring any medical attention. I was lucky—my travail resolved within 24 hours, and aside from a missed class, the incident had no notable repercussions.

That scenario is fairly typical: most cases of lower back pain subside on their own within 12 weeks. For some sufferers, however, the pain becomes chronic, seriously disrupting home and work life.

For most patients, treatment is about helping them manage the pain until it passes. Doctors have over the years prescribed bed rest, pills and, in extreme cases, surgery. Altogether these treatments exact a high cost. The U.S. spends more on lower back and neck pain than almost any other health condition, excepting diabetes and heart disease—topping $87 billion in 2013, according to an analysis of national health records conducted last year.

Researchers have been questioning the costs for a long time, however, and increasingly, the medical community is considering a much simpler solution. Mounting evidence suggests that exercise is among the best remedies because it is able to reduce pain, improve mobility and prevent future discomfort. "[Back pain is] not the only thing that's been overmedicalized," says back pain specialist Daniel C. Cherkin of the University of Washington. "But it's probably the poster child for how things can go wrong in terms of patient outcomes and cost to society."

Someday, the research hints, insurance companies could do well to cover special courses of yoga, tai chi or physical therapy as a safer alternative to painkillers and invasive procedures.

DO NO HARM

THE THINKING on how to treat lower back pain has shifted several times in the past few decades. For example, physicians long suspected bed rest would be the ideal way to recuperate. Then a series of studies in the 1980s and 1990s revealed that resting actually slowed recovery.

Doctors also explored surgical options, only to find that these physical fixes were thwarted by the complexity of the lower back. The best candidates for surgery are patients whose pain derives from a specific, identifiable source—such as a tumor or an infection. But 90 percent of cases are untraceable. Insults to the muscles, ligaments, joints, nerves or bones—or some combination thereof—can all cause lower back pain. And the specific sensations are unique to the individual; the same nerve damage in two people can elicit entirely different symptoms. In short, it is hard to know where the pain comes from or how to intervene surgically to make it stop.

In light of the limited efficacy of surgical intervention, doctors have been tackling chronic back pain with pills. Painkillers disrupt the body's efforts to relay nerve signals to the brain, dulling the subsequent discomfort. But here, too, back pain sufferers should be cautious. In three separate large analyses published between 2015 and this year, researchers at the University of Sydney and their colleagues compared evidence from dozens of studies to determine how well various pharmaceutical options assuage back pain and found all the drugs lacking. Acetaminophen, for example, was no more effective than a placebo. Other drugs *did* provide some relief but came with costs, particularly when used for long periods. Some over-the-counter nonsteroidal anti-inflammatory drugs, such as ibuprofen, can cause stomach ulcers and gastrointestinal bleeding. Prescription opioids, meanwhile, can be addictive and may lead to overdose. "Drugs can be an ally, but they shouldn't be the core of treatment," says back pain researcher Manuela Ferreira, one of the Sydney scientists who worked on the anti-inflammatory and acetaminophen study.

The fact that opioids are the most commonly prescribed back pain medication has put added pressure on the medical community to find different solutions. To that end, this past February the American College of Physicians released new guidelines on noninvasive treatments for lower back pain. The group's primary message was that pharmaceutical options, and opioids in particular, should be treatments of last resort. In their stead, the authors suggested superficial heat as a well-studied method for relieving acute low back pain. They also found some evidence supporting the use of techniques such as acupuncture and spinal manipulation for acute and chronic pain—although it should be noted that several researchers have questioned whether these treatments are superior to placebo or sham therapies.

For chronic low back pain, the group recommended exercise,

Daisy Yuhas is a freelance science writer based in Austin, Tex.

rehabilitation therapy, tai chi and yoga, among other approaches. In fact, the authors found exercise to be one of the better studied and supported chronic back pain interventions available. Much of this research focuses on well-rounded fitness regimens, designed by a physical therapist to suit the patient's goals and often incorporating both cardiovascular and strength training.

ON YOUR FEET

IN RETROSPECT, researchers should not be surprised that movement is an important part of back pain management. Animal studies throughout the last quarter of the 20th century, in which investigators used a cast to restrict exercise after an injury, have revealed that muscular health and functioning rely on regular use. In other words, muscles need to bear weight, stretch and move to continue supporting the body effectively.

That principle applies equally to chronic and acute low back pain cases, but it may be especially crucial for people whose pain lingers. In 2016 another group of Sydney researchers and their colleagues scoured the available literature and found that exercise was the only treatment approach studied to date that prevented the recurrence of lower back pain. Reviewing the evidence, the team concluded that exercise and education together could cut the risk for another attack of back pain within the year by nearly one half.

Exercise can strengthen the body and back, as well as teach proper posture and lifting techniques. It also offers psychological benefits. The prospect of experiencing pain is frightening to most people; learning how to face that fear and get moving again is part of the healing process, Ferreira notes.

In July a team at the Boston Medical Center and others published findings from a study of 320 chronic lower back pain sufferers who were assigned to yoga, physical therapy or a series of educational reading materials about their condition. For the yoga group, the researchers tailored courses to focus on gentle back stretches such as cat-cow (in which practitioners alternatively round and arch their backs while positioned on all fours) and child's pose (in which the body faces the floor in a modified fetal position). The physical therapy intervention included one-on-one coaching, instructions for at-home exercise and aerobic workout sessions. After three months, the yoga and physical therapy groups were significantly less likely to use pain medication to deal with their discomfort than people who simply received educational material. Overall, the team found yoga to be just as effective as physical therapy; both options reduced pain and improved mobility. In addition, the researchers followed up with participants who continued their exercises (either at home or with an instructor or therapist) for a full year and found these benefits persisted.

TRIAL AND ERROR

ONE IMPORTANT CAVEAT: no one solution for chronic low back pain works well for everyone. Instead most treatments studied—whether pills, push-ups or acupuncture—help some people cope with their pain but fail to help others.

That conclusion may sound discouraging, but in practice, it means that most individuals will need to try a few options to find a treatment that works well. As a solution, exercise excites many therapists and physicians because it can provide relief and boost mobility with few side effects at comparatively low cost, all while improving overall quality of life.

As to which form of exercise to try first, there are not enough head-to-head comparisons to pick a winner, nor is there consensus on whether a specific form of exercise is a bad choice, per se. The lower back is so central to the body that even adding a daily walk through the park can give the region a needed workout.

Sydney's Chris Maher, who is an author on the exercise and drug studies, suspects that the particular kind of exercise you end up choosing may be much less important to solving the problem than simply finding a way to be more active. "The best form of exercise," he asserts, "is the one you're going to stick with." SA

Illustration by Wenjia Tang

Your Security Cam Is Watching You

It's weird to see how you act when nobody's looking

By David Pogue

I'll never forget being creeped out by "Private Eye," a 1949 short story by Henry Kuttner and C. L. Moore. In it, a futuristic technology lets "forensic sociologists" replay anything that's ever happened, going back 50 years, by analyzing walls and surfaces. The protagonist plans a murder entirely in his head, knowing that everything he says and does is being recorded. "It is nerve-racking to know you're living under the scrutiny of an extratemporal Eye," he thinks to himself.

No kidding. He ultimately engages in 18 months of serving and flattering the man he intends to kill, all to throw off the future investigation.

I remembered that story when I reviewed a home security camera called the Nest Cam IQ. Like most Wi-Fi cameras, it lets you peek in on your home from anywhere, using your phone—and even rewind into the past. For a fee, this camera stores up to 30 days' worth of continuously recorded video.

I set the camera up downstairs, with a full 130-degree view of our kitchen and eating area. It never did capture a burglary. It did, however, reveal all kinds of things I was not expecting.

They started small. Rewinding the footage one morning, I discovered something I'd never known about our cat, Wilbur. My wife and I have always thought he sleeps all night at the foot of our bed. In fact, in the middle of every night he slips downstairs and makes a few nonchalant circuits through the kitchen—some ancient, instinctual mouse patrol he's kept secret from us for 15 years.

Another time I caught something else surprising on video: me. I'd snuck downstairs for a midnight snack in my T-shirt and underwear, forgetting about the camera. For the first time I can remember, I was watching video of myself when I didn't *know* I was on camera. Think about it: When do you ever get to see extended footage of yourself, shot from the side, without your knowledge? Unless you hold up a 7-Eleven and watch the security camera footage at your trial, probably never.

It wigged me out a little. I'd never realized that my posture disintegrates when I'm tired.

If the difference between conscious and unconscious video recording hadn't quite sunk in yet, my wife hammered it home. At the moment, she and I live on opposite coasts some of the time. When we're apart, we use video calls, text messages and nightly chats to keep in constant contact.

So I thought it'd be supercool to introduce a little telepresence into our relationship. I proposed buying one of these Nest-type cameras and setting it up in her San Francisco apartment so I could feel like I was always there. We could even converse at will because the camera has built-in microphone and speakers.

She did not find the idea supercool. She found it creepy.

She was right, of course.

Over the years I've done my share of scoffing at people who make a fuss over privacy. Yeah, yeah, the big tech companies are collecting data about us. What's the big deal? If you have nothing to hide, why would you care? You're expressing an irrational fear.

But this Nest Cam experience has taught me something: the desire not to be observed unknowingly *is* irrational. It's emotional—primal, in fact. It doesn't matter that we've done nothing wrong. It doesn't matter if we're married to the observer. It doesn't even matter if we ordinarily *enjoy* being on camera, as I do. (I've been a show-off since elementary school.) We simply want to know when the camera's rolling.

We don't mind when *we're* doing the watching, of course. We love it when hidden cameras catch wrongdoing, whether it's a corrupt politician on *60 Minutes,* burglars in our homes or police brutality caught on phone video. By behaving badly, those people waive their right to video privacy—right?

We're not in the "Private Eye" world quite yet. But with every passing year we're unwittingly being recorded by more cameras. There may soon come a time when we have to start considering how we behave in "private"—whether we may have something to hide or not. SA

David Pogue is the anchor columnist for Yahoo Tech and host of several *NOVA* miniseries on PBS.

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Illustration by Jay Bendt

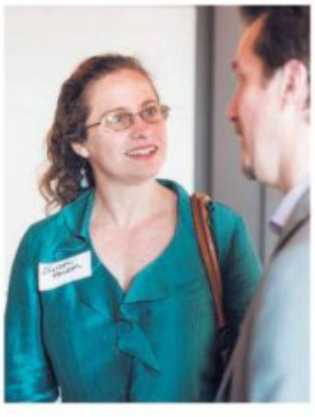
The Agenda Setters

Bringing Science to Life







Vaccines: Our Best Shot

The Loft at 600 F | Washington, DC | June 13, 2017

Immunomic Therapeutics, Inc. and **Scientific American's Custom Media Group** kicked-off an event series exploring vaccine innovation with a unique salon in Washington, DC where experts in policy, science, public health and communications shared insights, case studies, and strategies for moving the cultural dialogue around vaccines forward. Scientific American's Publisher, **Jeremy Abbate** and **Cliff Ransom**, Executive Editor for Partnerships, moderated a lively and timely discussion, drawing in the perspectives of those on the front line in the vaccine arena. Participants included **Bruce Gellen** of the Sabin Vaccine Institute, **Brian Harvey** of the Global Liver Institute, and **Phyllis Arthur** from the Biotechnology Innovation Organization. In opening remarks, ITI's **Bill Hearl** helped the assembled guests understand the innovation challenges and opportunities in the vaccine space, and frame the topic from a historical context.

Future events and content pieces will focus on the science driving today's (and tomorrow's) vaccines, as well as the unique partnering and business opportunities in the field.

PARTICLE PHYSICS

The Neutrino Puzzle

The largest experiment ever to probe these mysterious particles could point the way to new physics

By Clara Moskowitz

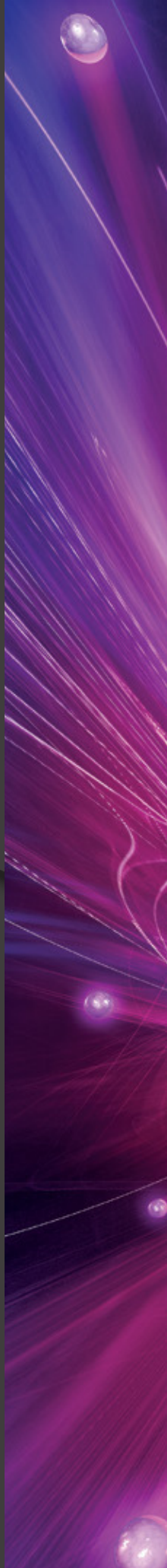


Illustration by Mark Ross Studios

Clara Moskowitz is *Scientific American*'s senior editor covering space and physics. She has a bachelor's degree in astronomy and physics from Wesleyan University and a graduate degree in science journalism from the University of California, Santa Cruz.

I'M STANDING ON A CATWALK IN A GIANT CAVE CRAMMED WITH INDUSTRIAL EQUIPMENT, AND I'm told that trillions of neutrinos are flying through every inch of my body each second. I reach out my arms as if to heighten the sensation, but of course, I can't feel a thing. Nearly massless, traveling close to the speed of light, the ghostly particles traverse the empty space between my atoms without a trace. They also move mostly unimpeded through the hulking metal box that dominates the cavern. But a few times a day one will collide with an atom inside the school bus–size contraption, liberating charged particles that leave light trails visible to scientists. And these trails, physicists hope, will lead them into unknown territory.

The apparatus is part of the NuMI Off-Axis Electron Neutrino Appearance experiment, or NOvA, here at Fermi National Accelerator Laboratory (Fermilab) in Batavia, Ill. A similar but larger detector is buried 800 kilometers away in Minnesota, where it catches neutrinos that have passed through this one and all the ground in between. NOvA, which has been operating since 2014, is the world's longest-distance neutrino experiment, but it is laying the groundwork for something much larger—the Deep Underground Neutrino Experiment (DUNE). DUNE will start at Fermilab, where an accelerator will speed up and smash protons into graphite to create a beam of neutrinos. Those neutrinos will then fly through 1,300 kilometers of earth from Illinois to South Dakota. The additional 500 kilometers of travel should make it more likely that the neutrinos will display some of their trademark odd behavior.

DUNE is the most ambitious particle physics experiment to be attempted on U.S. soil since the failed Superconducting Super Collider (SSC) of the 1990s. The $1.5-billion project is scheduled to start up in the 2020s and should run for at least 20 years. But it is not just Americans who are excited—the project involves 1,000 researchers from 30 countries and counting. It will be the biggest neutrino experiment on the planet. It will also mark the first time that Europe's major particle physics laboratory, CERN, has ever invested in a project outside the continent. Just as the Large Hadron Collider (LHC) discovered the famed Higgs boson in 2012, revealing the presence of a hidden field that fills the cosmos, scientists hope DUNE can use neutrinos to understand the universe on a deeper level. "We want to do for neutrinos what the LHC did for Higgs," says DUNE's co-spokesperson Mark Thomson, an energetic Brit from the University of Cambridge, who is helping to lead the charge on the experiment. "We believe we are on the verge of launching the next major revolution in particle physics."

Neutrinos stoke such extravagant hopes because they are the first particles to break from the so-called Standard Model, physicists' best description of nature's fundamental particles and the rules that govern them. The Standard Model, which explains the behavior of every other known particle with extraordinary precision, predicts that neutrinos should be massless. And that's what scientists thought until about 15 years ago, when experiments in Canada and Japan discovered

IN BRIEF

Neutrinos may be the least understood fundamental particles that we know of. Chargeless and insubstantial, neutrinos rarely interact with other particles and were originally predicted to be massless. Now physicists know that they do have a small amount of mass, but the reason why is a mystery. **An ambitious project** under construction called the Deep Underground Neutrino Experiment (DUNE) will beam neutrinos 1,300 kilometers from Illinois to South Dakota. **As they make the journey,** the particles are likely to morph from one type, or flavor, to another, a phenomenon known as neutrino oscillation. By studying this peculiar behavior, physicists hope to elucidate the origin of neutrino mass and other quandaries.

that neutrinos *do* have the slightest bit of mass. But neutrinos don't seem to acquire mass the way other particles do. Instead, it appears, they come by their heft through so-called new physics—some particle, force or phenomenon that scientists have not yet found.

Over the past few years neutrinos have come to look like an ever more promising bridge to the future of physics because other attempts to reach that frontier have come up short. So far the LHC has failed to produce any particles not predicted by the Standard Model. Experiments designed to reveal the particles that make up dark matter, the invisible stuff that dominates the cosmos, have also come up empty. "We know the Standard Model is not complete—there are other things going on, but we don't know what," says Fermilab neutrino physicist Stephen Parke. "Some people are betting on the LHC with their careers. Others of us are betting on neutrinos."

MASSIVE MYSTERY

THE DAY AFTER my visit to the NOvA cave, I find myself sitting in an empty office on the third floor of Robert Rathbun Wilson Hall, Fermilab's main building. Parke, who is here along with theorist André de Gouvêa of Northwestern University, says he chose this room for our meeting because it was once the office of Leon Lederman, the retired former director of Fermilab, who developed a way to create a beam of neutrinos with a particle accelerator. That work, the bedrock of DUNE, revealed the existence of one of the three known types of neutrinos in 1962 and later won Lederman a Nobel Prize. Parke and de Gouvêa admit that although the field has come a long way since Lederman's day, scientists are still puzzled. "The thing about neutrinos is, the more you understand, the more questions you have," Parke says. "They're very mischievous particles."

Parke, a native of New Zealand, got hooked on neutrinos shortly after coming to the U.S. for graduate school in the 1970s. In the subsequent decades, neutrinos lost their reputation as massless, boring particles. "There have been these revolutions one after the other," he says. "The question is, Are there more revolutions out there?" He and de Gouvêa are betting yes. "We've only just begun to measure neutrino properties at a level comparable to other particles," de Gouvêa says. "We don't know their masses, there could be new [types of neutrinos], the neutrinos could talk to other particles that don't talk to anybody else."

DUNE will focus on neutrinos' bizarre tendency to swap identities, a process called oscillation. The particles come in three varieties, or flavors: electron neutrinos, muon neutrinos and tau neutrinos. Researchers can tell them apart because when they interact with atoms in detectors, they produce different end products—electron neutrinos create electrons, muon neutrinos produce muons and tau neutrinos make tau particles (muons and taus are heavier cousins of electrons). Strangely, these three flavors are mutable. The particles might leave Fermilab as muon neutrinos and arrive in South Dakota as electron neutrinos. Or they might show up as tau neutrinos. As far as physicists know, neutrinos are the only particles that undergo this bizarre act of identity transformation.

When physicists discovered the shape-shifting tendency of neutrinos a decade and a half ago, it solved a long-standing mystery. In the 1960s, when scientists began studying neutrinos streaming out of the sun, they measured only about a third of the output predicted by theory. Oscillation explained why: the missing two thirds were morphing from electron neutrinos into muon and tau neutrinos as they traveled to Earth, but the instruments were set up to see only electron neutrinos. Although the discovery put to bed the so-called solar neutrino problem, it exposed another mystery: according to theory, the only way for neutrinos to switch flavors is for them to have mass—and that is something that the Standard Model did not predict.

The reason physicists know neutrinos must have mass is a head-scratcher that comes from quantum theory. For neutrinos to change flavors, each flavor must be made up of different "mass states." Weirdly, each neutrino flavor does not appear to have a definitive mass; instead the flavors are a mix of three possible masses. (If that sounds strange, blame quantum mechanics, which tells us that particles are not definite entities but uncertain hazes of probability.) As neutrinos fly through space, the parts associated with each mass state travel at slightly different rates, a consequence of Einstein's special theory of relativity, which established that the velocity of a particle traveling near the speed of light depends on its mass. Over time this difference is thought to cause the mixture of masses in each neutrino to change, so a particle that starts out as, say, a muon neutrino, defined by its precise mass mixture, can turn into an electron or tau neutrino.

Scientists still do not know what the precise neutrino mass states are—only that they are different and nonzero. But by counting how many neutrinos oscillate during the journey from Illinois to South Dakota, DUNE aims to determine how the different neutrino masses compare with one another. Theory suggests that the three possible neutrino masses might be ordered so that two are very lightweight and one is heavy or, alternatively, that two of the masses are heavy and one is smaller. The first of these two options is known as the normal hierarchy, whereas the second arrangement is called the inverted hierarchy. DUNE should be able to distinguish between the two because the matter inside Earth is thought to affect neutrino oscillations; if the normal hierarchy were correct, scientists would expect to see different ratios of the three flavors than if the inverted hierarchy were right. "By firing neutrinos through matter, you can determine that difference very easily, and the farther you fire your neutrinos, the clearer your signal is," Thomson says. "That's a bit of physics that DUNE is absolutely guaranteed to nail within a few years."

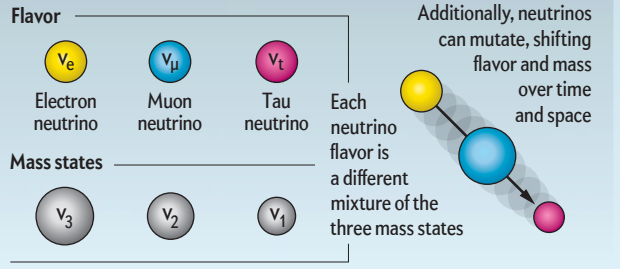
Perplexing Particles

Neutrinos are tiny particles that fly through matter at near light speed. They come in three types, called flavors. Weirdly, as they travel through space neutrinos that started out as one flavor can switch, or "oscillate," into another. Scientists aim to investigate this strange behavior in the Deep Underground Neutrino Experiment (DUNE), the most ambitious neutrino project ever undertaken, due to start operating in the 2020s. Physicists will shoot a stream of neutrinos from the Fermi National Accelerator Laboratory (Fermilab) in Illinois to the Sanford Underground Research Facility in South Dakota and watch how many oscillate between flavors over the journey. Through this phenomenon scientists hope neutrinos will lead to a deeper understanding of physics.

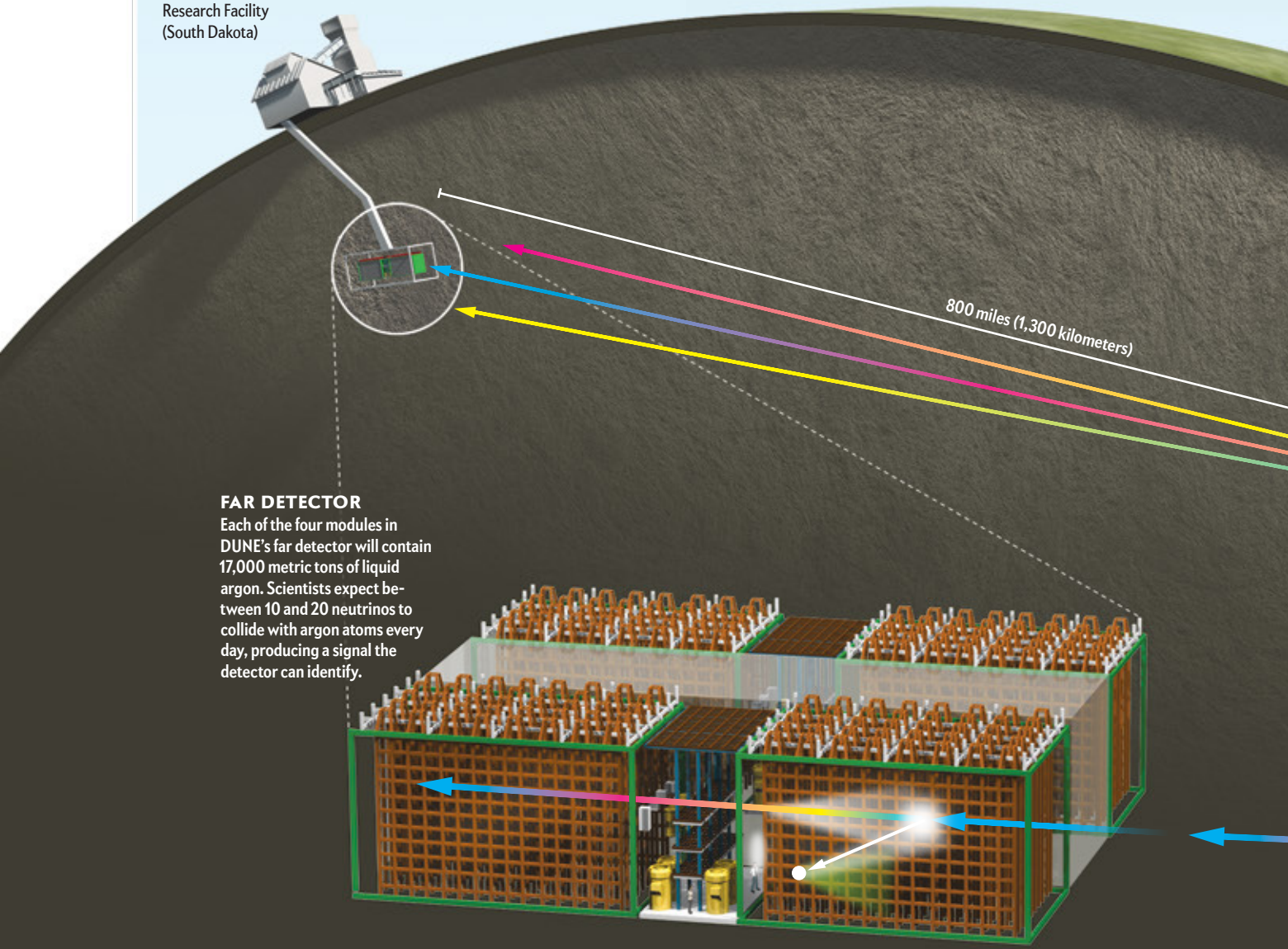
NEUTRINO PRIMER

The three neutrino flavors—electron neutrino, muon neutrino and tau neutrino—are named after the particles they interact with—electrons, muons and taus. Neutrinos are not, as scientists once thought, massless. Because of the oddities of quantum mechanics, the flavors do not have definite masses; rather each flavor is a unique mix of three different "mass states." The precise values of the mass states remain a mystery.

NEUTRINO PROPERTIES



Sanford Underground Research Facility (South Dakota)

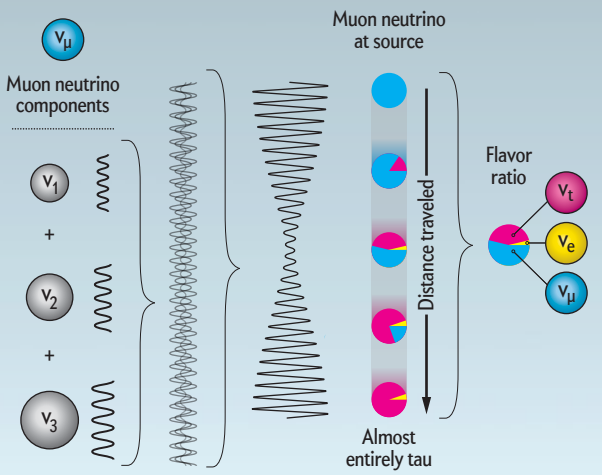


FAR DETECTOR
Each of the four modules in DUNE's far detector will contain 17,000 metric tons of liquid argon. Scientists expect between 10 and 20 neutrinos to collide with argon atoms every day, producing a signal the detector can identify.

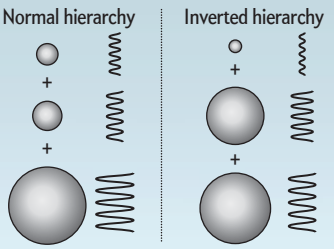
Illustrations by Don Foley (DUNE schematic) and Jen Christiansen (neutrino primer)

FLAVOR OSCILLATIONS AND THE ROLE OF MASS

As a neutrino moves through space, the different mass states of which it is composed travel at slightly different rates. Over time this lag causes the mix of mass states within a neutrino to change, and its flavor shifts accordingly. In this way, a neutrino that starts out as muon-flavored may turn into a tau or electron neutrino.



Scientists do not know the values of the three mass states, but theory suggests either that two are lightweight and one is relatively heavy (a configuration known as the normal hierarchy) or that one is light and two are heavy (the inverted hierarchy). DUNE should be able to determine which hierarchy is correct.



GOING THE DISTANCE

DUNE will send neutrinos over 1,300 kilometers from Fermilab in Batavia, Ill., to the Sanford Underground Research Facility in Lead, S.D. This stretch, the longest yet for a neutrino experiment on the earth, should allow ample time for neutrinos to oscillate.

NEAR DETECTOR

A smaller version of the far detector. Scientists will compare the measurements taken at the two facilities to estimate how many neutrinos have oscillated between flavors over the journey.

Beam of muon neutrinos

Particle accelerator creates a neutrino beam

If a neutrino strikes an argon atom, it produces particles such as electrons and photons the detector can see.

Neutrino beam path

Charged particle

Fermilab (Illinois)

FERMILAB'S main injector, an underground particle accelerator ring, ramps up protons to create beams of neutrinos to be studied by the DUNE experiment.

COURTESY OF DEPARTMENT OF ENERGY AND FERMILAB

THE ORIGIN OF MASS

ONCE THEY KNOW the ordering of the neutrino masses, researchers can tackle the larger question of how neutrinos get their mass. Most particles, such as the protons and neutrons inside atoms, acquire mass by interacting with the Higgs field; this field, which pervades all of space, is associated with the Higgs boson found at the LHC. But the Higgs mechanism works only on particles that come in both right-handed and left-handed versions, a fundamental difference related to the orientation of their spin relative to their direction of motion. So far neutrinos have been seen only in left-handed form. If they got mass from the Higgs field, then right-handed neutrinos must also exist. But right-handed neutrinos have never been observed, which suggests that if they are real they do not interact at all with any other forces or particles in nature—and that prospect strikes some physicists as far-fetched. Furthermore, if the Higgs field did work on neutrinos, theorists would expect them to have similar masses to the other known particles. Yet neutrinos are inexplicably light. Whatever the mass states are, they are less than one hundred-thousandth of the mass of the already puny electron. "Very few people think it's the Higgs mechanism that gives mass to the neutrinos," says Fermilab's director Nigel Lockyer. "There's probably a completely different mechanism, and therefore there should be other particles associated with how that happens."

One possibility that excites physicists is that neutrinos could be Majorana particles—particles that are their own antiparticles. (This is possible because neutrinos have no electric charge, and it is a difference in charge that distinguishes a particle from its antimatter counterpart.) Theorists think Majorana particles have a way of getting mass without involving the Higgs field—perhaps by interacting with a new, undiscovered field. The mathematics behind this scenario also requires the existence of a very heavy set of neutrinos that has yet to be discovered; these particles would have up to a trillion times the mass of some of the heaviest known particles and would, in a sense, counterbalance the light neutrinos. For particle physicists, the prospect of discovering a new mass scale is enticing. "Historically we've always made progress by exploring nature at different scales," de Gouvêa says. And if some new field gives mass to neutrinos, maybe it affects other particles as well. "If nature knows how to do it to neutrinos, where else does it do it?" Lockyer speculates. "Theorists are asking: Could dark matter be a Majorana mass?"

DUNE will not directly test whether neutrinos are Majorana particles, but by measuring the mass hierarchy, it will help scientists interpret the results of experiments that do, which are going on now in Japan, Europe, the U.S. and elsewhere. Plus, DUNE should help elucidate the origin of neutrino mass by providing details about how neutrinos switch between mass combinations during oscillation. "We want to do the best possible neutrino oscillation experiment," de Gouvêa says, "because that's the one place where we know we're going to learn something about neutrino masses."

MATTER VS. ANTIMATTER

PROBING THE ODDITIES of these minuscule particles could also help solve a mystery of cosmic proportions: why the universe is made of matter and not antimatter.

Cosmologists predict the two should have existed in equal amounts after the big bang. Somehow, after

most of the matter annihilated with most of the antimatter (as the two do on contact), there was a slight excess of matter left over. That matter makes up the galaxies, stars and planets that we see today.

To account for this asymmetry, scientists are on the lookout for a type of particle that behaves differently from its antimatter counterpart, and various clues, including hints seen at other experiments, point to neutrinos. DUNE will search for signs of so-called CP (charge parity) violation—in other words, evidence that antineutrinos oscillate from flavor to flavor at different rates than neutrinos. For example, theory suggests that DUNE might see antimatter muon neutrinos turning into electron neutrinos at anywhere between half to twice the rate at which matter neutrinos make this transition—a difference that Parke calls "enormous" and that could explain why matter won out in that initial battle. (Bizarrely, neutrinos could still oscillate differently from antineutrinos even if the two turn out to be same thing—in other words, if neutrinos are Majorana particles. In that case, the only thing separating neutrinos from antineutrinos would be their handedness, related to their direction of spin. Matter neutrinos, being left-handed, could act differently from antimatter neutrinos, which would be right-handed.)

DUNE will also be able to determine whether neutrinos come in only three flavors or whether there are more waiting to be discovered, as some theories speculate. The additional neutrino flavors would be so-called sterile neutrinos because they would not interact with normal matter at all. Earlier experiments, including the Liquid Scintillator Neutrino Detector at Los Alamos National Laboratory and the Mini Booster Neutrino Experiment (MiniBooNE) at Fermilab saw inconclusive signs that an extra type of neutrino was interfering with oscillations, suggesting that sterile neutrinos exist that are heavier than the regular three. Researchers hope DUNE will either confirm or rule out that possibility. "Sterile neutrinos can change the pattern of oscillations we see at DUNE by quite a large amount," Thomson says.

BETTING BIG

TO ADDRESS ALL THESE QUANDARIES, scientists designed DUNE to collect far more data at far greater levels of precision than every previous neutrino experiment. The project will use a beam of neutrinos about twice as powerful as the strongest existing high-energy neutrino stream, and it will blast it at a detector that is more than 100 times larger than the biggest of its kind.

The centerpiece of the experiment will be the far detector to be installed in the Sanford Underground Research Facility in Lead, S.D. That machine will consist of four detector modules, each as long as an Olympic pool but six times as deep, that will be filled with 17,000 metric tons of liquid argon. When a neutrino strikes the nucleus of an argon atom in either the far or near detector, it will become, depending on its flavor, an electron, a muon or a tau particle. Muons will travel through the liquid argon in straight lines, kicking electrons out of argon atoms as they go, leaving a trail of electrons the detector can see. If the neutrino produces an electron, on the other hand, the process will create a photon that will then spawn two electrons, and then more photons, and so on, in a cascade of new particles. Tau neutrinos, likewise, would result in tau particles but only if the initial neutrino was energetic enough; taus, being more massive than electrons or muons, take more energy to create. Scientists at CERN will begin testing miniature versions of DUNE's far detector in 2018. "These detectors, it's kind of like a space mission in that once you turn them on you really can't stop them and take them apart to fix things," says Joseph Lykken, Fermilab's deputy director. "Once you put the 17,000 tons of liquid argon in, it's just too hard to get it out."

> **"The thing about neutrinos is, the more you understand, the more questions you have."**
> *—Stephen Parke, Fermilab*

To succeed, DUNE will have to overcome the political and funding hurdles that have killed large physics projects before. In July scientists and officials held a groundbreaking ceremony at the Sanford facility to mark the start of major excavation, which will take at least three years. Of course, plenty of excavation took place for the SSC, which was planned to be even bigger than the LHC. The SSC probably would have discovered the Higgs boson, but it was canceled in 1993 because of cost overruns and changing political tides. "You can go back in history and look at the Supercollider, and, boy, is that a sad story," Lockyer says. "The international nature of DUNE is such a step forward." Having commitments and funding from more than just one country should help DUNE avoid the SSC's fate. "I'll say it's definitely happening," Lockyer says. And then he catches himself: "But could it not happen? Yes." SA

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CONSERVATION

LOVED TO DEATH

The wild pet trade may surpass habitat loss as a factor in the growing silence of the natural world

By Richard Conniff

JATINEGARA pet market in Jakarta, Indonesia, sells crickets in bamboo tubes (*center*) and an array of birds and other animals collected illegally in the wild.

Richard Conniff is an award-winning science writer for magazines and a contributing opinion writer for the *New York Times*. His books include *House of Lost Worlds* (Yale University Press, 2016) and *The Species Seekers* (W. W. Norton, 2010).

Conservation biologist David S. Wilcove was on a birding trip to the Indonesian island of Sumatra in 2012, when he began to notice that house after house in every village he visited had cages hanging outside, inhabited by the kinds of wild birds he had expected to see in the forest. One in five households in Indonesia keeps birds as pets. That got him thinking, "What is this doing to the birds?"

To find out, Wilcove, who teaches at Princeton University, made a detour from his planned itinerary to visit the Pramuka bird market in the capital city of Jakarta, Southeast Asia's largest market for birds and other wildlife, from bats to monkeys. "It was this sort of Walmart-size space filled with hundreds of stalls," each of which was filled with hundreds of birds, he recalls. "An awful lot of them were in very poor condition, with signs of disease, feathers frayed, behaving listlessly—or thrashing around in their cages because a lot of these are wild birds that are not at all suited to living as caged birds." Some were species that even zoos with highly trained professional staff cannot maintain in captivity; they would die soon after purchase, "the cut-flower syndrome," Wilcove remarks. "It was really a shocking sight. I've never seen anything like it."

Research by Wilcove and his colleagues subsequently linked demand for birds in Indonesia's pet marketplace to the decline of numerous species in the wild. Prices in the pet market, they suggested in a 2015 study in *Biological Conservation,* can even serve as an alarm system for species declines that might not show up in field studies until years later, if at all: when the average price for a white-rumped shama, a popular species in Indonesian songbird competitions, shot up by 1,500 percent from 2013 to 2015, the shift tipped off conservationists that these birds were vanishing from the wild.

Follow-up field studies in Indonesia by Bert Harris, a co-author of the 2015 study now at the Virginia-based Rainforest Trust, found no trace of white-rumped shamas, even in seemingly intact habitats where they should thrive, such as forests five kilometers from the nearest roads. Buyers were paying especially high prices for vulnerable island populations of the birds, many of them now recognized as separate species but valued by collectors for novel features such as long tails or distinctive songs. The pet trade has "the potential to drive species to extinction even when they have suitable habitat," Wilcove observes, "and to do so without anyone being aware of it."

The problem is not just about birds. Nor is it limited to Indonesia or other developing nations. The trade in wild-caught pets is driven at least as much by demand from collectors in the U.S. and Europe. Aquariums in the U.S., for example, are the final destination for about 11 million fish, along with other marine creatures, plucked from coral reefs every year, by some estimates. American pet dealers annually import 225 million live animals on average. They brought in more than three billion over the first 14 years of

IN BRIEF

Conservationists have traditionally viewed habitat loss as the greatest threat to biodiversity.

But the trade in exotic pets has become a major driver in the vanishing of wildlife across the globe.

Much of the demand for wild-caught pets comes from collectors in the U.S. and Europe.

PRECEDING PAGES: MARK LEONG *Redux Pictures*; THIS PAGE: ALAMY (*loris*); GETTY IMAGES (*parrots*)

BULLIT MARQUEZ AP Photo (snakes); SUBHENDU SARKAR Getty Images (birds in cages)

WILD ANIMALS are harvested by the millions for the exotic pet trade. The creatures are often sold illegally in local markets or smuggled overseas. Many die in transit from the poor conditions.

this century, according to a recent study in *EcoHealth*. Despite the widespread belief that our love of pets is one of the finer aspects of human nature, researchers increasingly suggest that it has become a major force in what they call defaunation, the great vanishing of wildlife from habitats of all kinds, almost everywhere.

BEYOND HABITAT LOSS

FOR DECADES conservationists emphasized the role of ecosystem destruction in driving biodiversity decline. But the booming trade in wild animals, with more species taken to meet international demand for pets than for any other purpose, has caused increasing alarm. "The idea that habitat loss is the greatest threat to species survival is starting to be questioned," says Crawford Allan of the wildlife trade-monitoring network TRAFFIC, a collaboration between the WWF and the International Union for Conservation of Nature (IUCN). "There are certain species that have plenty of habitat; however, they are being sucked up from the wild at alarming rates."

Consumer demand for rare species has made the pet trade a source of special concern among conservationists. The IUCN Red List of Threatened Species already includes many species pushed to the brink by trapping for the pet trade, among them birds (the Bali myna and South America's Spix's macaw), a primate (Southeast Asia's greater slow loris), ornamental fishes (Asia's red line torpedo barb) and reptiles (Madagascar's radiated and ploughshare tortoises). And these are just the well-studied species, according to Wilcove and Harris. For the vast majority of vertebrates sold in markets and pet stores, researchers have not even begun to assess how the pet trade affects wild populations.

Field studies to answer such questions inevitably progress slowly, but the market for pets can move with devastating and unpredictable speed. In one notorious case from the 1990s, researchers published the first scientific description of the Roti Island snake-necked turtle, including the standard details about where it lives—an island in southern Indonesia. Collectors pounced, and the species is now critically endangered. Having learned this painful lesson, biologists withheld precise location information in 2011, when they described the new Matilda's horned viper from the highlands of southern Tanzania. Dealers nonetheless had the snakes on the market that same year at more than $500 apiece, according to a 2016 study of the European reptile trade published in *Biological Conservation*.

Dealers and collectors justify the sale of wild-caught animals as pets under the guise of conservation, observes a reptile trade investigator who asked not to be named: "They say, 'We are maintaining insurance populations.' Or, 'The wild habitat is being destroyed, so we are protecting these animals.' In the vast majority of cases, that's not true." Rather, the investigator asserts, the pet trade itself is decimating wild populations.

For instance, the critically endangered ploughshare tortoise, a handsome species with a domed, golden shell, lives only in Baly Bay National Park in northwestern Madagascar. Commercial exploitation has been banned since 1975 under the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), and conservationists worked for decades to rebuild the population in the wild to an estimated 600 to 800 individuals. But over the past five years a surge in poaching to supply collectors has reduced the ploughshare population at Baly Bay to fewer than 100 adults. In countries such as Thailand, Indonesia and China, which tend to honor CITES rules on paper but not in practice, speculators have driven the price for a large ploughshare adult up to $100,000.

Financial speculation was also the apparent motivation in 2015, when a Chinese businessman paid more than $200,000 for a red-necked pond turtle, a species from southern China now thought to be extinct in the wild. "The more rare species get, the closer to extinction, the more these dealers promote that as a sales thing, and the higher the prices become," says Rick Hudson, a herpetologist and president of the Texas-based nonprofit Turtle Survival Alliance.

The same players who supply the trade in wild animal parts—from rhinoceros horn to crocodile skin—are also fueling the pet trade. "Many of these people who were doing the traditional medicine trade are now branching out because the high-end pet trade

in China has grown immensely" and has escalated prices in Europe and the U.S., says Brian Horne, a herpetologist for the Wildlife Conservation Society. Criminal elements have also gotten involved, at times targeting the captive breeding facilities set up by conservationists to rebuild populations of imperiled species. Thieves broke into one such facility last year in Thailand and stole six ploughshares and 72 radiated tortoises. They also target collectors. In Hong Kong last year, for instance, robbers broke into a family's home, scaling drainpipes and bypassing security cameras to steal 23 endangered turtles worth an estimated $116,000.

Catching and prosecuting people who traffic in illegal wildlife is one obvious way to slow the emptying of natural habitats. In 2016 a judge sentenced a Pennsylvania man to two years in prison in a scheme to export North American wood turtles, a threatened species. According to federal investigators, John Tokosh, then age 54, collected 750 of them from a small area south of Pittsburgh, immobilized them with duct tape for shipping and sold them at $400 apiece to middlemen supplying the pet trade in Hong Kong. That case also led to jail terms for a postal worker in Louisiana and collaborators in Chicago and California.

ENDANGERED TORTOISES from Madagascar are seized from smugglers by customs officials in Malaysia.

But such prosecutions are relatively rare. The enormous scale of the pet trade, both into and out of the country, inevitably overwhelms port inspectors working to spot contraband. "We do a lot of these blitzes, we call them, and it's such an absolute needle in a haystack," says one U.S. Fish and Wildlife Service inspector who asked to not be named because he was not authorized to speak to the press. "We have all the tools. We've gotten more equipment and more people. We have a great intelligence unit. It just seems like we're always behind the eight ball. By the time we figure it out, everything has changed." In one case, a dealer smuggled an orangutan into the country by trimming its hair, dyeing it brown and mixing it into a legal shipment of another primate.

The sheer variety of species being traded also reduces the likelihood of detection. "There's nobody out there who knows all the birds," says Eric Goode, founder of the nonprofit Turtle Conservancy, based in New York City. "Tropical fish, unless you get the world's top ichthyologist, they don't know how to identify all those species. In the case of turtles [and tortoises], there are only 340 species on the planet," but inspectors typically "can't tell a Burmese star tortoise from an Indian star tortoise or one softshelled turtle from another." CITES may ban all trade in a critically endangered turtle or parrot, he adds, but traffickers "just label it as a more common variety" and go on about their business.

CATCH OR BREED?

GOODE AND OTHERS argue that if the pet trade cares about conservation, suppliers should stop harvesting animals from the wild and focus on breeding them in captivity. "There's a point when you have to walk the walk," he says. "Let's really stop the importation of wildlife, stop the importation of wild birds, stop the Russian tortoises," a species from Central Asia commonly sold in U.S. pet stores. "Go to any of these warehouses and see the staggering mortality that occurs every day. Why do you need this constant flow of animals into the U.S. that are caught in the wild?"

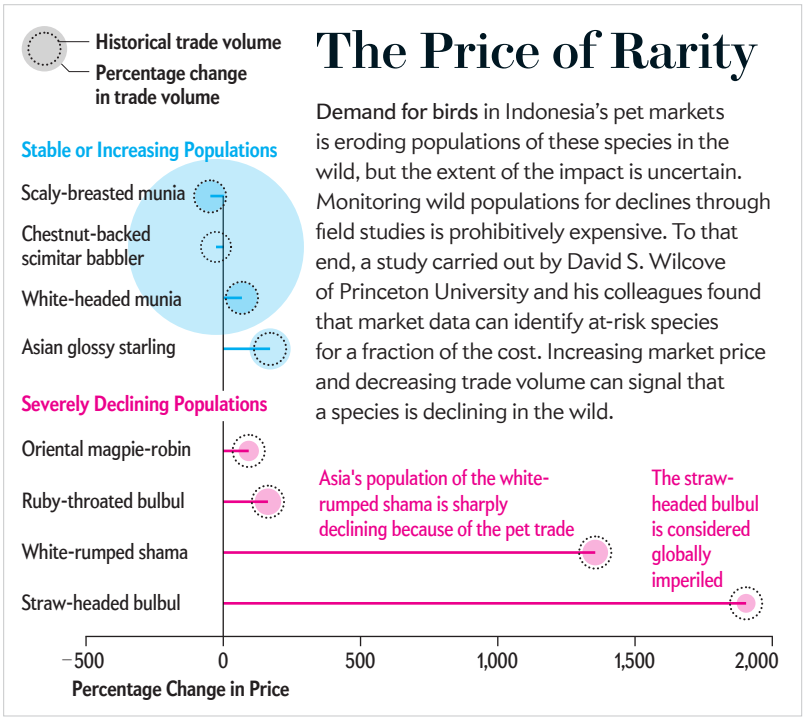
Captive breeding could be the answer to the bird trade in Indonesia, where many households already keep captive-bred lovebirds, Wilcove says. A program aimed at increasing availability of inexpensive budgerigars, canaries and other pet-friendly species might help persuade people that they do not "need to own a shama or to buy some of these wild-caught birds that are not suited to living in a cage." As a child, he adds, he used a recording by "the Pavarotti of the canary world" to train his pet canary to sing. "There's no reason canaries couldn't become fierce competitors" in Indonesian singing competitions, Wilcove observes.

But captive breeding can also be harder than it might seem. In 2014 EcoHealth Alliance, a New York City–based nonprofit, established its EcoHealthy Pets Web site, modeled on the Monterey Bay Aquarium's Seafood Watch, to alert consumers to the best and worst choices in exotic pets. The list emphasizes captive breeding as a way to reduce both health risks and pressure on the natural world. But lack of financial support to expand this program has so far limited the list to just 52 species, not nearly enough to satisfy even many beginning hobbyists.

The pet industry has remained ambivalent about a broad commitment to captive breeding, in part because no one has figured out how to breed many animal groups that are popular as pets. And when they do figure it out, they may find that raising an animal to maturity is far more expensive than simply catching it from the wild. When breeders in the lucrative saltwater aquarium fish trade learned how to rear colorful mandarinfish, for instance, "the mass market didn't want to pay $40 for a captive-bred fish they could get for $12 from wild-caught sources," Scott Fellman, an aquarium trade retailer, complained in an online forum. "Shame on us, as a hobby, for not doing more to support efforts like this," he added.

Further complicating matters, many self-styled captive-breeding facilities also replenish their stock from the wild and may thus serve merely to launder the wholesale removal of wildlife from habitats. For instance, the number of purportedly captive-bred Papuan hornbills being exported "far exceeds what breeding facilities can hold or yield, given the species' slow reproductive rate," conservation geneticist Laura Tensen of the University of Johannesburg reported in a survey of wildlife farming published in 2016 in *Global Ecology and Conservation*. Likewise, many frog and chameleon species appear to be economically unsuited to breeding programs because of low repro-

MANAN VATSYAYANA *Getty Images*



SOURCE: "USING MARKET DATA AND EXPERT OPINION TO IDENTIFY OVEREXPLOITED SPECIES IN THE WILD BIRD TRADE," BY J. BERTON C. HARRIS ET AL., IN *BIOLOGICAL CONSERVATION*, VOL. 187; JULY 2015

ductive success in captivity, and yet, Tensen noted, they "are being traded as pets in their thousands under the guise of captive breeding."

Even if traders could figure out how to breed all of the species people want as pets in captivity, not all conservationists think that they should. When Australian herpetologists Daniel Natusch and Jessica Lyons made a detailed investigation of the trade in green pythons from Indonesia, all supposedly from captive-bred stock, they found that many facilities did not actually know how to breed reptiles successfully. Some did not even have premises on which to attempt breeding. The researchers estimated that 80 percent of these snakes exported to the pet trade are in fact caught in the wild. But the wild-caught trade in green pythons appeared to be sustainable because of their abundance in the wild.

In such cases, Natusch says, the wild-caught trade may be better for conservation than captive breeding: "You can incentivize people to protect the habitat. If you can harvest these animals sustainably, you can have an income from the forest, and you don't have to cut down the forest."

Natusch, who works as a consultant to the IUCN, acknowledges that exporters can do horrible things for the trade—for instance, cramming snakes into suitcases and soda bottles to smuggle them through customs. He also agrees that taking snakes from endemic populations restricted to islands or outcrops can pose a threat to their survival. But the trouble with captive breeding, he notes, is that "once you take those animals from the wild, you have completely disassociated" the trade from any reason to care about the natural habitat. In contrast, he says, an entirely illegal trade in green pythons from Indonesia's Raja Ampat archipelago has motivated islanders to keep their forests intact. (A rare yellow color morph makes the snake trade there particularly lucrative.)

DEMAND AND SUPPLY

PEOPLE WHO COLLECT rare species are often "convinced they are doing wonderful things for animals" by taking them out of the wild and sheltering them from hunger, predation and other natural threats, says University of Oxford conservation biologist Tom P. Moorhouse, lead author of a 2017 study of consumer attitudes toward exotic pets published in *Conservation Letters*. He observes that buyers also typically assume "their ethical duties have been taken care of by the time an animal reaches the market." They have not. "We need a campaign to convince people that this isn't the case and that their choices have a massive effect," Moorhouse adds. "If there were no demand, no market for wild-caught exotics, there'd be no point paying someone to capture animals from the wild."

The pet industry has yet to come to terms with the issue of how the trade is affecting animal populations in the wild. Still, it does care about conservation, insists Mike Bober, president of the Pet Industry Joint Advisory Council. "We think that there is a place for wild-caught and captive-bred in most of these communities—the important thing being the methods used for collection," he says. "When the animals are collected sustainably, especially when they are collected by indigenous people who depend on that for their livelihood, we are proud of that. When they are collected badly, it is a direct problem for our industry. We rely on healthy ecosystems for healthy animals, and without healthy pets, there is no healthy pet trade."

But healthy ecosystems are vanishingly rare in the human era, and no adequate standards of sustainable collecting exist. Sooner or later pet lovers and the trade will need to face up to that reality and devise better ways of sourcing animals in a world where forests, oceans and other habitats are running empty. SA

MORE TO EXPLORE

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Graphic by Amanda Montañez

DEVELOPMENT

BABY'S FIRST ORGAN

The placenta, arguably the least studied of all human body parts, turns out to be full of surprises

By Adrian Erlebacher and Susan J. Fisher

PLACENTA (*left*) is still attached to a newborn here, although it is typically delivered soon after the baby emerges and the umbilical cord is cut.

Adrian Erlebacher is a professor in the department of laboratory medicine at the University of California, San Francisco, School of Medicine. He conducts studies in mice to tease out the properties of the pregnant uterus that enable it to immunologically tolerate the placenta.

Susan J. Fisher is a professor in the department of obstetrics, gynecology and reproductive sciences at the U.C. San Francisco School of Medicine. Her laboratory explores placenta formation in normal human pregnancy and how flaws in the process contribute to complications.

FOR DECADES PUBLIC HEALTH OFFICIALS THOUGHT THE ZIKA VIRUS CAUSED ONLY relatively mild illnesses in people. Since the start of an outbreak in Brazil in 2015, however, it has become horribly clear that the virus can pass from pregnant women to their fetuses, with devastating consequences. The virus kills some of the unborn children and leaves others with severe brain damage, including smaller than normal heads (a condition called microcephaly). How the virus reaches the fetus is a mystery because to get there, it must cross the placenta, a pancake-shaped organ that connects the developing infant to the mother and that manages to block transmission of other closely related mosquito-borne viruses, such as dengue and yellow fever, from mother to baby.

In the past several years this puzzle and others have drawn new research attention to the placenta, which is the first and largest organ to develop after conception. It is a product of the embryo, not the mother, and among other things, it supplies the fetus with nutrients and oxygen and disposes of waste products. Yet despite its critical role in pregnancy, it is arguably the least understood organ in the human body.

The placenta's vulnerability to Zika is not the only conundrum. Researchers have long wondered why a mother's immune system does not recognize the placenta and the fetus as genetically foreign and therefore target them for attack. In fact, not only does the mother's immune system keep itself in check, it actually aids in the proper development and functioning of the placenta.

Research carried out by our laboratories and others has begun to yield fascinating insights into these questions. Through these findings, we are increasingly realizing that certain complications of pregnancy—once thought to be caused entirely by problems in the mother's body—are attributable to defects in the placenta or its interaction with the uterus. What is more, subtle variations in the placenta might affect a person's health later in life.

RAPID DEVELOPMENT

ALTHOUGH MYSTERIES related to the placenta abound, two aspects are well understood: the organ's structure and the basic steps of its development. At the time of delivery, the slablike placenta weighs just more than a pound and has two distinct sides: the part attached to the mother's uterine wall before delivery, which has the appearance of a blood-soaked sponge, and the one facing the baby, which contains an array of blood vessels that traverse the umbilical cord [*see illustration on page 52*].

The placenta develops quickly because it has to do the jobs of other developing organs until they become fully functional—like the liver, it metabolizes nutrients; like the lungs, it exchanges oxygen for carbon dioxide; like the kidneys, it excretes wastes. Less than a week after a sperm fertilizes an egg, specialized cells called trophoblasts emerge on the surface of the embryo. The first task for these cells (which also produce hormones that alert the mother's body to the presence of the embryo) is to burrow

IN BRIEF

A successful pregnancy depends on the proper development and functioning of the placenta—an unusual organ that both separates and connects a pregnant woman and her fetus.

Recent studies suggest why the mother's immune system does not reject her unborn child as foreign tissue—and how certain maternal cells actually help the placenta form and infiltrate the uterus.

A better understanding of malfunctions at the maternal-fetal interface could explain dangerous complications of pregnancy, such as preterm birth, intrauterine growth restriction and preeclampsia.

Scientists are also trying to figure out how some viruses, such as Zika, are able to breach the placenta, whereas others cannot.

PRECEDING PAGES: MONET MOUTRIE

FIVE-WEEK-OLD PLACENTA already has a branching structure but is relatively pale because it is not yet perfused by the mother's blood. This one is from an aborted pregnancy; normally at this stage it would entirely surround the embryo and its amniotic sac.

JOO LEE Getty Images

into the uterine wall. There the trophoblasts divide rapidly, forming projections that radiate into the uterus. One layer is composed of cells known as cytotrophoblasts. Another layer of fused cells (known as syncytiotrophoblasts) becomes the surface of the placenta. Eventually the placenta takes the form of a disk that is attached to the uterine wall by branching structures.

During the second and third weeks after fertilization, these branches begin to fill with support cells and blood vessels. By around the time a woman learns she is pregnant, the mature configuration of these structures, now known as chorionic villi, has been established.

In the placenta's race with time to become fully functional early in pregnancy, its ability to reroute maternal blood flow to itself is paramount. The extraordinary journey that cytotrophoblasts take makes this feat possible. First, the cells attach themselves to the surface of the uterine wall, then they migrate ever deeper inside. Nearly two decades ago one of us (Fisher) discovered that the cytotrophoblasts transform themselves during this process so that they mimic the cells that typically line the blood vessels. This mimicry enables the cytotrophoblasts to breach the mother's oxygen-laden arteries [*see box on next two pages*]. Once inside, they climb up each vessel's inner lining, replacing it as they go.

Because of the cells' machinations, the mother's arteries in the uterus expand and lose their normal "tone," which would otherwise restrict the amount of blood they can carry. By the end of the first trimester, the arteries open into the spaces between the chorionic villi, delivering the large quantities of maternal blood (and thus nutrients and oxygen) required for the offspring's growth. The cytotrophoblasts also invade the uterine veins, enabling blood to flow from the placenta back to the mother's body, which completes the circuit and carries carbon dioxide and other waste products away from the fetus.

Blood from the mother's arteries bathes the surface of the placenta just a few cell layers away from the offspring's own blood vessels. This proximity maximizes the exchange of nutrients, gases and waste products. Researchers have also determined in the past few years that the placenta releases large quantities of the offspring's DNA into maternal blood, which makes it possible to do prenatal genetic testing with only a blood sample from the mother. Such tests are rapidly replacing older, more invasive procedures, such as chorionic villus sampling and amniocentesis.

ENVIRONMENTAL INFLUENCES

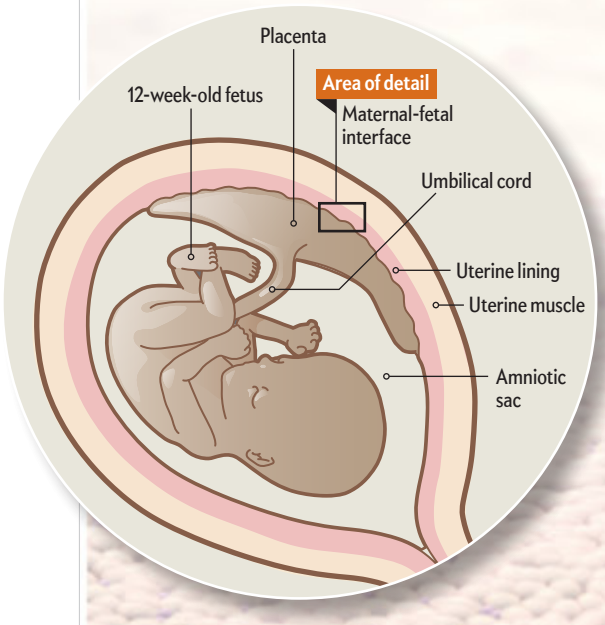
THE GENES of the fetus direct much of the placenta's development, but the microenvironment surrounding the organ also plays a vital role. Research over the past two decades has begun to reveal how much a successful pregnancy relies on the interchange between maternal cells in the uterine tissue and the invading branches of the placenta. The areas where the placenta and uterus meet—the so-called maternal-fetal interface—harbor various kinds of immune cells called leukocytes that migrate to the site from the mother's blood. The trophoblasts from the fetus maintain an ongoing dialogue with these leukocytes and other uterine cells to keep the placenta working properly.

The behavior of the maternal immune cells is surprising. The placenta, which derives half of its genes from the father, is inherently foreign to the mother. This foreignness raises the question of how the placenta escapes rejection by immunological processes that would otherwise recognize and destroy such an invader, as in the case of a conventional organ transplant. Investigators now know that changes in a mother's immune system help her "tolerate" the placenta. Local processes that operate within the uterus also play a part. For example, research on mice published in 2012 by one of us (Erlebacher) showed that the leukocytes that usually reject organ transplants are unable to accumulate in the uterine wall near the invading placenta.

The mother's body does not simply tolerate the placenta, however. It actively promotes the invasive growth of fetal tissues. Starting in the 1980s, for example, researchers discovered that a type of leukocyte called a natural killer cell is abundant on the uterine side of the maternal-fetal interface. As a general rule, these specialized cells kill tumors and virus-infected cells.

Pregnancy in Progress

A successful pregnancy depends on activities at the interface between a pregnant woman's body and her fetus, where the placenta (a product of embryonic cells) meets the uterine wall. Proper development and functioning of this interface, including delivery of oxygen, nutrients and fluid from the maternal blood to the fetus (an "embryo" becomes a "fetus" at the end of the eighth week after fertilization), require coordination among the cells of the placenta, the uterus and, new findings show, the mother's immune system. The flow of maternal blood to the placenta normally begins 10 to 12 weeks after fertilization.



Decidual cells composing uterine lining (*not all cells are shown to scale in this illustration*)

Spiral artery

Invasion of the Uterus

1 Artery Remodeling
The placenta contains branching structures called chorionic villi, which are composed of cells called trophoblasts. The surface of the villi consists of trophoblasts that have fused (forming what are termed syncytiotrophoblasts); these cells in turn sit on a layer of trophoblasts that do not fuse (known as cytotrophoblasts). Some of the cytotrophoblasts break through the fused-cell layer to invade the uterine spiral arteries, where they mimic the mother's own blood vessel cells.

2 Materials Exchange
The mother's transformed arteries open into the spaces between the chorionic villi branches (most of which are free-floating rather than anchored to the uterine lining by cytotrophoblasts), bathing the syncytiotrophoblasts in maternal blood and facilitating the exchange of materials between the mother and fetus. Uterine veins carry deoxygenated blood away from these spaces.

Oxygenated maternal blood

Floating chorionic villi

Cytotrophoblast

Syncytiotrophoblast

Transfer of nutrients and oxygen

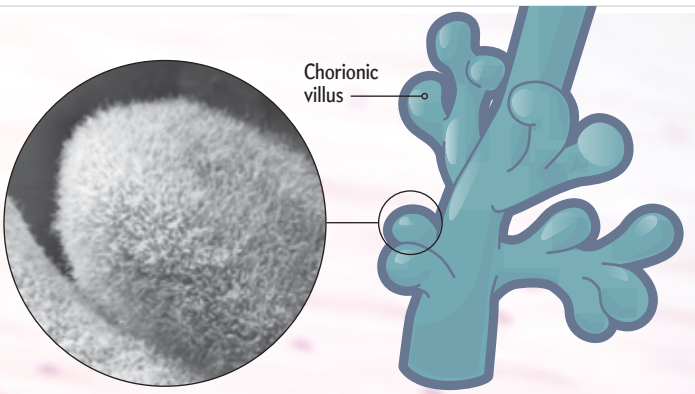
Fetal blood

Anchoring chorionic villus with invading cytotrophoblasts

Transfer of wastes, carbon dioxide and hormones

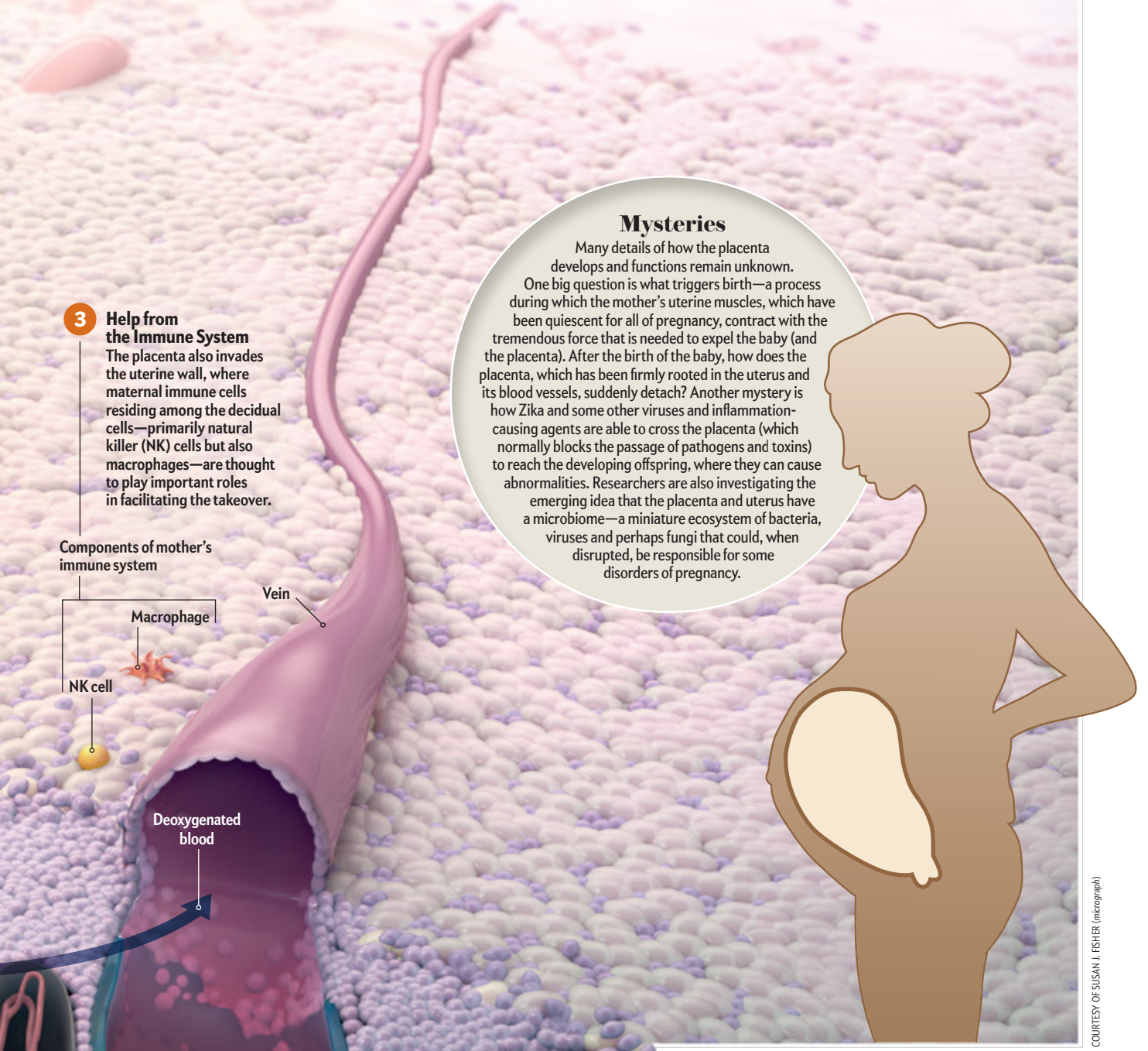
The Benefit of Branches

The size and complexity of the placenta's chorionic villi increase as the treelike organ grows and develops branches. As the branches form, they quickly become covered with micro branches only a tenth of a micron in length, resulting in an enormous overall increase in surface area. Only a slim layer of placental cells separates maternal blood delivered to the spaces between chorionic villi from fetal blood in vessels of the chorionic villi. This arrangement maximizes the exchange of oxygen, nutrients, hormones and waste products. Before blood flow to the placenta begins, the fetus receives nourishment from material secreted by the uterine lining.



Mysteries

Many details of how the placenta develops and functions remain unknown. One big question is what triggers birth—a process during which the mother's uterine muscles, which have been quiescent for all of pregnancy, contract with the tremendous force that is needed to expel the baby (and the placenta). After the birth of the baby, how does the placenta, which has been firmly rooted in the uterus and its blood vessels, suddenly detach? Another mystery is how Zika and some other viruses and inflammation-causing agents are able to cross the placenta (which normally blocks the passage of pathogens and toxins) to reach the developing offspring, where they can cause abnormalities. Researchers are also investigating the emerging idea that the placenta and uterus have a microbiome—a miniature ecosystem of bacteria, viruses and perhaps fungi that could, when disrupted, be responsible for some disorders of pregnancy.



COURTESY OF SUSAN J. FISHER (*micrograph*)

Illustration by AXS Biomedical Studio

But in the 1990s investigators led by B. Anne Croy, now at Queen's University in Ontario, made the counterintuitive discovery that natural killer cells also support placental development—in particular, the remodeling of uterine arteries by cytotrophoblasts. Presumably uterine natural killer cells produce substances that promote the loss of the original maternal cells that line the arteries, thus facilitating the subsequent takeover of these vessels by placental cells.

PROBLEMS AT THE INTERFACE

GIVEN THE BREAKNECK PACE of placental development and the many cell types that make up the placenta and the uterine wall, it should perhaps come as no surprise that errors can arise during the formation of the maternal-fetal interface. Such mistakes can cause a diverse array of pregnancy complications, the most important of which are termed the "great obstetrical syndromes." They include preterm birth (delivery occurs before 37 weeks of pregnancy), intrauterine growth restriction (the baby is smaller than expected), and preeclampsia (the mother suddenly develops high blood pressure and vascular damage).

Recent studies of the placenta have helped elucidate the origins of some of these conditions. Preeclampsia, for example, was once known as toxemia: physicians believed that it occurred because the placenta released toxins into the mother's blood. Although the precise mechanisms that cause preeclampsia—which affects about 8 percent of first-time pregnancies—are still unknown, investigators have found that it is associated with distinct structural deformities in the maternal-fetal interface. Experts now believe that the condition stems from an insufficient cytotrophoblast invasion of the uterine arteries during the first half of pregnancy. The inadequate blood supply restricts fetal growth. Eventually the abnormally developed placenta does release substances that are toxic to the mother, particularly to her circulatory system, but these toxins do not appear to be the root cause, as was previously thought. Rather they are likely a consequence of the disease. If left untreated, preeclampsia can lead to serious or even fatal damage to both mother and child.

Exactly why the placenta fails to work properly in cases of preeclampsia remains obscure. The dysfunction may arise within the cytotrophoblasts or the various maternal cells, or some combination thereof. Intriguingly, the ability of natural killer cells to detect foreign tissue may be a contributing factor. Research conducted by Ashley Moffett, a specialist in reproductive immunology at the University of Cambridge, suggests that if the placenta and mother are too similar immunologically, the natural killer cells may not be able to fully support the replacement of maternal cells from the inner lining of the uterine arteries with cells from the placenta.

Another of the great obstetrical syndromes—preterm birth—has recently raised alarm bells because its incidence is increasing worldwide. According to the Centers for Disease Control and Prevention, this disorder now affects about one in 10 pregnancies in the U.S. Although intrauterine infection can trigger early delivery, many preterm births have no clear-cut cause. In fact, scientists still do not understand what triggers a *normal* birth at the end of pregnancy, one of the major unsolved questions in human biology. Presumably a "clock" counts down the 280 days of human gestation. We know that when the alarm goes off, it initiates an inflammatory cascade within the uterus that is probably the immediate cause of uterine contraction and delivery. But where is the clock ticking? Is it in the fetus, placenta or uterus? It is easy to imagine that defective placental development early in gestation might gum up the inner workings of a birth clock, although this idea remains speculative.

THIS SIDE of the placenta, shown after birth with the umbilical cord, faced the baby during pregnancy. The flip side, which resembles a blood-filled sponge, was attached to the mother's uterine wall.

NORM BARKER

The great obstetrical syndromes overlap in their signs and in their underlying mechanisms. Shallow cytotrophoblast invasion, which is consistently associated with preeclampsia, for example, is also a feature of intrauterine growth restriction and some cases of preterm birth. A better understanding of how problems at the maternal-fetal interface diverge into very different complications might suggest ways to intervene more effectively.

LASTING IMPRINTS

SUCH MAJOR GESTATIONAL IRREGULARITIES have obvious harmful effects on newborns, from treatable conditions that require hospitalization in neonatal intensive care units to permanent neurological impairments. The ill effects of an inadequate environment for fetal growth do not end with infancy, however; they may manifest decades later as adult diseases, and there is reason to believe that flaws in placental function play a part here, too.

The idea that conditions in the womb can affect health in later life is termed the fetal origins hypothesis. It was first proposed in the 1980s by the late British epidemiologist David Barker to try to explain the high incidence of cardiovascular disease and diabetes in poor areas of England. Barker noted that adults with these chronic conditions were more likely

A successful pregnancy relies on the interchange between the maternal cells in the uterine tissue and the invading branches of the placenta.

to have been underweight at birth, possibly reflecting suboptimal nutritional status. Some investigators think that malnutrition and faulty placental function may change the way a baby's genes direct its development during pregnancy—but the mechanics that underlie this process are unknown. Epidemiological evidence also strongly indicates that children born to women who contract certain infections—such as an influenza virus—during pregnancy have an increased risk of neurodevelopmental and psychiatric disorders, including autism, bipolar disorder and schizophrenia.

A mouse study published in 2016 by immunologists Dan R. Littman of New York University and Jun R. Huh of the University of Massachusetts Medical School suggests how a flu infection might subtly change the course of brain development in a way that only becomes evident years or decades later. Previously scientists knew that virus-mimicking agents that cause systemic inflammation in pregnant mice also cause autismlike behaviors in their offspring. Littman, Huh and their colleagues showed that the inflammation-inducing agent is interleukin-17 (IL-17) and that it is produced by the mother's immune cells. Using sophisticated imaging techniques, the team showed that the protein was directly responsible for subtle structural changes in the brains of affected mice.

But how does maternal IL-17 cross the placenta to reach the fetal brain when many other molecules of a similar size cannot get through? One possibility is that, for some reason, the placenta actively transports IL-17 from maternal blood to the fetal circulatory system, enabling it to access the brain. Another intriguing possibility is that some of the mother's cells that are making IL-17 themselves traverse the placenta to reach the fetus.

CROSSING OVER

THE ZIKA PANDEMIC is a graphic illustration of the damage that can be done when a virus that infects the mother learns how to cross the placenta. At the moment, though, researchers have more questions than answers as to how Zika causes the health problems that have arisen in affected babies.

Given that investigators only recently made the association between Zika virus infections during pregnancy and adverse outcomes, it is not surprising that very little is known about how Zika reaches the fetus. Even the rate of birth defects is unclear and seems to vary by location. In a U.S.-based study published this past January in *JAMA,* researchers at public health departments and the CDC found birth defects in only 6 percent of the fetuses or infants of mothers with possible Zika infections. A Brazilian study published the previous month in the *New England Journal of Medicine,* however, suggested that almost half of infected fetuses could have some form of damage. In addition, some Brazilian babies have developed neurological problems after initially being evaluated as normal. Because Zika's most damaging effects—particularly microcephaly—seem to be more prevalent in Brazil than elsewhere, some researchers have speculated that a chemical in the Brazilian environment may weaken the placenta and make it more susceptible to Zika. Alternatively, simultaneous infection with another microbe prevalent in Brazil might be the culprit.

Also in question is how Zika reaches the fetus. Does it plow through the placenta from the maternal side, infecting every cell type in its way, or is it chaperoned by particular cell types—such as maternal immune cells? Alternatively, we know that certain pathogens can ascend from the vagina to the uterus, thereby gaining access to fetal tissues. However the Zika virus reaches the fetal tissues, it establishes a firm foothold once there: molecular pathologists at the CDC have reported that the Zika virus can persist in the placenta for months and can continue to replicate in an infant's brain even after birth.

Zika is not, of course, the only pathogen that can cross the placenta and harm the fetus. Around the globe, an estimated 100,000 babies are born every year with congenital rubella, which can cause deafness, eye abnormalities, heart disease and other serious problems. Malaria, herpes and Ebola can all cause lethal damage during pregnancy. The precise means by which they invade the fetus remain to be determined. But it appears likely that some pathogens are better able to infect the placenta's trophoblasts, particularly in early gestation. Immune defense mechanisms at the maternal-fetal interface are probably also poor gatekeepers at times, given that the uterine lining has two inherently contradictory jobs. On the one hand, it must protect the fetus and placenta from infection. On the other hand, as alluded to earlier, it must prevent maternal immune responses from becoming so robust that the placenta is harmed.

With so much left to learn about the placenta and pregnancy, the Eunice Kennedy Shriver National Institute of Child Health and Human Development three years ago launched the Human Placenta Project, which aims to understand this enigmatic organ that "influences not just the health of a woman and her fetus during pregnancy, but also the lifelong health of both." Along with efforts to cure HIV, cancer and cardiovascular disease, understanding the placenta should be given the highest priority on the national health research agenda. SA

MORE TO EXPLORE

The "Great Obstetrical Syndromes" Are Associated with Disorders of Deep Placentation. Ivo Brosens et al. in *American Journal of Obstetrics and Gynecology,* Vol. 204, No. 3, pages 193–201; March 2011.

Immunology of the Maternal-Fetal Interface. Adrian Erlebacher in *Annual Review of Immunology,* Vol. 31, pages 387–411; 2013.

Uterine NK Cells: Active Regulators at the Maternal-Fetal Interface. Ashley Moffett and Francesco Colucci in *Journal of Clinical Investigation,* Vol. 124, No. 5, pages 1872–1879; May 1, 2014.

Placenta: The Forgotten Organ. Emin Maltepe and Susan J. Fisher in *Annual Review of Cell and Developmental Biology,* Vol. 31, pages 523–552; 2015.

FROM OUR ARCHIVES

The Placenta. Peter Beaconsfield; August 1980.

scientificamerican.com/magazine/sa

JOURNEY TO GUNLAND

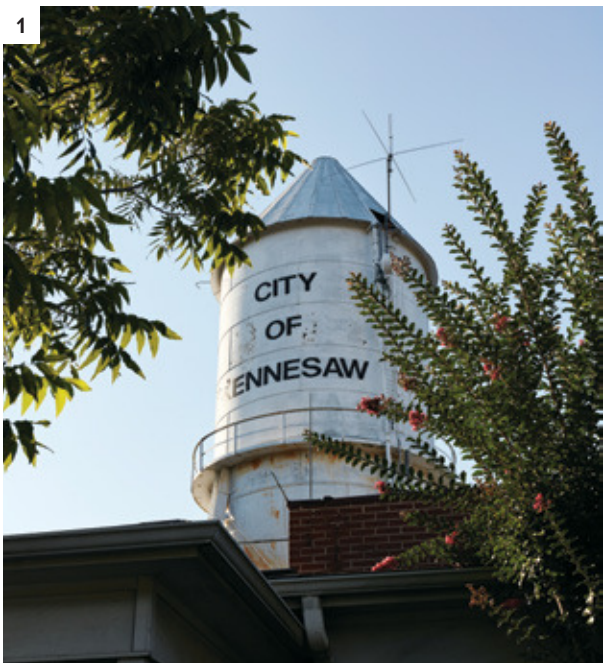
More firearms do not keep people safe, hard numbers show. Why do so many Americans believe the opposite?

By Melinda Wenner Moyer

Photographs by Ben Rollins

AFTER I PULLED THE TRIGGER AND RECOVERED FROM THE RECOIL, I SLOWLY REFOCUSED MY EYES ON THE TARGET. THERE IT WAS—A TINY BUT DISTINCT CIRCLE NEXT TO THE ZOMBIE'S EYE, THE FIRST BULLET HOLE I'D EVER MADE. I LOOKED DOWN AT THE SHAKING GLOCK 19 IN MY HANDS. A SWIFT AND STRONG EMOTIONAL TRANSFORMATION SWEPT OVER ME. IN SECONDS, I WENT FROM FEELING NERVOUS, EVEN TERRIFIED, TO EXHILARATED AND UNASSAILABLE—AND RIGHT THEN I UNDERSTOOD WHY MILLIONS OF AMERICANS BELIEVE GUNS KEEP THEM SAFE.

Writer **Melinda Wenner Moyer** won an Award for Excellence in Health Care Journalism for her December 2016 *Scientific American* article "The Looming Threat of Factory-Farm Superbugs."



GUN CITY: Kennesaw, Ga., near Atlanta, has a law requiring citizens to own firearms (*1*). At the Governors Gun Club outside town, people practice shooting targets (*2*).

I was standing in a shooting range 15 miles south of Kennesaw, Ga., a place known as "America's Gun City" because of a law requiring residents to own firearms. It was day two of a four-day road trip I'd embarked on to investigate a controversial and popular claim made by the gun lobby: that more guns protect more people from crime.

Guns took more than 36,000 U.S. lives in 2015, and this and other alarming statistics have led many to ask whether our nation would be better off with firearms in fewer hands. Yet gun advocates argue exactly the opposite: that murders, crimes and mass shootings happen because there aren't enough guns in enough places. Arming more people will make our country safer and more peaceful, they say, because criminals won't cause trouble if they know they are surrounded by gun-toting good guys.

After all, since 1991, Americans have acquired 170 million new guns while murder rates have plummeted, according to the National Rifle Association of America (NRA). Donald Trump, when running for president, said of the 2015 shooting massacre in San Bernardino, Calif., that "if we had guns in California on the other side, where the bullets went in the different direction, you wouldn't have 14 or 15 people dead right now." Mike Watkins, a cop–turned–firearm instructor at the Kennesaw range, put it this way: "If I'm a bad guy, and I know this place has guns, it's not a place I'm obviously going to want to go and do something bad."

Is there truth to this claim? An ideal experiment would be an interventional study in which scientists would track what happened for several years after guns were given to gun-free communities and everything else was kept the same. But alas, there are no gun-free U.S. communities, and the ethics of doing such a study are dubious. So instead scientists compare what happens to gun-toting people, in gun-dense regions, with what happens to people and places with few firearms. They also study whether crime victims are more or less likely to own guns than others, and they track what transpires when laws make

IN BRIEF

The claim that gun ownership stops crime is common in the U.S., and that belief drives laws that make it easy to own and keep firearms.

But about 30 careful studies show more guns are linked to more crimes: murders, rapes, and others. Far less research shows that guns help.

Interviews with people in heavily gun-owning towns show they are not as wedded to the crime defense idea as the gun lobby claims.

2

it easier for people to carry guns or use them for self-defense.

Most of this research—and there have been several dozen peer-reviewed studies—punctures the idea that guns stop violence. In a 2015 study using data from the FBI and the Centers for Disease Control and Prevention, for example, researchers at Boston Children's Hospital and Harvard University reported that firearm assaults were 6.8 times more common in the states with the most guns versus those with the least. Also in 2015 a combined analysis of 15 different studies found that people who had access to firearms at home were nearly twice as likely to be murdered as people who did not.

This evidence has been slow to accumulate because of restrictions placed by Congress on one of the country's biggest injury research funders, the CDC. Since the mid-1990s the agency has been effectively blocked from supporting gun violence research. And the NRA and many gun owners have emphasized a small handful of studies that point the other way.

I grew up in Georgia, so I decided to travel around that state and in Alabama, where the belief that guns save good people is sewn into the fabric of everyday life. I wanted to get a read on the science and listen to people with relevant experience: cops, elected officials, gun owners, injury researchers and firearm experts such as Watkins, who stood by my side as I pulled the Glock's trigger.

FOR CLUES ON HOW GUNS AFFECT VIOLENCE, Kennesaw is an obvious place to start. On March 15, 1982, this city 24 miles north of Atlanta passed a controversial law: to "provide for and protect the safety, security and general welfare of the city and its inhabitants," Kennesaw would require that every head of a household own a firearm and ammunition.

Nearly 35 years to the day after the law passed, I drove down Cherokee Street in Kennesaw until I reached the Bobby Grant Center police annex, a small brick building perched in front of a large water tower. The annex houses the city's detectives; the main police department is a quarter of a mile down the street. I picked up the entry phone next to the locked door and buzzed. One second later a big man with a moustache and goatee, who was clearly waiting for me, let me in. He introduced himself as Lieutenant Craig Graydon, the man I was there to meet.

Graydon heads up Kennesaw's Criminal Investigations Division and keeps track of all the city's crime statistics. He led me back to his dark office, where a computer glowed with a screen saver of the cast of the old *Untouchables* TV show, starring Robert Stack as federal agent Eliot Ness. Graydon's great-grandfather and father were both in law enforcement. "I've been around weapons of all kinds for as long as I can remember," he said.

Kennesaw is proud of its gun law. "Inmates have been picked up on other charges around the area, and they've said, 'No, I would never break in a house in Kennesaw,' " Graydon said. City officials tout that a year after the law was implemented, burglaries in Kennesaw dropped by more than half; by 1985 they were down by 80 percent. "It was a selling point for the town," according to David McDowall, a criminologist at the University

at Albany, S.U.N.Y. The lavish media attention that the law received probably helps: it's not just that Kennesaw residents have guns; it's that everyone *knows* Kennesaw residents have guns. (That said, the rule has never been enforced, and Graydon estimates that only about half of Kennesaw's residents actually own firearms.)

But while burglary numbers did drastically decline in Kennesaw after 1981, those statistics can be misleading. McDowall took a closer look at the numbers and noticed that 1981 was an anomaly—there were 75 percent more burglaries that year than there were, on average, in the previous five years. It is no surprise that the subsequent years looked great by comparison. McDowall studied before-and-after burglary numbers using 1978, 1979 or 1980 as starting points instead of 1981 and, as he reported in a 1989 paper, the purported crime drop disappeared. Kennesaw has always had pretty minimal crime, which may have more to do with the residents and location than how many guns it has.

But the sense I got in Kennesaw—which feels like a typical small city, not some gun-frenzied town—is that data don't matter to a lot of people. It was similar in other places I visited. What matters more is apparent logic: guns stop criminals, so they keep people safer. The night before I met Graydon, I attended a lecture by a Second Amendment lawyer in Stone Mountain, Ga., 30 miles southeast of Kennesaw. At one point, the lawyer mentioned Samuel Colt, who popularized the revolver in the mid-19th century. "I haven't seen the statistics, but I've got to assume that the instances of rape and strong-arm robberies plummeted when those became widespread," he said. Numbers and statistics, in other words, were almost unnecessary—everyone just *knows* that where there are more guns, there is less crime.

But what does the research say? By far the most famous series of studies on this issue were conducted in the late 1980s and 1990s by Arthur Kellermann, now dean of the F. Edward Hébert School of Medicine at the Uniformed Services University of the Health Sciences, and his colleagues. In one, published in 1993 in the *New England Journal of Medicine* and funded by the CDC, he and his colleagues identified 444 people who had been killed between 1987 and 1992 at home in three U.S. regions—Shelby County, Tennessee, King County, Washington State, and Cuyahoga County, Ohio—and then collected details about them and their deaths from local police, medical examiners and people who had been close to the victims. They found that a gun in the home was associated with a nearly threefold increase in the odds that someone would be killed at home by a family member or intimate acquaintance.

These findings directly contradict the rationale I kept hearing in Georgia, and that could be because human behavior is a lot messier than simple logic predicts. Researchers posit that even if keeping a gun at home does thwart the odd break-in, it may also change the gun owner's behavior in ways that put that person and his or her family more at risk. "The fact that you have a gun may mean that you do things you shouldn't be doing: you take chances you shouldn't otherwise take; you go to places where it's really not safe but you feel safe," says David Hemenway, director of the Harvard Injury Control Research Center. This added risk may overpower any protective effects.

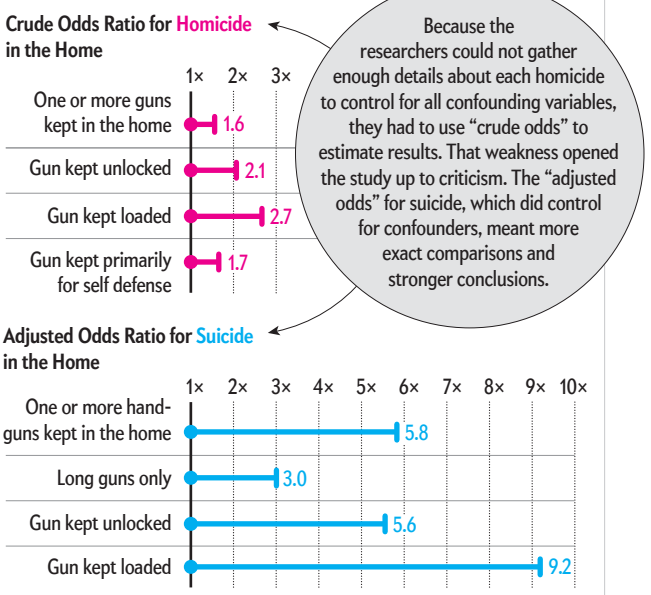
There's also the fact that where there are more guns, more opportunities exist for people to steal them and use them nefari-

An Armed Home Is Not a Safer Home

A common belief is that guns in the house protect those who live there from crime. Not so, according to several studies dating back to the 1980s and 1990s that are supported by more recent work. Guns in the home have been repeatedly linked to an increased risk for homicide and suicide.

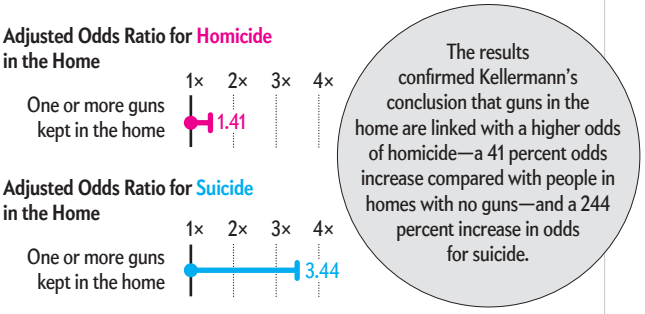
High-Impact Studies

In the late 1980s and early 1990s, Arthur Kellermann, now at the Uniformed Services University of the Health Sciences, and his colleagues published a number of studies suggesting that murder and suicide were more common among people who kept guns in their homes. The risks were indicated by "odds ratios": ratios greater than 1 meant more people with guns in their homes would be victims than would people in gun-free homes. The figures they reported reflected increased odds. For instance, in homes that owned guns for self-defense, the odds ratio of 1.7 referred to a 70 percent increased odds of being murdered at home.



Supporting Work

In 2003 Douglas Wiebe, now at the University of Pennsylvania, and his colleagues conducted a similar study comparing gun ownership levels among 3,679 murder and suicide victims and 21,619 similar nonvictims. The researchers were able to gather more information about each subject, allowing them to adjust their odds ratios to account for variables with precision.



Graphics by Jen Christiansen

BELIEF VS. NUMBERS: Craig Graydon of the Kennesaw police says criminals may be afraid to break into houses in his city, but an analysis of crime rates does not link a decrease to the firearms law.

ously. Indeed, one of Kennesaw's crime problems, Graydon told me, is gun theft, so the Kennesaw Police Department encourages residents to lock their guns up. The NRA, on the other hand, opposes legislation that requires secure gun storage.

The initial work by Kellermann and his colleagues was criticized for not using enough statistical controls. So they went on to publish other studies confirming the link between guns and more violence. In one, they found that a gun in the home was tied to a nearly fivefold increase in the odds of suicide. (More Americans die from gun suicides every year than gun homicides.) In another, published in 1998, they reported that guns at home were four times more likely to cause an accidental shooting, seven times more likely to be used in assault or homicide, and 11 times more likely to be used in a suicide than they were to be used for self-defense.

The research made headlines in the *New York Times* and the *Washington Post.* It also infuriated the gun lobby, which launched a war against gun research that persists today.

ONE VETERAN OF THAT WAR is injury researcher Mark Rosenberg. I drove to Rosenberg's Atlanta-area home—only 15 miles from where I lived as a child—after leaving the Kennesaw Police Department, and we sat down in his living room. In the late 1990s Rosenberg was the director of the CDC's National Center for Injury Prevention and Control, which then funded and studied gun violence. He said he was fired from the agency in 1999 for pushing ahead with this research despite political opposition, although his boss at the time, whom I contacted, disagreed that Rosenberg's actions on gun research caused his dismissal.

I asked Rosenberg what happened after the Kellermann studies came out. "The NRA started a multipronged attack on us," he recounted. "They called the CDC a cesspool of junk science." Indeed, soon after Kellermann's early studies were published, the NRA ran an article in its official journal, the *American Rifleman,* encouraging readers to protest the CDC's use of tax dollars to "conduct anti-gun pseudo-scientific studies disguised as research." The association also asked the National Institute of Health's Office of Scientific Integrity to investigate Kellermann and his colleagues, but it declined. Todd Adkins, current director of research and information at the NRA's Institute for Legislative Action, told me via e-mail that the association was reacting because CDC scientists had started a campaign to persuade Americans that firearms are a menace to public health and ignored data that did not support this idea.

As the dispute continued, Representative Jay Dickey of Arkansas introduced a rider into the CDC's 1996 spending bill mandating that none of its funding be used to advocate or promote gun control. Congress also cut out $2.6 million of the CDC's budget, the exact amount that had been allocated for firearm research the previous year. (Later, that funding was restored but was earmarked for traumatic brain injury.) Harvard's Hemenway says that the move "was a shot across the bow: 'We're watching you.'" He adds that "the CDC recognized that they better be really, really, really, really careful about guns if they wanted to have an Injury Center."

Dickey's addition to the CDC's funding bill has been renewed every year since. In fact, in 2011 the language was extended to cover all Department of Health and Human Services agencies, including the NIH. But Dickey later said that he did not intend to put a stop to all gun research—and he wished that he hadn't. He died this past April.

The CDC's hands are still tied. After the 2012 school shooting that took the lives of 20 children and six adults in Newtown, Conn., President Barack Obama signed an executive order requesting that the CDC spend $10 million on gun violence research. But Congress did not appropriate the funds. In fact, according to Linda DeGutis, who directed the CDC's Injury Center from 2010 to 2014, agency employees weren't even allowed to discuss Newtown. "We couldn't talk to the media except on background. We couldn't be quoted on anything," she recalls. "There were CDC staff members who wouldn't even mention the word 'gun.'" (Current staffers declined to be interviewed for this article.)

Garen Wintemute, a physician and noted gun violence researcher at the University of California, Davis, is not terribly surprised that everything went down the way it did. "It's like doing work in any other controversial field that threatens established interests. Those interests respond in a way to minimize the threat," he says. Rosenberg, after leaving the CDC, became CEO of a nonprofit that works to improve health in developing countries (he retired from that role last year). But Wintemute and others have continued with gun research, procuring grants from private foun-

SOURCES: "GUN OWNERSHIP AS A RISK FACTOR FOR HOMICIDE IN THE HOME," BY ARTHUR L. KELLERMANN ET AL., IN *NEW ENGLAND JOURNAL OF MEDICINE,* VOL. 329, NO. 15; OCTOBER 7, 1993; "SUICIDE IN THE HOME IN RELATION TO GUN OWNERSHIP," BY ARTHUR L. KELLERMANN ET AL., IN *NEW ENGLAND JOURNAL OF MEDICINE,* VOL. 327, NO. 7; AUGUST 13, 1992; "HOMICIDE AND SUICIDE RISKS ASSOCIATED WITH FIREARMS IN THE HOME: A NATIONAL CASE-CONTROL STUDY," BY DOUGLAS J. WIEBE, IN *ANNALS OF EMERGENCY MEDICINE,* VOL 41, NO. 6; JUNE 2003

dations and government agencies such as the National Institute of Justice. In 2005 Wintemute started using his own private money to fund his research and has spent about $1.7 million so far.

More than 30 peer-reviewed studies, focusing on individuals as well as populations, have been published that confirm what Kellermann's studies suggested: that guns are associated with an increased risk for violence and homicide. "There is really uniform data to support the statement that access to firearms is associated with an increased risk of firearm-related death and injury," Wintemute concludes. Gun advocates argue the causes are reversed: surges in violent crime lead people to buy guns, and weapons do not create the surge. But if that were true, gun purchases would increase in tandem with all kinds of violence. In reality, they do not.

When I asked people I met on my trip to Georgia for their thoughts on how guns influence violence, many said they couldn't believe that guns were a root cause. "It's easier to go after the object than it is to go after the motive," Graydon told me. He does have a point: A growing body of research suggests that violence is a contagious behavior that exists independent of weapon or means. In this framework, guns are accessories to infectious violence rather than fountainheads. But this does not mean guns don't matter. Guns intensify violent encounters, upping the stakes and worsening the outcomes—which explains why there are more deaths and life-threatening injuries where firearms are common. Violence may be primarily triggered by other violence, but these deadly weapons make all this violence worse.

MY NEXT STOP, SCOTTSBORO, ALABAMA, is within a county where nearly one in every five people has a permit to carry a concealed weapon. Overall in Alabama, an estimated 12 percent of residents have permission to carry concealed firearms, possibly the highest such rate in the country. Jackson County, home to Scottsboro, ranks close to the top of the state with that nearly one-in-five figure. I wanted to know if people in this sleepy town just north of the Tennessee River commonly used these hidden guns to thwart crime.

I left Rosenberg's home and drove 120 miles northwest. I drove past an Econo Lodge, a No. 1 China Buffet and a CashMart and then parked at the Jackson County courthouse, an impressive Neoclassical brick building with a clock tower. Scottsboro gained notoriety in 1931, when eight black youths were sentenced to death in its courthouse by an all-white jury after being falsely accused of raping two white women, a decision that was appealed up to the U.S. Supreme Court. After passing through the metal detectors, I meandered around in search of the sheriff's office, which I eventually found at the back of the ground floor. A receptionist walked me in to meet Sheriff Chuck Phillips, who was sitting at his desk with his chief deputy, Rocky Harnen. A sheet entitled "Handgun Fundamentals" hung on the wall behind the desk.

"I promise you, everybody here that wants a gun has got one or 100," Phillips told me, drawling out the number so it sounded like "hunnerd." I asked how many times Scottsboro residents had used their guns to protect themselves. "I've been doing this for 35 years, and I just can't recall one," the sheriff answered. Harnen, though, suddenly remembered something. "We did have a lady that was in one of our firearms classes. She had a guy try to break into her house," he recalled. "She yelled and said, 'I've got a gun,' and she opened the door, and he was running away—she fired at him."

CRIME STOPPERS? Mike Watkins, a firearms instructor in Georgia, argues that "if I'm a bad guy, and I know that this place has guns, it's not a place I'm obviously going to want to go."

But they could not think of any other examples. Graydon, back in Kennesaw, also could not remember a time when a resident used a gun in self-defense, and he has been working for the police department for 31 years.

The frequency of self-defense gun use rests at the heart of the controversy over how guns affect our country. Progun enthusiasts argue that it happens all the time. In 1995 Gary Kleck, a criminologist at Florida State University, and his colleague Marc Gertz published a study that elicited what has become one of the gun lobby's favorite numbers. They randomly surveyed 5,000 Americans and asked if they, or another member of the household, had used a gun for self-protection in the past year. A little more than 1 percent of the participants answered yes, and when Kleck and Gertz extrapolated their results, they concluded that Americans use guns for self-defense as many as 2.5 million times a year.

This estimate is, however, vastly higher than numbers from government surveys, such as the National Crime Victimization Survey (NCVS), which is conducted in tens of thousands of households. It suggests that victims use guns for self-defense only

The Rarity of Self-Defense

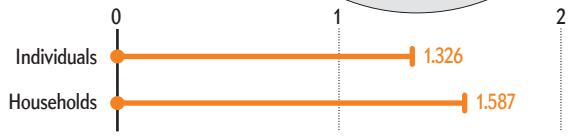
Claims that people frequently need guns to defend themselves from criminals usually rely on one 1995 survey. That survey concluded that Americans used guns to ward off crime up to 2.5 million times in a year. But subsequent research, involving much larger samples, has come up with much smaller numbers, indicating that defensive gun use is unusual.

High-Impact Study

The 1995 work, published by Gary Kleck of Florida State University and his colleague Marc Gertz, randomly asked 5,000 Americans if they, or another member of the household, had used a gun for self-protection in the past year. Just over 1 percent said yes, and the researchers extrapolated this percentage to the entire U.S. population, giving them up to 2.5 million annual instances of defensive gun use.

The figures in this survey are much higher than in other research. The National Crime Victimization Survey, which questions tens of thousands of households, suggests that annually Americans use guns 65,000 times in self-defense. The NCVS questions first establish that people are actual attack victims, whereas the Kleck questions do not. Some worry that Kleck's findings include spurious reports of self-defense use by people who were not actually victimized.

Percent Surveyed Who Said They Had Used a Gun in Self-Defense in the Previous Year



Contradictory Work

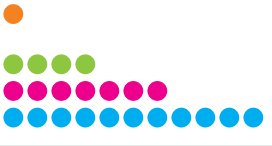
In 2015 researcher David Hemenway of Harvard University and his colleagues combed through NCVS data and found there were far fewer uses than Kleck and Gertz reported. The 2015 research involved about 14,000 people who were confirmed victims of crime, unlike the Kleck work. The conclusions indicate gun use for self-defense is quite rare.

This percentage is telling because not only is it lower than the Kleck data, but it also comes from people who were in real crime situations, not a random sample of the general population. Other data from this study indicate that strategies such as calling for help were about as effective as gun use at preventing injury.

Crime Victims Who Used a Gun in Self-Defense during the Incident (percent, 2007–2011)

In 1998 Arthur Kellermann analyzed 626 shootings that occurred around homes in three cities. He found that accidental shootings, homicides, assaults and suicides were much more common than gun use for self-defense:

"Every time a gun in the home was used in a self-defense or legally justifiable shooting, there were four unintentional shootings, seven criminal assaults or homicides, and 11 attempted or completed suicides."



SOURCES: "ARMED RESISTANCE TO CRIME: THE PREVALENCE AND NATURE OF SELF-DEFENSE WITH A GUN," BY GARY KLECK AND MARC GERTZ, IN *JOURNAL OF CRIMINAL LAW AND CRIMINOLOGY*, VOL. 86, NO. 1; FALL 1995; "THE EPIDEMIOLOGY OF SELF-DEFENSE GUN USE: EVIDENCE FROM THE NATIONAL CRIME VICTIMIZATION SURVEYS 2007–2011," BY DAVID HEMENWAY AND SARA J. SOLNICK, IN *PREVENTIVE MEDICINE*, VOL. 79; OCTOBER 2015; "INJURIES AND DEATHS DUE TO FIREARMS IN THE HOME," BY ARTHUR L. KELLERMANN ET AL., IN *JOURNAL OF TRAUMA: INJURY, INFECTION, AND CRITICAL CARE*, VOL. 45, NO. 2; AUGUST 1998

HOME ON THE RANGE near Kennesaw. In a recent survey of American gun owners, 88 percent said they bought handguns for self-defense, and many thought they could be targets of violent crime.

65,000 times a year. In 2015 Hemenway and his colleagues studied five years' worth of NCVS data and concluded that guns are used for self-defense in less than 1 percent of all crimes that occur in the presence of a victim. They also found that self-defense gun use is about as effective as other defensive maneuvers, such as calling for help. "It's not as if you look at the data, and it says people who defend themselves with a gun are much less likely to be injured," says Philip Cook, an economist at Duke University, who has been studying guns since the 1970s.

Kleck and Getz's survey and the NCVS differ in important ways that could help explain the discrepancy between them. The NCVS first establishes that someone has been the victim of an attack before asking about self-defense gun use, which weeds out yes answers from people who might, say, wave their gun around during a bar fight and call it self-defense. Kleck and Getz's survey could overestimate self-defense use by including such ambiguous uses. Kleck counters that the NCVS might underestimate self-defense because people who do not trust government surveyors will be afraid to admit that they used their gun. Yet people who participate in the NCVS are told at the start that they are protected under federal law and that their responses will remain anonymous.

A closer look at the who, what, where and why of gun violence also sheds some light on the self-defense claim. Most Americans with concealed carry permits are white men living in rural areas, yet it is young black men in urban areas who disproportionately encounter violence. Violent crimes are also geographically concentrated: Between 1980 and 2008, half of all of Boston's gun violence occurred on only 3 percent of the city's streets and intersections. And in Seattle, over a 14-year-period, every single juvenile crime incident took place on less than 5 percent of street segments. In other words, most people carrying guns have only a small chance of encountering situations in which they could use them for self-defense.

YET THESE NUMBERS DON'T RESONATE with many gun owners. "Absolutely, owning a firearm makes you safer," Phillips told me. Watkins opined that "by having a gun, it gives you the opportunity to refuse to be a victim." (Watkins, who used to be a cop in upstate New York, did later concede that guns are rarely shot in

self-defense, even by law enforcement.) In a June 2017 study, researchers surveyed American gun owners about why they owned handguns, reporting that 88 percent bought them for self-defense; many felt they were likely to become targets of violent crime at some point. This belief is so pervasive that companies have even started selling self-defense insurance. At the lecture I attended in Stone Mountain, a representative of Texas Law Shield, a firearms legal defense program, tried to get me to sign up for a service that would provide free legal representation in the event that I ever shot someone to protect myself. "You don't need it till you need it, but when you need it, you daggone sure glad you got it," he said.

But even as the belief that we are all future crime targets has taken hold, violent crime rates have actually dropped in the U.S. in recent decades. According to the FBI, rates were a whopping 41 percent lower in 2015 than they were in 1996. The NRA attributes this decrease to the acquisition of more guns. But that is misleading. What has increased is the number of people who own multiple guns—the actual number of people and households who own them has substantially dropped.

Recently researchers have tried to assess the value of self-defense gun use by studying "stand your ground" laws, which gained notoriety after teenager Trayvon Martin was killed by George Zimmerman in Florida in 2012. These laws allow people to kill in self-defense when they feel they are in danger. Progun groups argue that they should deter crime because criminals will know that victims have no reason not to fight back. But a January 2017 study reported that when "stand your ground" was passed in Florida, the monthly homicide rate went up by nearly a quarter. And a 2012 study found that states that adopted these laws experienced an abrupt and sustained 8 percent increase in homicides relative to other states. Mark Hoekstra, a co-author of the 2012 paper and an economist at Texas A&M University, put it this way: "We found that making it easier to kill people resulted in more dead people."

But some argue that even an unused gun can thwart crime. The logic here is that in areas with high rates of concealed carrying, criminals don't want to victimize people who might have guns, so they don't commit violent crimes. The most famous study, published in 1997 by John R. Lott, Jr., then a research fellow at the University of Chicago, and David B. Mustard, an economist now at the University of Georgia, looked at county crime rates in several states that had passed laws making it easy to get gun permits at various times prior to 1992. They compared such rates to crime levels in places that did not have easy access to guns during that period. Their hypothesis: when areas make it easier for people to get permits, more people will get guns and start carrying—and then violence will drop. Lott and Mustard developed a model, based on this comparison, that indicated that when it was easier to get permits, assaults fell by 5 percent, rapes by 7 percent and murders by 7.65 percent. Lott went on to publish a book in 1998 called *More Guns, Less Crime,* which tracked concealed carry laws and crime in more than 3,000 counties and reported similar findings.

Many other researchers have come to opposite conclusions. John Donohue, an economist at Stanford University, reported in a working paper in June 2017 that when states ease permit requirements, most violent crime rates increase and keep getting worse. A decade after laws relax, violent crime rates are 13

Gun Access Does Not Reduce Crime

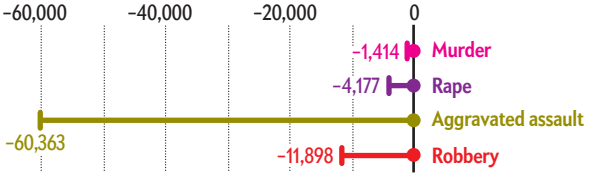
Gun advocates have argued that allowing more citizens to carry more guns—streamlining concealed carry permits—will deter crime. The idea rests largely on a controversial 1997 study that analyzed crime rates and concluded that criminal activity dropped when areas eased permit rules. But the study has been widely criticized and contradicted by other research.

High-Impact Study

The 1997 work by John R. Lott, Jr., now at the Crime Prevention Research Center, and David B. Mustard analyzed U.S. county crime data between 1977 and 1992. It found that murder rates dropped by 7.65 percent in 10 states after they made it easier to carry concealed weapons. The research calculated other crime rates decreased as well.

These figures are projections of the number of crimes that would have been avoided if all states had eased their permit laws in 1992, according to Lott and Mustard's model. Reviewers at the National Research Council concluded, however, that very tiny changes to the model created large variations in outcomes—either weakening or strengthening the link between permit laws and crime—so it was impossible to say with their model how permit law changes affect crime.

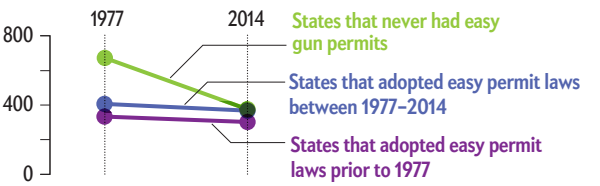
Projected Change in Number of Crimes If States without Easier Permit Laws in 1992 Had Adopted Such Laws (Estimates Using County-Level Data)



Contradictory Work

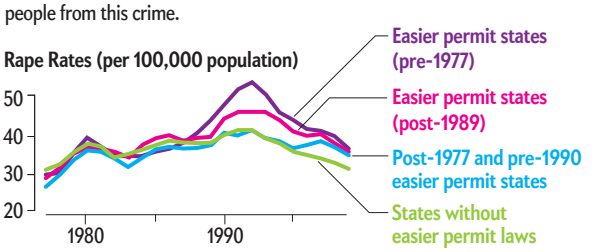
Research published this year explicitly gainsays Lott and Mustard's model. Economist John Donohue of Stanford University found that violent crime rates dropped dramatically in states that did not have easy-to-obtain gun permits but decreased just a little in states that allowed such permits.

Violent Crime Rates (per 100,000 residents)



Focusing on rape in a 2003 study, Donohue and his colleagues found no protective effect in states that made it easier to carry guns. Over a decade such states had similar or higher rape rates than did states that never eased gun permit laws. Laws that made it easier to carry guns did not protect people from this crime.

Rape Rates (per 100,000 population)



to 15 percent higher than they were before. And in 2004 the National Research Council, which provides independent advice on scientific issues, turned its attention to firearm research, including Lott's findings. It asked 15 scholars to reanalyze Lott's data because "there was such a conflict in the field about the findings," recalls panel chair and criminologist Charles Wellford, now a professor emeritus at the University of Maryland. Lott's models, they found, could be tweaked in tiny ways to produce big changes in results. "The analyses that we did, and that others have done, show that these estimates are very fragile," Wellford explains. "The committee, with one exception, concluded that you could not accept his conclusion that more guns meant less crime." Wintemute summarized it this way: "There are a few studies that suggest that liberalizing access to concealed firearms has, on balance, beneficial effects. There are a far larger number of studies that suggest that it has, on balance, detrimental effects."

OFF TARGET: This progun shirt, along with bumper stickers advocating that guns protect good people from crime, reflect a sentiment undercut by dozens of studies showing firearms are poor deterrents.

Lott, who now runs the nonprofit Crime Prevention Research Center, says the panel was biased and "set up to try to go against my work." The NRA takes a related tack: it says research highlighting the danger of weapons is part of a gun-control agenda to confiscate firearms.

It is crucial, though, to distinguish the leadership of progun organizations from their constituents, who often have more nuanced opinions. "I do own a firearm, I'm licensed, I'm actually able to train others in using a firearm—and my goal in life is to never, ever, ever have to use it," says Tina Monaghan, a city clerk in Nelson, Ga. (In 2013 Nelson, like Kennesaw, passed a law mandating that residents own guns, but the ordinance was relaxed later that year in response to a lawsuit.) According to a 2015 survey published by Johns Hopkins University researchers, 85 percent of gun owners support background checks for all gun sales, including sales through unlicensed dealers—even though the NRA strongly opposes them.

I HEARD A LOT MORE about divergence from NRA positions on my last stop in Alabama: Scottsboro Gun and Pawn, a shop perched at the end of Broad Street, one of the town's main drags. The co-owner, Robert Shook, told me about the ongoing push in the Alabama State Senate to eliminate concealed carry permits altogether, a move that would make it legal for anyone older than 18 to carry a hidden gun. (The bill passed in the Alabama Senate in April of this year but did not come up for a vote in the state's House of Representatives during the 2017 session.) "There's a lot of stuff that the NRA does that I don't agree with," he said, standing behind a glass case filled with handguns. "They've gone farther right than the other side left. They're throwing common sense out the window." Indeed, the NRA of today is actually more extreme than the organization used to be. In the 1930s NRA president Karl Frederick testified in Congress in support of the National Firearms Act, which restricted concealed carrying. "I do not believe in the general promiscuous toting of guns," Frederick said.

The belief that more guns lead to fewer crimes is founded on the idea that guns are dangerous when bad guys have them, so we should get more guns into the hands of good guys. Yet Cook, the Duke economist, says this good guy/bad guy dichotomy is a false and dangerous one. Even upstanding American citizens are only human—they can "lose their temper, or exercise poor judgment, or misinterpret a situation, or have a few drinks," he explains, and if they're carrying guns when they do, bad things can ensue. In 2013 in Ionia, Mich., a road rage incident led two drivers—both concealed carry permit holders—to get out of their cars, take out their guns and kill each other.

As I drove from Scottsboro to Atlanta to catch my flight home, I kept turning over what I had seen and learned. Although we do not yet know *exactly* how guns affect us, the notion that more guns lead to less crime is almost certainly incorrect. The research on guns is not uniform, and we could certainly use more of it. But when all but a few studies point in the same direction, we can feel confident that the arrow is aiming at the truth—which is, in this case, that guns do not inhibit crime and violence but instead make it worse.

The popular gun-advocacy bumper sticker says that "guns don't kill people, people kill people"—and it is, in fact, true. People, all of us, lead complicated lives, misinterpret situations, get angry, make mistakes. And when a mistake involves pulling a trigger, the damage can't be undone. Unlike my Glock-aided attack on the zombie at the gun range, life is not target practice. SA

SOURCES: "CRIME, DETERRENCE, AND RIGHT-TO-CARRY CONCEALED HANDGUNS," BY JOHN R. LOTT, JR., AND DAVID B. MUSTARD, IN *JOURNAL OF LEGAL STUDIES*, VOL. 26, NO. 1; JANUARY 1997; "RIGHT-TO-CARRY LAWS AND VIOLENT CRIME: A COMPREHENSIVE ASSESSMENT USING PANEL DATA AND A STATE-LEVEL SYNTHETIC CONTROLS ANALYSIS," BY JOHN J. DONOHUE, ABHAY ANEJA AND KYLE D. WEBER. NATIONAL BUREAU OF ECONOMIC RESEARCH WORKING PAPER NO. 23310. JUNE 2017; "SHOOTING DOWN THE 'MORE GUNS, LESS CRIME' HYPOTHESIS," BY IAN AYRES AND JOHN J. DONOHUE III, IN *STANFORD LAW REVIEW*, VOL. 55; APRIL 2003

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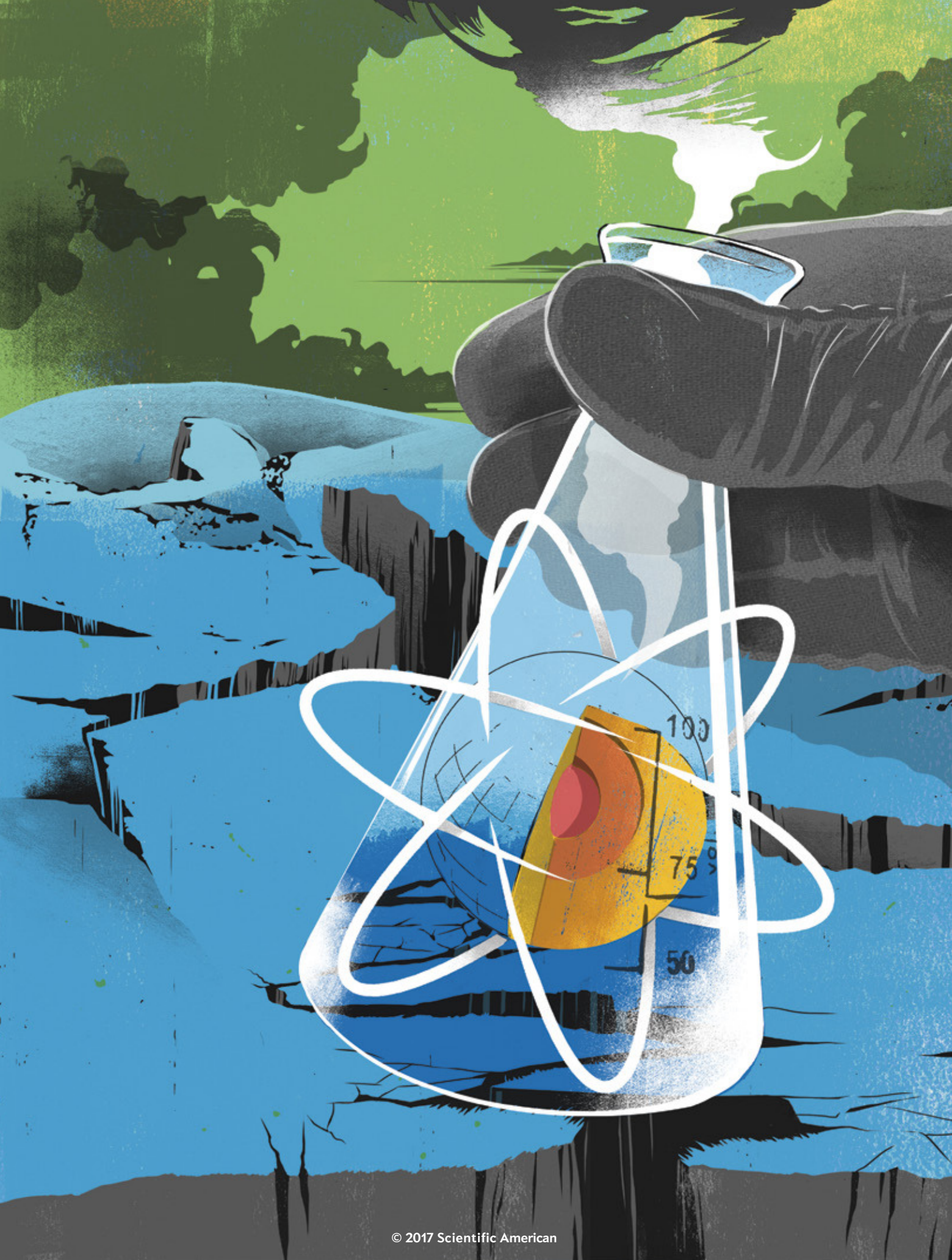
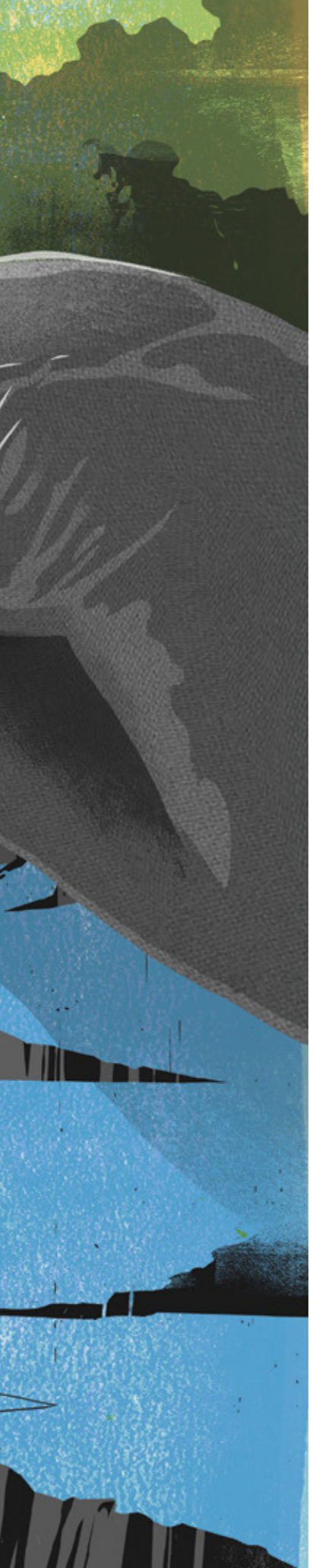




Reason on the Ropes

Elections, as they say, have consequences. In the U.S., the Trump administration threatens to roll back environmental protections, cut research funding and undermine the very concept of objective truth. The U.K.'s decision to leave the European Union is destabilizing science throughout Europe. Not everyone is moving backward: some nations, such as China, see opportunity in the upheaval. But it's safe to say that everyone with a stake in the future of science is asking themselves, What comes next?

IN BRIEF

It has been a grim year. In the U.S. and the U.K, tribalism and anti-intellectualism seem to have triumphed over facts and reason. The effects have rippled around the globe. Some nations, such as China, stand to benefit while historical science powerhouses stumble.

Moving forward will require understanding the cultural and psychological reasons people reject scientific thinking. Many researchers are reconsidering their traditional detachment from politics and learning that public opinion is a force to take seriously.

Illustrations by Jörn Kaspuhl

The Roots of Science Denial

It has nothing do with science itself

By Katharine Hayhoe, as told to Jen Schwartz

Although she's technically Canadian, atmospheric scientist Katharine Hayhoe might understand America's polarized attitudes toward science better than anyone. Her bona fides have serious range: she is co-director of the Climate Science Center and a political science professor at Texas Tech University, CEO of a climate-impact consulting group, creator of the myth-busting Web series Global Weirding *and an electric-car-driving evangelical Christian. Self-described as "on the fringes of many tribes," Hayhoe is equally adept at presenting to church groups and speaking on panels alongside people like Barack Obama and Leonardo DiCaprio. As a result, she has become one of the most lauded and sought-after climate communicators in the country—and the recipient of much hate mail. Hayhoe spoke with* Scientific American *about the war on facts and the forces driving climate skepticism. Edited excerpts from that conversation follow.*

Science denial is basically anti-intellectualism. It's a thread that has run though American society for decades, possibly even centuries. Back in 1980, Isaac Asimov said that it's "nurtured by the false notion that democracy means that 'my ignorance is just as good as your knowledge.'" Today we're dealing with its most recent manifestation, at its peak.

Climate change is a special case of science denial, which of course goes back to Galileo. The Catholic Church didn't push back on Galileo until he stuck his head out of the ivory tower and published in Italian rather than in Latin, so that he could tell the common people something that was in direct opposition to the church's official program. Same with Darwin. The church didn't have a problem with his theory of evolution until he published a popular book that everyone could read.

Similarly, we've known about the relationship between carbon dioxide and global warming since the 1890s. It's been about 50 years since scientists warned President Lyndon B. Johnson about the dangers of a changing climate. But scientists back then didn't get the deluge of hate mail that I get now. So what shifted? It started, possibly, with [Columbia University climate scientist] James Hansen's testimony before Congress in 1988. He announced that a resource we all rely on—and makes many of the world's biggest companies rich—is harming not just the environment but all of humanity. I think it's no accident that Hansen is the most vilified and attacked climate scientist in the U.S. because he was the first person to emerge from ivory tower and start talking about global warming in a sphere where its implications became apparent for policy and politics.

So you can see that the problem people have with science is never the actual science. People have a problem with the *implications* of science for their worldview and, even more important, for their ideology. When anti-intellectualism rises to the surface, it's because there are new, urgent results coming out of the scientific community that challenge the perspective and status quo of people with power. Renewable energy is now posing a very significant threat to them. The more viable the technologies, the greater the pushback. It's a last-ditch effort to resist change, which is why denial is at a fever pitch.

Today, although many of the objections to climate science are couched in science-y terms—*it's just a natural cycle, scientists aren't sure, global cooling, could it be volcanoes*—or even religious-y terms—*God is in control*—99 percent of the time, that language is just a smokescreen. If you refuse to engage these arguments and push through for even five minutes, the conversation will naturally lead to profound objections to climate change *solutions*.

WHAT'S REALLY AT PLAY

THE NUMBER-ONE QUESTION I get from people is, "Could you just talk to my father-in-law, my congressman, my colleague? If you just explain the facts to them, I'm sure it will change their mind." This is a trap. It turns us into Don Quixote, willing to tilt with these people and say, "Here's how we know it's not a natural cycle!" It almost never works. The only way to have a constructive dialogue with a dismissive person is on the level at which he or she really has the issue.

How did the narrative of climate change become a polarized, faith-based system? If we look at surveys, the level of political polarization in the U.S. now compared with 20 or 30 years ago is staggering. Polarization implies a rise in tribalism: an unthinking, unquestioning adherence to the tenets of my tribe. Unfortunately, because climate solutions appear to challenge the ideology of the right-hand side of the political spectrum, it's become one of the most polarized issues in the U.S. We've become so tribal that if you're on the left, it's like a statement of faith to say climate change is real. And if you're on the right, it's a tenet to say climate change isn't real. That's why this "belief" language has come in more naturally rather than artificially.

That said, climate change is deliberately framed as a false religion by those who want people of faith to reject it. You'll see some conservative politicians say, "I'm a true believer, I reject that God is not in charge." It's a very clever messaging technique because if I'm a Christian—and more than 70 percent of Americans are—I'm taught to beware of false prophets. Beware of people saying things that sound good but are actually leading you to worship the created instead of the creator, Earth instead of God.

After presentations to skeptical audiences, I've had people say to me, "You know, this makes sense, and I wish I could agree with you, but I just can't because that would mean I'm agreeing with Al Gore." Any perceived Earth worship immediately triggers an ingrained response to reject. One of the funny images I show in some of my talks is called the Church of Climatology, with Al Gore as the preacher, and other politicians and celebrities as the choir. Once somebody photoshopped my head onto

Polarization implies tribalism. We've become so tribal that if you're on the left, it's like a statement of faith to say climate change is real. And if you're on the right, it's a tenet to say it isn't real.

one of the choir members. And I thought it was absolutely hilarious because, yes, I get how people feel. We have to laugh together before we can move on to talk about beliefs versus evidence.

That's why Al Gore is one of the best and one of the worst messengers for climate change. The best because he's so passionate and informed and has such a great reach. At the same time—I know he recognizes this—in this politically polarized society, he firmly belongs to only one tribe. So by definition, it means the other tribe must reject him—and everything he stands for.

Climate change, of course, is also a tragedy of the commons, and it requires communal action. Yet the U.S. is the number-one most individualistic country in the world, founded on a revolt against big government and taxes. For many Americans, we have to talk more about market-based and technological solutions that appeal to their values instead of trying to change their identity. Take [Australian cognitive scientist] John Cook, who founded the blog Skeptical Science, which evaluates and pushes back on global warming denial. John couldn't even get his own father to accept climate change. But then his fiscally conservative dad used a rebate program to get solar panels on his house. He saved all kinds of money and started telling everyone how wonderful these panels are. And later, his dad says to John, "You know, this climate change thing, it's probably real, and I'm doing my part." He didn't need to be a wide-eyed tree hugger saving the whales; he could now align climate change with his own identity.

Even in the science community, there's so much confusion over how to communicate. The deficit model—just give them the facts!—does not work in public discourse unless everybody is politically neutral. That's why social science is increasingly important. I was the experimental method in a recent paper where a researcher asked me to speak at an evangelical Christian college. He asked the students about global warming before and after my talk and found statistically significant differences on their perspectives. Many people are now doing this kind of message testing. How humans interact with information is an emerging area of research that's desperately important.

Scientists also tend to understate the impact of climate change. We tend to, in the words of one researcher, "[err] on the side of least drama." We tracked 20 years' worth of studies and found that we systematically underestimate the rate and speed of change. Climate science is under such a microscope now that we like to be 99.9 percent sure of results before we say anything. But are we being too conservative? It's a challenge I confront every day.

THE WORK AHEAD

LOOK, WE CAN'T FIX ALL these issues—cultural, political, psychological—before we take necessary action on climate change. People say to me, "Well, if you could just get everyone onboard with the science…." I'm like, good luck with that! How did that work out the past few centuries? This climate problem is urgent. The window is closing. We have to fix it with the flawed, imperfect society we have today.

We have to start by asking what people's values are, where they're coming from, what they love, what they fear, what gets them up in the morning. I say, "We can agree to disagree, but don't you support solar energy bringing all these jobs to Texas? Did you know Fort Hood gets energy from solar because it's cheaper?" If someone thinks solar power protects us from immigrants or terrorists or the Antichrist, then great, fine. With some groups, I don't even use the words "climate" and "change" sequentially. With Christians, we talk about the Bible's message of stewardship. With libertarians, we talk about free-market strategies. With moms' groups, we talk about pollution affecting

our kids' health. With farmers, I say, "Hey, you're the backbone of our food system, how have drought patterns changed?" I don't validate the concept that there is a left and right side to climate science. And neither should the media. We should focus instead on solutions and impacts.

My number-one piece of advice for people doing climate—or any science—outreach is, Don't focus on the dismissive people. They're really a very small part of the population, and they're primarily older white men. Granted, the majority of them seem to be clustered in Washington, D.C., these days. Still, for people who react so emotionally, it's because they've staked their identity on that denial. It's as much a part of them as their kidneys or heart. When you're asking them to change their mind, you are literally seen as a threat. It's worth standing up to them in a public forum and saying, "You are lost. Here is the evidence." Not for the purpose of changing their mind but to show everybody else that we have answers.

Because here's the thing: If you look at Yale University's climate communication surveys, most Americans agree that climate change is real, that humans are causing it and that it's important to do something about it. But the number-one problem we're facing is that most Americans do not think climate change affects them personally. They think it's a problem for poor people in poor counties or for future generations. It's in our psychology to deny an overwhelming problem that isn't immediately bearing down on us. And until recently, we've been shielded by our infrastructure, our crop insurance and home insurance programs. Of course, all of that is up against the wall now, and it's my job to connect those dots.

That's why we [the authors of the government's National Climate Assessment] decided to write a supplemental Climate Science Special Report this year. It's the first time we've done it, and it's the most comprehensive, definitive report on climate change that the government has ever published. It's going through federal clearance now, slated for release in November, so we'll see what happens. [*Editors' note: A draft of the report was leaked to the press shortly after this interview was conducted.*] We made a lot of effort to write in a language that people can understand, and I think it really shuts down the whole "blue versus red" debate. It brings the science down to the level of where we live. You can see how climate change is affecting our food, water, economy, agriculture, infrastructure and security.

The goal of the report is to provide a scientific basis for anyone who wants to know both broadly and specifically why climate change matters to us, now. Many, many more people in this country are in the cautious, disengaged category, but they often seem very quiet. We have to filter out the noise from the dismissive people and talk with those who are lurking at the edges, listening, not sure what they think yet about what should be done but open to dialogue. So forget this elaborate smoke screen. By falling for the illusion that climate deniers can be convinced with more facts, we are distracted from engaging with a much larger group of people who want to understand why and how we should move forward with solutions. And that's exactly what the deniers want.

Jen Schwartz is senior editor for technology and mind for *Scientific American*.

Message Control

Scientists are trying new ways to win over a skeptical public

By Brooke Borel

In 1999 Robert Shapiro, then head of Monsanto, gave a stunning mea culpa at a Greenpeace conference in London. Monsanto's first genetically engineered (GE) crops had been on the market for only three years, but they were facing fierce public backlash. After a botched rollout marred by lack of transparency, the company, Shapiro said, had responded with debate instead of dialogue. "Our confidence in this technology … has widely been seen, and understandably so, as condescension or indeed arrogance," he said. "Because we thought it was our job to persuade, too often we've forgotten to listen."

The damage was already done. Fifteen years later only 37 percent of the Americans thought that GE foods were safe to eat, compared with 88 percent of scientists, according to the Pew Research Center. Regulatory bodies in the U.S. fought for years over whether and how to label GE foods. In 2015 more than half of the European Union banned the crops entirely.

Science doesn't happen in a vacuum. But historically, many researchers haven't done a great job of confronting—or even acknowledging—the entangled relation between their work and how it is perceived once it leaves the lab. "The dismal experience we had with genetically engineered foods was an object lesson in what happens when there's a failure to engage the public with accurate information and give them an opportunity to think through trade-offs for themselves," says R. Alta Charo, a bioethicist and professor of law at the University of Wisconsin–Madison. When communication breaks down between science and the society it serves, the resulting confusion and distrust muddies everything from research to industry investment to regulation.

In the emerging era of CRISPR and gene drives, scientists don't want to repeat the same mistakes. These new tools give researchers an unprecedented ability to edit the DNA of any living thing—and, in the case of gene drives, to alter the DNA of wild populations. The breakthroughs could address big global problems, curtailing health menaces such as malaria and breeding crops that better withstand climate change. Even if the expectations of CRISPR and gene drives do come to fruition—and relevant products are safe for both people and the environment—what good is the most promising technology if the public rejects it?

"Without transparency, we might see a kind of hyperpolarization," says Jason Delborne, a professor of science, policy and society at North Carolina State University. Concerned groups will feel marginalized, and advocates won't receive critical feedback need-

ed to improve design and safety. "This puts the technology at risk of a knee-jerk moratorium at the first sign of difficulty," he notes.

To avoid that outcome, some researchers are taking a new tack. Rather than dropping fully formed technology on the public, they are proactively seeking comments and reactions, sometimes before research even starts. That doesn't mean political and social conflict will go away entirely, Delborne says, "but it does contribute to a context for more democratic innovation." By opening an early dialogue with regulators, environmental groups and communities where the tools may be deployed, scientists are actually tweaking their research plans while wresting more control over the narrative of their work.

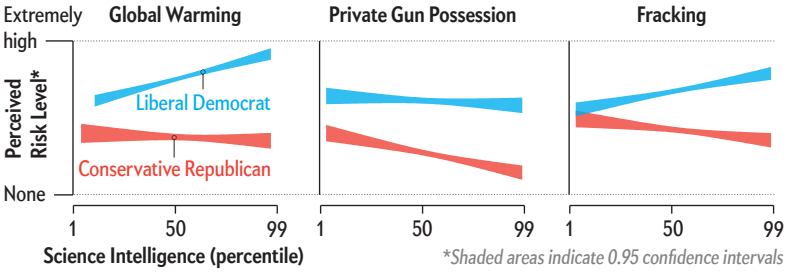
Take evolutionary geneticist Austin Burt. In 2003 he published the first theoretical paper on GE gene drives. Shortly after, with funding from the Bill & Melinda Gates Foundation, he and his colleagues launched a research project to see if gene drives could control *Anopheles* mosquitoes, which spread malaria. Back then, in the pre-CRISPR days, the technology was so speculative that doing outreach "didn't seem worth taking up people's time," Burt says. Now that a working gene drive may be ready for regulatory assessment within five years, it's essential to talk to communities where the technology may be deployed, he adds, "so we can make things that are going to be acceptable not just to regulators but to the public at large."

This push for reflection has especially come from those wielding the checkbooks. In 2016 the National Academies of Sciences, Engineering, and Medicine published *Gene Drives on the Horizon: Advancing Science, Navigating Uncertainty, and Aligning Research with Public Values.* The sponsors—various federal agencies, the Gates Foundation and the Foundation for the National Institutes of Health—specifically asked for comprehensive recommendations on ethics and public engagement, says Keegan Sawyer, project director for the report. Other National Academies reports have included these elements, but the combination that appeared in the gene drive report was "unusual," Sawyer says.

DARPA is among those listening to the guidelines. Its new Safe Genes initiative, which will fund seven research projects aimed at understanding how to deploy and control gene drives, requires all its projects to have thorough public engagement

The Deficient Deficit Model

The gold standard for science communication used to be the deficit model, which assumed that the key to acceptance was education. Just explain the science of vaccines or GMOs to the skeptical public, and distrust will fall away. But recent work by researchers, including Dan M. Kahan of Yale Law School, suggests a more complicated relation that involves personal identity and belief. Kahan's work shows that people with contrasting political values will draw different conclusions from the same evidence even when they are scientifically literate.



SOURCE: "WHAT IS THE 'SCIENCE OF SCIENCE COMMUNICATION'?" BY DAN M. KAHAN, IN *JOURNAL OF SCIENCE COMMUNICATION*, VOL. 14, NO. 3. PUBLISHED ONLINE AUGUST 25, 2015

Graphic by Amanda Montañez

plans. One DARPA grant recipient is a team at N.C. State, which includes Delborne. He is overseeing social engagement on a gene drive project that aims to remove invasive mice from remote islands to protect seabirds and other wildlife. Although the research is under way, Delborne says the partners "have been really clear since the very beginning that if people reject this technology for ethical reasons or because there are concerns about the risks—even if the scientists don't see it that way—there is essentially a pathway to no." Simply put, the scientists are willing to halt the project.

On the even more extreme end of this trend is Kevin Esvelt, an evolutionary engineer at the Massachusetts Institute of Technology. He's considering genetic technologies to alter wild mice so that they cannot carry and spread the pathogen that causes Lyme disease. Last year, before starting any work in the lab, Esvelt visited Lyme-plagued Nantucket, Mass., to gauge if residents would be interested in genetic approaches—including gene drives, although he advised against this option because he doesn't think it is suitable in this case. Nantucket followed Esvelt's lead on gene drives, although the community is exploring the possibility of an alternative technology to immunize mice against the pathogen.

Esvelt was addressing head-on a special ethical quandary of gene drives, which are designed to spread and persist in the shared environment: Who should get to decide whether and how to use such technology? "To me, it is mind-boggling that we got so much attention just for going to the communities before we did anything else," Esvelt says. "I think that says something about how science is typically done."

Whether the emergence of these efforts will reduce fear and skepticism "depends on how responsive the people listening to the engagement are to those concerns," says Jennifer Kuzma, co-director of the Genetic Engineering and Society Center at N.C. State. In other words, researchers must be willing not only to hear the public's confusion and pushback but also to adapt—even if that means shelving a technology they think could change the world.

Brooke Borel is a journalist and author who frequently reports on biotechnology.

Continental Divide

Brexit is already destabilizing science in the U.K.—and all of Europe

By Inga Vesper

British society has always prized the scientific mind, producing such luminaries as engineering whiz Isambard Kingdom Brunel, developmental biologist Anne McLaren and World Wide Web inventor Tim Berners-Lee. But in June 2016 the U.K.'s reputation as a future-looking nation suffered a devastating blow. Fifty-two percent of voters decided they wanted to leave the European Union, a club of nations that foster peace and economic growth. On March 29 the government officially started the exit, or "Brexit," process: a tangle of 143 British and E.U. negotiators must make some 1,000 changes to existing laws and determine what to do with the three million Europeans living in the U.K.—and the 1.2 million Brits living in the E.U. David Davis, the Brexit minister, has called this endeavor "as complicated as the moon landings."

Brexit voters framed their choice as a move toward sovereignty. But for scientists caught in the fray, the referendum sparked an ongoing nightmare of depleting talent, funding uncertainty, and turmoil that is both political and personal. "There isn't a clear plan," says Mike Galsworthy, an anesthetics researcher who co-founded the London-based pressure group Scientists for EU in the run up to the vote. "Britain is fundamentally less stable, and that makes it hard for scientists to have a career or do any long-term planning." An ongoing survey by the group found that more than a fifth of scientists said they were considering leaving the country or knew someone who was. The consequences of a scientist diaspora from the U.K. could throw the entirety of European research into disarray.

Brexit is exposing how modern science is an increasingly interconnected system in which political and societal shocks reverberate. One country's instability has repercussions for all its partners, as well as for the scientists who reside there, regardless of whether they are citizens or foreigners. Scientific work depends on collaboration, yet a central theme of Brexit is limiting free movement. As politicians pander to right-wing views on immigration by suggesting open borders hurt the U.K.'s economy, many scientists are reporting that their European partners are wary about working with, or in, the country. For example, Anne Glover, a biologist at the University of Aberdeen in Scotland and a former chief scientific adviser to the president of the European Commission, says that student intake from the E.U. is markedly down at Aberdeen and that some European staff have already left. Cesare Terracciano, an Italian cardiologist at Imperial College London, reports that discussions about collaborations between his institution and European laboratories have been put on hold. U.K. heads of European projects, such as Gerry Gilmore, who leads the European Commission's Optical Infrared Coordination Network for Astronomy, could lose their roles as institutions move to mainland Europe.

These anecdotes are borne out in numbers that are a harbinger of the chaos to come. According to the U.K. Office for National Statistics, a total of 117,000 Europeans permanently left the nation in 2016, a 36 percent increase compared with the previous

year. The science world looks to be particularly hard-hit: around 18 percent of those who hold non-British E.U. postdoctoral positions in the U.K. are looking for jobs elsewhere, according to a report for the British government's Science and Technology Select Committee. With the fall of the pound, postdoc salaries are now less competitive, especially compared with compensation in the U.S. The Higher Education Workforce Survey, released on July 31, found that about a third of universities reported a negative impact from Brexit on recruiting or retaining E.U. staff.

The fallout goes beyond practical logistics: a flagrant expression of anti-immigrant sentiments is also on the rise. Scientists for EU says that some researchers have been abused in the streets and that their children have been bullied at school. "They are now mindful of their accent or the language that they speak with their kids, so it's a much more uncomfortable environment," Galsworthy says. For German-born Stefan Söldner-Rembold, who heads the particle physics department at the University of Manchester, these "soft" factors can be just as powerful as financial decisions when it comes to deciding where to pursue a career. "There are difficulties for colleagues, whose families are being told, 'Why are you still here?'" he says. "You want to make sure your kids and partner have a perspective in this country. Right now that's not clear."

EXPOSING FRAGILITY

A MAJOR THREAT to the continuity of European science is the question of the U.K.'s membership in the 33-year-old E.U. framework for funding research. Horizon 2020, the program's current installment, has a hefty budget of €80 billion to be allocated between 2014 and 2020; its successor, Framework Program 9, is pegged at €120 billion. The U.K. is one of its most successful participants and has received about 15.5 percent of Horizon 2020's total awarded funds so far.

Horizon 2020 is open only to E.U. member states or associated countries, such as Norway. If a non-E.U. country wants access, it must pay a share into the common pot based on its gross domestic product. The political mood in the U.K. is such that any payments to the E.U. post-Brexit will be aggressively opposed. Under Prime Minister Theresa May, the government has tried to reassure scientists by saying any potential loss of funding would be matched with homegrown money. But scientists are not buying it. "Looking at the state of the British economy, this funding will likely not be replaced in the same way," Söldner-Rembold says.

Glover, who has been involved in multiple Horizon 2020 projects, asserts that the program's value goes beyond money. When she works with the U.S., for instance, scientists from each country have to submit separate bids and hope that both get green-lit. But Horizon 2020 members can whip up a single application for each project. "It allows me to work seamlessly with colleagues in, say, Estonia or Italy," Glover says. "Science is an international pursuit. You can't hope to be at the leading edge of achievements if you cannot collaborate freely with the best in the world." And, Galsworthy adds, if freedom-of-movement restrictions affect permits and visas, "it could well mean we will be cut out of Horizon 2020."

With that potential outcome on the horizon, neighboring competitors—as well as emerging science giants such as China and India—are eager to welcome scientists fleeing from the U.K.

The nation may produce some of the highest-quality papers in the world, but other E.U. countries are catching up in terms of both publication volume and esteem. The E.U. now produces 34 percent of global research output, and countries such as Germany, France, Sweden and the Netherlands see Brexit as an opportunity to poach talent.

Indeed, the U.K.'s science is excellent but fragile. With a population of just 65 million, the country is fairly small, and its labs rely on teams of handpicked, international experts, with 20 percent of its scientists coming from the E.U. Lose one hyperspecialized expert, and an entire organization might fall apart. According to the lobby group Universities UK, more than half of the U.K.'s research output stems from international collaborations, compared with less than 40 percent in the U.S. Shocks to its system could destroy the country's leadership position.

The idea, however, that what hurts the U.K. will somehow elevate its neighbors is preposterous, says Thomas Jørgensen, senior policy coordinator at the European University Association, an interest group for universities. The U.K. hosts some of Europe's best scientific institutions, including the University of Oxford and the University of Cambridge, which regularly top global rankings. (Both universities get around 13 percent of their research funding from the E.U.) The British science system is unique in Europe, not least because it uses a language that nearly every European child learns in school. "Britain does well because its research environment relies on an infinite amount of variables that you cannot simply re-create," Jørgensen explains. "Science is not a factory. You cannot just take it somewhere else." He fears the damage from turning off the talent tap will weaken the scientific competitiveness of the entire continent: "On the systemic level, diminishing the strongest partner is bad for everybody."

Now many universities, often accused of being detached from the hullabaloo of emotionally driven politics, are acknowledging they are painfully dependent on it. Scientists for EU is pushing to ensure that the British government uses empirical facts to facilitate Brexit, but it is an uphill struggle in a political climate dominated by slogans and misinformation. Late last year the Science and Technology Select Committee recommended that the newly founded Department for Exiting the European Union take on a chief scientific adviser to provide fact-based evidence around Brexit. That post remains unfilled. Of course, Brexit was never about facts and logic. The referendum narrowly won on a narrative of hurt pride and citizens feeling shortchanged. Subsequently, in a strange reversal, frustrated European scientists are voting "leave" with their feet.

Terracciano, the cardiologist from Italy, has spent many sleepless nights worrying about British science, which, he fears, is on the brink of a vicious cycle. The potential loss of funding, coupled with a damaged reputation, makes the country less attractive for research, which will in turn compound the loss of talent, he says. Yet Terracciano understands what is motivating his fellow Europeans to seek new research homes. "People are leaving because their years of service and dedication are unrecognized," he says. "We are all angry that we have invested in the wrong horse."

Inga Vesper is a German-British journalist based in London who specializes in climate, environment and politics. She has covered E.U. science for 10 years.

China's Moment

Seeing a chance to lead, China is deploying clean energy, quantum satellites and genomics

By Lee Billings

In June, when U.S. president Donald Trump announced he would withdraw from the Paris climate accord, all eyes anxiously looked to China. Without participation from the nation that historically has been the world's biggest polluter, pundits worried President Xi Jinping would see a way out of his country's carbon-reduction pledge, and the deal would unravel. Instead Xi, a former chemist, staunchly reaffirmed his country's commitment to investing in renewable energy and meeting its emissions goals. In fact, China is already blowing past some of its targets.

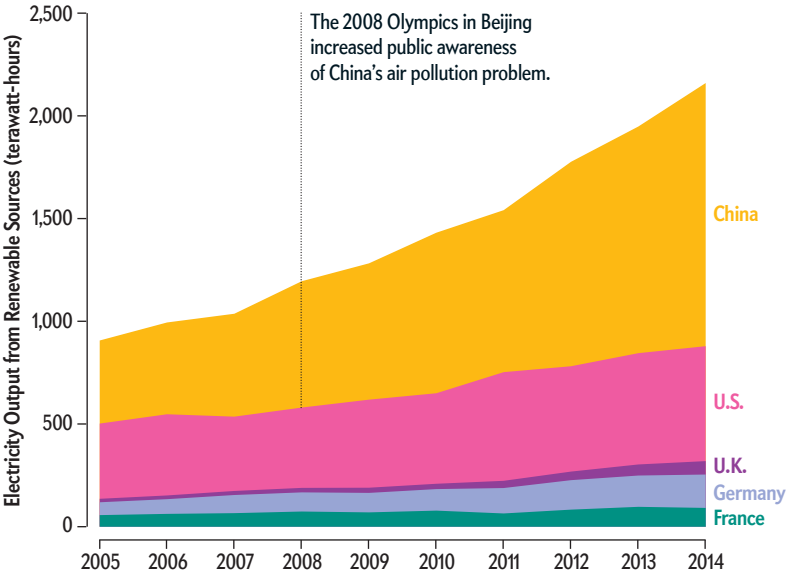
Innovating with solar cells and next-generation nuclear reactors is just one part of China's massive investment in scientific research. If technological development is increasingly an engine for economic growth and national strength, then support for basic research and applied science is its fuel. For much of the past century the U.S. maintained dominance in this arena. But as the current administration attempts to reinvigorate the coal industry, slashes research budgets, questions the value of the Environmental Protection Agency and discounts evidence-based policy making—willfully ceding the mantle of global scientific leadership—China is rushing to fill the void, with potentially profound consequences for the world.

"The development of Chinese technology will have benefits for everyone," says Robert Daly, director of the Kissinger Institute on China and the United States at the Woodrow Wilson International Center for Scholars in Washington, D.C. "But as China increases its comprehensive national power, it is increasingly able to shape a global environment that is more amenable to the goals of the Chinese Communist Party and its illiberal ideas about how individuals, institutions and information relate to the state." That includes the thorny issues of regulation and intellectual property, which are much looser in China than in the West.

The backbone of China's rise in this realm is its 13th "Five-Year Plan," which counts on scientific research and technology to be key drivers of economic growth. The result is a staggering $1.2 trillion devoted to R&D between 2016 and 2020. Of that, $373 billion is slated to go to renewable energy alone. Additionally, a 10-year "Made in China 2025" initiative sup-

Green Motivation

Much of China's push toward developing renewable energy can be seen as a response to rising social unrest over dangerous levels of pollution. With rampant industrialization came rampant environmental degradation, including cities clogged with sooty air. But that is not the only motivation. China also sees an opportunity to develop and deploy renewable energy technologies that, presumably, many nations will want in the near future for carbon mitigation. That is partly why Bill Gates's nuclear reactor company, TerraPower, partnered with China. The interest, investment and timeliness simply did not exist at home.



SOURCE: INTERNATIONAL ENERGY AGENCY

ports progress in areas such as artificial intelligence, cloud computing, robotics, biotechnology and electric vehicles.

These plans are bearing fruit. In terms of relative purchasing power, China currently spends more on research and development than the European Union. And according to the Organisation for Economic Co-operation and Development, it is on track to surpass U.S. spending by 2020. In the past decade China's contributions to the world's total volume of research articles has surged from 13 to 20 percent, and today only the U.S. generates more high-quality scientific papers. It now lays claim to the world's longest electric high-speed rail network, the largest radio telescope and the top two fastest supercomputers. It is launching a carbon-emissions cap-and-trade market this year that will dwarf the planet's largest one, in the E.U. Also the top producer of rare earth metals for high-tech manufacturing, China leads the globe in solar, wind and hydropower capacity and is or will soon be the strongest market for goods such as electric cars, nuclear reactors, smart devices, industrial robots and 3-D printers.

China still faces obstacles. Daly says its higher-education system is "lousy at spurring creative thinking." Writing in 2016 in *Nature,* Wei Yang, president of the National Natural Science Foundation of China, acknowledged criticisms "that China's universities have become paper mills induced by metrics that value quantity over quality." Yet China continues to establish sweeping science programs and build gargantuan facilities. One prominent example is Shenzhen-based BGI (formerly the Beijing Genomics Institute), by many metrics the largest gene-sequencing company in the world. BGI's 5,000 workers in 47 laboratories aim to sequence the genomes of as many organisms as possible, from ancient hominins to rice to giant pandas. In July, after a successful pilot project, it announced plans to sequence 10,000 plant and microbe genomes—potentially unleashing a flood of data that could revolutionize the field.

China's motivation to lead in science goes beyond prestige and revenue. Consider the case of its Quantum Experiments at Space Scale (QUESS) satellite, a spacecraft the nation launched in 2016 as part of a broader program of space science missions. In low Earth orbit, QUESS's specialized system of lasers and optics tests the fundamentals of quantum mechanics. But the satellite's most noteworthy achievement, reported this past June, involved the first ever transmission of entangled photons to ground stations separated by a distance of 1,200 kilometers. A network of such satellites could form the backbone of an unhackable quantum communications network.

Some in the West may view China's growing power as a geopolitical threat. It is true that "China is undertaking a series of massive state-led investments that happen to be occurring while the U.S. is losing its appetite for risk," says Ben Shobert of the National Bureau of Asian Research in Seattle. But China's R&D-fueled rise is, at this point, inevitable, says Michael O'Hanlon of the Brookings Institution in Washington, D.C. "Impressive budgets for scientific research and technology development are the next stage in becoming a great power," he adds. "It's not a phase—it's a new reality. They're going to keep pushing forward without letting up. And if I were in their shoes, I wouldn't, either."

Lee Billings is an associate editor for *Scientific American.* He covers space and physics.

MORE TO EXPLORE

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FROM OUR ARCHIVES

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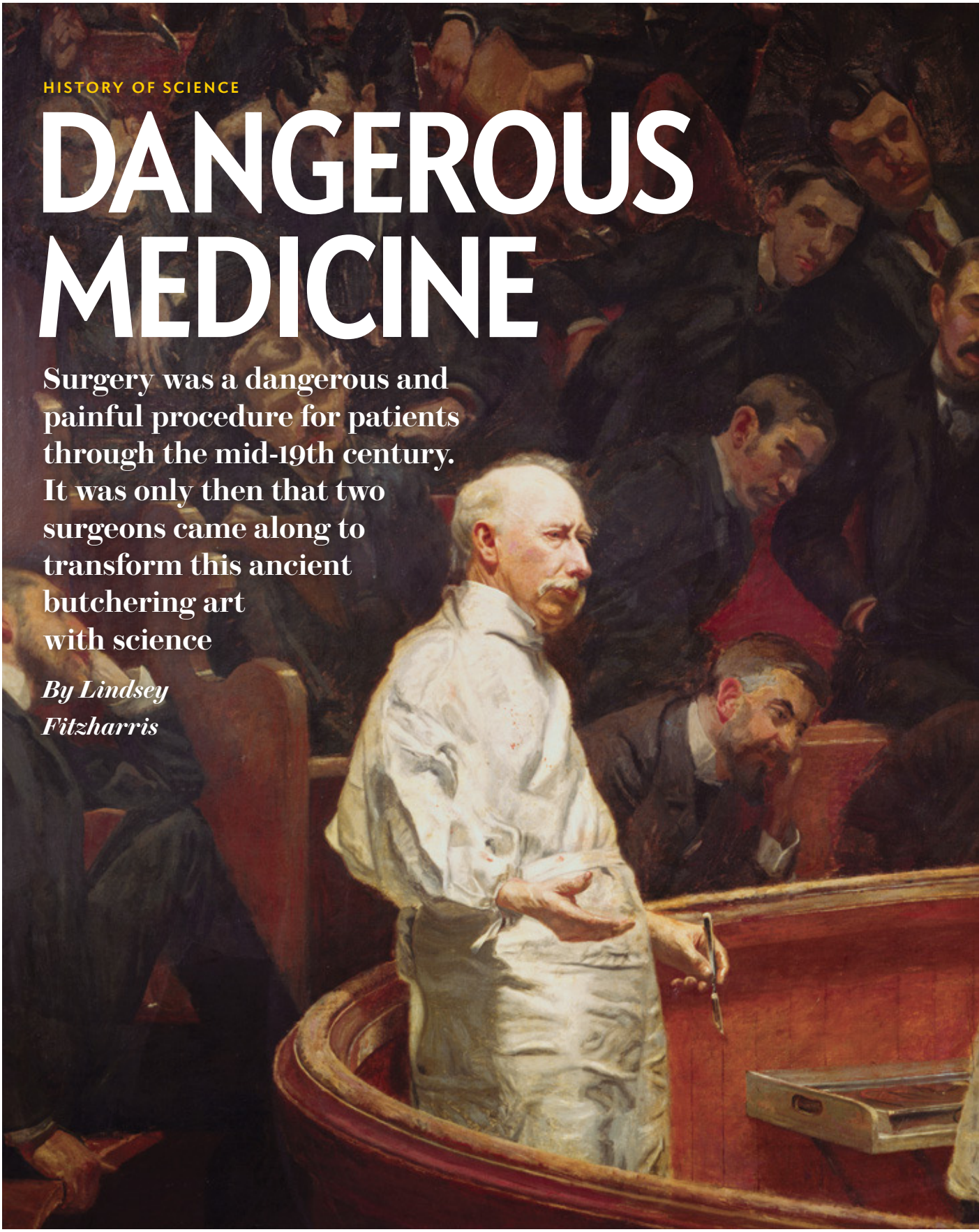
Graphic by Amanda Montañez



HISTORY OF SCIENCE

DANGEROUS MEDICINE

Surgery was a dangerous and painful procedure for patients through the mid-19th century. It was only then that two surgeons came along to transform this ancient butchering art with science

By Lindsey Fitzharris

THE AGNEW CLINIC, an 1889 painting by Thomas Eakins, depicts an American operating theater after the arrival of anesthetic surgery.

Lindsey Fitzharris, author of *The Butchering Art*, is a medical historian who runs Web sites and video series dedicated to the little-known stories behind the history of medicine. She has written for the *Lancet*, *New Scientist* and other publications.

As the veteran surgeon Robert Liston stood before those gathered in the new operating theater of University College London a few days before Christmas 1846, he held in his hands the jar of clear liquid ether that might do away with the need for speed in surgery. If it lived up to American claims, the nature of surgery might change forever. Still, Liston couldn't help wondering whether the ether was just another product of quackery that would have little or no useful application in surgery.

Tensions were high. Just 15 minutes before Liston entered the theater, his colleague William Squire had turned to the packed crowd of onlookers and asked for a volunteer to practice on. A nervous murmur filled the room. In Squire's hand was an apparatus that looked like an Arabian hookah made of glass with a rubber tube and bell-shaped mask. The device had been fashioned by Squire's uncle Peter, a pharmacist in London, and used by dental surgeon James Robinson to extract a tooth just two days prior. It looked foreign to those in the audience. None dared volunteer to have it tested on them.

Exasperated, Squire finally ordered the theater's porter Shelldrake to submit to the trial. He wasn't a good choice, because, as retired surgeon Harold Ellis wrote, he was "fat, plethoric, and with a liver no doubt very used to strong liquor." Squire gently placed the apparatus over the man's fleshy face. After a few deep breaths of ether, the porter reportedly leaped off the table and ran out of the room, cursing the surgeon and crowd at the top of his lungs.

There would be no more tests. The unavoidable moment had arrived.

END OF AGONY

At 25 minutes past two in the afternoon, Frederick Churchill—a 36-year-old butler from Harley Street—was brought in on a stretcher. The young man had been suffering from chronic osteomyelitis of the tibia, a bacterial bone infection, which had caused his right knee to swell and become violently bent. His first operation came three years earlier, when the inflamed area was opened up and, as a 1915 article in the *American Journal of Surgery* would describe, "a number of irregularly shaped laminated bodies" ranging from the size of a pea to that of a large bean were removed. On November 23, 1846, Churchill was once again back in the hospital. A few days later Liston made an incision and passed a probe into the knee. Using his unwashed hands, Liston felt for the bone to ensure it wasn't loose. He ordered that the opening be washed with warm water and dressed and that the patient be allowed to rest. Over the next few days, however, Churchill's condition deteriorated. He soon experienced sharp pain that radiated from his hip to his toes. This occurred again three weeks later, after which Liston decided the leg must come off.

Churchill was carried into the operating theater on a stretcher and laid out on the wooden table. Two assistants stood nearby in case the ether did not take effect and they had to resort to restraining the terrified patient while Liston removed the limb. At Liston's signal, Squire stepped forward and held the mask over Churchill's mouth. Within a few minutes the patient was unconscious. Squire then placed an ether-soaked handkerchief over Churchill's face to ensure he wouldn't wake during the operation. He nodded to Liston and said, "I think he will do, sir."

Liston opened a long case and removed a straight amputation knife of his own invention. An observer in the audience that afternoon noted that the instrument must have been a favorite, for on the handle were little notches showing the number of times he had used it before. Liston grazed his thumbnail over the blade to test its sharpness. Satisfied that it would do the job, he instructed his assistant William Cadge to "take the artery" and then turned back to the crowd.

"Now, gentlemen, time me!" he yelled. A ripple of clicks rang out as pocket watches were pulled from waistcoats and flipped open.

Liston turned back to the patient and clamped his left hand around the man's thigh. In one rapid movement, he made a deep incision above the right knee. One of his assistants immediately tightened a tourniquet around the leg to halt the flow of blood, while Liston pushed his fingers up underneath the flap of skin to pull it back. The surgeon made another series of quick maneuvers with his knife, exposing the thighbone. He then paused.

Many surgeons, once confronted with exposed bone, felt daunted by the task of sawing through it. Earlier in the century Charles Bell cautioned students to saw slowly and deliberately. Even those who were adept at making incisions could lose their nerve when it came to cutting off the limb. In 1823 Thomas Alcock proclaimed that humanity "shudders at the thought, that men unskilled in any other tools than the daily use of a knife and fork, should with unhallowed hands presume to operate upon their suffering fellow-creatures." He recalled a spine-chilling story about a surgeon whose saw became so tightly wedged in the bone that it wouldn't budge. His contemporary William Gibson ad-

IN BRIEF

Until the mid-19th century, surgery meant almost certain agony for the patient.
With the adoption of ether as a general anesthetic, more surgical procedures were performed, but the rates of infection and complications also increased.
After witnessing the start of painless surgery as a young medical student, Joseph Lister began his quest to find a way to operate without placing patients in postoperative peril.

PRECEDING PAGES: GEOFFREY CLEMENTS *Getty Images (photograph)*

vised that novices practice with a piece of wood to avoid such nightmarish scenarios.

Liston handed the knife to one of the surgical dressers, who, in return, handed him a saw. The same assistant drew up the muscles, which would later be used in forming an adequate stump for the amputee. The great surgeon made half a dozen strokes before the limb fell off, into the waiting hands of a second assistant, who promptly tossed it into a box full of sawdust just to the side of the operating table.

Meanwhile the first assistant momentarily released the tourniquet to reveal the severed arteries and veins that would need to be tied up. In a midthigh amputation, there are commonly 11 to secure by ligature. Liston closed off the main artery with a square knot and then turned his attention to the smaller blood vessels, which he drew up one by one using a sharp hook called a tenaculum. His assistant loosened the tourniquet once more while Liston stitched together the remaining flesh.

It took all of 28 seconds for Liston to remove Churchill's right leg, during which time the patient neither stirred nor cried out. When the man awoke a few minutes later, he reportedly asked when the surgery would begin and was answered by the sight of his elevated stump, much to the amusement of the spectators who sat astounded by what they had just witnessed. His face alight with the excitement of the moment, Liston announced, "This Yankee dodge, gentlemen, beats mesmerism hollow!"

The age of agony was nearing its end.

Two days later surgeon James Miller read a hastily penned letter from Liston to his medical students in Edinburgh, "announcing in enthusiastic terms, that a new light had burst on Surgery." During the first few months of 1847 both surgeons and curious celebrities visited operating theaters to witness the miracle of ether. Everyone from Sir Charles Napier, colonial governor of what is now a province of Pakistan, to Prince Jérôme Bonaparte, the youngest brother of Napoleon I, came to see the effects of ether with their own eyes.

The term "etherization" was coined, and its use in surgery was celebrated in newspapers around the country. News of its powers spread. "The history of Medicine has presented no parallel to the perfect success that has attended the use of ether," the *Exeter Flying Post* proclaimed. Liston's success was also trumpeted in the London *People's Journal:* "Oh, what delight for every feeling heart … the announcement of this noble discovery of the power to still the sense of pain, and veil the eye and memory from all the horrors of an operation … WE HAVE CONQUERED PAIN."

UNSEEN FOE

EQUALLY MOMENTOUS to Liston's triumph with ether was the presence that day of a young man named Joseph Lister, who had seated himself quietly at the back of the operating theater. Dazzled and enthralled by the dramatic performance he had just witnessed, this aspiring medical student realized that the nature of his future profession would forever be changed as he walked out of the theater onto Gower Street. No longer would he and his classmates have to behold "so horrible and distressing a scene" as that observed by William Wilde, a surgical student who was reluctantly present at the excision of a patient's eyeball without anesthetic. Nor would they feel the need to escape, as surgeon John Flint South had done whenever the cries of those being butchered by a surgeon grew intolerable.

Nevertheless, as Lister made his way through the crowds of men shaking hands and congratulating themselves on their choice of profession and this notable victory, he was acutely aware that pain was only one impediment to successful surgery.

He knew that for thousands of years the ever looming threat of infection had restricted the extent of a surgeon's reach. Entering the abdomen, for instance, had proved almost uniformly fatal because of it. The chest was also off-limits. For the most part, whereas physicians treated internal conditions—hence the term "internal medicine," which still persists today—surgeons dealt with peripheral ones: lacerations, fractures, skin ulcers, burns. Only with amputations did the surgeon's knife penetrate deep into the body. Surviving the operation was one thing. Making a full recovery without any complications was another.

As it turned out, the two decades immediately after the popularization of anesthesia saw surgical outcomes worsen. With their newfound confidence about operating without inflicting pain, surgeons became ever more willing to take up the knife, driving up the incidences of postoperative infection and shock. At Massachusetts General Hospital, for instance, mortality rates for amputations went from 19 percent before ether to 23 percent afterward. Operating theaters became filthier than ever as the number of surgeries rose. Surgeons still lacking understanding of the causes of infection would operate on multiple patients in succession using the same unwashed instruments. The more crowded the theater became, the less likely it was that even the most primitive sanitary precautions would be taken. Of those who went under the knife, many either died or never fully recovered and then spent their lives as cripples and invalids. This problem was universal. Patients worldwide came to further dread the word "hospital," while the most skilled surgeons distrusted their own abilities.

With Robert Liston's ether triumph, Lister had just witnessed the elimination of the first of the two major obstacles to successful surgery—that it could now be performed without pain. Inspired by what he had seen on the afternoon of December 21—but mindful of the dangers still hindering his profession—the deeply perceptive Joseph Lister would soon embark on devoting the rest of his life to elucidating the causes and nature of postoperative infection and finding a solution for it. In the shadow of one of the profession's last great butchers, another surgical revolution was about to begin. SA

MORE TO EXPLORE

Historical Development of Modern Anesthesia. Daniel H. Robinson and Alexander H. Toledo in *Journal of Investigative Surgery,* Vol. 25, No. 3, pages 141–149; 2012.

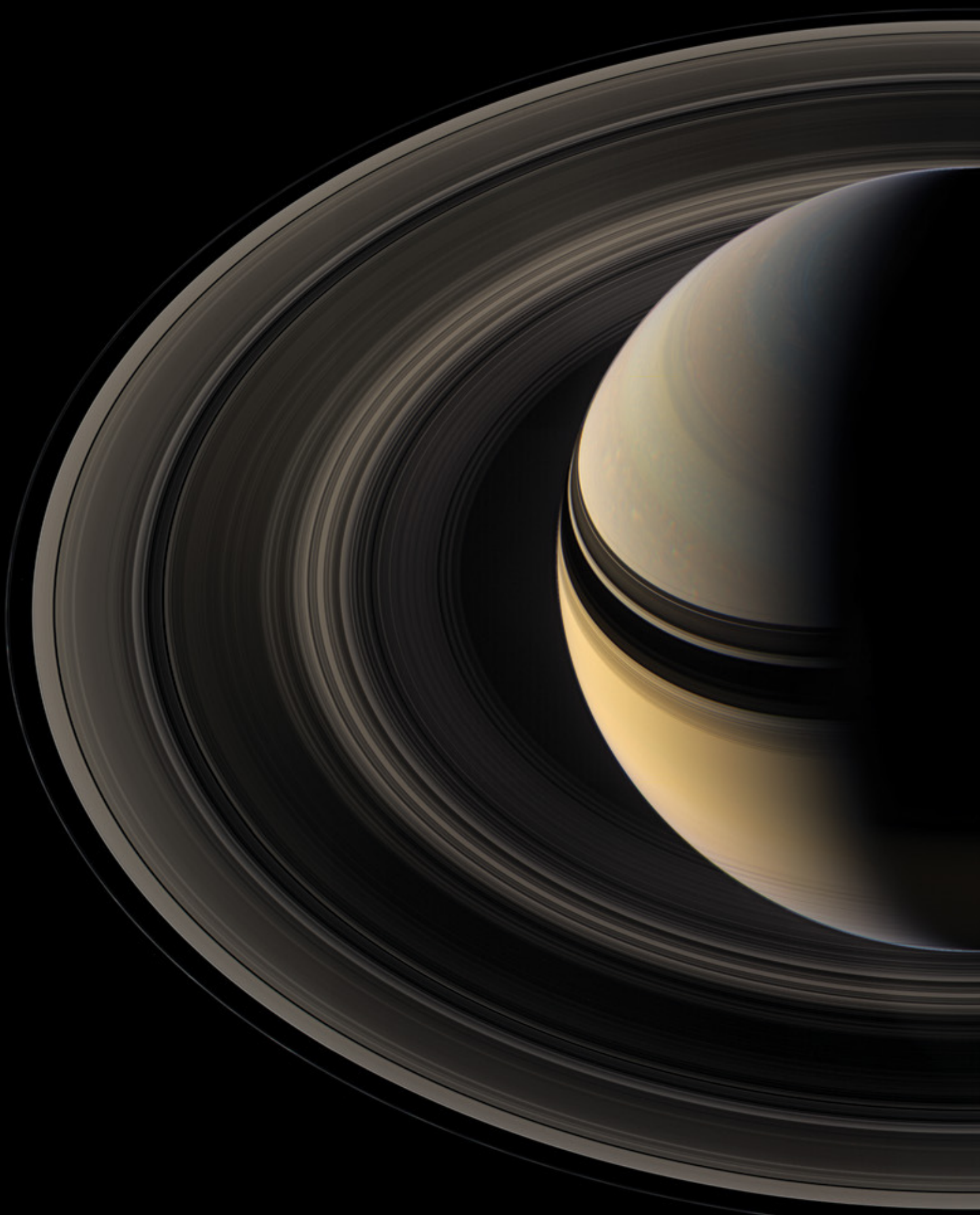
Mangling the Dead: Dissection, Past and Present. Lindsey Fitzharris in *Lancet,* Vol. 381, pages 108–109; January 12, 2013.

Joseph Lister and the Performance of Antiseptic Surgery. Michael Worboys in *Notes and Records,* Vol. 67, No. 3, pages 199–209; September 20, 2013.

FROM OUR ARCHIVES

The Late Joseph Lister. John B. Huber; February 24, 1912.

scientificamerican.com/magazine/sa



PLANETARY SCIENCE

CASSINI AT SATURN

A historic exploration of the ringed planet, unprecedented in magnitude and spectacle, comes to an end

By Carolyn Porco

Carolyn Porco is a planetary scientist at the Space Science Institute in Boulder, Colo., and leader of the Cassini mission's imaging team. She is a visiting scholar at the University of California, Berkeley, and a member of *Scientific American*'s board of advisers. This article was written, in part, while she was the science writer in residence at the Huntington Library, Art Collections, and Botanical Gardens in San Marino, Calif.

SOME EVENING WHEN SATURN IS HIGH IN THE SKY and the night is clear and dark, take a look through a backyard telescope. When you have had your fill of the planet's awe and beauty, search online for images that NASA's Cassini spacecraft has returned over the past 13 years in its travels around this ringed wonder. It will likely hit you hard: how far we have traveled, how proficient we have become as interplanetary explorers and how extraordinary an accomplishment it has been to come so intimately to know a world as distant as Saturn.

As of this writing, Cassini is scheduled to end its travels around Saturn in mid-September by diving, on command, into the planet's atmosphere. It will be incinerated in a fireball that likely no one will see, ensuring that it will never accidentally hit and thereby contaminate any Saturnian moons that might harbor conditions suitable for life.

As the leader of the mission's imaging team, I, along with many of my colleagues on both sides of the Atlantic, began working on Cassini in late 1990, when it was still nothing more than an idea, a vision in the mind. I saw it through the planning and construction process, watched in person as the spacecraft launched on October 15, 1997, from Cape Canaveral, Fla., endured its seven-year voyage to Saturn and had a front-row seat as it arrived at its final destination in 2004. There and then Cassini began revolutionizing our view of Saturn and everything that surrounds it.

No mission has ever explored a planetary system as rich as Saturn's in such depth for so long. On its moon Titan, we found seas of hydrocarbons and a surface environment whose complexity rivals that of Earth. We observed the meteorology of Saturn's atmosphere and witnessed the birth, evolution and demise of giant storms. We saw new phenomena in Saturn's rings that told of the processes involved in the formation of solar systems, including our own. Like the cartographers of old, we mapped the moons of Saturn for future explorers and uncovered new ones, including an entire class of small bodies embedded within the rings themselves. And then there is what I regard as Cassini's most profound discovery of all: at the south pole of the moon Enceladus, more than 100 geysers spouting from an underground ocean that could be home to extraterrestrial organisms. For 13 years my life has been lived out there in the outer reaches of the solar system. And now that bountiful scientific expedition has come to an end.

AN INTIMATE VIEW

THE NEED FOR A DETAILED, comprehensive examination of the Saturn system became clear during the early 1980s, after the two Voyager spacecraft made flybys of the planet. These celebrated events were the opening acts in the story of humanity's exploration of Saturn. They gave the planet dimension and personality but left behind questions that demanded answers. Voyager found Saturn to be a planet with a complex interior, atmosphere and magnetosphere. In its rings—a vast, gleaming disk of icy rubble—the mission recorded signs of the same physical mechanisms that were key in configuring the early solar system and similar disks of material around other stars. Voyager's passage through Saturn's inner system exposed diverse moons with dynamic forces at work. Titan, Saturn's largest moon, whose surface remained invisible through its thick, ubiquitous haze, nonetheless teased observers with hints of a possible ocean of liquid hydrocarbons. Altogether the Saturn system seemed an ideal destination for further in-depth study and exploration.

Cassini was an international undertaking, led by NASA and the European Space Agency and designed to be, in every dimension, a dramatic advance over Voyager. At the size of a school bus, it was bigger than Voyager and outfitted with the most sophisticated scientific instruments ever carried into the outer solar system. Cassini also carried the Huygens probe—a four-meter-wide, aerodynamically shaped device, equipped with a six-instrument payload, that descended to the surface of Titan.

After traversing the solar system, Cassini flawlessly took up residence around Saturn on June 30, 2004. Its trajectory around Saturn was both convoluted and precise, unfurling over the course of

IN BRIEF

After 13 years in Saturn's orbit, the Cassini spacecraft ended its mission in September 2017 by making a planned dive into the planet's atmosphere.
Over the course of its voyage Cassini surveyed Saturn's atmosphere, rings and moons in exquisite detail. In 2005 Cassini's Huygens probe descended to the surface of Saturn's moon Titan.
Among its many discoveries, Cassini found liquid-methane lakes on Titan and a buried liquid-water ocean on the moon Enceladus that escapes to the surface via geysers. Scientists suspect this underground sea might be capable of hosting alien life.
Cassini also uncovered mountainous waves of rubble and "moonlets" in Saturn's rings and an effect that turns its atmosphere blue in the winter.

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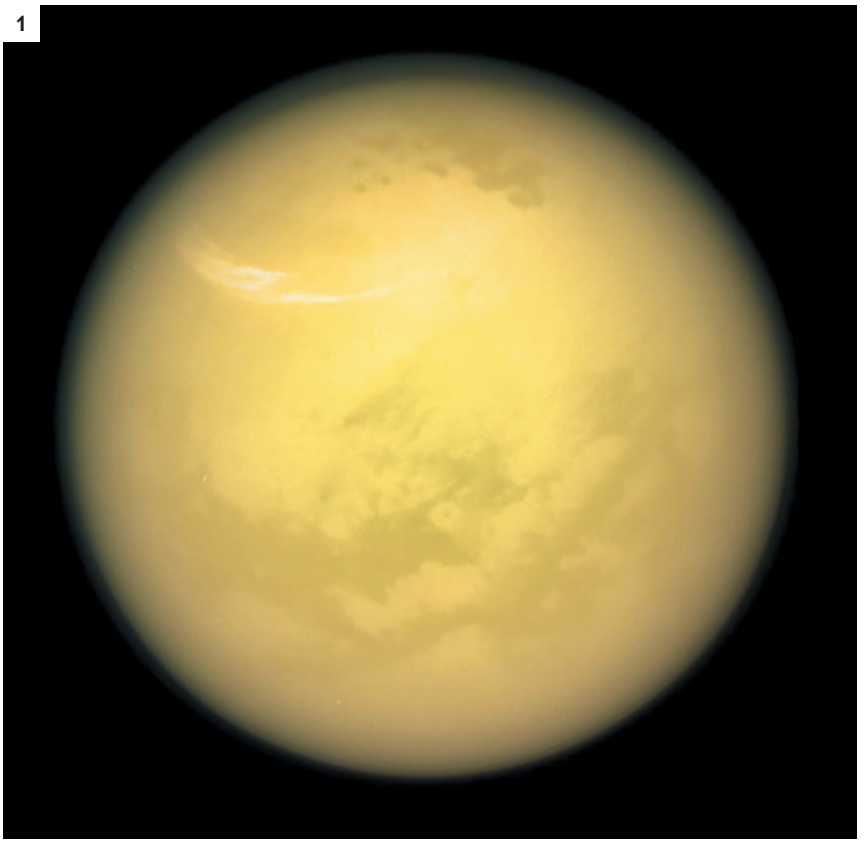
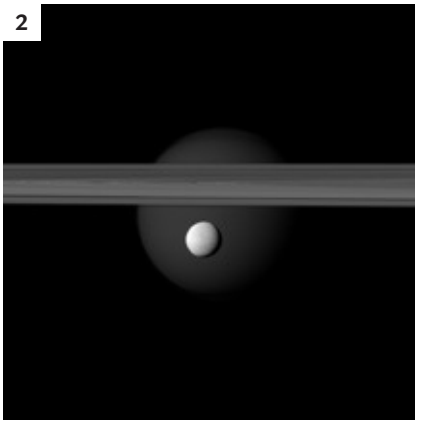




TITAN, Saturn's largest moon, shines in a false-color image (*1*) and looms in the distance (*2*) behind the smaller moon Enceladus and Saturn's rings.

its 13-year tour like the opening petals of a blossom. To enable close-up viewing of everything in the inner Saturnian system, its orbits varied in size, tilt and orientation. We also had the luxury of modifying orbits to dive in for another look—in some cases, many looks—at things we had discovered earlier.

The length of Cassini's stay at Saturn was also critical to our success. Prolonged monitoring is the only way to catch unpredictable processes such as meteoroid impacts on Saturn's rings. Furthermore, the slow, steady orbital migrations of Saturn's moons, along with atmospheric changes that arise from the large seasonal variations in solar illumination, required us to collect observations over as lengthy a time span as possible. Cassini's nominal mission was four years long and slated to end on June 30, 2008. But the spacecraft's resounding triumphs in that time and the indisputable logic of keeping such a productive asset at work helped us press the case for continuing Cassini's mission. Our arguments were successful, garnering several extensions and ensuring, for example, that we witnessed the rare illumination conditions of Saturn's equinox in August 2009, when the sun's shallow rays on Saturn's rings revealed the presence of vertical structures protruding above the ring plane that cast long, easily seen shadows.

Ultimately Cassini's orbital operations ended nearly one half of a Saturnian year (or, on Earth, 13 years and two and a half months) after they began. We arrived a bit past the height of the planet's southern summer, and the mission will close at the height of its northern summer. This time frame allowed us to observe over almost a full seasonal cycle: we watched Saturn's and Titan's southern hemispheres go from summer to winter and their northern hemispheres go from winter to summer. It was somewhat of a cosmic cheat, but it worked.

THE MOONS

BEFORE THE SPACE AGE, scientists thought the moons of the outer solar system would be featureless, geologically dead balls of ice. Voyager proved that assumption wrong; Cassini's mission was to survey Saturn's horde of satellites and return some understanding of their histories. In some cases, those histories turned out to be remarkable.

Take Iapetus. The origin of its two-toned appearance—one hemisphere as white as snow and the other deep black—was a long-standing mystery. From Cassini's high-resolution images, we learned that even on small scales, the moon is a piebald mix of dark and light patches. Together Cassini's cameras and thermal instrument showed us why this is so. Both the hemisphere-scale color variations and the local piebald patches are caused by a runaway thermal process found only on the slowly rotating Iapetus. Regions that start out dark get hot enough to sublimate ice and thus become darker and hotter. Regions that start out white are colder and become the sites where those sublimated vapors condense. Over time all the ice in the dark region disappears and reaccumulates in the white regions. How did an entire hemisphere partake in this process? In its orbit around Saturn, Iapetus barrels through a cloud of dark, fine-grained material originating from Phoebe, one of Saturn's outer irregular satellites. This cloud turns Iapetus's entire leading hemisphere dark, keeping it warmer and ice-free. Mystery solved.

Another standout moon is Titan. Cassini's visible and near-infrared cameras as well as its radar instrument were able to cut through Titan's haze. And, of course, the early 2005 descent of the Huygens probe through Titan's atmosphere for two and a half hours captured panoramic images and measurements of atmospheric composition, transparency, winds and temperature before the probe came to rest on the moon's surface. In all, what Cassini found on Titan was a world out of science fiction, where the scenery—landforms and clouds—are recognizable but made

COURTESY OF NASA, JPL-CALTECH AND SPACE SCIENCE INSTITUTE (*1*); COURTESY OF NASA, JPL-CALTECH, SPACE SCIENCE INSTITUTE (*2*)

13 Years at Saturn

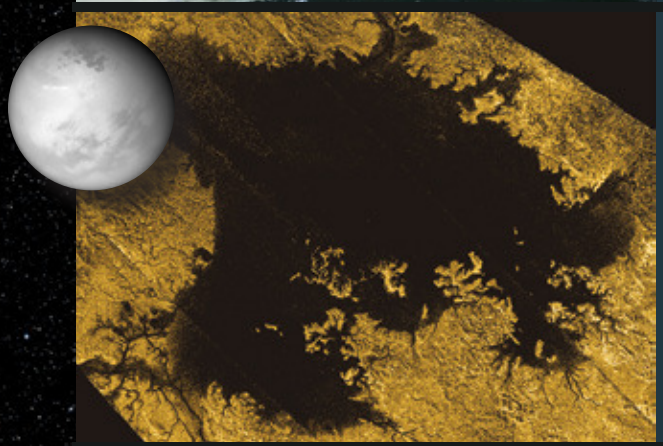
With its fuel source dwindling, the Cassini spacecraft is scheduled to dive into the atmosphere of Saturn in mid-September after 13 years in orbit. Over the course of its mission the probe delivered unprecedented discoveries about the complex planet, as well as about its varied moons and rings. It revealed worlds where rivers of methane flow into vast lakes, where jets of ice crystals from an underwater ocean spew into space, and where a single storm can encircle a giant planet. Here are some highlights.

—Edward Bell

MOONS

ENCELADUS

On this moon Cassini found towering geysers erupting from the south polar region, as seen in this artist's rendering. Evidence suggests they spring from a global subsurface water ocean that contains organic compounds and may be capable of hosting life.

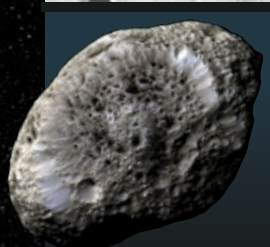


TITAN

Saturn's largest satellite is the only place in the solar system other than Earth that has known stable liquid on its surface. Titan has many geologic and atmospheric processes similar to those on our planet, which generate methane rains that build river channels and form lakes and seas containing liquid methane and ethane. One lake is shown here in this false-color radar image from Cassini.

IAPETUS

This odd moon presented a mystery with its two-faced surface, which is half black and half white. Dark dust in Iapetus's orbital path lands on the leading face of the moon, and a thermal process transfers ice from the dark face to the light. This close-up image reveals that the same thermal process acts on small spatial scales as well.

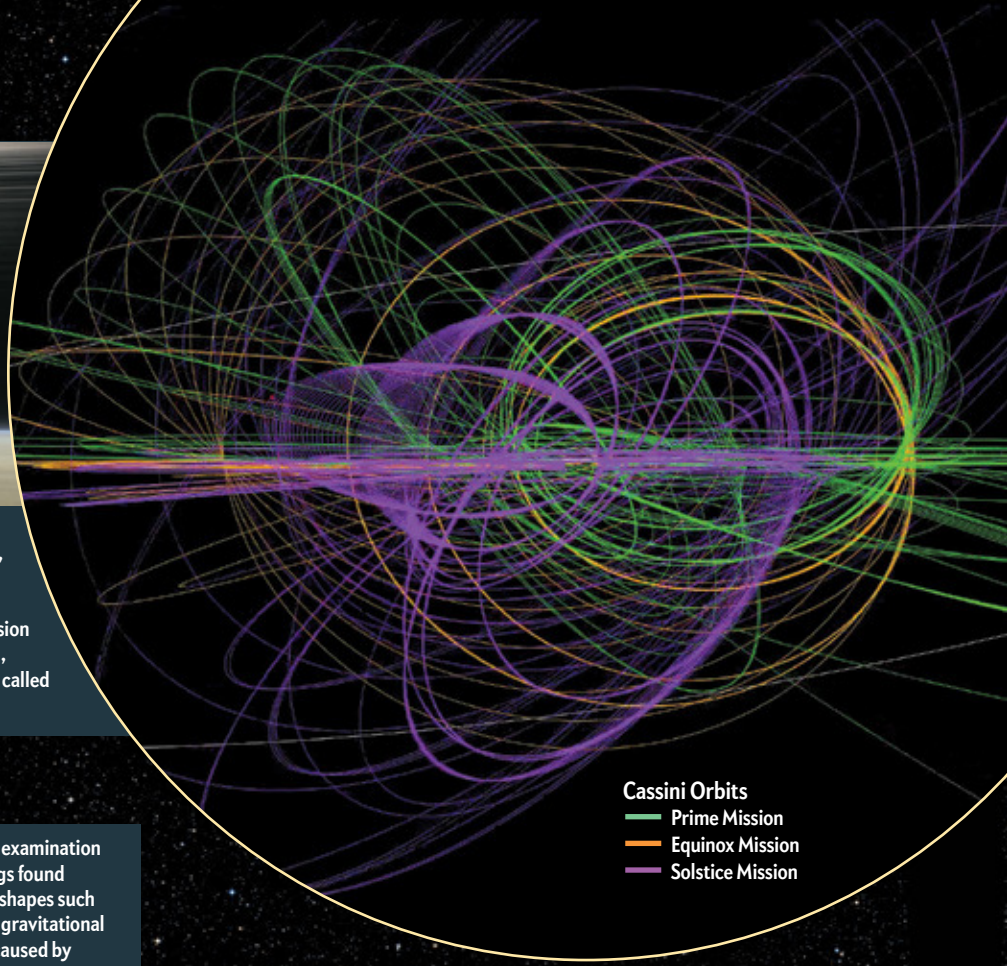


HYPERION

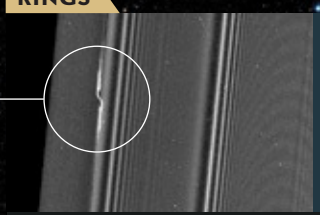
Cassini found this hamburger-shaped moon is pockmarked like a sponge. Scientists think that its unusually low density causes impacts to indent the surface rather than excavating it.

SPACECRAFT

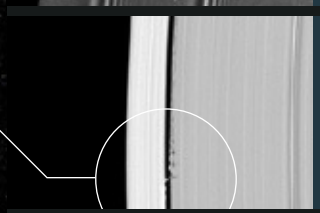
Since Cassini took up residence around Saturn on June 30, 2004, its 293 orbits of Saturn varied in size, orientation and angle to give it both up-close and panoramic views of many locales in the system. The spacecraft completed its four-year initial Prime Mission in 2008 and then began a two-year Equinox Mission, followed by a second extension running seven years called the Solstice Mission.



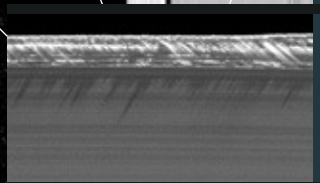
RINGS



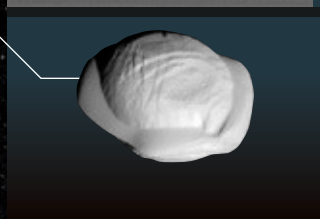
Cassini's close examination of Saturn's rings found that propeller shapes such as this one are gravitational disturbances caused by a moonlet too small to clear the area.



The tiny moon Daphnis, seen as a small dot in the Keeler ring gap, makes waves in the edges of the rings as it passes through.



A mountainous wall of ring rubble rises vertically in places 3.5 kilometers from Saturn's B ring and stretches at least 20,000 kilometers across.

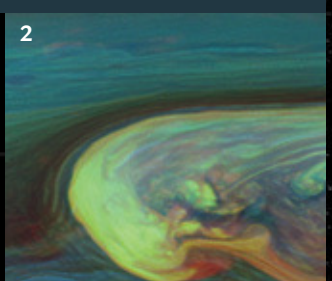


Pan, a 28-kilometer-wide moon in the Encke gap, got its cartoonish configuration from ring material falling onto it.

ATMOSPHERE

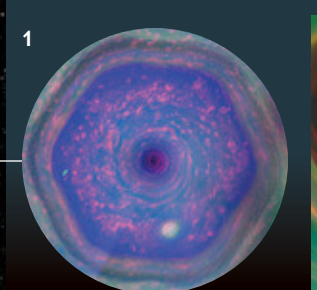
SUPERSTORM

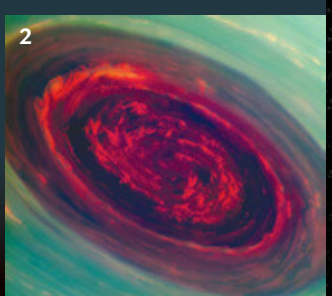
In 2010 Saturn's atmosphere erupted with an immense storm that began to spread around the planet (*1*). Within months this storm grew to encircle the globe, eventually meeting up with itself. Cassini imaged a false-color detail of the storm's various cloud layers (*2*).



POLAR VORTEX

A swirl of clouds at Saturn's north pole forms a mysterious hexagon shape (*1*), with a raging hurricane at its center (*2*). Cassini measured the eye at an astonishing 2,000 kilometers across.





RON MILLER (*Enceladus surface illustration*); NASA, JPL-CALTECH, ASI AND CORNELL (*Titan surface*); COURTESY OF NASA, JPL-CALTECH AND SPACE SCIENCE INSTITUTE (*all other photographs*); EDWARD BELL (*Saturn vertical composite*)

of unusual substances, where the look of the place is familiar but the feel is not.

Titan, we discovered, has lakes and seas made not of water but of liquid methane. At the moon's south pole, Cassini's high-resolution camera sighted such a liquid body close to the size of Lake Ontario (and hence named Ontario Lacus) amid a district of smaller similar features. Other Cassini instruments later verified that Ontario Lacus indeed holds liquid methane. We have since found many bodies of liquid methane of varying sizes; for some reason, they mostly inhabit the high northern latitudes. Radar observations have revealed craggy, rocky shorelines that resemble the coast of Maine. In contrast, the equatorial plains, where the Huygens probe landed, are dry and covered with dunes that continue for long stretches, interrupted here and there by higher ground, all the way around the moon.

The lakes and seas of liquid organics on Titan's surface have naturally raised speculation about whether they might contain life. But the surface temperature on Titan is exceedingly cold: −180 degrees Celsius. It would be surprising to find chemical reactions similar to those we believe are required for water-based biochemistry operating at such temperatures. But should we ever detect truly "alien" biochemistry thriving in methane, it would be a remarkable and historic find.

In my mind, though, the site of Cassini's greatest discovery is without question Enceladus, an icy moon a tenth the size of Titan. There Voyager had laid bare vast, surprisingly smooth stretches that told of a past marked by intense internal activity and maybe even a liquid-water layer buried below its icy shell—both on a moon seemingly too small for such phenomena.

The first inkling we had of any activity on Enceladus came early in the mission, in January 2005, when we discovered a plume of icy particles coming off the south pole. Our images were immediately made available to the public, and Cassini followers on the Internet pulsed with excitement. Very soon thereafter other Cassini instruments confirmed that the plume was indeed real. Cassini's operators responded quickly, altering trajectories to have a closer look. What we learned about Enceladus during that early part of the mission absolutely astounded us, but it was not until after 2008, when we received NASA's blessing to extend the mission, that we were able to devote significant time and resources to examining this fascinating place.

Enceladus, we now know, is a moon being flexed and pulled by the gravitational tidal forces of Saturn. This tidal energy produces more than enough internal heat to create a global water ocean, possibly as thick in places as 50 kilometers, buried under an outer layer of ice a few kilometers thick. More than 100 geysers spout from four prominent fractures in the south polar terrain, creating a plume of tiny ice particles and vapor that extends hundreds of kilometers above the surface. Most of the solid mass in this plume falls back to the surface, but a small fraction extends farther to form Saturn's diffuse but large E ring.

Cassini was able to fly through the plume a dozen times and analyze its material. We found that the particles seen in our images, which were droplets of ocean only hours earlier, bore evidence of large organic molecules and compounds that indicated hydrothermal activity similar to that observed at deep-sea vents on Earth's seafloor. They also indicated an ocean salinity comparable to Earth's. The vapor accompanying these particles was mostly water but contained trace amounts of simple organic compounds, as well as carbon dioxide and ammonia—all ingredients important for the sustenance and even origin of life.

SATURN'S RINGS are made of countless icy particles, some as big as houses, and contain gaps due to the gravitational tug of moons.

Cassini's results point clearly to a subsurface environment on Enceladus that could contain biological activity. We now must confront the goose-bump-raising questions: Did this small icy world host a second genesis of life in our solar system? Could there be signs of life in its plume? Could microbes be snowing on its surface? No other body so demonstrably possesses all the characteristics we believe are necessary for habitability. It is, at present, the most promising, most accessible place in the solar system to search for life. And some of us are so enthralled by this possibility that we are designing return missions to Enceladus to find out.

THE RINGS

THE RINGS, of course, are what make Saturn the glorious spectacle it is, and understanding their intricate workings was a major objective for Cassini. They are the natural end state of the collapse of a rotating cloud of debris, and as such, they are the closest analogue to the rubble disk we think provided the raw ingredients for our own solar system. They are also a model for the protostellar disks from which new solar systems are born and even for the billions of pinwheels of dust and gas we call spiral galaxies. Of all there was to study at Saturn, the rings presented the greatest scientific reach, extending from our local neighborhood to clear across the cosmos.

Through Cassini's measurements, we have come to understand the origin of most of the structure in the rings of Saturn. In certain places, we find that the gravitational handiwork of some distant orbiting moon has disturbed the orbits of ring particles, creating sharp edges or wave disturbances that propagate out in a spiral pattern. In others, where moons are embedded in the rings, gravity has nudged particles into beautiful structures. Pan, for instance, a roughly 30-kilometer-wide moon in the Encke ring gap, has done this to the particles in its vicinity; in turn, infalling ring material has reshaped Pan, making the moon look as if it were wearing a tutu.

COURTESY OF NASA, JPL AND SPACE SCIENCE INSTITUTE

In regions of the rings where particles are especially dense, we uncovered self-generating waves, with wavelengths ranging from 100 meters to hundreds of kilometers, propagating through the disk. These waves can reflect off sharp discontinuities in particle concentrations and interfere with themselves and one another, creating a chaotic-looking geography. And our understanding of ring structure now includes the gratifying confirmation of a prediction Mark Marley, now at NASA's Ames Research Center, and I made in 1993: that acoustic oscillations within the body of Saturn could also create features in the rings. In this way, Saturn's rings behave like a seismograph.

Cassini found its most stunning ring surprises during the time surrounding the August 2009 equinox. Along the sharp outer edge of the most massive ring (the B ring), we found an incredible 20,000-kilometer-long continuous string of spiky shadows betraying the presence of "ring mountains"—waves of particles extending three kilometers above the ring plane. These formations might result from the extreme compression of material passing around small "moonlets" that have been caught in the resonance at the ring's edge like rushing water splashing against a large cliff face on the shore.

In another revelation, we saw a very subtle, tightly wound spiraling pattern continuing without interruption for 19,000 kilometers across the inner C and D rings. Some meticulous sleuthing by Matt Hedman, now at the University of Idaho, and his colleagues revealed that an impact of cometary debris within the inner rings in 1983 likely forced all the ring particles in the impact region into tilted orbits; these orbits precessed like a top, the inner ones precessing faster than the outer ones. Since then, this disturbance has wound up ever tighter, creating a three-meter-high spiral corrugation pattern in the rings. This structure did not even exist during the Voyager flybys. The solar system, we have come to see, is a dynamic marvel, and in their myriad and fluid forms, Saturn's rings are an object lesson in the universality, scalability and endless complexity of gravity. No artist could do better.

THE ATMOSPHERE

CASSINI HAS ALSO INVESTIGATED the makeup and behavior of Saturn's atmosphere in great detail, uncovering some unexpected features in the process. Its instruments were able to study Saturn's atmosphere at a wide range of altitudes, revealing its global circulation patterns, composition and vertical structure. The atmosphere is divided into wide bands like Jupiter's, although Saturn's bands are less obvious from the outside because of a thick layer of haze lying above the upper ammonia cloud deck. When Cassini probed below the haze and into the troposphere, it revealed that the width of Saturn's bands alternates with latitude: narrower ones are darker and coincident with rapid jet streams, and the wider bands tend to be brighter, aligned with jets that are slower and maybe even stationary, relative to the general rotation of the planet. Overall, Saturn's atmosphere seems fairly static over time—even the surprising hexagon-shaped jet stream over the north pole has changed little, Cassini showed, since Voyager first sighted it. We are learning that stability is a common feature of large-scale atmospheric systems in the giant planets: with no solid surface underlying the gas, there is no friction to dissipate atmospheric motions. Once started, they endure.

We were delighted to find, however, that Saturn's atmosphere is not totally unresponsive to the changing seasons. Above the clouds in the northern winter hemisphere, the planet was putting on quite the unexpected show when Cassini first arrived: it was blue! Because the two Voyager flybys occurred near an equinox and thus returned no views of winter, this extreme coloration came as quite a surprise. Our best guess is that the lower flux of ultraviolet radiation during the winter, along with the sun-blocking effect of the ring shadows on the winter hemisphere, reduces the production of the overlying haze. A clearer atmosphere means better opportunity for Rayleigh scattering, the process that turns our own atmosphere blue, and for methane in the atmosphere to absorb the red rays of the sun. The gorgeous sliver of azure that colors the winter hemisphere in our images of Saturn is, in effect, a slice of Neptune's atmosphere spliced onto Saturn's. Who knew?

One distinctive property of Saturn, which has been known for a century, is that on timescales of decades, it is prone to the eruption of colossal storms. So we were thrilled to greet one such storm in late 2010. Over a period of about 270 days, we watched this thundering, lightning-producing behemoth be born as a small disturbance in the northern hemisphere, then grow, spread clear around the planet until its tail met its head, and eventually fade. This was yet another phenomenon that no spacecraft had ever witnessed. We suspect that water, the constituent of Saturn's deepest cloud deck, can suppress convection in the lighter hydrogen atmosphere for a period of decades, until finally buoyancy wins out and a large convective outburst ensues.

SURVEYOR OF WORLDS

FROM ITS INCEPTION in 1990 to its final dramatic conclusion this September, Cassini has been a major, extraordinarily successful component of humanity's six-decade-long exploration beyond our home planet. Its historic expedition around Saturn has shown us intricate details in the workings of an alluring and remarkably alien planetary system. It has expanded our understanding of the forces that made Saturn and its environs, our solar system and, by extension, other stellar and planetary systems throughout the cosmos what they are today.

It is doubtful that we will soon see a mission as capable as Cassini return to Saturn. To have been part of this magnificent adventure has been to live the taxing but rewarding life of an explorer of our time, a surveyor of distant worlds. I sign off now, grateful in knowing that the story of Cassini is one that will inspire humankind for a very long time to come. SA

MORE TO EXPLORE

Saturn's Curiously Corrugated C Ring. M. M. Hedman et al. in *Science*, Vol. 332, pages 708–711; May 6, 2011.

Enceladus's Measured Physical Libration Requires a Global Subsurface Ocean. P. C. Thomas et al. in *Icarus*, Vol. 264, pages 37–47; January 15, 2016.

Could It Be Snowing Microbes on Enceladus? Assessing Conditions in Its Plume and Implications for Future Missions. Carolyn C. Porco et al. in *Astrobiology*. Published online August 11, 2017.

FROM OUR ARCHIVES

The Restless World of Enceladus. Carolyn Porco; December 2008.

scientificamerican.com/magazine/sa

RECOMMENDED

By Andrea Gawrylewski

BELUGA STURGEON (*Huso huso*) is critically endangered.

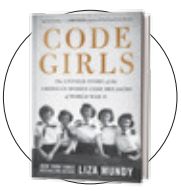
Endangered

Photographs
by Tim Flach.
Text by Jonathan Baillie.
Abrams Books,
2017 ($65)

We have entered into the sixth great extinction of the earth's species, according to many biologists. The previous five were caused by natural events—meteorite impacts and global temperature change—but this latest is decidedly human-generated, primarily through habitat destruction. Around 20 percent of all species on the planet are now threatened with extinction. In this collection (with descriptions by conservationist Baillie), photographer Flach captures the personality and character of some of the earth's most threatened denizens. He looks into the eyes of the very last male northern white rhino; captures a curled-up pangolin—the most heavily trafficked mammal in the world; and immortalizes a pair of red-crowned cranes in the throes of their graceful mating dance. Each image is a reminder of all we could lose if we don't stand up for these creatures.

Code Girls: The Untold Story of the American Women Code Breakers of World War II

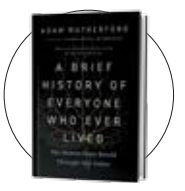
by Liza Mundy. Hachette Books, 2017 ($28)



A group of Wellesley College students answered two questions for the chance at a secret job for the U.S. Navy in 1941: Did they like crossword puzzles, and were they engaged to be married? If the answers were "yes" and "no," respectively, they made it into a classified training course that, if they passed, led to a job in Washington, D.C. Those two questions were one way to join the roughly 11,000 American women who ultimately worked as government code breakers during World War II. They deciphered intercepted enemy communications and aided the Allies in encoding their own missives. Journalist Mundy tells the story of the female cryptanalysts, who, she argues, made a vital difference between winning and losing for the Allies. *—Clara Moskowitz*

A Brief History of Everyone Who Ever Lived: The Human Story Retold through Our Genes

by Adam Rutherford. The Experiment, 2017 ($25.95)



Geneticist and writer Rutherford takes a sweeping new view of the human evolution story, using the latest science of DNA as the central guide. The tale begins with our early ancestors—where they traveled and with whom they consorted. He covers the evolution of unique human traits—red hair, lactose tolerance—and delves into the genetics of historical celebrities—Richard III and Jack the Ripper, to name two. Some stories are still playing out. Scientists are hunting for genes that code for behavioral traits. So far the search has been futile. Remaining mysteries notwithstanding, one truth from the human genetic code: all people on earth, to some degree, are distant cousins.

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Michael Shermer is publisher of *Skeptic* magazine (www.skeptic.com) and a Presidential Fellow at Chapman University. His next book is *Heavens on Earth.* Follow him on Twitter @michaelshermer

Sky Gods for Skeptics

Is belief in aliens a religious impulse?

By Michael Shermer

In *Star Trek V: The Final Frontier,* Captain James T. Kirk encounters a deity that lures him to its planet in order to abscond with the *Enterprise*. "What does God need with a starship?" the skeptical commander inquires. I talked to Kirk himself—William Shatner, that is—about the film when I met him at a recent conference. The original plot device for the movie, which he directed, was for the crew to go "in search of God." Fearful that some religious adherents might be offended that the Almighty could be discoverable by a spaceship, the studio bosses insisted that the deity be a malicious extraterrestrial impersonating God for personal gain.

How could a starship—or any technology designed to detect *natural* forces and objects—discover a *supernatural* God, who by definition would be beyond any such sensors? Any detectable entity would have to be a natural being, no matter how advanced, and as I have argued in this column [see "Shermer's Last Law"; January 2002], "any sufficiently advanced extraterrestrial intelligence [ETI] is indistinguishable from God." Thus, Shatner's plot theme of looking for God could only turn up an ETI sufficiently advanced to appear God-like.

Perhaps herein lies the impulse to search. In his 1982 book *Plurality of Worlds* (Cambridge University Press), historian of science Steven J. Dick suggested that when Isaac Newton's mechanical universe replaced the medieval spiritual world, it left a lifeless void that was filled with the modern search for ETI. In his 1995 book *Are We Alone?* (Basic Books), physicist Paul Davies wondered: "What I am more concerned with is the extent to which the modern search for aliens is, at rock-bottom, part of an ancient religious quest." Historian George Basalla made a similar observation in his 2006 work *Civilized Life in the Universe* (Oxford University Press): "The idea of the superiority of celestial beings is neither new nor scientific. It is a widespread and old belief in religious thought."

Now there is experimental evidence in support of this hypothesis, reported in a 2017 article entitled "We Are Not Alone" in the journal *Motivation and Emotion,* in which North Dakota State University psychologist Clay Routledge and his colleagues found an inverse relation between religiosity and ETI beliefs. That is, those who report low levels of religious belief but high desire for meaning in life show greater belief in ETIs. In the team's first study, subjects who read an essay "arguing that human life is ultimately meaningless and cosmically insignificant" were statistically significantly more likely to believe in ETIs than those who read an essay on the "limitations of computers."

In the second study, subjects who self-identified as either atheist or agnostic were statistically significantly more likely to report believing in ETIs than those who reported being religious (primarily Christian). In studies 3 and 4, subjects completed a religiosity scale, a meaning in life scale, a well-being scale, an ETI belief scale, and a religious/supernatural belief scale. "Lower presence of meaning and higher search for meaning were associated with greater belief in ETI," the researchers reported, but ETI beliefs showed no correlation with supernatural beliefs or well-being beliefs.

From these studies the authors conclude: "ETI beliefs serve an existential function: the promotion of perceived meaning in life. In this way, we view belief in ETI as serving a function similar to religion without relying on the traditional religious doctrines that some people have deliberately rejected." By this they mean the supernatural: "accepting ETI beliefs does not require one to believe in supernatural forces or agents that are incompatible with a scientific understanding of the world." If you don't believe in God but seek deeper meaning outside our world, the thought that we are not alone in the universe "could make humans feel like they are part of a larger and more meaningful cosmic drama," they observe.

Given that there is no more evidence for aliens than there is for God, believers in either one must take a leap of faith or else suspend judgment until evidence emerges to the contrary. I can conceive of what that might be for ETI but not for God, unless the deity is a sufficiently advanced ETI as to appear divine. Perhaps Captain Kirk has it right in his final reflections on God to the ship's doctor at the end of *Star Trek V:* "Maybe He's not out there, Bones. Maybe He's right here [in the] human heart." SA

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Illustration by Izhar Cohen

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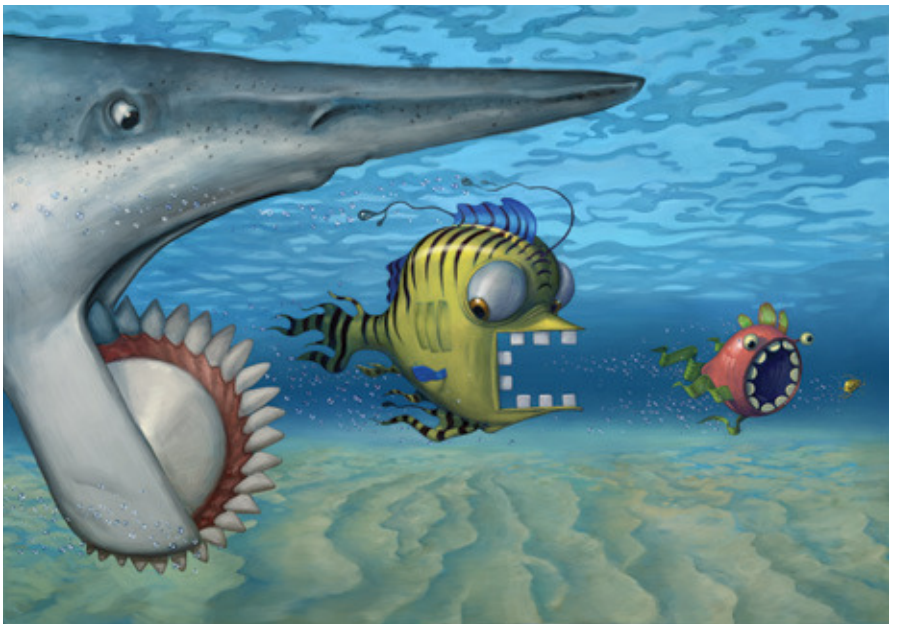
Steve Mirsky has been writing the Anti Gravity column since a typical tectonic plate was about 36 inches from its current location. He also hosts the *Scientific American* podcast Science Talk.



What the Heck *Is* That Thing?

An extinct monster fish shows that, yes, evolution *could* be that crazy

By Steve Mirsky

After watching the movie *Jaws,* I had a deep sense of dread about going into the water—even if the water was in a swimming pool. A similar hydrophobia came over me while reading the riveting new book *Resurrecting the Shark,* by Bozeman, Mont.–based writer Susan Ewing. And this anxiety was even less rational than any arising from a *Jaws* viewing, as the book's subtitle makes clear: *A Scientific Obsession and the Mavericks Who Solved the Mystery of a 270-Million-Year-Old Fossil.* That's right—the cartilaginous creature in question, now called *Helicoprion,* was extinct before dinosaurs ever existed. But in its time, *Helicoprion* was quite the sea monster.

You know the *Jaws* scene in which the shark chomps away at Quint? It starts at the hunter's toes, bites away at his calves, rips into his knees, and so on. If *Helicoprion* had been working his way up Quint, it wouldn't have hit pay dirt until it got to the top of his inseam. Because its teeth weren't spread out along the long axis of its mouth, the way teeth are in great white sharks, humans and pretty much anything you can think of that has teeth. From Quint's point of view, the dental death coming at him would have looked like the cutting edge of a vertical buzz saw, like you'd see in an old lumber mill in a silent movie. Yikes.

Before continuing, two things: the teeth of *Helicoprion* (from the Greek for "spiral" and "saw") were actually one humongous tooth, with dozens of visible crowns erupting from a single, continuous root. And to be taxonomically truthful, *Helicoprion* was not a shark. More on that bothersome bite … I mean, bit … of accuracy in a moment.

The first fossil finds of *Helicoprion* and related species were made in the 19th century. They were shaped like the remains of ammonoids, spiral-shelled marine mollusks. But with studs along the spiral. Trained eyes recognized the fossils as, well, lots of different things. Definitely fishy. Some kind of weapon. But where did it go on the fish?

"Scientists threw themselves into contortions keeping that tooth spiral out of the animal's mouth," Ewing told me. "They put it on its head, they put it curling up over its nose, they put it on its tail, they put it on its back. They wanted to put it everywhere except in the mouth." Because not even evolution could be that crazy, they thought. But, as Kramer said to Seinfeld, "Mother Nature's a mad scientist!" (Season Eight, Episode 19: "The Yada Yada.")

Only in the past decade did researchers doing painstaking analysis of CT scans of fossils find evidence for the connective cartilage that nailed down the way the whorl was actually situated. "The thing that was so confusing about *Helicoprion,*" Ewing says, "was that that tooth whorl was a midline structure. So it was like a pizza cutter stuck in a quart of ice cream in the middle of the shark's lower jaw."

But what could *Helicoprion* possibly chomp on with a vertical row of tooth-teeth? Well, its whorl's similarity in appearance to ammonoids was actually a clue: the shape made it good for snagging ammonoid flesh and then ripping them out of their shells. As Ewing writes, "The eminent French paleontologist Philippe Janvier likened the tooth whorl to a *fourche d'escargot,* a snail fork." But the size of a large dinner platter or even a bicycle wheel and embedded in a sharky beast at least 20 and perhaps 30 feet long.

As to *Helicoprion*'s sharkitude: "Because of the way *Helicoprion*'s jaws were attached to its skull," Ewing explains, "it technically is not a true shark. And it's not in the lineage that became the true sharks … the purists really don't like us to call *Helicoprion* a shark, but it's really hard not to … it surely looked like a shark." And it led what would look to us like the epitome of a shark's life: an apex predator ruling the waters 270 million years before the first orthodontist adjusted an improper bite. SA

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Illustration by Matt Collins

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Compiled by Daniel C. Schlenoff

OCTOBER

1967 Shantytowns: Unseen Structure and Evolution

"The common view is that the squatters populating the Peruvian shantytowns are Indians from the rural mountains who still speak only the Quechuan language, that they are uneducated, unambitious, disorganized, an economic drag on the nation—and also that they are a highly organized group of radicals who mean to take over and communize Peru's cities. I found that in reality the people of the barriadas around Lima do not fit this description at all. Most of them had been city dwellers for some time (on the average for nine years) before they moved out and organized the barriadas. They speak Spanish (although many are bilingual); indeed, their educational level is higher than that of the general population in Peru. At first glance the barriadas appear to be formless collections of primitive straw shacks. Actually the settlements are laid out according to plans, often in consultation with architectural or engineering students. As time goes on most of the shanties are replaced by more permanent structures."

1917 Volcano Power

"In central Tuscany in 1906, volcanic steam was first used in an ordinary steam engine of about forty horse-power, but the borax salts and other accompanying chemicals seriously corroded the machinery. Then the superheated steam was applied to an ordinary multitubular boiler in which it was used in place of fuel. An experimental plant worked successfully, supplying power to the works and the villages around Lardarello. Its success led Prince Ginori-Conti to develop a power plant on a large scale, and three 3,000-kilowatt turbogenerators were installed in 1916. The new undertaking has proved a great boon in industrial Tuscany, where the present war-price of coal ranges from $40 to $50 per ton."

Warhorses

"Like everything else, horses and mules are found in this war in numbers never before approached. As it has been necessary to exercise greater scrutiny of resources in every direction, it has been essential that the ultimate pound of energy be obtained from every animal, that no mount or beast of burden be permitted to go into the last discard until every expedient to save him has been exhausted. For horses are scarce; no longer can the army chief shoot them or work them to death or turn them off with calm confidence that plenty more are to be had. Rather he must conserve them in every possible way; and so we have the field hospital for horses, illustrated here."

More archive images on the horse in the First World War can be found at www.ScientificAmerican.com/oct2017/warhorse

1917: Medical care for warhorses on the Western Front.

1967

1917

1867

1867 Quinine for Malaria

"Among the many remedial agents which organic chemistry has afforded us, quinine occupies the first place, chloroform the second. Without quinine, large tracts, indeed whole countries, would be simply uninhabitable for Europeans. The 'quinine famine' in the Mauritius demonstrated to thousands how small a thing even gold itself might become in comparison with this lifesaving salt. The search for artificial quinine, though, has been as unsuccessful as that for the Philosopher's Stone. This circumstance has induced certain enterprising men to cause the cinchonas to be introduced into India, and the cinchona plantations in India are now so flourishing that there need be no apprehension of the supply of quinine ever failing."

Be Careful What You Wish For

"Why should not every house have its telegraphic wire? When gas was first applied to purposes of illumination it was used only in the public buildings and streets, and even now on the continent of Europe it has been introduced but sparingly into private dwellings. Why may not the telegraph wire be extended and diffused as the gas pipe has been? Suppose a network of such wires laid from a central point in the city to the library or sitting room of every dwelling, and an arrangement made for collecting news similar to that controlled by the associated press. Through the wires, then, this news might be instantly communicated to each family. A fire, a murder, a riot, the result of an election, would be simultaneously known in every part of the city. Of course, this would do away with newspapers, but what of that? All things have their day, and why should such ephemeral things as newspapers be an exception to the rule?"

SCIENTIFIC AMERICAN, VOL. CXVII, NO. 15, OCTOBER 13, 1917

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SPEAKERS:

David Stevenson, Ph.D.

Dr. David Stevenson is the Marvin L. Goldberger Professor of Planetary Science at the California Institute of Technology and an expert on the origin, evolution, and structure of planets. He is a New Zealander who came to the United States as a graduate student, obtaining a Ph.D. in theoretical physics at Cornell University in 1976, where he worked on the interior of Jupiter. Most of his subsequent career has been in the USA and he has been on the faculty at Caltech since 1980, serving as a Division Chair and Chair of the Faculty along the way. His awards and honors include membership in the National Academy of Science, Fellow of the Royal Society (London), the Urey Prize (awarded by the American Astronomical Society) and the Hess Medal (awarded by the American Geophysical Union). On occasion, he has participated in advising movie and TV directors on the science in their productions.

Chris Stringer, Ph.D.

Dr. Chris Stringer has worked at The Natural History Museum London since 1973, and is now Research Leader in Human Origins and a Fellow of the Royal Society. His early research was on the relationship of Neanderthals and early modern humans in Europe and he now collaborates with archaeologists, dating specialists, and geneticists in attempting to reconstruct the evolution of modern humans globally. He has excavated at sites worldwide, and is currently co-directing the Pathways to Ancient Britain project, funded by the Calleva Foundation. He has published over 200 scientific papers, and his recent books include *The Complete World of Human Evolution* (revised edition 2011, with Peter Andrews), the award-winning *Homo Britannicus* (2006), *The Origin of Our Species* (UK 2011), alternative title (US, March 2012): *Lone Survivors: How We Came to Be the Only Humans on Earth, and Britain: One Million Years of the Human Story* (2014, with Rob Dinnis).

Max Tegmark, Ph.D.

A native of Stockholm, Dr. Max Tegmark received his B.Sc. in Physics from the Royal Institute of Technology and a B.A. in Economics at the Stockholm School of Economics. He studied physics at the University of California, Berkeley, earning his Ph.D. in 1994. Dr. Tegmark was a research associate with the Max-Planck-Institut für Physik in Munich, a Hubble Fellow and member of the Institute for Advanced Study, Princeton,





and an Assistant Professor at the University of Pennsylvania before arriving at MIT in September 2004. Dr. Tegmark is an author on more than 200 technical papers, and has featured in dozens of science documentaries. His awards include a Packard Fellowship (2001–06), Cottrell Scholar Award (2002–07), and an NSF Career grant (2002–07), and he is a Fellow of the American Physical Society. His work with the SDSS collaboration on galaxy clustering shared the first prize in Science magazine's "Breakthrough of the Year: 2003."

Stephen Ressler, Ph.D.

Dr. Stephen Ressler is Professor Emeritus from the United States Military Academy at West Point and a Distinguished Member of the American Society of Civil Engineers (ASCE). He served for 34 years as a commissioned officer in the U.S. Army Corps of Engineers and retired at the rank of Brigadier General in 2013. In 2007, he deployed to Afghanistan to create a civil engineering program for the newly created National Military Academy of Afghanistan in Kabul. Dr. Ressler is passionate about communicating the joys of engineering to inquiring minds of all ages. His three video lecture series — *Understanding the World's Greatest Structures*, *Understanding Greek and Roman Technology*, and *Everyday Engineering* — are among the most highly-rated offerings in The Great Courses' catalog. Dr. Ressler has received numerous awards and his Bridge Designer software has been used by over two million students worldwide. He is also a developer and principal instructor for the ASCE Excellence in Civil Engineering Education Teaching Workshop.

For speakers' complete bios, visit **http://InsightCruises.com/events/sa34/#speakers.html**

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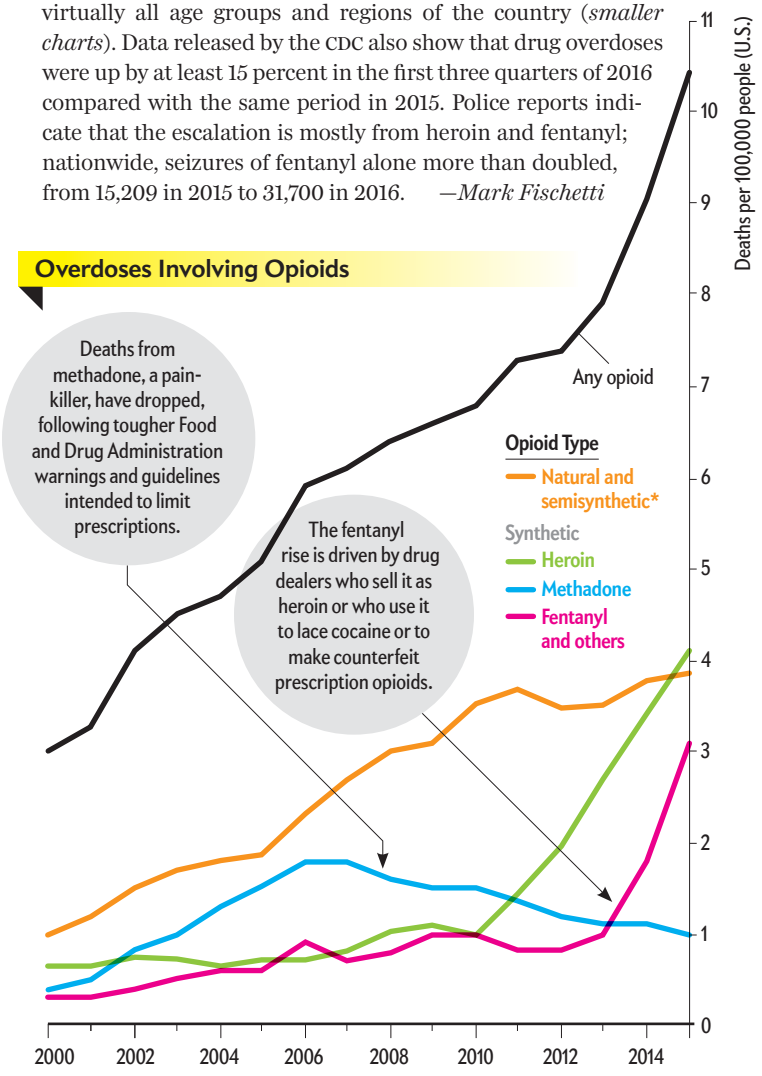
Opioid Deaths Soar

Men and women of all ages are dying from heroin and fentanyl overdoses

U.S. deaths from drug overdoses have skyrocketed since 2010 (*line graph*). Entire towns in states such as Ohio are being ravaged. In August an interim report from a Presidential Commission on the crisis described the toll as "September 11th every three weeks." According to the U.S. Centers for Disease Control and Prevention, two trends are driving the epidemic: "a 15-year increase in deaths from prescription opioid overdoses" and a recent surge in "overdoses driven mainly by heroin and illegally-made fentanyl." Rates are higher among men and women in virtually all age groups and regions of the country (*smaller charts*). Data released by the CDC also show that drug overdoses were up by at least 15 percent in the first three quarters of 2016 compared with the same period in 2015. Police reports indicate that the escalation is mostly from heroin and fentanyl; nationwide, seizures of fentanyl alone more than doubled, from 15,209 in 2015 to 31,700 in 2016. —*Mark Fischetti*

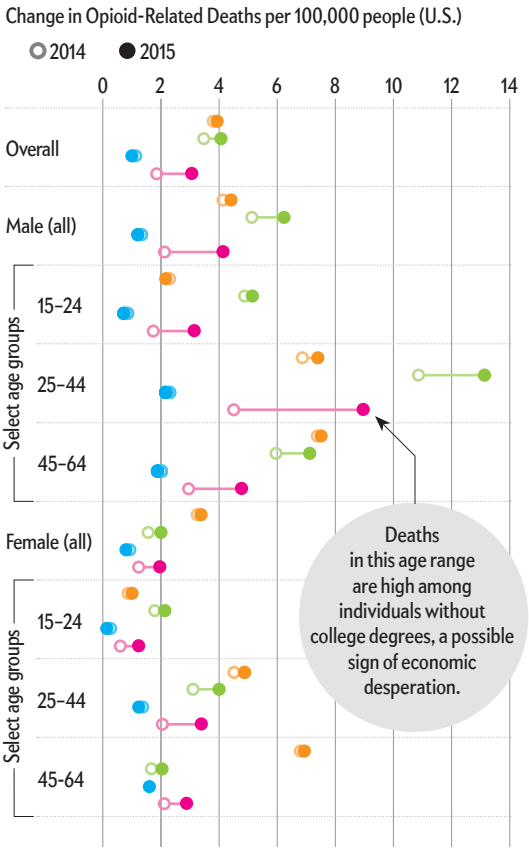
Overdoses Involving Opioids



*Natural includes morphine and codeine; semisynthetic includes oxycodone and others

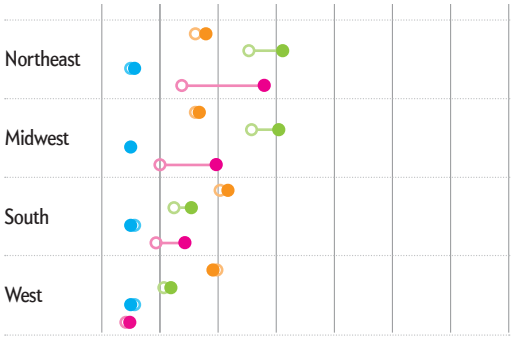
Middle-Aged Menace

Mortality from fentanyl and heroin rose significantly for both men and women, in all age categories, from 2014 to 2015 (the latest U.S. data). The change was especially high among people ages 25 to 44. Those two drugs pushed overall opioid death rates up in 2016, too, according to states that have finished reporting; in Massachusetts, deaths shot up 17 percent from 2015 to 2016.



Spreading East to West

Fatality rates are climbing most in the Northeast. One reason for a slower rise in the West may be that traffickers are only beginning to shift distribution of heroin there from black tar to the white powder form, which is easier to cut with deadly fentanyl.



SOURCES: DIVISION OF UNINTENTIONAL INJURY PREVENTION, NATIONAL CENTER FOR INJURY PREVENTION AND CONTROL, CENTERS FOR DISEASE CONTROL AND PREVENTION *www.cdc.gov/drugoverdose/data/analysis.html (line graph)*; "INCREASES IN DRUG AND OPIOID-INVOLVED OVERDOSE DEATHS—UNITED STATES, 2010–2015," BY ROSE A. RUDD ET AL., IN *MORBIDITY AND MORTALITY WEEKLY REPORT*, VOL. 65, NOS. 50–51; DECEMBER 30, 2016 *(demographic breakdowns)*

Graphic by Jen Christiansen

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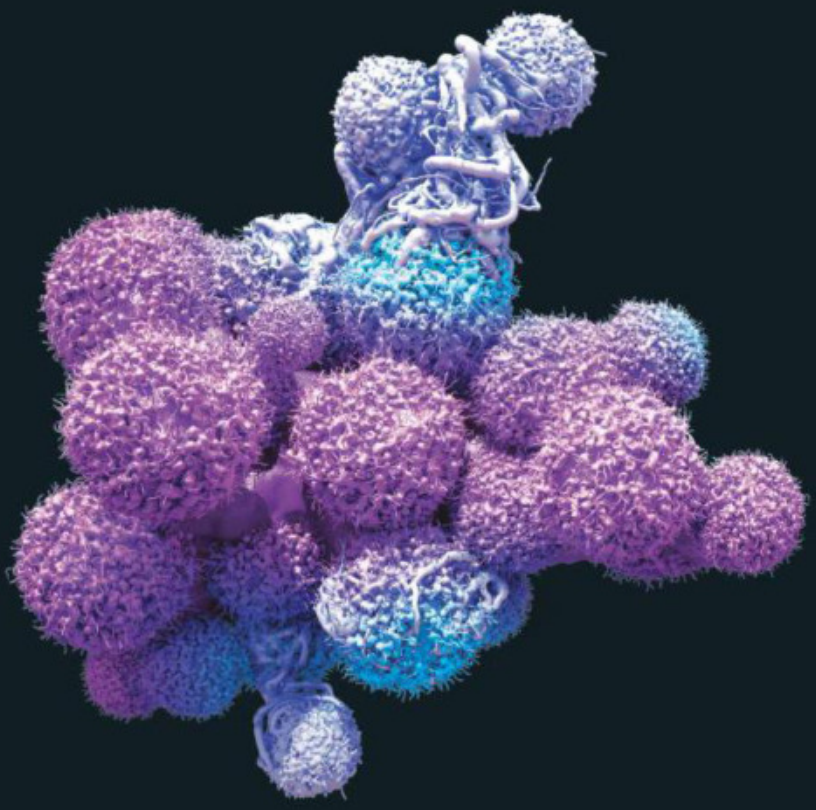

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