MEDICINE
The Truth about Prostate Tests

NEUROSCIENCE
What Football Does to Brains

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The Quantum Universe

Could foamlike fluctuations rule spacetime at the tiniest scales?

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ON THE COVER

Space appears to be smooth and continuous. But at the smallest scales, it may flake apart into discrete bits. Now a team of physicists is building an experiment that will look for evidence that space is, at root, digital. The research could influence how we understand the relations among space, time, matter and information. Image by Vault49.

SCIENTIFIC AMERICAN

February 2012 Volume 306, Number 2

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Photograph by Adam Voorhes

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SCIENTIFIC AMERICAN

DEPARTMENTS

ON THE WEB

Tech Trends to Watch in 2012
A report from the Consumer Electronics Show, the tech industry's annual Las Vegas spectacle, examines the state of the art in the digital world—and which companies are vying to sell you the next big thing.
Go to www.ScientificAmerican.com/feb2012/ces

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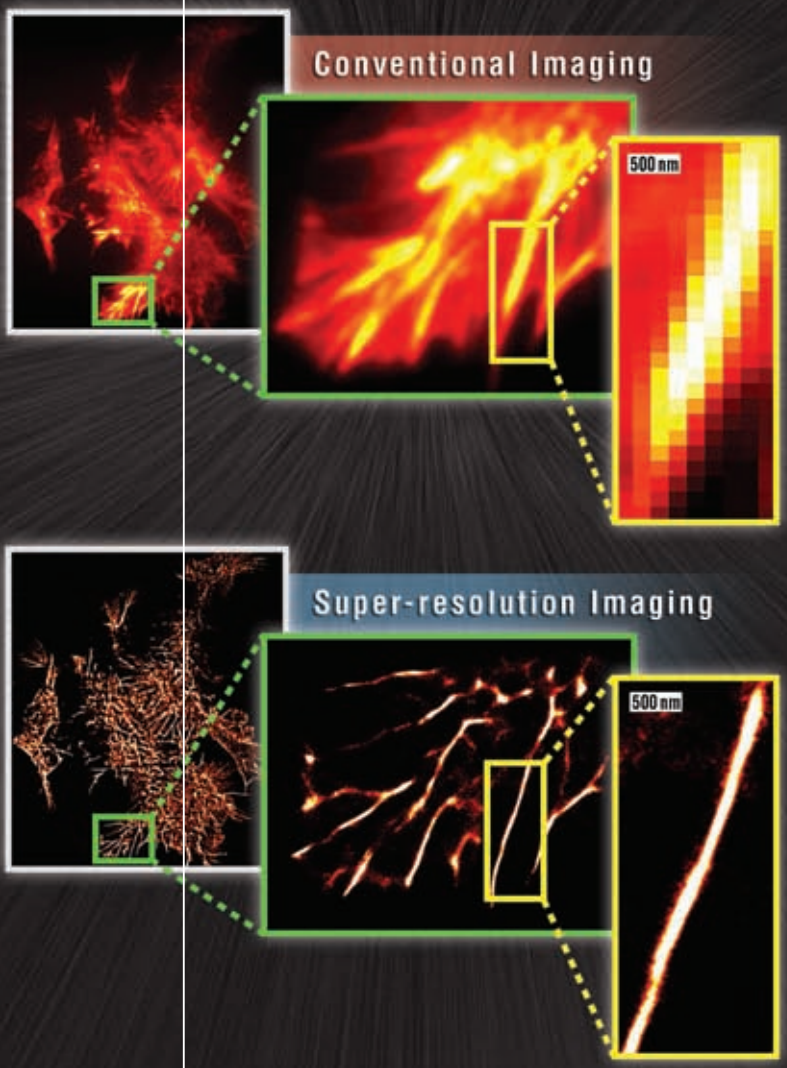
Enhancing "super resolution" in scientific imaging with new sCMOS camera technology...



A stack of 2500 image frames was used to construct the upper, conventional microscopic image of actin bundles—which when magnified become indistinct. The lower image is constructed from 2500 frames from an ORCA-Flash camera. It shows dramatically improved resolution and clearly reveals individual actin bundles.*

Going beyond optical resolution limits

Optical fluorescence microscopy has long been an essential tool for looking inside living cells. But it can't resolve features smaller than 200 nm. Electron microscopy can, but not on living cells...

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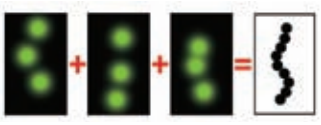

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sCMOS: Scientific Complementary Metal Oxide Semiconductor, CCD: Charge Coupled Device, EMCCD: Electron Multiplying Charge Coupled Device
*This data courtesy of Prof. Dr. Zhen-li Huang (Britton Chance Center for Biomedical Photonics, Wuhan National Laboratory for Optoelectronics - Huazhong University of Science and Technology)

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

A Sea of Spacetime Foam?

"IS SPACE DIGITAL?" STAFF EDITOR MICHAEL Moyer poses this fundamental question in our issue's cover story. We often speak of the fabric of space, as if it were continuous, but is it instead a kind of patchwork of jittering, foamy quantized bits? Craig Hogan, a physicist at the University of Chicago and director of the Fermilab Particle Astrophysics Center, is hoping to find out. He and his colleagues plan an experiment that will attempt to measure how information, matter and spacetime behave at the tiniest of scales—the Planck scale. If the experiment succeeds, it will change what we currently think we know about the nature of space and time, suggesting a new architecture of physics. Turn to page 30.

You can find another lesson in how little things can make a big difference by contemplating the surprising—and endless—journey of a handful of dust around the globe, as revealed in "Swept from Africa to the Amazon," by journalist Jeffrey Bartholet, starting on page 44. Long underappreciated, puny motes of natural dust turn out to have a tremendous influence on climate, cloud formation, and the fertilization of oceans and rain forests. "The story of dust," Bartholet writes, "is actually about the challenges of trying to figure out what is happening to the planet we inhabit." Indeed. SA

SCIENCE IN ACTION

"Tell me and I forget. Teach me and I remember. Involve me and I learn."

—Benjamin Franklin, 1706–1790

Kids are born scientists. They ask great questions, and as Franklin—one of the original "scientific Americans"—pointed out, we should foster their efforts to learn the answers firsthand. One such opportunity is the Google Science Fair. The online competition, launched in 2011, drew more than 7,000 entries from 91 countries; the fair has three age categories for 13- to 18-year-olds. Last July I was a finalist judge and master of ceremonies for the amazing awards event at Google's headquarters in Mountain View, Calif. The grand prizewinner, Shree Bose, won $50,000 for her work in improving a cancer therapy [see "Her Summer Pastime? Cancer Research," by John Matson; Advances, Scientific American, September 2011].

This year *Scientific American* is delighted to help expand the awards honors by sponsoring a $50,000 Science in Action award for a project that addresses a social, environmental or health issue to make a practical difference in the lives of a group or community. We will also bring that winner to the awards event in California in July and establish mentoring for a year. More information, along with an inspiring video of a Science in Action–style project by one of last year's finalists, Harine Ravichandran of India, is at www.ScientificAmerican.com and at www.google.com/sciencefair.

Entries are due March 30. I can't wait to see what questions the young scientists of tomorrow have been asking this time around. —*M.D.*

Illustration by Nick Higgins


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CHEMISTRY COMMENTARY

In reading "Toxins All around Us," by Patricia Hunt [Forum], and the text pertaining to how the environment influences our genes in "10 Unsolved Mysteries," by Philip Ball, I wonder about the following: If toxins in the environment are affecting our bodies in a negative way, as Hunt in particular asserts, and if some genes that were heretofore inactive are now being reactivated in response to chemicals in the environment, as Ball refers to, might these newly activated genes allow us to evolve to cope with all these toxic exposures? Perhaps that's what they are there for. Maybe our bodies of the future will be able to be healthy within this toxic mix.

John Maas Rua Ernesto do Oliveira
São Paulo, Brazil

Regarding the discussion of biofuels in "10 Unsolved Mysteries," you seem just as unwilling as other publications to discuss the economic law of diminishing returns. I don't know exactly when this law became taboo, but technology-related reporting is especially notorious in this regard. Given the time and money spent researching biofuels, hybrid engines, hydrogen fuel-cell technology, and the like, it seems reasonable to suppose that, at some point, all this effort could be better spent investing in something like effective mass transit.

David R. Witzling
via e-mail

"All the effort in developing alternative fuels could be better spent investing in effective mass transit."

DAVID R. WITZLING *VIA E-MAIL*

DARKNESS AND LIGHT

In "The Dark Side of the Milky Way," Leo Blitz states that what dark matter consists of "remains as elusive as ever," that the most conservative analysis is that it "consists of an exotic particle not yet detected in particle accelerators" and that it "reveals itself solely by its gravitational influence."

A person familiar with the history of physics cannot help but think of the "ether": that equally mysterious "substance" scientists of the 19th century supposed must exist, even though it could not be detected, to explain how light, then thought of exclusively as a wave, could propagate through space. The understanding of the dual nature of light made the ether's existence unnecessary. We should thus not be surprised if a future, more complete theory of the nature of gravity, space and time will also render dark matter nothing more than a historic construct.

Harvey Smith
Carrollton, Tex.

Blitz replies: It remains possible that modifications to Einstein's general theory of relativity could be responsible for the various phenomena that dark matter is invoked to explain. Nevertheless, despite the example of the ether, the history of astronomy is replete with dark objects that were later identified by other means. These include Neptune and the companion of Sirius, both of which, like dark matter, were first identified by their gravitational effects alone.

SCENT AND SENSIBILITY

While reading "The Scent of Your Thoughts," by Deborah Blum, I was somewhat startled to read a comment on University of Chicago researcher Martha McClintock's "friendly face and flyaway hair" and later a description of her clothes ("She wears a tweedy jacket over a bright, patterned shirt"). What has her appearance got to do with her considerable achievements as a scientist? I suspect that if she had been male, such comments would not have been written, and they are irrelevant, irrespective of gender. If I had read this in my local newspaper, I would have just rolled my eyes and sighed. Based on the usual standard of writing in *Scientific American,* such comments have no place in your journal.

Sam Vincent
Auckland, New Zealand

WASTE NOT?

In "Afghanistan's Buried Riches," Sarah Simpson discusses the availability of rare-earth elements, which are needed for high-tech manufacturing but are in short supply. She does not, however, note that these minerals are present in nuclear power plant "waste."

In roughly 50 years of operation the U.S. has accumulated about 60,000 metric tons of used nuclear fuel. Within that so-called waste stream, one can find significant amounts of cerium, samarium, gadolinium and europium, all rare-earth elements listed in the article.

One would also find actinides, heavy radioactive elements such as plutonium and uranium that can act as future fuel. That is, the waste still contains around 95 percent of the energy that could have been extracted had the fuel put into the reactors been used properly, as detailed in your December 2005 issue in "Smarter Use of Nuclear Waste," by William H. Hannum, Gerald E. Marsh and George S. Stanford.

Van Snyder
La Crescenta, Calif.

SYNC DIFFERENTLY?

One of David Pogue's points in "Big Progress on the Little Things" [TechnoFiles] is that the standardization of power cables is a highly desirable, and long overdue, trend in the gadget industry. He rightly points out that USB has become the industry standard (although he fails to emphasize that microUSB, not miniUSB, is becoming the de facto standard in the

U.S.) for devices from cell phones to e-readers to MP3 players. But what he should have added is "except for Apple."

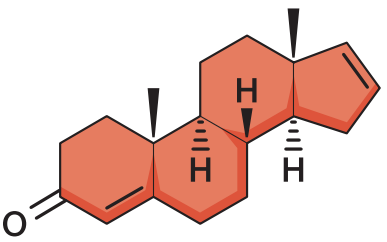
Apple continues to refuse to wholly conform to USB conventions but rather still mainly uses a proprietary 30-pin dock connector. And instead of condemning the company, he applauds it for being "standardized" within its own ecosystem, for forcing customers who buy products outside Apple to have multiple power cords and for adding to the stockpiles of proprietary Apple cabling that grow the size of our landfills.

ADAM ROYCE
San Diego

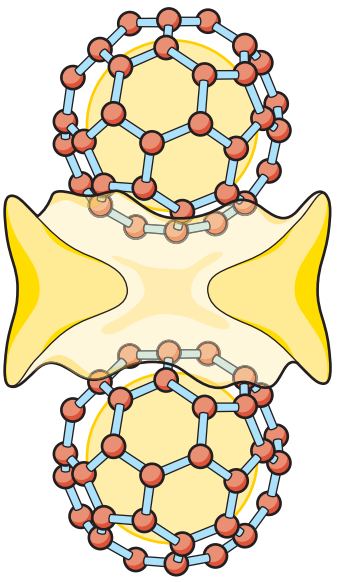
ERRATA

Two illustrations published in the "Special Year of Chemistry Celebration" articles contained errors. The corrected versions appear below.

Androstadienone



Bonded buckyballs



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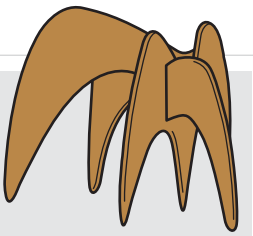

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Letters may be edited for length and clarity. We regret that we cannot answer each one. Post a comment on any article at ScientificAmerican.com/feb2012

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Unschooled in Hard Knocks

Concussion in children is a serious problem that deserves more attention

The dangers of life in the National Football League made headlines in 2009, when a study commissioned by the NFL found that retired players were 19 times more likely than other men of similar ages to develop severe memory problems. The obvious culprit: continued play after repeated head injuries. Indeed, head injury can imitate many types of neurodegenerative disease, including Parkinson's disease and, as journalist Jeffrey Bartholet reports in "The Collision Syndrome," on page 66, perhaps even amyotrophic lateral sclerosis, commonly referred to as Lou Gehrig's disease.

The problem is not unique to professional sports. About 144,000 people aged 18 and younger are treated every year in U.S. hospital emergency rooms for concussions, according to a December 2010 analysis in the *Journal of Pediatrics*. Nearly a third of these injuries occur while kids are playing organized sports. Forty percent of pediatric concussions seen in emergency rooms involve high school students. The figure is slightly higher—42 percent—for younger children. Overall, concussions are most common in football and ice hockey, followed by soccer, wrestling and other sports, and slightly more boys than girls suffer concussions.

Despite the prevalence of brain injury from kindergarten to high school, relatively little research on the long-term health consequences of concussion has been conducted on child athletes, compared with those in college and in the pros. Scientists have an incomplete understanding of what happens when a child's brain slams up against the inside of the skull during a blow to the head and how this affects neurological development. As participation in sports continues to grow (1.5 million youngsters now play on football teams in the U.S.), more head injuries are inevitable, making pediatric concussions an emerging public health crisis.

Doctors and public health experts are concerned about the effect of repeat concussions that occur before the brain has had a chance to heal from a prior impact. More research on how they affect younger brains is urgently needed. In addition, coaches, parents and school officials need to pay closer attention to what is already known about the hazards of concussions and how best to prevent permanent damage. (Visit www.cdc.gov/concussion for comprehensive information, including videos, on the topic.)

Most people assume, for instance, that loss of consciousness is the defining feature of all concussions. Yet "seeing stars," headache, nausea, dizziness, confusion, irritability, and an inability to remember events before or after the injury are the most common symptoms. Because people don't recognize these warning signs, however, youngsters may continue to play when they should not.

Similarly, because the most obvious symptoms usually disappear within a few minutes to hours, children often return to normal activities too quickly, which overtaxes their injured brain. Depending on age and symptoms, children should not take part in intense physical activity for several weeks to months after a concussion. Even the added neural exertion from mental activities like reading and video games can interfere with the cerebrum's ability to heal—particularly in the first 24 hours after injury.

Some efforts to protect young brains may actually backfire. In football, hockey and other contact sports, protective headgear seems to have increased the risk of concussion by providing a false sense of security that encourages athletes to hit harder with their head. Helmets do, however, protect against skull fracture.

To address the concussion problem, more states could follow the example of Minnesota. Legislators there passed a law, which took effect in 2011, that requires coaches to undergo training to recognize concussions and mandates the immediate removal from a game of any player at the first sign of dizziness or confusion. He or she can return to sports only with a doctor's authorization. The law could have the unintended effect of giving kids an incentive to hide their symptoms. The way around that problem, of course, is for schools, sports leagues and other organizations to join public health experts in raising ever greater awareness among coaches, parents and children to play it smart and take brain injury very seriously. SA

SCIENTIFIC AMERICAN ONLINE
Comment on this article at ScientificAmerican.com/feb2012

ERIK ISAKSON Getty Images

David Kaplan is an attending physician at University Hospitals Case Medical Center and a professor of pathology at Case Western Reserve University.

Science and Prejudice

The NIH may be biased in ways that harm not only African-American researchers but any whose ideas fall outside the mainstream

Biomedical research scientists send proposals to the National Institutes of Health in the hopes of being funded. A recent study of this process, published in *Science* by the University of Kansas's Donna Ginther and her colleagues, revealed that proposals from black applicants are significantly less likely to be funded than proposals from white applicants. This disparity was apparent even when controlling for the applicant's educational background, training, publication record, previous research awards and employer characteristics.

The authors conclude that racial bias is not a likely explanation for these findings because the race of the applicants is not provided to the reviewers. In an accompanying article in *Science,* several prominent black biomedical scientists also express doubts about racial bias, concluding that the NIH peer review grades only the science. But what, aside from bias, can explain the racial discrepancy? The study's lead author admits she has no idea. Understanding what causes bias is essential for developing a program to address it.

One possible explanation is that NIH peer review is structured to promote bias not so much against a racial group as against the unfamiliar and unconventional. Expert reviewers are asked to provide detailed assessments of long, highly complex, extraordinarily technical documents, and they are given little time to do it. The reviewers are usually conversant with the specific area of research that the proposal addresses, which means that they come to the application with preconceived notions. Short deadlines encourage them to rely on established knowledge and sensibilities. In this scenario, reviewers are more comfortable with proposals from scientists they are familiar with—scientists they either know or know of.

Black researchers, at least in the biomedical sciences, are often unfamiliar to reviewers, and their ideas may tend to be unconventional. This situation is in part because of their typical background. For instance, blacks and whites have different prevalence rates for some illnesses, such as end-stage kidney disease and malignant melanoma. Therefore, blacks may propose studies involving a different set of diseases than whites do.

Breaking into the ranks of funded investigators supported by the NIH is increasingly difficult, the data show. The average age of recipients of a first major grant from the NIH had climbed to 43 years in 2007, from 35 years in 1970. Black scientists also tend to make up smaller and smaller minorities in higher branches of science. In the period Ginther and her colleagues studied, blacks submitted 1.4 percent of total proposals compared with 69.9 percent for whites.

This statistic conforms with data collected by the National Science Foundation that indicate only 2.6 percent of doctoral-level biological scientists in the U.S. in 2006 were black. My sense is that the underrepresentation of blacks in biomedical research is even more definitive at the upper echelons: department chairs, research award winners, editorial board members, study section reviewers and members of the National Academy of Sciences. Because blacks have not shared proportionally in the power structure, it stands to reason that funding has been uneven, too.

NIH directors have recognized their failure to fund unusual proposals and have initiated awards, such as the NIH Director's New Innovator Award and Pioneer Award Program, in response. These steps, though, have not gone far enough. One solution might be for the NIH to establish multiple, distinct mechanisms for making funding decisions. A lottery, for instance, would not result in racial disparity in grant awards. Neither would having rigorous sampling procedures for reviewers or peer review by crowdsourcing. Supplementing traditional peer review with new ways of screening grant applications may be the only way to eliminate the racial gap once and for all. SA

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Photoillustration by O.O.P.S.

SPACE

Tensions over Taikonauts

During the cold war the U.S. found ways to collaborate with the Soviet Union on space missions. Should it do the same with China?

The next time humans set foot on the moon, they may well plant a five-starred red flag there. The Chinese space program is developing rapidly, and further progress should come this year when taikonauts, a colloquial term for Chinese astronauts, visit the Tiangong-1 space module.

The president's chief science adviser John Holdren has said the U.S. would benefit from cooperation with China. The two countries could tackle the problem of space debris and, possibly, lay groundwork for a joint mission to Mars. His thinking fits with the Obama administration's so-called Asian pivot, a shift in focus from the Middle East to China's growing influence; the idea is that science and technology cooperation could be a useful lever in negotiations.

But federal legislation now prohibits NASA from pursuing any such joint efforts. The relevant clause first popped up last April in a stopgap funding bill, and in November it reappeared in the legislation funding NASA for 2012. The author of the provision is Representative Frank Wolf of Virginia, who cites China's human-rights record and the threat of espionage. The "Wolf clause" has already had a visible effect: journalists from the state-owned Xinhua News Agency were barred from a shuttle launch last year.

One widely held concern is just who would be on the Chinese end of a hypothetical manned mission with the U.S. It is clear that the People's Liberation Army plays a major role in China's space missions, says Dean Cheng, a research fellow at the Heritage Foundation in Washington, D.C. "It begs the question of whether there is a civilian manned space program in any meaningful sense of the word," he says.

Many believe that limited collaboration, such as on unmanned missions, would be constructive. "We found ways to cooperate with the Soviet Union during the cold war," says Scott Pace, director of the Space Policy Institute at George Washington University. "I don't see why we couldn't do similar types of things with China."

So the White House is pushing back, trading legal memos with congressional investigators on the constitutionality of the Wolf clause, which also binds Holdren's Office of Science and Technology Policy. Although a court battle seems unlikely, a spokesperson says that Wolf plans to keep a close eye on Holdren and his colleagues in the coming year and "hold their feet to the fire" to ensure compliance.

—John Matson

Liftoff: China's Shenzhou-8 spacecraft, which has helped pave the way for manned missions this year.

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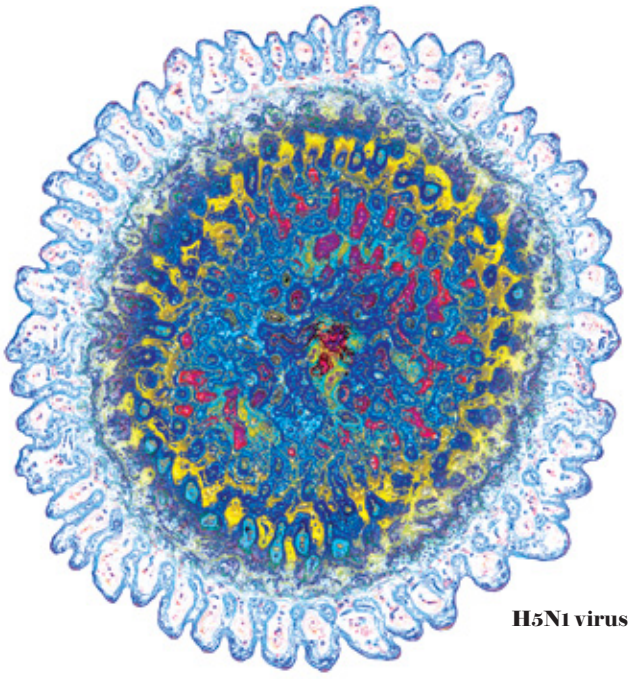


H5N1 virus

JAMES GAVALLINI *Photo Researchers, Inc.*

It's a rare kind of research that incites a frenzied panic before it is even published. But it's flu season, and influenza science has a way of causing a stir this time of year.

Epidemiologists have long debated the pandemic potential of H5N1, aka bird flu. On one hand, the virus spreads too inefficiently between humans to seem like much of a threat: it has caused fewer than 600 known cases of human flu since first emerging in 1997. On the other hand, when it does spread, it can be pretty deadly: nearly 60 percent of infected humans died from the virus. For years the research has suggested that any mutations that enhanced the virus's ability to spread among humans would simultaneously make it less deadly. But in a batch of studies submitted for publication late last year, two scientists—Yoshihiro Kawaoka of the University of Wisconsin–Madison and Ron Fouchier of Erasmus Medical Center in the Netherlands—have shown otherwise.

Working separately, they each hit on a combination of mutations (five, in Fouchier's case) that enables H5N1 to spread readily between humans without making it less deadly.

Efforts to publish those findings have been fraught. Critics say that making the methodology or gene sequences widely available amounts to giving would-be bioterrorists an easy recipe. They also worry that these man-made strains might escape from the lab.

Proponents counter that the threat of a global pandemic, were this mutated strain to arise in nature, is far greater than the threat of bioterrorism. Understanding what combination of mutations could transform H5N1 into a human pandemic virus gives epidemiologists a leg up on preparing countermeasures; they can, for example, test existing vaccines against the new strain.

As of mid-December, both papers were being reviewed by the government's National Science Advisory Board for Biosecurity (NSABB). In the meantime, most experts agree that we need a better way.

"Physicists have been doing sensitive, classified work for 70 years," says Michael T. Osterholm, an infectious disease expert at the University of Minnesota and a member of the NSABB. "We have to find a way to do the same in the health sciences, without compromising our safety and security."

—Jeneen Interlandi

TECHNOLOGY

It Detects Earthquakes and Lactose Intolerance

A new suitcase-size spectrometer has many functions

Nobel Prize winner C. V. Raman discovered in the 1920s that bombarding a substance with light excites its molecules and scatters the light in a signature pattern that can be analyzed like a fingerprint. Today Raman spectrometers are used in a variety of settings, but they tend to be large and expensive. A team led by physicist Manfred Fink of the University of Texas at Austin is developing a smaller, less expensive model that may improve earthquake detection and bring down the cost of some medical tests.

Fink's device, which is about the size of a suitcase, does not measure the entire light spectrum but only one featured line containing the known signature for a target molecule. Inside the device, called the Analytic Non-Dispersive Raman Spectrometer, is a small diode laser whose light beam bounces between two concave mirrors to amplify its power. This light amplification also increases the sensitivity of the device, making it possible to measure impurities in parts per billion.

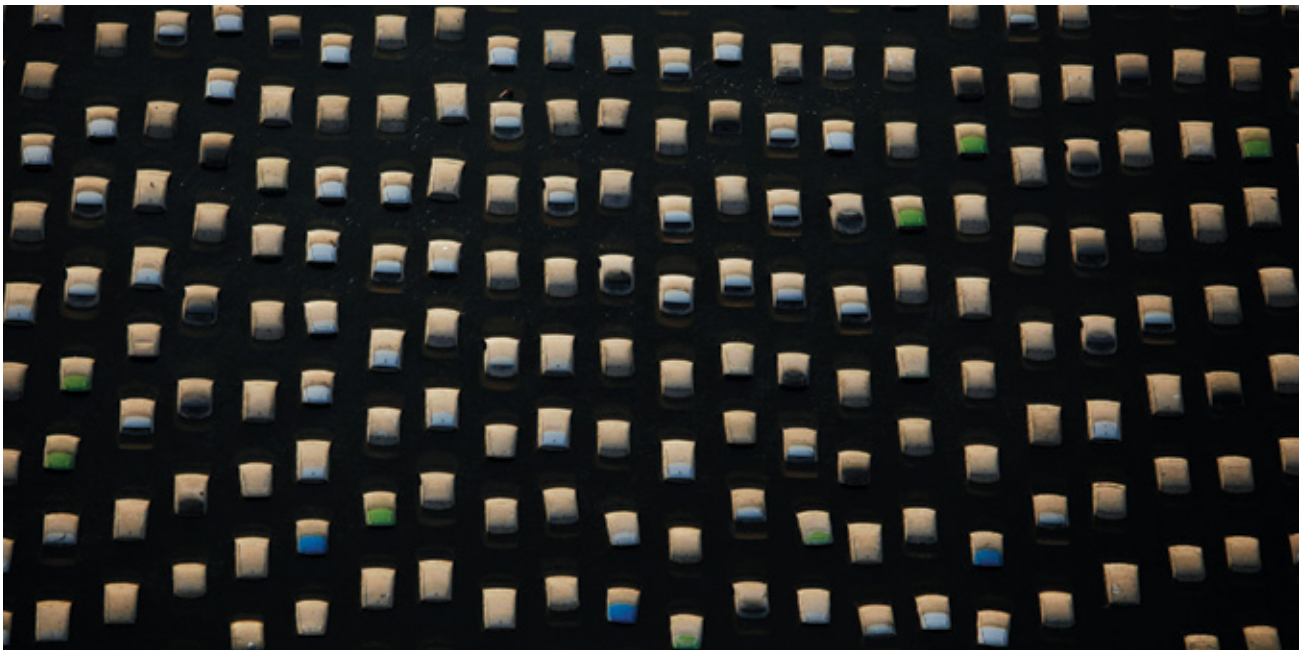
One aim would be to deploy the spectrometer in concert with seismographs to predict earthquakes as much as 45 minutes in advance. Seismographs have trouble distinguishing quake tremors from those that come from other sources, like construction. A spectrometer, however, could detect unusual proportions of gases released by seismic activity into hot springs and fissures in the ocean floor, which might indicate a coming quake.

Other researchers are looking into medical applications for the device. Shirish Barve, a gastroenterologist at the University of Louisville, is testing whether it can monitor liver disease by analyzing patients' breath, and Fink says the device may also be used to detect lactose intolerance in newborns. ***—Melissa Gaskill***

FURTHER READINGS AND CITATIONS ScientificAmerican.com/feb2012/advances

WHAT IS IT?

Submerged specks: Parts of Thailand were left unrecognizable at the end of last year, after the country experienced its worst floods in 50 years. The tops of vehicles at a Honda factory in Ayutthaya province (*pictured here*) peeked out from under receding water. The flooding, brought on by an unusually heavy monsoon season, immersed about one third of Thailand's provinces, displacing thousands and killing more than 650 people. Stagnant waters brought fears of mosquitoes carrying malaria and dengue fever. *—Ann Chin*



DAMIR SAGOLJ *Reuters*

LINGUISTICS

Just a Click Away

Sounds associated with African languages play a larger role in English than previously thought

Some Africans click, but English speakers don't. That's been the conventional wisdom about click sounds, which serve as regular consonants in Zulu and Xhosa and a few other African languages but which were presumed to just be used in English for encouraging a horse, imitating a kiss, or expressing emotions such as disapproval or amazement. But researchers have recently found that clicks are far more prevalent in the world's lingua franca than had been thought.

Speakers, it turns out, use clicks for a previously overlooked purpose: as a form of verbal punctuation in between thoughts or phrases. Melissa Wright of Birmingham City University in England recently analyzed click sounds in six large sets of recorded English conversations. She found that speakers used clicks frequently to signal that they were ending one stretch of conversation and shifting to a new one. For example, a speaker might say, "Yeah, that was a great game," produce a click, then say, "The reason I'm calling is to invite you to dinner tomorrow."

This pattern, which occurred for both British and American speakers, suggests that clicks have a meaning similar to saying "anyway" or "so." That is, clicks provide us with a phonetic resource to organize conversations and communicate our intentions to listeners. This finding had previously eluded linguists, whose research often focuses on words and sentences in isolation. Wright was able to uncover the new pattern because she analyzed clicks in the context of complete conversations, suggesting that this method could be important for making new discoveries about the nature of language.

These results, published in the *Journal of the International Phonetic Association,* could shake up current thinking about the origin of language. On the basis of linguistic and genetic data, some researchers have claimed that the ancestral population of humans lived in Africa and spoke a click language. As languages farther and farther away from Africa are examined, they argue, clicks become less and less integral, suggesting they are relics that have been lost as humans migrated away from their homeland and diversified their speech. Wright's research, however, shows that clicks can be important even in a modern language very far from Africa.

This discovery opens up the possibility that clicks are not relics at all but are flexible linguistic tools that can help meet the communication needs of any human population.

—Anne Pycha

PROBABILITY

The Not So Hot Hand

Pro basketball players are much more likely to try another three-point shot after making one than after missing one

Reggie Miller, Michael Jordan, Kobe Bryant. They've all gone on seemingly memorable shooting streaks. But past research has shown that the so-called hot hand is a myth, rooted in our tendency to see patterns where there are none.

Myth or no, the shooters still seem to think they're on fire when statistics show they're not. A recent study finds that professional basketball players put too much stock in the outcome of their last three-point shot. If they make a three-pointer, they are much more likely to try another one than if they had missed. The study, appearing in the journal *Nature Communications,* used game stats for hundreds of NBA and WNBA players. (*Scientific American* is part of Nature Publishing Group.)

The Lakers' Bryant was a prime example in his MVP season of 2007–2008. When Bryant made a three-pointer, he shot again from downtown nearly four times as often as he did following a missed three. But trying to ride a three-point streak is often bad strategy. Players actually tend to shoot a lower percentage after making shots than after missing them—once again sending the idea of the "hot hand" up in smoke.

—John Matson

GETTY IMAGES

Illustrations by Thomas Fuchs

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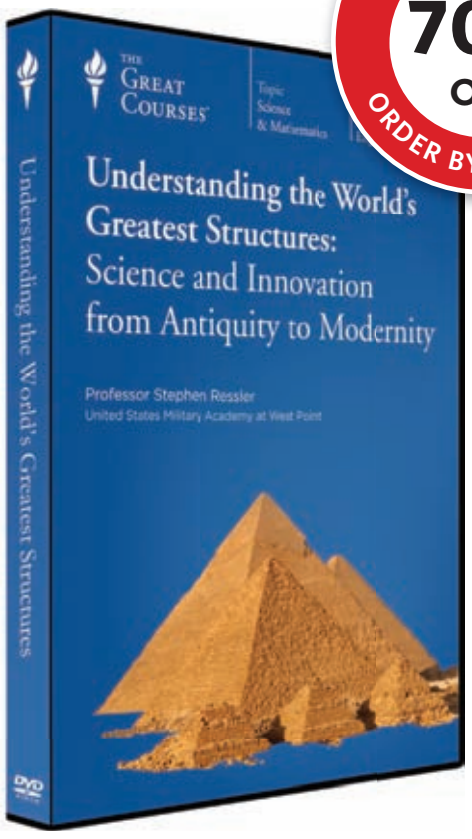

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ANTHROPOLOGY

Mom Is My Wingman

Male monkeys who live at home have more luck with females

Human males living with their moms may not expect to have much luck hooking up this Valentine's Day. But among the northern muriqui monkeys, males that spend the most time around their mothers seem to get an added boost when mating time rolls around.

The findings, published in the *Proceedings of the National Academy of Sciences USA*, suggest that females in some species may have evolved to play a critical role in their sons' reproductive success. Karen Strier, the paper's lead author and a professor of anthropology at the University of Wisconsin–Madison, says the paper "extends" the so-called grandmother hypothesis, a concept in which human females evolved to live past their prime reproductive years to spend more time helping offspring.

The research team observed and collected genetic data from a group of 67 wild monkeys living in a protected reserve in Brazil's Atlantic Forest: infants, mothers and possible sires. They found that six out of the 13 adult males they studied spent more time in close proximity to their mothers than would be expected by chance. These same six monkeys, on average, sired the greatest number of offspring.

The investigators are still trying to figure out why. "It's not like we see moms intervening and helping their sons out," Strier says. "Maybe by sitting near their moms, they get to see when females are sexually active, or maybe they just get more familiar with other females." Strier also found that there was no inbreeding among sons and their close female relatives, a process that might also be mediated by mothers. "Mating may be less random than we think, perhaps because of the influence of the mothers," she says.

The findings can help with future conservation efforts for the critically endangered species. "The last thing we would want to do is take a male out of its natal group," Strier observes. ***—Joan Raymond***

SCIENTIST IN THE FIELD

Peeling Away Microbes

Can feeding orange rind to cows help rid beef of *Salmonella* and *E. coli?*

PROFILE

name
Todd Callaway

title
Research microbiologist, U.S. Department of Agriculture

location
College Station, Tex.

A cow's rumen has an incredibly thick population of microbes, somewhere between 10 billion and 100 billion microbes per milliliter of its fluid. *Escherichia coli* and *Salmonella* are two, but they are found in relatively low levels, maybe one out of 10 million cells. For years we have been trying to reduce the amount of these pathogens after the cows are killed, and those efforts do really well. But at some point, you reach diminishing returns. So we're trying to move to the preharvest site, before the cows are killed.

In southeastern Florida and in California, where they produce orange juice, orange peels are a waste product. Instead of throwing them away, the juice company used to sell the peels to local dairies. Cows can eat pretty much anything, so farmers have been feeding cows these waste products because it's cheap and the cows like it.

We knew orange peels had antimicrobial properties, so we asked whether maybe they were having an effect on the cows. They set up an experiment, and, sure enough, it worked in some studies in the live animals and reduced the microbes a little over 10-fold. It's not a home run, but it has a role that it can play.

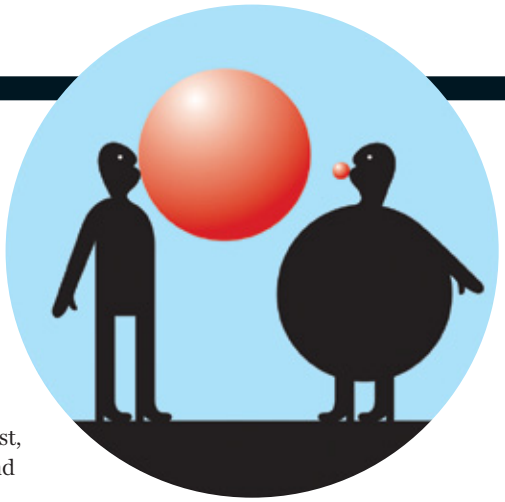
We'll combine the orange peels with all the other things we do. You would immunize cows when they are born and then, as they're growing up, start feeding them some probiotic and orange peel every day. Then, in the plant, they have acid washes and other methods. So everything working together should be able to reduce the pathogen load.

Imagine you see people running a race in the Olympics where they are jumping hurdle after hurdle, and eventually they start tripping because they get tired. A pathogen is the same way—we're trying to introduce multiple hurdles of various heights. No one has found that magic solution yet because pathogens have evolved to live in animals over time. There is no such thing as that magic bullet in biology.

—As told to Rose Eveleth

COURTESY CARLA B. POSSAMAI *Federal University of Espírito Santo (monkeys)*; ROSEMARY CALVERT *Getty Images (orange peel)*

COMMENT AT ScientificAmerican.com/feb2012



OBESITY

Gumming Up Appetite

The obese may soon have a new tool to curb hunger

Losing weight is not always about anticipating swimsuit season or squeezing into skinny jeans—for the obese, losing weight is about fighting serious illness and reclaiming health. Yet the primal part of the brain that regulates appetite will not place a moratorium on hunger just because someone has acknowledged the need to lose weight. Researchers at Syracuse University are working toward a unique solution: chewing gum that suppresses appetite.

There are many appetite-suppressing drugs on the market, but a large number are based on drugs similar to amphetamines that carry the risk of high blood pressure and heart failure. Syracuse chemist Robert P. Doyle is focusing on a hormone called human peptide YY (hPYY), which is released from cells that line the intestine whenever you eat and exercise. The more calories consumed, the more hPYY travels from intestinal cells into the bloodstream, eventually reaching the hypothalamus—an almond-size, evolutionarily ancient part of the brain that helps to regulate hunger, thirst, body temperature and sleep cycles.

Previous studies have shown that injections of PYY and hPYY suppress appetite in rodents, monkeys and people. In one study, both obese and lean people consumed about 30 percent fewer calories than usual at a buffet lunch only two hours after receiving a dose of hPYY.

The problem until now has been that peptides, chains of amino acids, are small and chemically fragile enough to be destroyed by the stomach and gut but too large to pass into the blood unaided. Doyle found a way to solve the problem by chemically linking hPYY to vitamin B_{12}, which the body ferries from the gut into the bloodstream.

Because recent research suggests that there are PYY receptors in the tongue, hPYY chewing gum could promote feelings of satiety very quickly.

If the drug eventually makes it through clinical trials, there is the danger that individuals might abuse it to stay unnaturally thin. "I understand the market would be vast for people who want to lose a few pounds," Doyle says. "But my aim is to help patients who have a medical need to lose weight." —*Ferris Jabr*

GENETICS

A Long Flight but No Baggage

The new monarch genome gives clues to how the butterflies travel

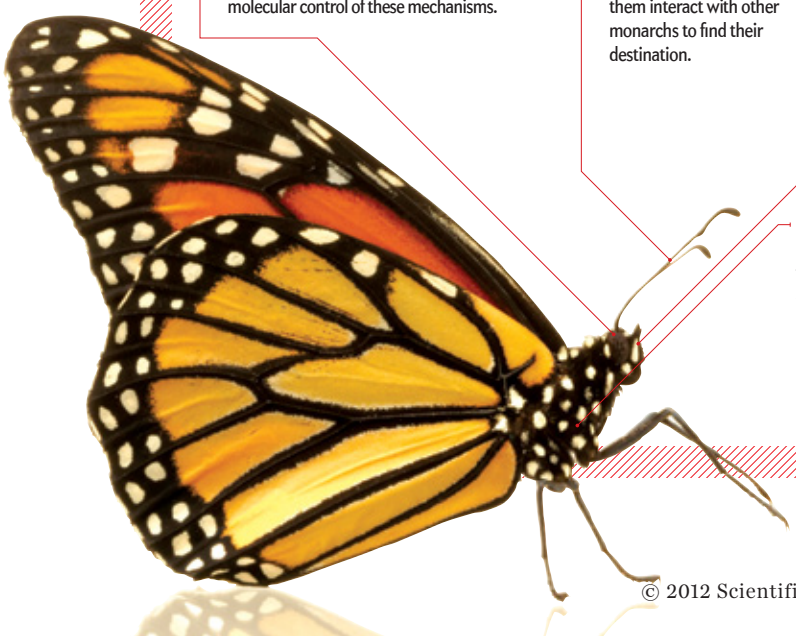
The millions of monarch butterflies (*Danaus plexippus*) that flit on fragile wings from North America to fir forests in Mexico have evolved a slew of special adaptations to allow this arduous flight, which can be as far as 4,000 kilometers. Now the draft genome of the species, published in the November 2011 *Cell*, suggests how genetic adaptations allow these lovely insects to survive their long journey.

Brain
Butterflies' circadian clocks help them sense decreasing day length and trigger the migration, says study co-author Steven Reppert, a neurobiologist at the University of Massachusetts. The genome reveals new information about the molecular control of these mechanisms.

Antennae
The butterflies have a large number of olfactory receptor genes, which, when activated in the antennae, might help them interact with other monarchs to find their destination.

Eyes
Genes involved in eye development might help the butterflies detect fine changes in the sun's position, as well as patterns of polarized light. These subtle differences most likely assist them in staying on track to their faraway wintertime destination.

Reproductive organs
Not all monarchs migrate, but those that do lack a key enzyme that produces the juvenile hormone, which stimulates the reproductive organs. Lacking this keeps the butterflies underdeveloped and disinterested in sex so they can focus on their flight.
—*Katherine Harmon*



DON FARRALL *Getty Images*

STAT

63

Percent of teenagers who have never considered a career in engineering

61: Percent who would be more likely to consider it after learning that those who graduate with a bachelor's degree in engineering earn an average of $75,000 a year

COMMENT AT ScientificAmerican.com/feb2012

NEUROSCIENCE

Inside the Mind of a Video Game Champ

Cognitive scientists are observing StarCraft 2 players to learn how humans multitask

If there is one general rule about the limitations of the human mind, it is that we are terrible at multitasking. When devoted to a single task, the brain excels; when several goals splinter its focus, errors become unavoidable.

Still, clear exceptions challenge that general rule. For decades chess has held the exalted position of the *Drosophila* of cognitive science—the model organism that scientists could poke and prod to learn what makes experts better than the rest of us. StarCraft 2, one of the world's hottest computer games, might be overtaking chess: its added complexity may confound researchers initially, but the answers could ultimately be more telling. In this real-time strategy game, players exert a godlike role over a cluster of creatures, leading them to develop their economy and prepare for skirmishes with a neighboring society. The winner is often the person who can make the most moves, as many as six actions a second.

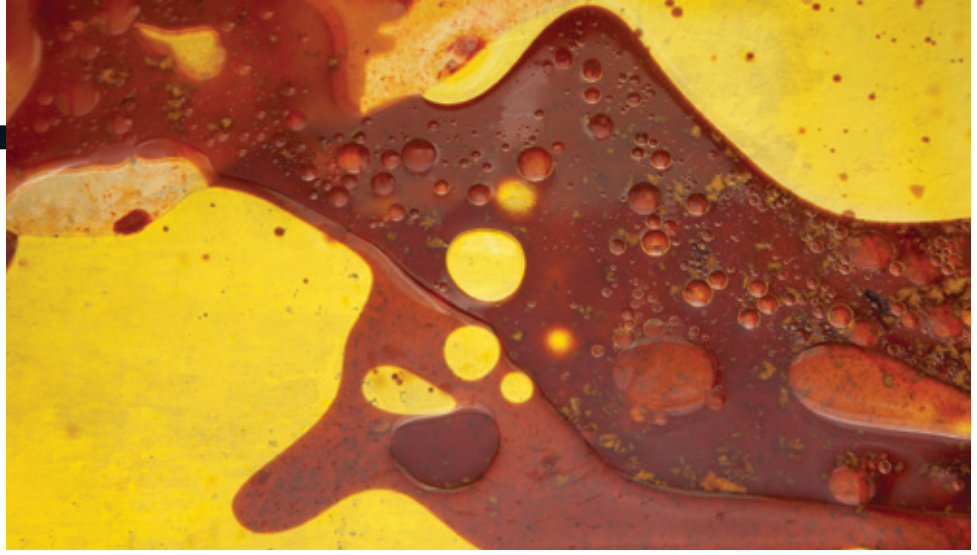
Game on: Players at a recent StarCraft 2 tournament.

ALAMY

For researchers the appeal lies in the data each game generates. When two players face off, their computers each produce a record of the actions taken during the game. These logs reflect what a gamer was thinking at every stage of play. "I can't think of a cognitive process that's not involved in StarCraft," says Mark Blair, a cognitive scientist at Simon Fraser University. "It's working memory. It's decision making. It involves precise motor skills. Everything is important, and everything needs to work together."

Thousands of these gamers are now contributing to a project under Blair's watch, called SkillCraft, to learn what separates experts from novices when it comes to attention, multitasking and learning. By comparing the techniques and attributes of low-level players with those of other gamers up the chain of ability, the researchers can start to discern how skills develop—and perhaps, over the long run, identify the most efficient training regimen. Blair sees parallels between the game and emergency management systems. In a high-stress crisis situation, the people in charge of coordinating a response may find themselves facing competing demands: fire alarms, a riot, contamination of drinking water. The mental task of keeping cool and distributing attention among equally urgent activities might closely resemble the core challenge of StarCraft 2.

—Sandra Upson



FOOD SCIENCE

Making Liquids Go Bipolar

It takes a lab to make a perfect salad dressing

For a slick, supple mouthfeel, there's nothing like a suspension of fine droplets of oil in water (or vice versa)—what scientists call an emulsion. Cream, butter and chocolate are emulsions, as are gravy, vinaigrette and cheese. But when an emulsion breaks, the results can get ugly: a layer of clear fat floating on top of the gravy boat, a salad dressing that comes out of the bottle all oil and no vinegar, a plate of nachos covered in greasy goo.

Making one means overcoming some powerful forces of nature. The repulsion between water and oil is electric. A water molecule is unbalanced, electrically speaking, in such a way that a polar charge develops among its atoms. As a result, groups of water molecules form exclusive cliques, aka droplets. Oil molecules, in contrast, are nonpolar and hydrophobic. It takes a surprising amount of force to persuade a polar liquid to mingle with a nonpolar one at an intimate level.

A blender is not always up to the job. The human tongue can detect particles (including liquid droplets) that are just seven to 10 microns across, but blenders generally cannot do better than 10 to 12 microns. When the cooks in our research kitchen were working out a recipe for eggless mayonnaise, they relied on a rotor-stator homogenizer instead. This countertop machine spins a small blade (the rotor) at up to 20,000 rpm within a slotted metal sheath (the stator). Tremendous shear forces rip the droplets down to just a few microns.

For another challenging recipe—a kosher, dairy-free veal "cream"—we tried even bigger iron: an ultrahigh-pressure homogenizer. Our model, which is about the size of a large sink, pressurizes the mixture to as much as 25,000 psi, then slams it into a metal wall to smash it to submicron bits. The result is delicious.

In the finest emulsions, the particles are just a few nanometers in diameter—so tiny the emulsion turns clear. Mountain Dew is a nanoemulsion, for example. To make a transparent nanoemulsion of essential oils from thyme and bay leaf for a chilled chicken soup, our cooks needed a handheld tool because the quantity of liquid was so small.

The solution was an ultrasonic homogenizer, which transforms several hundred watts of power into high-frequency sound waves that induce minuscule bubbles to form in the liquid. These cavitation bubbles then implode, tearing droplets apart as they do. The high-pitched tool gives new meaning to whine and dine. *—W. Wayt Gibbs and Nathan Myhrvold*

Myhrvold is author and Gibbs is editor of Modernist Cuisine: The Art and Science of Cooking *(The Cooking Lab, 2011).*

PHYSICS

In Sync, on a Quantum Level

Physicists make two diamonds vibrate as one

Diamonds have long been available in pairs—say, mounted in a nice set of earrings. Now physicists have managed to entangle the quantum states of two diamonds separated by 15 centimeters. Quantum entanglement is a phenomenon by which two or more objects share an unseen link bridging the space between them—a hypothetical pair of entangled dice, for instance, would always land on matching numbers, even if they were rolled in different places simultaneously. But that link is fragile, and for that reason entanglement experiments on physical systems usually take place in highly controlled laboratory setups—entangling, say, a pair of isolated atoms cooled to nearly absolute zero.

In the new study, scientists at the University of Oxford, the National Research Council of Canada and the National University of Singapore showed that entanglement could also be achieved in more ordinary objects at room temperature, in this case two different squares of synthetically produced diamond, each three millimeters across. The researchers split a laser beam in two and shone it through the diamonds; any photons that scattered off the diamond to generate a phonon, a quantum of vibrational energy, were funneled into a photon detector. The arrival of one of those photons signaled the presence of a vibration in the diamonds.

"We know that somewhere in that apparatus, there is one phonon," says Ian Walmsley, an experimental physicist at Oxford and a co-author of the study. "But we cannot tell, even in principle, whether that came from the left-hand diamond or the right-hand diamond." In quantum-mechanical terms, in fact, the phonon is not confined to either diamond. Instead the two diamonds enter an entangled state in which they share one phonon between them.

Walmsley notes that the diamonds are not perfect for quantum science—their entanglement is fleeting—but he hopes that investigators will consider using more ordinary materials in quantum technologies. "I think it gives a new scenario and a new instantiation of something that helps point in that direction," he says. ***—John Matson***

STAT

11

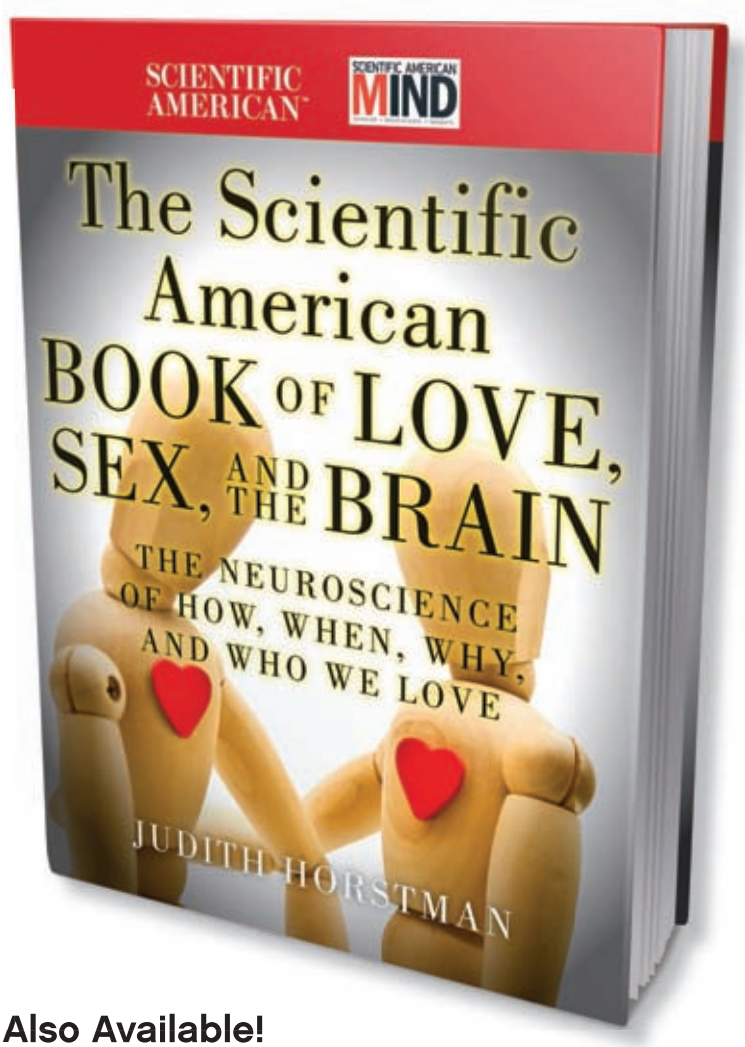
The rank that engineer occupies on a list of 19 professions with which teens are familiar. Teacher is number one, followed by doctor, nurse, police officer and chef.

SOURCE: Intel Corporation survey, released December 2011

RYAN MATTHEW SMITH *Modernist Cuisine LLC*

COMMENT AT ScientificAmerican.com/feb2012

A fascinating look at how the **brain** controls our **relationships** and **romances**.



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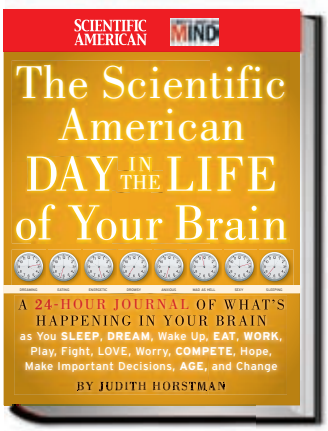

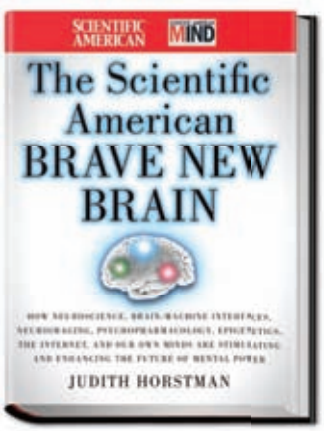

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SPACE

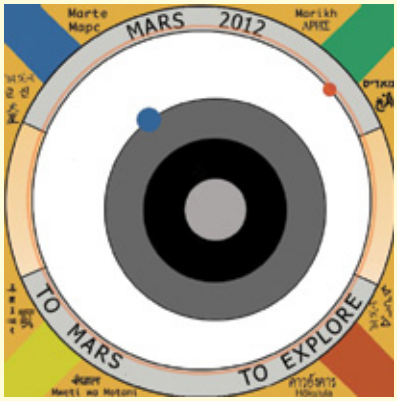
Storybook Wishes for Martian Rovers

A hand-painted sundial will help Curiosity focus its cameras

The Martian rovers Opportunity and Spirit have represented optimism, hope and even cuteness to millions of people dreaming about discoveries on the Red Planet.

How appropriate, then, that the newest rover, Curiosity, should carry a sundial with sentiments and illustrations worthy of classic children's literature. Curiosity blasted off onboard an Atlas 5 rocket on November 26 and is currently heading for Mars with an August 2012 landing date.

The sundial doubles as the color-calibration target for the Mast camera (Mastcam)



that will capture the Martian landscape. Its image will be transmitted from Mars to Earth many times, and students might use it to learn about the ways that such simple but elegant instruments can be used to determine the time, date, season and latitude on a planetary surface with atmospheric hues different from our own. And it will remain on Mars for the benefit of future space travelers.

Among the messages and illustrations on the sundial is the name "Mars" written in 16 different languages, including ancient Sumerian and Inuktitut, around the edges.

The artist behind this creation is Jon Lomberg, who was Carl Sagan's colleague and favorite artist and who has launched five message artifacts to Mars, with this sundial on Curiosity marking the fifth. Three others have made it, including the DVD he helped to curate entitled *Visions of Mars,* attached to the 2007 Phoenix lander. You can read more about the sundial on Lomberg's blog at www.citizenofthegalaxy.com.

Like the other rovers before it, maybe one day Curiosity will become the stuff of legend and storybook dreams. *—Glendon Mellow*

Adapted from the Symbiartic blog at blogs.ScientificAmerican.com/symbiartic

SUSTAINABILITY

The Impracticality of a Cheeseburger

A fast-food staple reveals the pros and cons of industrialization

What does the cheeseburger say about our modern food economy? A lot, actually. Over the past several years blogger Waldo Jaquith (http://waldo.jaquith.org) set out to make a cheeseburger from scratch, to no avail. "Further reflection revealed that it's quite impractical—nearly impossible—to make a cheeseburger from scratch," he writes. "Tomatoes are in season in the late summer. Lettuce is in season in spring and fall. Large mammals are slaughtered in early winter. The process of making such a burger would take nearly a year and would inherently involve omitting some core cheeseburger ingredients. It would be wildly expensive—requiring a trio of cows—and demand many acres of land. There's just no sense in it."

That the cheeseburger—our delicious and comforting everyman food—didn't exist 100 years ago is a greasy, shiny example of all that is both right and wrong with our modern food economy. Thanks to fertilizers, genetically modified crops, concentrated farming operations and global overnight shipping, much of the world was lifted out of starvation (but not malnutrition, ironically enough) because it could finally grow sufficient quantities of food with decreasing labor inputs.

But these same advances that allow food to be grown out of season and in all corners of the globe contribute to a whole host of environmental problems, from deforestation and nitrogen loading of water sources (and the resulting dead zones) to the insane quantities of water being consumed. The "industrialization of food," as author Paul Roberts puts it, is a relentless cycle driven by razor-thin price margins that force food processors to adopt more advanced techniques to produce even more food at lower prices. This system will only be exacerbated as food demand increases. Recently David Tilman and Jason Hill of the University of Minnesota released a study anticipating that global food demand could double by 2050. It's doubtful that our current, impractical food economy can sustain that demand. *—David Wogan*

Adapted from the Plugged In blog at blogs.ScientificAmerican.com/plugged-in

HEALTH

Oral Exam

New imaging techniques are helping scientists see what's really going on in your mouth

Personal oral hygiene notwithstanding, your mouth is teeming with hundreds of species of microorganisms. Until now, researchers have had a tough time sorting out all these small species—and how they interact. A new multicolor fluorescent-labeling technology is allowing microbiologists to peer into the human mouth's microscopic jungle and discover new dynamics among several key groups. The findings were presented last December at the American Society for Cell Biology's annual meeting in Denver.

Combinatorial labeling and spectral imaging (CLASI) was designed by a team at the Marine Biological Laboratory in Woods Hole, Mass., and at Brown University. In one dental sample, the team characterized 15 taxa and assessed their density and spatial distribution, giving some new insight into how plaque forms. The goal is to eventually be able to profile the full 600-plus species found in the human mouth. *—Katherine Harmon*

Adapted from the Observations blog at blogs.ScientificAmerican.com/observations

COURTESY OF JIM BELL, JON LOMBERG AND MER SUNDIAL TEAM *citizenofthegalaxy.com*

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Maryn McKenna is a journalist , a blogger and author of two books about public health. She writes about infectious diseases, global health and food policy.

A Diabetes Cliffhanger

Researchers are baffled by the worldwide increase in type 1 diabetes, the less common form of the disease

When public health officials fret about the soaring incidence of diabetes in the U.S. and worldwide, they are generally referring to type 2 diabetes. About 90 percent of the nearly 350 million people around the world who have diabetes suffer from the type 2 form of the illness, which mostly starts causing problems in the 40s and 50s and is tied to the stress that extra pounds place on the body's ability to regulate blood glucose. About 25 million people in the U.S. have type 2 diabetes, and another million have type 1 diabetes, which typically strikes in childhood and can be controlled only with daily doses of insulin.

For reasons that are completely mysterious, however, the incidence of type 1 diabetes has been increasing throughout the globe at rates that range from 3 to 5 percent a year. Although the second trend is less well publicized, it is still deeply troubling, because this form of the illness has the potential to disable or kill people so much earlier in their lives.

No one knows exactly why type 1 diabetes is rising. Solving that mystery—and, if possible, reducing or reversing the trend—has become an urgent problem for public health researchers everywhere. So far they feel they have only one solid clue.

"Increases such as the ones that have been reported cannot be explained by a change in genes in such a short period," says Giuseppina Imperatore, who leads a team of epidemiologists in the Division of Diabetes Translation at the U.S. Centers for Disease Control and Prevention. "So environmental factors are probably major players in this increase."

A CHALLENGE OF COUNTING

Type 1 and type 2 diabetes share the same underlying defect—an inability to deploy insulin in a manner that keeps blood sugar from rising too high—but they arise out of almost opposite processes. Type 1, which once was known as juvenile diabetes, is an autoimmune disease in which the body attacks its own cells—namely, the beta cells of the pancreas—destroying their ability to make insulin. In type 2, formerly known as adult-onset diabetes, tissues that need insulin to take up glucose (such as the liver, muscles and fat) become resistant to insulin's presence. The insulin-producing cells respond by going into overdrive, first making more of the hormone than normal and then losing the ability to keep up with the excess glucose in the blood. Some people end up unable to make insulin at all.

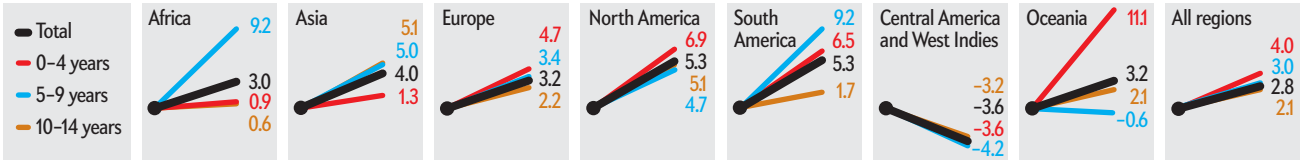
The first strong signal that the incidence of type 1 diabetes was on the rise came in 2006, from a World Health Organization project known as DIAMOND (a combination of words in several languages for worldwide diabetes). That survey, which looked at 10 years of records from 112 diabetes research centers in 57 countries, found that type 1 had risen an average of 5.3 percent a year in North America, 4 percent in Asia and 3.2 percent in Europe.

Statistics from Europe—where the single-payer health care systems that care for residents throughout their lives generate rich stores of data—back up that first finding. In 2009 researchers from a second project called EURODIAB compared diabetes incidence across 17 countries and found not only that type 1 was rising—by 3.9 percent a year on average—but also that it was increasing most quickly among children younger than five. By 2020, they predicted, new cases of type 1 diabetes in that age group will nearly double, from 3,600 children to an estimated 7,076 children.

Most assessments of diabetes in the U.S. have been more partial and local. There is one comprehensive national surveillance project, the federally funded SEARCH for Diabetes in Youth study, which published data in 2007. Because that was an initial report, however, researchers could not compare it with earlier

GETTY IMAGES

Annual Percent Change in Type 1 Diabetes Incidence by Region and Age Group (1990–1999)



Global mystery: **Although some regions (Africa, Asia) are starting from a lower base than others (North America, Europe), the incidence of type 1 diabetes is growing everywhere except the West Indies (where the decline can be traced to one country—Cuba).**

years. Still, when looked at against the findings of other studies, it suggests a rising tide. For example, the 2007 study found higher rates of type 1 in the U.S. than did the WHO's worldwide study of the year before. In addition, the SEARCH study results were sharply higher than regional studies from the 1990s in Alabama, Colorado and Pennsylvania.

COMPETING HYPOTHESES

The challenge for explaining the rising trend in type 1 diabetes is that if the increases are occurring worldwide, the causes must also be. So investigators have had to look for influences that stretch globally and consider the possibility that different factors may be more important in some regions than in others.

The list of possible culprits is long. Researchers have, for example, suggested that gluten, the protein in wheat, may play a role because type 1 patients seem to be at higher risk for celiac disease and the amount of gluten most people consume (in highly processed foods) has grown over the decades. Scientists have also inquired into how soon infants are fed root vegetables. Stored tubers can be contaminated with microscopic fungi that seem to promote the development of diabetes in mice.

None of those lines of research, though, have returned results that are solid enough to motivate other scientists to stake their careers on studying them. So far, in fact, the search for a culprit resembles the next-to-last scene in an Agatha Christie mystery—the one in which the detective explains which of the many suspects could not possibly have committed the crime.

The last scene in the drama, unfortunately, still has not been written. Currently the suspects getting the closest scrutiny are infections with bacteria, viruses or parasites. The presumptive etiology: a version of the "hygiene hypothesis" that links clean modern lifestyles and allergies.

The hygiene hypothesis proposes that early exposure to infections or soil organisms teaches the developing immune system how to maintain itself in balance and so keeps it from reacting in an uncontrolled way later in life when it encounters allergens such as dust and ragweed. Living hygienically, it goes on to say, has deprived children of those early exposures, fueling an epidemic of allergies. The diabetes version of the hygiene hypothesis proposes that when the immune system learns not to overreact to allergens, it also learns to tolerate compounds from the body's own tissues—and therefore prevents the autoimmune attack that destroys the ability to make insulin.

Some circumstantial evidence supports that proposal. Children with multiple siblings—who might bring infections home from day care or school—are less likely to be hospitalized for type 1 diabetes (a proxy measure for incidence). The disease is also less common in children who attend day care themselves, and it is more common in specially bred mice that do not encounter infections because they are raised in a sterile environment .

By themselves, however, those findings do not make the case. Christopher Cardwell, a lecturer in medical statistics at Queen's University Belfast, has conducted meta-analyses of associations between type 1 and birth order, maternal age at birth, and birth by cesarean section, all of which affect the organisms to which young children are exposed. "All of these seemed to be associated," he says, "but they all were in my opinion fairly weak associations. None were of a magnitude that could explain the increasing incidence over time."

BACK TO FAT

Recently the search for a cause behind the rise of type 1 diabetes has taken an unexpected turn. Some investigators are reconsidering the role of an old adversary: being overweight or obese.

That suspicion might seem counterintuitive given that diabetes dogma holds that being overweight tugs the body toward producing large amounts of insulin (as in type 2), not too little insulin. But some contend that the stress of producing all that extra insulin can burn out the insulin-producing beta cells of the pancreas and push a child whose beta cells are already under attack into developing type 1 diabetes. This idea, called the accelerator or overload hypothesis, proposes that "if you have a kid who is chubby, that extra adiposity is going to challenge the pancreatic beta cells," says Rebecca Lipton, an emeritus professor at the University of Chicago. "In a child who has already started the autoimmune process, those beta cells are just going to fail more quickly, because they are being forced to put out more insulin than in a thin child."

Overweight makes a logical perpetrator. People are packing on the pounds in rich countries and poor ones. Of course, investigators want to do more than just to explain the rise of type 1 diabetes; they want to prevent it. Unfortunately, if excess weight is a major contributor to the problem, that task will not be easy. No one, so far, has been able to slow the global obesity epidemic. (By 2048, according to researchers from Johns Hopkins University, all American adults will be at least overweight if present trends continue.) Until societies can ensure that most children (not to mention adults) are more physically active, eat healthfully and maintain a normal weight, diabetes researchers will be in the position of detectives who, having solved a murder, realize they can do nothing to prevent the next one. SA

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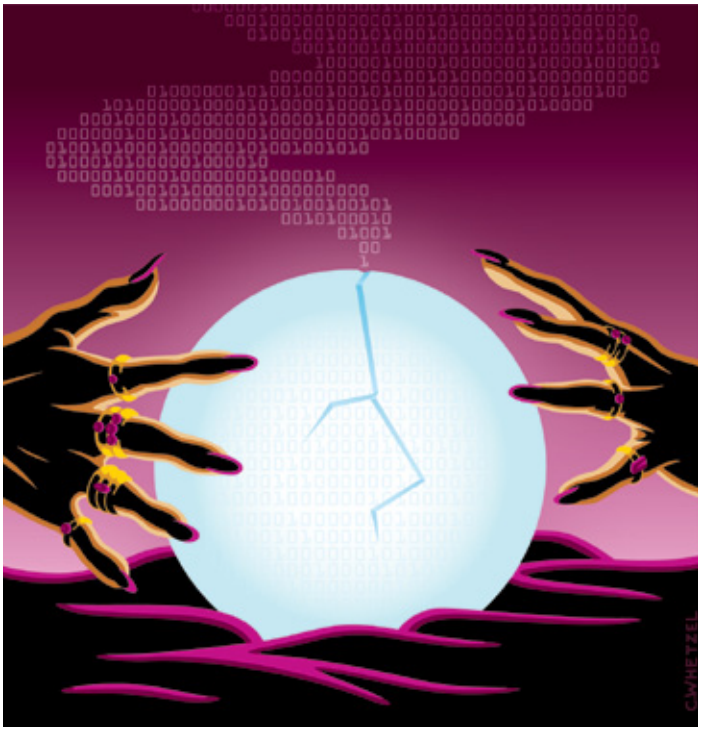
SOURCE: "INCIDENCE AND TRENDS OF CHILDHOOD TYPE 1 DIABETES WORLDWIDE 1990–1999," BY DIAMOND PROJECT GROUP, IN *DIABETIC MEDICINE*, VOL. 23, NO. 8; AUGUST 2006

Graphic by Jen Christiansen

David Pogue is the personal-technology columnist for the *New York Times* and an Emmy Award–winning correspondent for *CBS News*.

The Future Is for Fools

A few guidelines for anyone attempting to predict the future of technology



As a tech columnist, I'm often asked to speak about the future of technology. Well, sure. Who doesn't want to know what the future holds? Yet I'd be in much better shape if I were asked to predict the future of politics or bass fishing. Because *nothing* changes faster, and more unpredictably, than consumer technology.

Everybody who takes a stab at these kinds of predictions inevitably winds up looking like an idiot. Surely you've seen these things go around by e-mail: "I think there is a world market for maybe five computers," said the chairman of IBM in 1943. "This 'telephone' has too many shortcomings to be seriously considered as a means of communication," went an 1876 Western Union internal memo. "Who the hell wants to hear actors talk?" asked Harry M. Warner (one of the Warner Brothers) in 1927.

It's not predictions in general that will get you into trouble, though. The danger lies in predicting that things can't be done or will never work. Those are the forecasts that will make you look shortsighted.

In general, it's much safer to predict things that *will* happen. If you're right, you'll look like a genius. Take Jules Verne, whose articles and stories described electric submarines, TV news, solar sails, "phonotelephote" (video calling), "atmospheric advertisements" (skywriting) and "electronic control devices" (tasers).

Or Arthur C. Clarke's "newspad" (iPad), Ray Bradbury's "thimble radios" (earbuds), Isaac Asimov's pocket calculators and George Orwell's security cameras.

And if you're wrong, well, who can blame you? After all, if you predict something that hasn't come true, you can always cover yourself by adding "yet."

So the first rule of making tech predictions is this: make predictions about things that will come to pass, not about things that won't.

Here's the second rule: history is going to repeat itself. Experience has shown, over and over again, that certain trends are virtually inviolable.

For example, black-and-white formats always go to color: photographs, TV, movies. So back in 1970 you could have confidently predicted the proliferation of color newspapers.

In addition, analog formats always go digital. Audio, video, photos. So in 1990 you could have safely predicted the dawn of digital TV and e-book readers.

We know that Internet access is becoming more ubiquitous, and more gadgets are getting online. Thus, you're safe describing a future where things that currently aren't generally online will be, like cars, kitchen appliances and clothing.

If you insist on predicting the demise of things, stick to extrapolating from obvious trends. Look at the way recent college graduates live and assume that they are the future. They don't subscribe to printed newspapers. They don't sign up for home phone service. They film with phones or still cameras instead of camcorders. They download their movies.

They expect to get everything on demand—songs, books, magazines, newspapers, TV shows, movies—and you'd be foolish to bet against that trend.

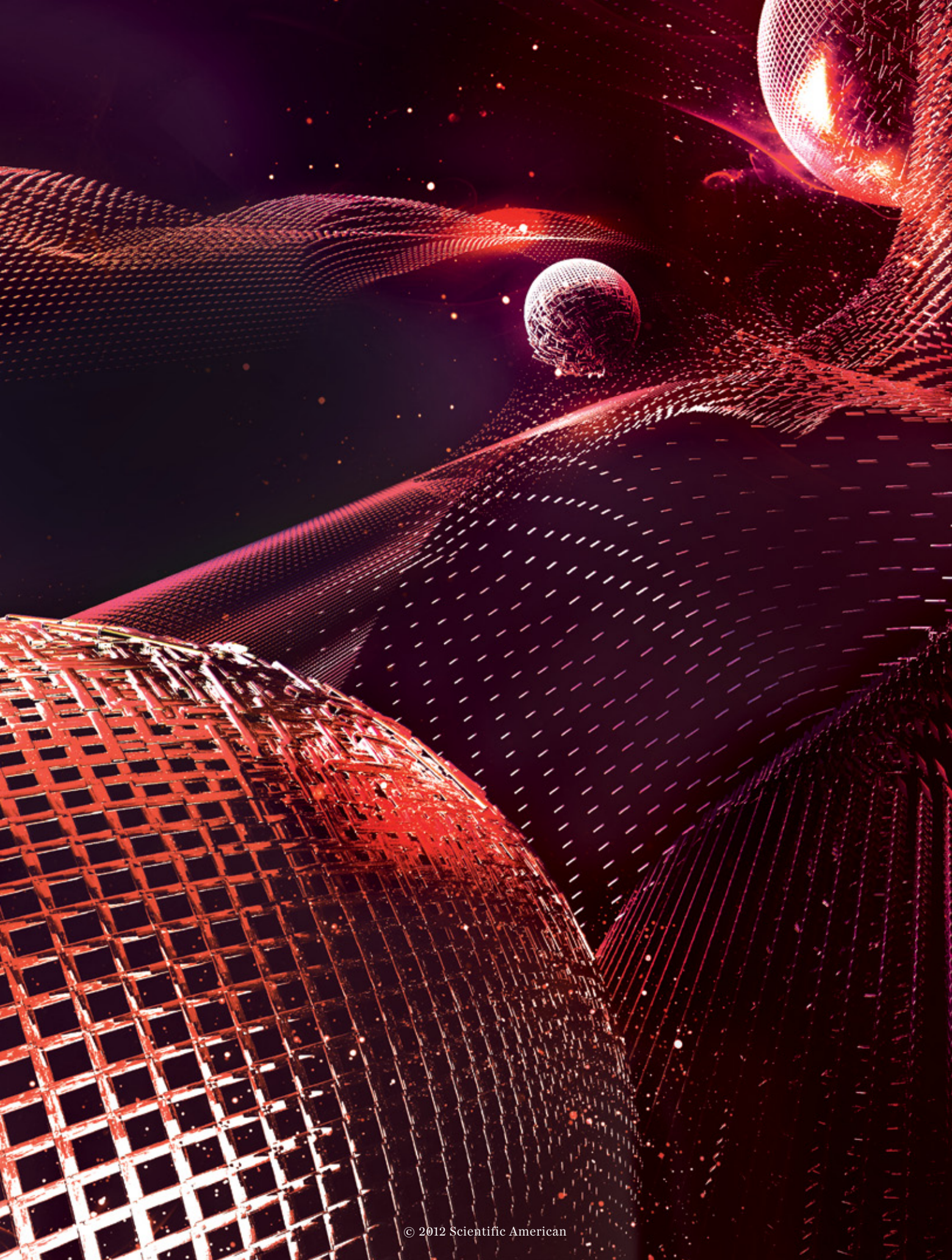
But what about specific products? Is there any way to predict what we'll be carrying in our pockets in 2020? Can anyone see the next iPhone, iPad or Wii?

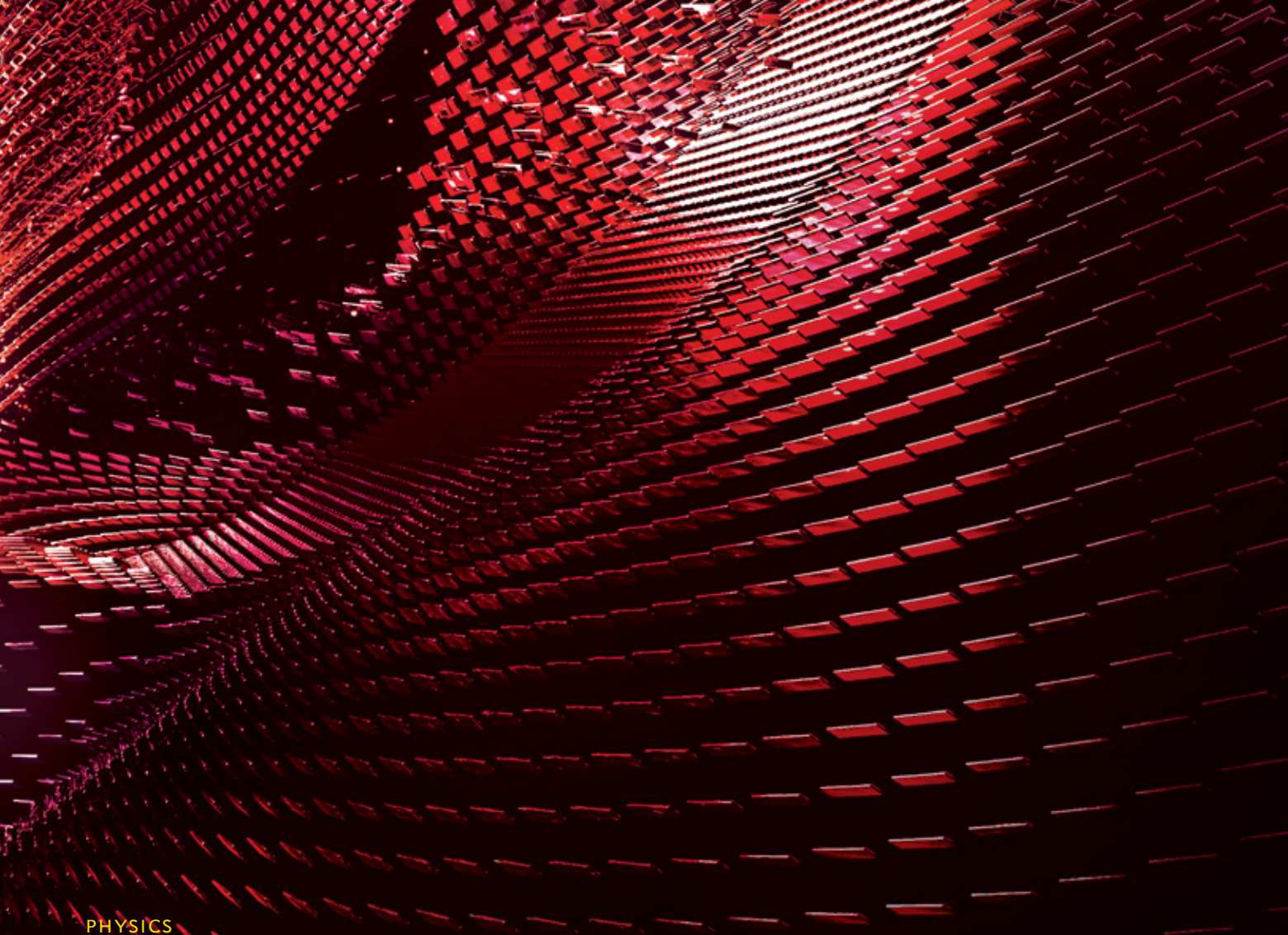
Probably not. If they could, electronics companies wouldn't release flopperoos like Microsoft Zune, the BlackBerry PlayBook and the Iridium satellite phone.

In the end, it's a blessing we can't predict the future of tech—because it means we'll keep trying. If we don't know if something will succeed or fail, we'll keep innovating. We'll heed the words of Alan Kay: "The best way to predict the future is to invent it." SA

SCIENTIFIC AMERICAN ONLINE
The worst predictions in tech history: ScientificAmerican.com/feb2012/pogue

Illustration by Chris Whetzel





PHYSICS

IS SPACE DIGITAL?

An experiment going up outside of Chicago will attempt to measure the intimate connections among information, matter and spacetime. If it works, it could rewrite the rules for 21st-century physics

By Michael Moyer

Illustration by Vault49

CRAIG HOGAN BELIEVES THAT THE WORLD IS FUZZY. THIS IS NOT A METAPHOR. HOGAN, a physicist at the University of Chicago and director of the Fermilab Particle Astrophysics Center near Batavia, Ill., thinks that if we were to peer down at the tiniest subdivisions of space and time, we would find a universe filled with an intrinsic jitter, the busy hum of static. This hum comes not from particles bouncing in and out of being or other kinds of quantum froth that physicists have argued about in the past. Rather Hogan's noise would come about if space was not, as we have long assumed, smooth and continuous, a glassy backdrop to the dance of fields and particles. Hogan's noise arises if space is made of chunks. Blocks. Bits. Hogan's noise would imply that the universe is digital.

It is a breezy, early autumn afternoon when Hogan takes me to see the machine he is building to pick out this noise. A bright-blue shed rises out of the khaki prairie of the Fermilab campus, the only sign of new construction at this 45-year-old facility. A fist-wide pipe runs 40 meters from the shed to a long, perpendicular bunker, the former home of a beam that for decades shot subatomic particles north toward Minnesota. The bunker has been reclaimed by what Hogan calls his Holometer, a device designed to amplify the jitter in the fabric of space.

He pulls out a thick piece of sidewalk chalk and begins to write on the side of the cerulean shed, his impromptu lecture detailing how a few lasers bouncing through the tubes can amplify the fine-grain structure of space. He begins by explaining how the two most successful theories of the 20th century—quantum mechanics and general relativity—cannot possibly be reconciled. At the smallest scales, both break down into gibberish. Yet this same scale seems to be special for another reason: it happens to be intimately connected to the science of information—the 0's and 1's of the universe. Physicists have, over the past couple of decades, uncovered profound insights into how the universe stores information—even going so far as to suggest that information, not matter and energy, constitutes the most basic unit of existence. Information rides on tiny bits; from these bits comes the cosmos.

If we take this line of thinking seriously, Hogan says, we should be able to measure the digital noise of space. Thus, he has devised an experiment to explore the buzzing at the universe's most fundamental scales. He will be the first to tell you that it might not work—that he may see nothing at all. His effort is an experiment in the truest sense—a trial, a probe into the unknown. "You cannot take the well-tested physics of spacetime and the well-tested physics of quantum mechanics and calculate what we'll see," Hogan says. "But to me, that's the reason to do the experiment—to go in and see."

And if he does see this jitter? Space and time are not what we thought. "It changes the architecture of physics," Hogan says.

FOR MANY YEARS PARTICLE PHYSICS HAS NOT OPERATED on this sort of exploratory model. Scientists spent the late 1960s and early 1970s developing a web of theories and insights that we now know as the Standard Model of particle physics. In the decades since, experiments have tested it with increasing depth and precision. "The pattern has been that the theory community has come up with an idea—for example, the Higgs boson—and you have a model. And the model makes a prediction, and the experiment rules it out or not," Hogan says. Theory comes first, experiments later.

This conservatism exists for a very good reason: particle physics experiments can be outrageously expensive. The Large Hadron Collider (LHC) at CERN near Geneva required around $5 billion to assemble and currently occupies the attention of thousands of physicists around the world. It is the most sophisticated, complex and precise machine ever built. Scientists openly wonder if the next generation of particle collider—at higher energies, larger sizes and greater expenses—will prove too ambitious. Humanity may simply refuse to pay for it.

A typical experiment at the LHC might include more than 3,000 researchers. At Fermilab, Hogan has assembled a loosely knit team of 20 or so, a figure that includes senior advisers at the Massachusetts Institute of Technology and the University of Michigan who do not participate in day-to-day work at

IN BRIEF

Space may not be smooth and continuous. Instead it may be digital, composed of tiny bits. Physicists have assumed that these bits are far too small to measure with current technology.

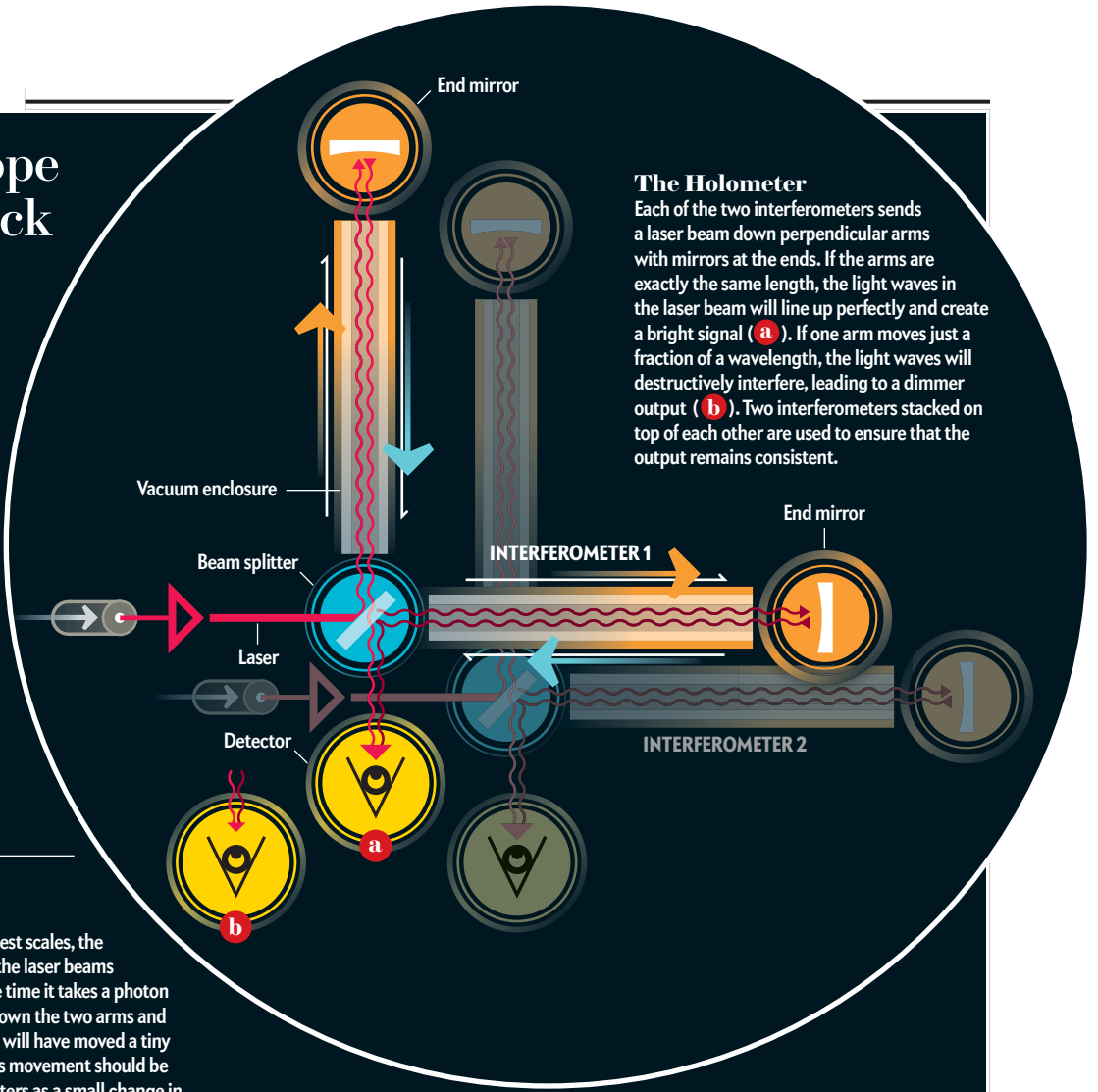
Yet one scientist thinks that he has devised a way to detect the bitlike structure of space. His machine—currently under construction—will attempt to measure its grainy nature.

The experiment is one of the first to investigate the principle that the universe emerges from information—specifically, information that is imprinted on two-dimensional sheets.

If successful, the experiment will shift the foundations of what we know about space and time, providing a glimpse of a new physics that could supplant our current understanding.

A Microscope to the Planck Length

With his Holometer, Craig Hogan will try to measure a fundamental jitter in spacetime at the smallest scale. The device consists of two interferometers, instruments that amplify very small changes in distance (*right*). Detecting a jitter would indicate that spacetime is digital—divided into discrete packets (*bottom*).

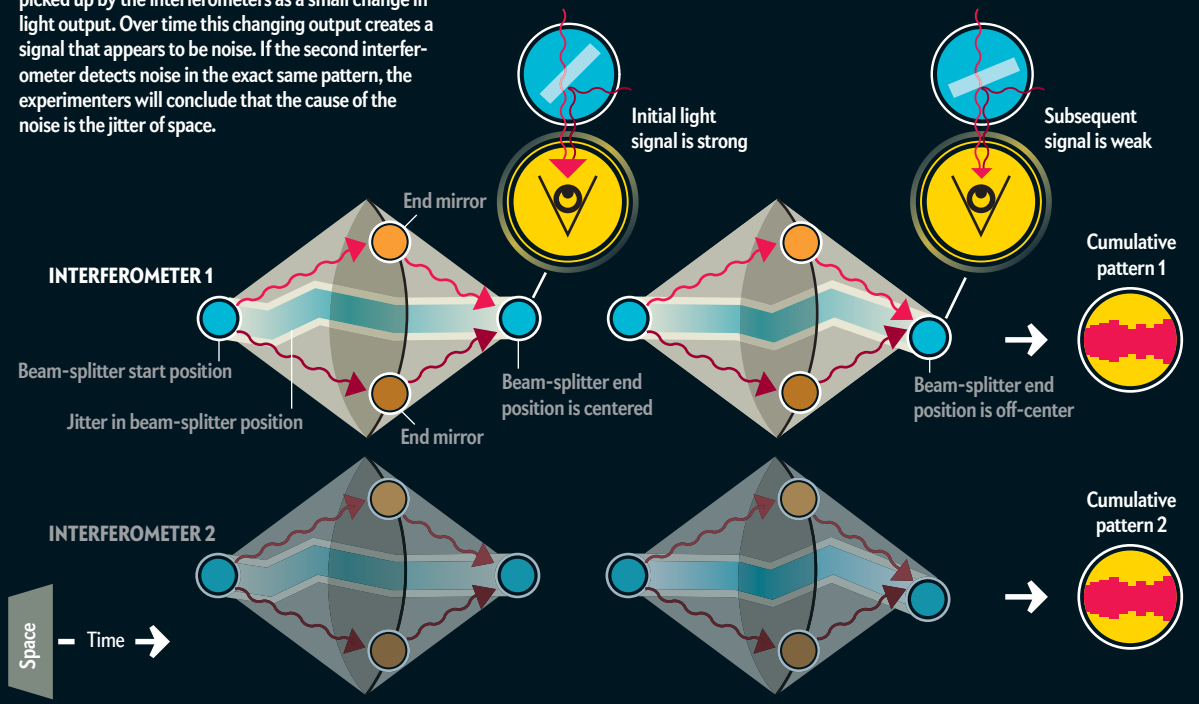


The Holometer

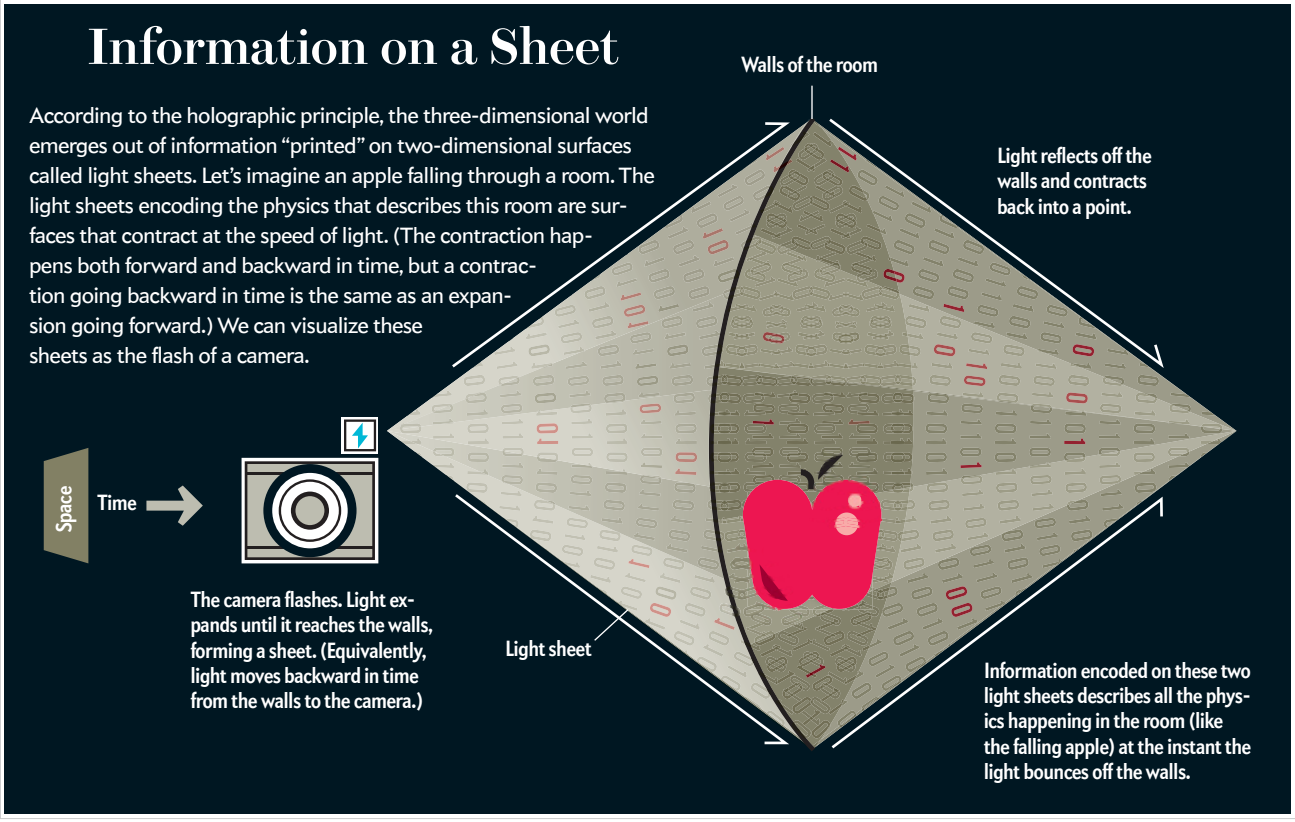
Each of the two interferometers sends a laser beam down perpendicular arms with mirrors at the ends. If the arms are exactly the same length, the light waves in the laser beam will line up perfectly and create a bright signal (a). If one arm moves just a fraction of a wavelength, the light waves will destructively interfere, leading to a dimmer output (b). Two interferometers stacked on top of each other are used to ensure that the output remains consistent.

The Jitter of Space

If space is frothy on the smallest scales, the beam splitter that separates the laser beams should bounce around. In the time it takes a photon to travel out from the laser, down the two arms and back again, the beam splitter will have moved a tiny bit in a random direction. This movement should be picked up by the interferometers as a small change in light output. Over time this changing output creates a signal that appears to be noise. If the second interferometer detects noise in the exact same pattern, the experimenters will conclude that the cause of the noise is the jitter of space.



Illustrations by Leandro Castelao



the site. Hogan is primarily a theoretical physicist—largely unfamiliar with the vagaries of vacuum pumps and solid-state lasers—and so he has enlisted as co-leader Aaron Chou, an experimentalist who happened to arrive at Fermilab at about the same time Hogan was putting his proposal forward. Last summer they were awarded $2 million, which at the LHC would buy you a superconducting magnet and a cup of coffee. The money will fund the entire project. "We don't do any high-tech thing if low-tech will do," Hogan says.

The experiment is so cheap because it is basically an update of the experiment that so famously destroyed the 19th century's established wisdom about the backdrop of existence. By the early 1800s physicists knew that light behaved as a wave. And waves, scientists knew. From a ripple in a pond to sound moving through the air, all waves seemed to share a few essential features. Like sculptures, waves always require a medium—some physical substrate that the waves must travel through. Because light is a wave, the thinking went, it must also require a medium, an invisible substance that permeated the universe. Scientists called this hidden medium the ether.

In 1887 Albert Michelson and Edward Morley designed an experiment that would search for this ether. They set up an interferometer—a device with two arms in the shape of an L that was optimized to measure change. A single source of light would travel the length of both arms, bounce off mirrors at the ends, then recombine where it began. If the length of time it took the light to travel down either arm changed by even a fraction of a microsecond, the recombined light would glow darker. Michelson and Morley set up their interferometer and monitored the light for months as the earth moved around the sun. Depending on which way the earth was traveling, the stationary ether should have altered the time it took for the light to bounce down the perpendicular arms. Measure this change, and you have found the ether.

Of course, the experiment found no such thing, thus beginning the destruction of a cosmology hundreds of years old. Yet like a forest obliterated by fire, clearing the ether made it possible for revolutionary new ideas to flourish. Without an ether, light traveled the same speed no matter how you were moving. Decades later Albert Einstein seized this insight to derive his theories of relativity.

Hogan's interferometer will search for a backdrop that is much like the ether—an invisible (and possibly imaginary) substrate that permeates the universe. By using two Michelson interferometers stacked on top of each other, he intends to probe the smallest scales in the universe, the distance at which both quantum mechanics and relativity break down—the region where information lives as bits.

THE PLANCK SCALE IS NOT JUST SMALL—IT IS THE smallest. If you took a particle and confined it inside a cube less than one Planck length on each side, general relativity says that it would weigh more than a black hole of that same size. But the laws of quantum mechanics say that any black hole smaller than a Planck length must have less than a single quantum of energy, which is impossible. At the Planck length lies paradox.

Yet the Planck length is much more than the space where quantum mechanics and relativity fall apart. In the past few de-

cades an argument over the nature of black holes has revealed a wholly new understanding of the Planck scale. Our best theories may break down there, but in their place something else emerges. The essence of the universe is information, so this line of thinking goes, and the fundamental bits of information that give rise to the universe live on the Planck scale.

"Information means distinctions between things," explained Stanford University physicist Leonard Susskind during a lecture at New York University last summer. "It is a very basic principle of physics that distinctions never disappear. They might get scrambled or all mixed up, but they never go away." Even after this magazine gets dissolved into pulp at the recycling plant, the information on these pages will be reorganized, not eliminated. In theory, the decay can be reversed—the pulp reconstructed into words and photographs—even if, in practice, the task appears impossible.

Physicists have long agreed on this principle except in one special case. What if this magazine were to be thrown into a black hole? Nothing can ever emerge from a black hole, after all. Throw these pages into a black hole, and that black hole will appear almost exactly the same as it did before—just a few grams heavier, perhaps. Even after Stephen Hawking showed in 1975 that black holes can radiate away matter and energy (in the form that we now call Hawking radiation), this radiation seemed to be devoid of structure, a flat bleat at the cosmos. He concluded that black holes must destroy information.

Nonsense, argued a number of Hawking's colleagues, among them Susskind and Gerard 't Hooft, a theoretical physicist at Utrecht University in the Netherlands who would go on to win the Nobel Prize. "The whole structure of everything we know would disintegrate if you opened the door even a tiny bit for the notion of information to be lost," Susskind explains.

Hawking was not easily convinced, however, and so over the following two decades physicists developed a new theory that could account for the discrepancy. This is the holographic principle, and it holds that when an object falls into a black hole, the stuff inside may be lost, but the object's information is somehow imprinted onto a surface around the black hole. With the right tools, you could theoretically reconstruct this magazine from a black hole just as you could from the pulp at the recycling plant. The black hole's event horizon—the point of no return—serves double duty as a ledger. Information is not lost.

The principle is more than just an accounting trick. It implies that whereas the world we see around us appears to take place in three dimensions, all the information about it is stored on surfaces that have just two dimensions [see "Information in the Holographic Universe," by Jacob D. Bekenstein; Scientific American, August 2003]. What is more, there is a limit to how much information can be stored on a given surface area. If you divide a surface up like a checkerboard, each square two Planck lengths on a side, the information content will always be less than the number of squares.

In a series of papers in 1999 and 2000 Raphael Bousso, now at the University of California, Berkeley, showed how to extend this holographic principle beyond the simple surfaces around black holes. He imagined an object surrounded by flashbulbs popping off in the dark. Light that traveled inward defined a surface—a bubble collapsing at the speed of light. It is on this two-dimensional surface—the so-called light sheet—that all the information about you (or a flu virus or a supernova) is stored [*see box on opposite page*].

This light sheet, according to the holographic principle, does a lot of work. It contains information about the position of every particle inside the sheet, every electron and quark and neutrino, and every force that acts on them. Yet it would be wrong to think about the light sheet as a piece of film, passively recording the real stuff that happens out in the world. Instead the light sheet comes first. It projects the information contained on its surface out into the world, creating all that we see. In some interpretations, the light sheet does not just generate all the forces and particles—it gives rise to the fabric of spacetime itself. "I believe that spacetime is what we call emergent," says Herman Verlinde, a physicist at Princeton University and a former student of 't Hooft. "It will come out of a bunch of 0's and 1's."

One problem: although physicists mostly agree that the holographic principle is true—that information on nearby surfaces contains all the information about the world—they know not how the information is encoded, or how nature processes the 1's and 0's, or how the result of that processing gives rise to the world. They suspect the universe works like a computer—that information conjures up what we perceive to be physical reality—but right now that computer is a big black box.

Ultimately the reason why physicists are so excited about the holographic principle, the reason they spent decades developing it—other than convincing Hawking that he was mistaken, of course—is because it articulates a deep connection between information, matter and gravity. In the end, the holographic principle could reveal how to reconcile the two tremendously successful yet mutually incompatible pillars of 20th-century physics: quantum mechanics and general relativity. "The holographic principle is a signpost to quantum gravity," Bousso says, an observation that points the way toward a theory that will supersede our current understanding of the world. "We might need more signposts."

Into all this confusion comes Hogan, with no grand theory of everything, armed with his simple Holometer. But Hogan does not need a grand theory. He does not have to solve all these difficult problems. All he has to do is figure out one fundamental fact: Is the universe a bitlike world, or isn't it? If he can do that, he will indeed have produced a signpost—a giant arrow pointing in the direction of a digital universe, and physicists would know which way to go.

According to Hogan, in a bitlike world, space is itself quantum—it emerges from the discrete, quantized bits at the Planck scale. And if it is quantum, it must suffer from the inherent uncertainties of quantum mechanics. It does not sit still, a smooth backdrop to the cosmos. Instead quantum fluctuations make space bristle and vibrate, shifting the world around with it. "Instead of the universe being this classical, transparent, crystalline-type ether," says Nicholas B. Suntzeff, an astronomer at Texas A&M University, "at a very, very small scale, there are these little foamlike fluctuations. It changes the texture of the universe tremendously."

The trick is getting down to the level of this spacetime foam and measuring it. And here we run into the problem of the Planck length. Hogan's Holometer is an attempt to flank a full-

scale assault on the Planck length—a unit so small that measuring it with a conventional experiment (such as a particle accelerator) would involve building a machine the approximate size of the Milky Way.

Back when Michelson and Morley were investigating the (nonexistent) ether, their interferometer measured a tiny change—the change in the speed of light as the earth moved around the sun—by comparing two light beams that had traveled a reasonably long way. In effect, that distance multiplied the signal. So it is with Hogan's Holometer. His strategy for getting down to the Plank length is to measure the accumulated errors that accrue when dealing with any jittery quantum system.

"If I look at my TV set or my computer monitor, everything looks nice and smooth," Chou says. "But if you look at it close-up, you can see the pixels." As it would be with spacetime. At the level we humans are comfortable with—the scale of people and buildings and microscopes—space appears to be this smooth, continuous thing. We never see a car move down the street by instantaneously leaping from one place to the next as if lit by God's own strobe light.

Yet in Hogan's holographic world, this is exactly what happens. Space is itself discrete—or, in the parlance of our times, "quantized" [see "Atoms of Space and Time," by Lee Smolin; Scientific American, January 2004]. It emerges out of some deeper system, some fundamentally quantum system that we do not yet understand. "It's a slight cheat because I don't have a theory," Hogan says. "But it's only a first step. I can say to these gravitational theorists, 'You guys figure out how it works.' "

Space does not sit still, a smooth backdrop to the cosmos. Instead quantum fluctuations make space bristle and vibrate, shifting the world along with it.

Hogan's holometer is set up much like Michelson and Morley's, if Michelson and Morley had access to microelectronics and two-watt lasers. A laser hits a beam splitter that separates the light into two. These beams travel down the two 40-meter-long arms of an L-shaped interferometer, bounce off mirrors at each end, then return to the beam splitter and recombine. Yet instead of measuring the motion of the earth through the ether, Hogan is measuring any change in the length of the paths as a result of the beam splitter being jostled around on the fabric of space. If at the Planck scale, spacetime thrashes around like a roiling sea, the beam splitter is the dinghy pitching through the froth. In the time it takes the laser beams to travel out and back through the Holometer, the beam splitter will have jiggled just enough Planck lengths for its motion to be detected [*see box on page 33*].

Of course, you might imagine a lot of reasons why a beam splitter might move a few Planck lengths here and there—the rumbling of a car engine outside the building, for instance, or a stiff Illinois wind shaking the foundations.

Such concerns have bedeviled the scientists behind another interferometry project, the twin Laser Interferometer Gravitational-Wave Observatory (LIGO) detectors outside of Livingston, La., and Hanford, Wash. These massive experiments were built to observe gravitational waves—the ripples in spacetime that follow cosmic cataclysms such as neutron star collisions. Unfortunately for the LIGO scientists, gravitational waves shake the ground at the same frequency as other not so interesting things—passing trucks and falling trees, for instance. As such, the detectors have to be completely isolated against noise and vibration. (A proposed wind farm near the Hanford facility caused much consternation among physicists because the mere vibration of the blades would have swamped the detectors with noise.)

The shaking that Hogan is looking for happens much faster—a vibration that jitters back and forth a million times a second. As such, it is not subject to the same noise concerns—only the possible interference from nearby AM radio stations broadcasting at the same frequency. "Nothing moves at that frequency," says Stephan Meyer, a University of Chicago physicist and LIGO veteran who is working on the Holometer. "If we discover that it's moving anyway, that's one of the things that we'll take as a sure sign" that the jitter is real.

And in the world of particle physics, sure signs can be hard to come by. "This is old-fashioned in a way," Hogan says. "It appeals to this old-fashioned style of physics, which is, 'We're going to go and find out what nature does, without prejudice.' " To illustrate, he likes to tell a parable about the origins of relativity and quantum mechanics. Einstein invented the theory of general relativity by sitting at his desk and working out the mathematics from first principles. There were few experimental quandaries that it solved—indeed, its first real experimental test would not come for years. Quantum mechanics, on the other hand, was imposed on the theorists by the puzzling results of experiments. ("No theorist in his right mind would have invented quantum mechanics unless forced to by data," Hogan says.) Yet it has become the most successful theory in the history of science.

In the same way, theorists have for many years been building beautiful theories such as string theory, although it remains unclear how or if it can ever be tested. Hogan sees the purpose of his Holometer as a way to create the puzzling data that future theorists will have to explain. "Things have been stuck for a long time," he says. "How do you unstick things? Sometimes they get unstuck with an experiment." SA

Michael Moyer *is a senior editor at* Scientific American.

MORE TO EXPLORE

The Holographic Principle. Raphael Bousso in *Reviews of Modern Physics,* Vol. 74, No. 3, pages 825–874; 2002. http://arxiv.org/abs/hep-th/0203101

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Atoms of Space and Time. Lee Smolin in *Scientific American,* Vol. 290, No. 1, pages 66–75; January 2004.

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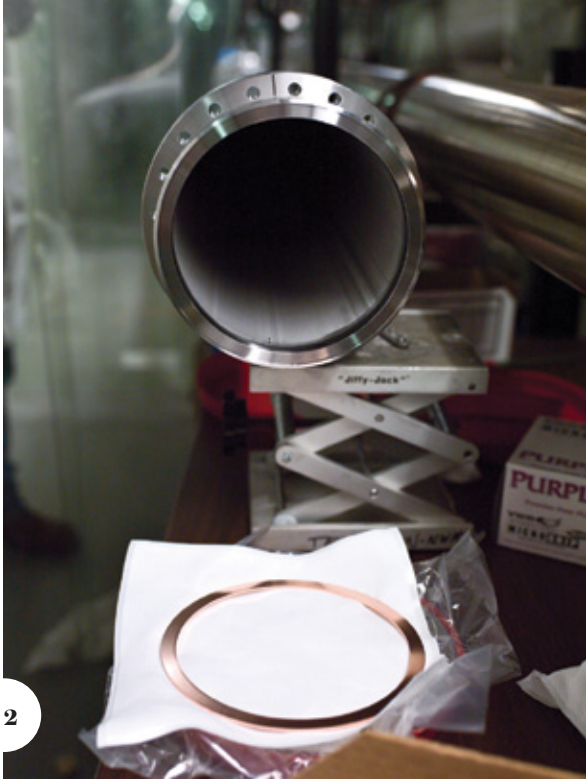
Interferometers as Probes of Planckian Quantum Geometry. Craig J. Hogan. http://arxiv.org/abs/1002.4880

SCIENTIFIC AMERICAN ONLINE

Take a tour of the Holometer: ScientificAmerican.com/feb2012/holometer

1

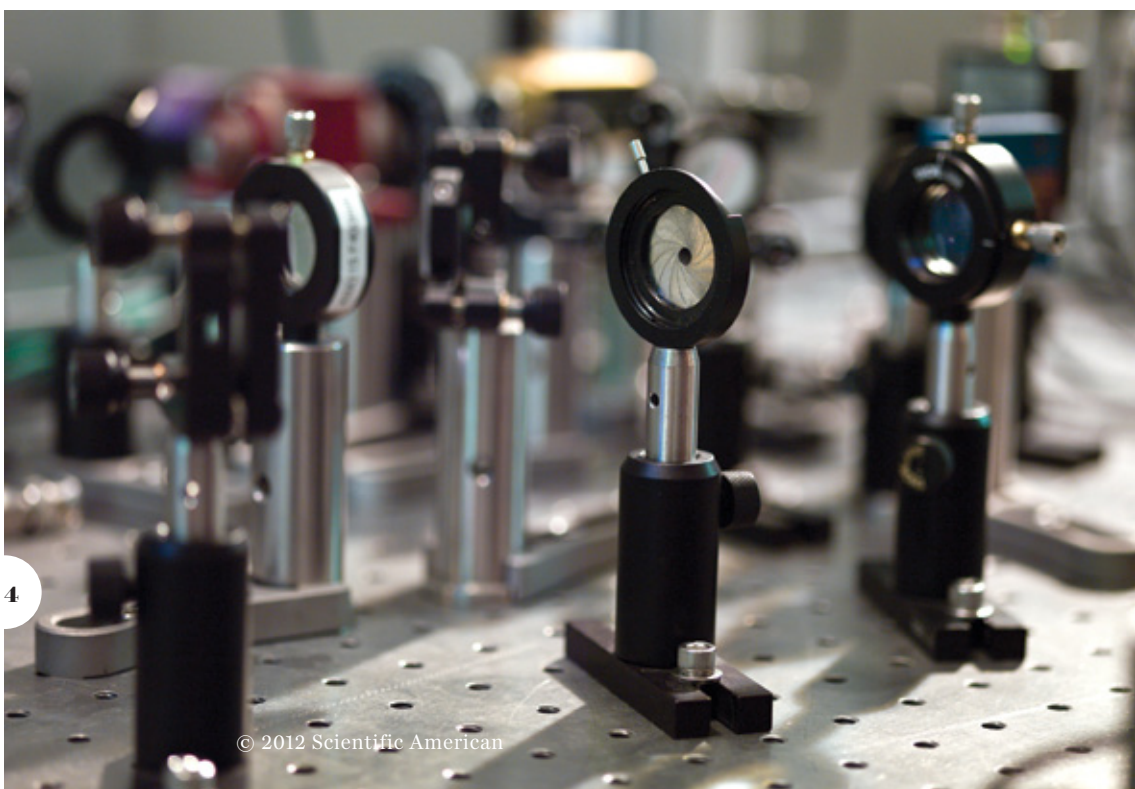


2

3

Craig Hogan (*1*), director of the Fermilab Center for Particle Astrophysics, pauses in his office. Hogan and his team are building the Holometer at a site about a kilometer away. The experiment will send laser beams down 40-meter-long beam tubes (*2*) under vacuum. One set of beam tubes is being housed in a bunker formerly used for particle beams; the other juts out into the countryside, ending at a blue shed that houses a mirror and focusing optics (*3*). Precise optical equipment (*4*) is used to focus and align the beams.

Photographs by Matt Siber



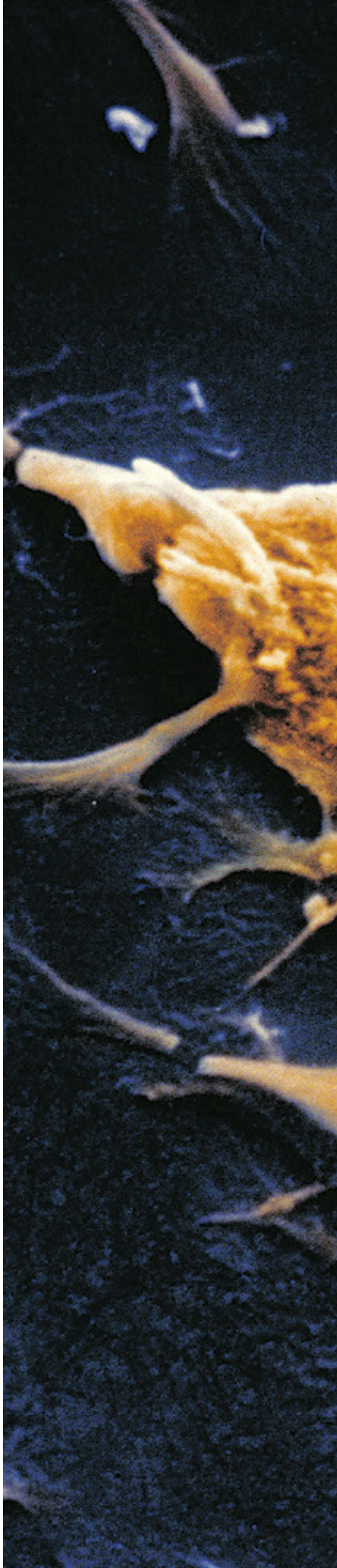
4

MEDICINE

THE GREAT PROSTATE CANCER DEBATE

Evidence shows that screening does more harm than good. Now what?

By Marc B. Garnick



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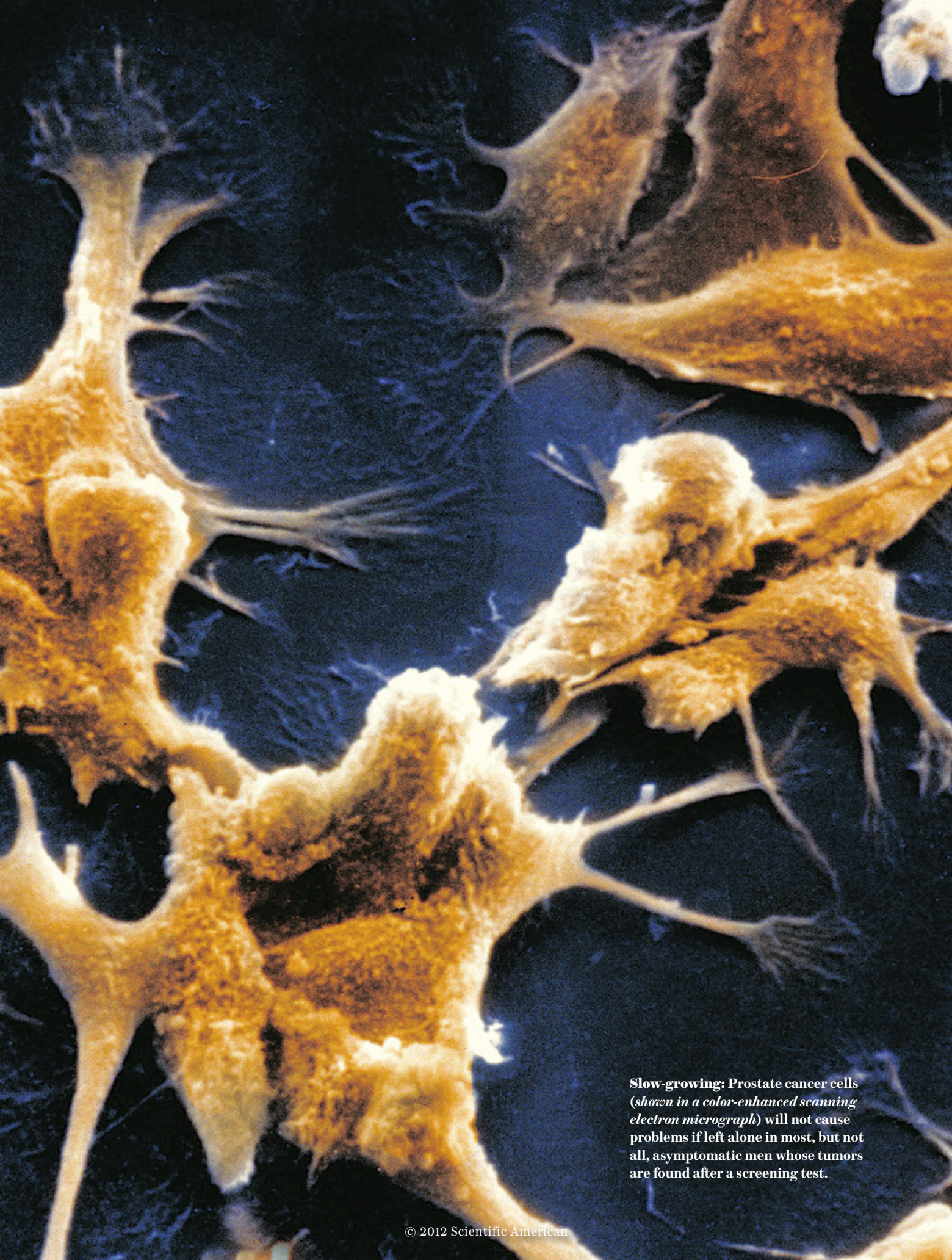


Slow-growing: Prostate cancer cells (*shown in a color-enhanced scanning electron micrograph*) will not cause problems if left alone in most, but not all, asymptomatic men whose tumors are found after a screening test.

Marc B. Garnick, a physician and researcher, is a prostate cancer expert at Harvard Medical School and Boston's Beth Israel Deaconess Medical Center, as well as editor in chief of Harvard's *Annual Report on Prostate Diseases*.

LAST FALL THE U.S. PREVENTIVE SERVICES TASK FORCE DROPPED A BOMBSHELL, ARGUING that healthy men should stop undergoing a routine blood test as a screen for prostate cancer. An analysis of the best available evidence, it argued, had shown little or no long-term benefit from the measure—called the prostate-specific antigen (PSA) test—for most men with no symptoms of the disease. Use of the screening was not saving lives. In fact, it was needlessly exposing hundreds of thousands of men who were tested and found to have prostate cancer to such common complications as impotence and urinary incontinence (from surgical removal of the prostate) and rectal bleeding (from radiation treatment). Indeed, the task force estimated that more than one million men have been treated because of PSA testing who otherwise would not have been since 1985. At least 5,000 of them died soon after treatment, and another 300,000 men suffered impotence or incontinence, or both. Instead of praise for sparing more men from suffering similar fates, however, the task force's announcement quickly drew outrage and counterarguments from several professional medical groups, including the American Urological Association.

The controversy is not new. Experts have long debated the value of the PSA test, but until now the weight of opinion in the U.S. fell on the side of doing the test. As a medical oncologist specializing in prostate cancer, however, I essentially agree with the task force's assessment of the evidence. Most people outside the medical community do not realize how flimsy the evidence has been in favor of the screening tests. (Make no mistake, the PSA test still provides valuable information after a prostate cancer has already been diagnosed, however.) Nor does the public realize how common complications can be—even from sophisticated treatment that proponents advertise as the most advanced.

As the debate over PSA testing continues, controversy also swirls over a related question: when and if to treat people who ultimately turn out to have prostate cancer after testing positive on a screening test. Here, too, the evidence favors a significant change in course—away from aggressive early treatment for all and toward taking a more cautious, individualized approach.

At the root of these changing attitudes is the realization that prostate cancer can behave very differently from one patient to another and that "early" treatment is not the panacea that most physicians, including myself, used to think it would be.

THE SOURCE OF THE CONTROVERSY

THE CONTROVERSIES have arisen because the screening test and treatments are both deeply flawed. In a perfect world, a screening test would identify only cancers that would prove lethal if untreated. Then men who had small, curable cancers would be treated, and their lives would be saved. Ideally, the treatments would not only be effective, they would have no serious side effects. Such a scenario would justify massive screening and treatment of everyone with a positive test.

But the reality is far different. The PSA test does not tell you if a man has cancer, just that he might have it. The test measures the amount of a protein called prostate-specific antigen, which is produced by the cells of the prostate and whose levels can rise for a variety of reasons—including benign growth of the prostate gland with age, infection, sexual activity or the proliferation of malignant cells. So a positive test means men have to have a bi-

IN BRIEF

Studies show that use of a blood test to screen for prostate cancer does not greatly decrease the risk of death.

Hundreds of thousands of men have likely suffered severe side effects as a result of unnecessary treatment.

Yet many physicians and professional medical societies believe that widespread screening saves lives.

Screening for prostate cancer but delaying treatment in most cases may prove to be an effective compromise.

opsy, which involves some discomfort and risk. And that is not the worst if it. A biopsy can, at least, distinguish men who actually do have cancer from those who probably do not. The real problem, though, is that doctors do not have a reliable way to determine which of these very small cancers that are caught by a biopsy are potentially dangerous and which will never bother a man in his lifetime. (Indeed, autopsy studies show that more than half of men in their 50s and three quarters of men in their 80s in the U.S. had prostate cancer but died of something else.) That uncertainty means doctors do not know who absolutely needs treatment to survive and who would be fine without it.

Such ambiguity would not be so bad if the treatments were virtually risk free. In that case, treating everyone might be worth the extra effort and cost to save the few who actually needed it. Yet the treatments are far from risk free. Unfortunately, the prostate is situated close to the rectum, bladder and penis, making it difficult to remove surgically or to treat with radiation without long-lasting complications.

Each type of treatment comes with its own side effects. Surgery (open radical prostatectomy) often results in urinary leakage because the removal of the prostate requires the lower portion of the bladder to be disconnected from the urinary tube running through the penis. The surgeon later reconnects the bladder and urethra, but damage to the nearby muscle that controls urination may lead to incontinence. Meanwhile the nerves and blood vessels controlling erections may be severed during surgery, causing erectile dysfunction (impotence). Although advertisements typically extol lower complication rates with robot-assisted surgery, large independent studies that rigorously compare the two approaches have not been conducted.

In addition to impotence, radiation therapy of the prostate often ends up damaging the rectum and bladder because it is hard to avoid radiation scatter, which hits the front of the rectum and the base of the bladder. Moreover, rectal bleeding and fecal soiling are frequent but commonly underreported side effects of both radiation therapy (including radioactive seed implants) and surgical approaches. (As an aside, side effects of the medical therapies that are used for advanced cancer that requires treatment—hormonal treatments, immune therapies or chemotherapy—include loss of sexual drive, impotence, weight gain, bone thinning, hot flashes, and heart and liver abnormalities.) Thus, when a decision is made to offer treatment, the true risks must be carefully weighed against potential benefits.

UPDATING THE GUIDELINES

THE EVIDENCE against PSA screening has been growing for some time. In 2008, which was the last time the Preventive Services Task Force looked at the PSA guidelines, it recommended that physicians stop testing asymptomatic men older than the age of 75. The data showed that most men with prostate cancer at 75 were more likely to die of something else. Just one year later two very large prospective studies were published that seemed to settle the question for younger men as well.

Referred to as the European study and the U.S. study, respectively, the two reports took otherwise healthy men, most of whom were in their 50s and 60s, and randomly divided them into two groups. One group of men was periodically screened for prostate cancer with either the PSA test or a digital rectal exam (in which a physician inserts a finger into the rectum to feel for abnormalities in the prostate), or both. If either test was abnormal, a biopsy was performed, and if the biopsy showed cancer, treatment was generally recommended. The second group of men was not offered routine testing; however, they received standard medical care as needed. For example, if they started showing symptoms of prostate cancer—such as trouble urinating (which is also a sign of benign enlargement of the prostate gland)—then they were tested. At the end of the specified study periods, participants were evaluated for two important outcomes:

- Did the tested and treated men live any longer than those not tested?
- Did the tested and treated men lessen their chance of dying of prostate cancer, compared with those not tested?

Remarkably, in neither study did the tested and treated men live any longer, and in the European study only those who were tested and treated had about a 20 percent lower likelihood of dying of prostate cancer. Such a decrease in prostate cancer mortality was not found in the U.S. study.

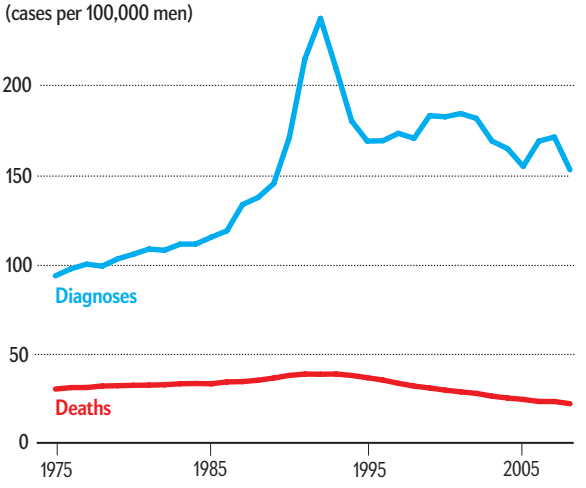
The European study went on to calculate how many men would need to be screened and treated to prevent a single death resulting from prostate cancer. Determining this so-called number needed to screen (NNS) ratio has become increasingly im-

UNDERSTANDING THE NUMBERS

Disappointing Data

Starting in the 1990s, the widespread use of the PSA test to screen for prostate cancer led to a surge in tumor diagnoses (*blue*). Soon after, the number of deaths from prostate cancer (*red*) started to fall. But these trends do not prove cause and effect. In fact, in 2009 two scientifically rigorous, prospective studies found that the PSA screening test offered little or no benefit with respect to cause of death. The decline in deaths seen below could be the result of lifestyle changes or perhaps the increasing use of cholesterol drugs called statins, which have an anti-inflammatory effect that may protect against cancer.

Changes in Prostate Cancer Diagnoses and Deaths in the U.S.
(cases per 100,000 men)



NOTE: Data adjusted to minimize effect of overall aging of U.S. population over time

SOURCE: SEER CANCER STATISTICS REVIEW 1975–2008, BY NATIONAL CANCER INSTITUTE

Graphic by Jen Christiansen

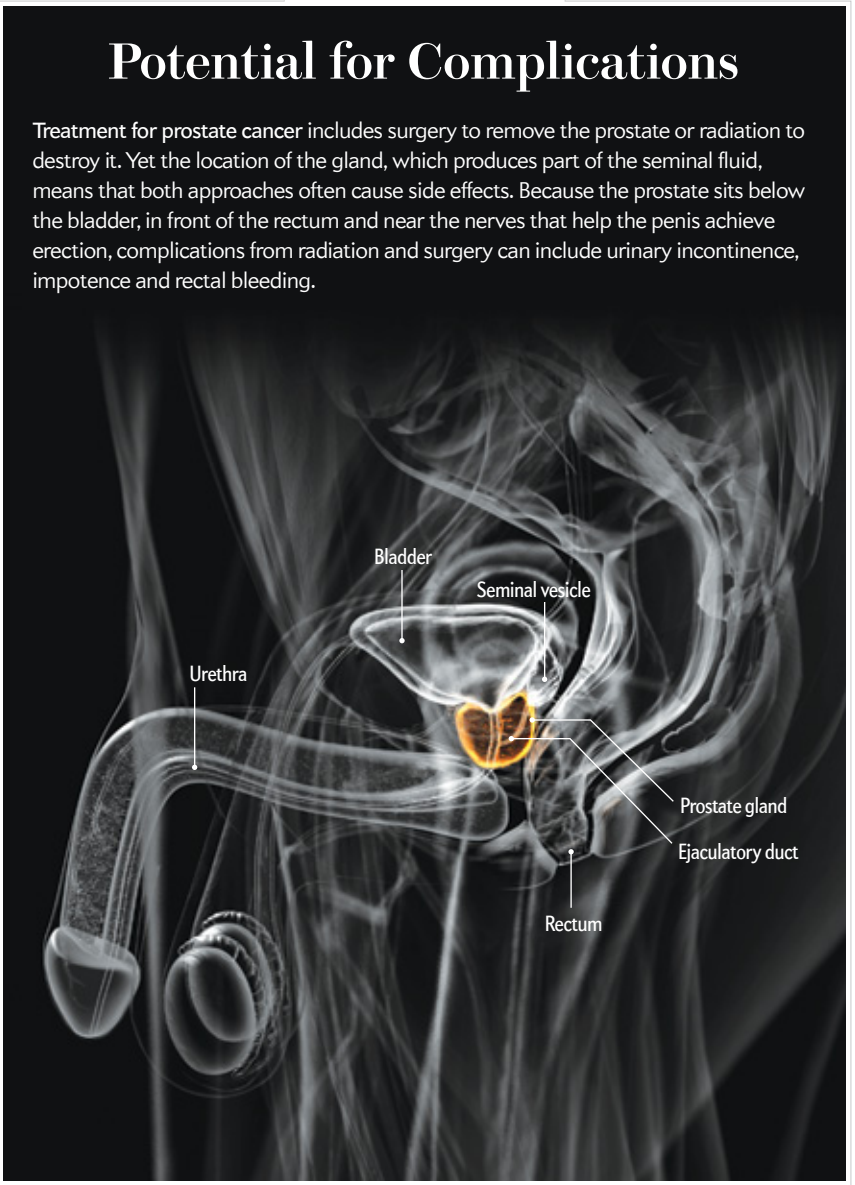
portant in trying to figure out which screening tests are most helpful. The European researchers determined that to save one life from prostate cancer, about 1,400 men would have to be screened, leading 48 men to undergo treatment. So 47 men would be treated unnecessarily—many of whom would suffer fairly serious side effects—so that one man's death from prostate cancer could be prevented. And yet, despite successfully preventing a death from prostate cancer, the value of screening for even that one person is debatable because the overall death rate from all causes was identical in both the screened and unscreened groups. More recent analyses of subgroups in the European study have suggested that the number needed to treat may be as low as 12. The more favorable results all come from one area in Sweden, however, and therefore may not be widely applicable.

As always with medical studies, a few caveats must be kept in mind. Whereas the data strongly suggest that most healthy, asymptomatic men do not have to undergo routine screening, those with a strong family history of prostate cancer—men who, for example, had a father, an uncle or a grandfather die of the disease before the age of 70—may reasonably decide to undergo routine PSA screening. Practically speaking, as a physician, I would find it hard to deny offering them the PSA test, especially if they requested it. They probably have inherited a genetic predisposition to the illness that makes them particularly susceptible and thus unlike the general population. In a few more years we may be able to use specific genetic tests to identify individuals who need to pay closer attention to their risks.

ANATOMY OF RISK

Potential for Complications

Treatment for prostate cancer includes surgery to remove the prostate or radiation to destroy it. Yet the location of the gland, which produces part of the seminal fluid, means that both approaches often cause side effects. Because the prostate sits below the bladder, in front of the rectum and near the nerves that help the penis achieve erection, complications from radiation and surgery can include urinary incontinence, impotence and rectal bleeding.



MR. H. SAYS NO

AS IT HAPPENS, one of my patients unknowingly anticipated the position of the Preventive Services Task Force 16 years ago, when he was 54 years old. In 1996, against the advice of every cancer specialist that he consulted (including me), he decided to forgo any therapy after a routine PSA test led to a diagnosis of prostate cancer. Even then, his reading of the available research led him to conclude that his particular cancer was unlikely to kill him, at least for the foreseeable future. Moreover, he reasoned, the delay might prove beneficial if newer, more effective therapies came along in a few years' time. Therefore, he refused immediate treatment, although he adopted healthier habits and lost weight. Every year after his bold decision, I would advise Mr. H., as I will refer to him, to undergo treatment. Every year he would just as steadfastly refuse my advice.

Sixteen years later Mr. H. is still very much alive, and the tumor remains confined to his prostate gland. He has not received surgery, radiation or medicinal treatments for his cancer. His PSA level has risen from seven to 18 units—a very slow rate of rise, indicating that the cancer is growing very slowly. (Of course, had we known that in 1996 the decision not to treat would have been an easier one.) By demanding to know what proof we had for our recommendations, he was able to make a reasoned decision and avoided trading almost certain harms for uncertain benefits.

CHANGING ASSUMPTIONS

IN FACT, WHEN I first met Mr. H., our recommendations were based not on strong clinical trials but on a mistaken idea of how prostate cancer behaves over time. We knew that some prostate tumors were slow-growing and others were very aggressive. Still, we assumed that most tumors eventually progressed

Illustration by Bryan Christie

from small cancerous growths to bigger ones to metastatic tumors that spread throughout the body and became incurable. Catching a cancer in its early stages and removing or destroying it would, therefore, nearly always mean we had saved someone's life. That seemingly logical assumption led us to advise our patients to undergo treatment whenever a cancer was caught in its earliest stages—and count themselves lucky that they had. Indeed, this logic is the support for all our screening programs in cancer.

Unfortunately, the mortality data collected over the past 25 years show that the natural history of prostate cancer is not as straightforward as my colleagues and I once believed. True enough, the death rate from prostate cancer has fallen from its peak in the 1990s. While proponents of screening argue that this decline must be related to PSA testing, their conclusion is not, as we have seen, borne out by prospective studies. Furthermore, if our understanding of how prostate cancers grow and progress had been correct, the death rate should have fallen much further and faster. In fact, we now know that many prostate cancers do not progress at all. Their growth is slower than slow. It is stalled.

The initial decision to forgo treatment is not necessarily the final one. Other therapies are still available later on, and the outcome will not change.

As researchers discover more examples of cancers that are diagnosed by their cellular abnormalities but nonetheless grow so slowly that they neither spread or turn fatal, there is talk of giving these growths a different name, such as indolent tumor, to underscore the fact that they do not necessarily have to be treated for a very long time or perhaps ever. Of course, we do not know which ones are indolent at first diagnosis, but we can have strong suspicions based on various characteristics of the tumor and can confirm the hunch by monitoring patients over time.

CHANGING PRACTICE

CHANGING INGRAINED HABITS is just as hard in medicine as it is in other areas of life. There are bound to be many men (not to mention their physicians) who simply will not feel comfortable forgoing a PSA test after all the years of advice to the contrary. And some individuals will swear that the PSA test saved their life. Fortunately, I think we can manage their care in ways that protect them from unnecessary treatment. This approach can also offer a way out of the "to treat or not to treat" dilemma. It consists of delaying therapy until a cancer more definitively shows itself to be indolent, slow-growing or potentially lethal.

In my own practice, a substantial percentage of the men I care for with prostate cancer are not receiving any treatment at present. Rather they are enrolled in a program that used to be called "watchful waiting" and is now more sophisticated and known as "active surveillance with delayed intention to treat." In other words, these men have elected to undergo PSA screening and have learned they have a tumor but have chosen not to be treated right away. Instead they continue to have their PSA levels monitored and undergo periodic biopsies of the prostate gland to keep a watch on the activity of the tumor. Last December a consensus panel of experts convened by the National Institutes of Health examined the evidence and declared that "active surveillance has emerged as a viable option that should be offered to patients with low-risk prostate cancer."

Treatment is considered if further biopsies show that the growth has gotten bigger, PSA results increase rapidly or the newly biopsied cells look markedly more dangerous under a microscope as measured by the so-called Gleason score. Results of a long-term Canadian study indicate that the death rate from the disease for men who elect active surveillance is 1 percent over 10 years—compared with a 0.5 percent risk of dying from complications in the first month after prostate cancer surgery.

The point is that the initial decision to forgo treatment is not necessarily the final one. Surgery, radiation and other therapies are still available later on, and the data indicate that the outcome will not be negatively affected by the delay. For those who eventually need treatment, newer techniques that destroy just the cancerous part of the prostate (so-called prostate lumpectomy or focal therapy) may be appropriate and result in fewer side effects—although rigorous comparison studies have not yet been completed.

As for the 4 percent of U.S. men with prostate cancer whose disease has spread to the bones or other organs, there is still no cure, but treatments are slowly becoming more effective. Testosterone-blocking medication—which interferes with the cancer's ability to grow—is the standard of care for advanced cases. Eventually, however, a few tumor cells overcome the effects of this chemical castration and continue to wreak havoc. More recently, the U.S. Food and Drug Administration has approved two new approaches to treating late-stage disease. The first involves a complex biochemical process that boosts the immune system's ability to destroy malignant cells [see "A New Ally against Cancer," by Eric von Hofe; SCIENTIFIC AMERICAN, October 2011].

The second is a drug called abiraterone, which stops the production of testosterone in prostate cancer cells. Studies of both therapies show that they prolong survival by an average of four months. Other treatments, which target molecules that the cancer cells need to grow and spread, are under investigation.

We have learned a good deal about prostate cancer in the years since Mr. H. first opted against treatment for what turned out to be a very slow growing tumor. That knowledge is improving our ability to tailor treatments for individuals rather than always treating everyone the same. It has also taught doctors that we have to be very clear both with ourselves and with our patients about what we really know, from a scientific point of view, and what we do not know—and have the courage to act on the evidence and not just our beliefs. SA

MORE TO EXPLORE

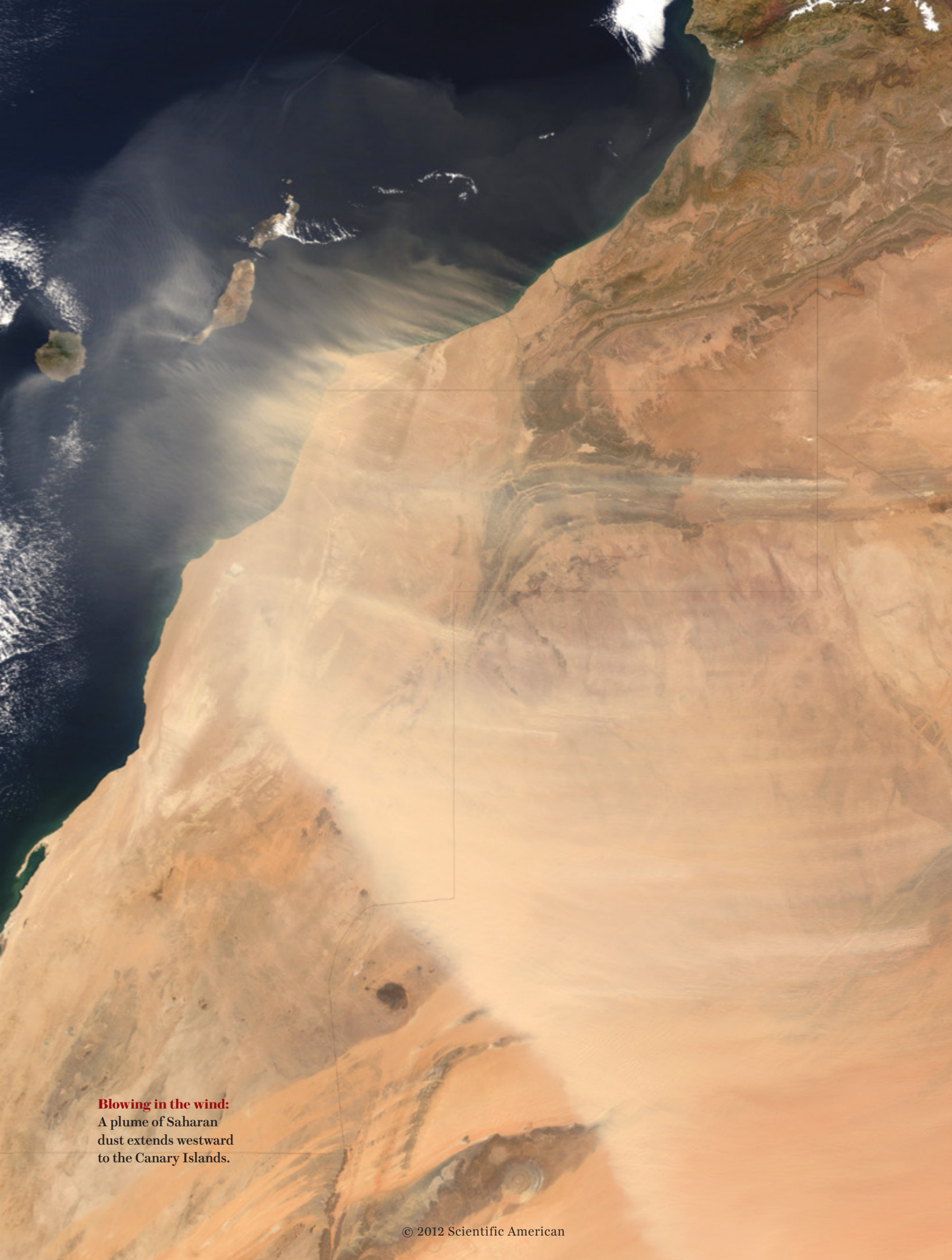
Screening for Prostate Cancer: A Review of the Evidence for the U.S. Preventive Services Task Force. Roger Chou et al. in *Annals of Internal Medicine*, Vol. 155, No. 11, pages 762–771; December 6, 2011. www.annals.org/content/155/11/762

2012 Annual Report on Prostate Diseases. Edited by Marc B. Garnick and Ann MacDonald. Harvard Health Publications, 2012. www.harvardprostateknowledge.org

American Urological Association's response to the U.S. Preventive Services Task Force's 2011 draft recommendations on prostate cancer testing: http://bit.ly/aua-letter

SCIENTIFIC AMERICAN ONLINE

Hear the author discuss treatment options for prostate cancer at ScientificAmerican.com/feb2012/prostate-cancer



Blowing in the wind: A plume of Saharan dust extends westward to the Canary Islands.

ENVIRONMENT

SWEPT FROM AFRICA TO THE AMAZON

What the journey of a handful of dust tells us about our fragile planet

By Jeffrey Bartholet

THE BODELE DEPRESSION AT THE SOUTHERN EDGE OF THE Sahara is a fearsome, forsaken place. Winds howl through the nearby Tebesti Mountains and Ennedi Plateau, picking up speed as they funnel into a parched wasteland nearly the size of California. Once there was a massive freshwater lake here. Now the lake is a shrunken puddle of its former self. Across most of the landscape, there is nothing.

Or so it would seem. But as the winds sweep the ancient lake bed, which has not been inundated in much of this area for several thousand years, they carry trillions of tiny particles skyward in vast, swirling white clouds. The dust then starts a mysterious journey—or a series of mysterious journeys—that scientists are trying to better understand.

Only a few decades ago researchers did not pay much attention to dust. Like the rest of us, they cleaned under their furniture and occasionally took note of drifting flurries of house motes—concoctions of particles that generally include bits of dead insects, plant fibers and kitchen crumbs. Scientists studying the earth's atmosphere were far more interested in man-made particulate matter—pollution. Few bothered to recognize that millions of metric tons of soil or mineral dust were circulating around the globe at any given time, affecting the climate, fertilizing the oceans and contributing vital nutrients to the Amazon rain forest, among other places.

Joseph M. Prospero was one of the pioneers. A professor emeritus in marine and atmospheric chemistry at the University of Miami, he has been called the grandfather of dust studies in the U.S. Yet he also recalls that when he published papers in the 1960s and early 1970s suggesting a massive transport of African dust across the Atlantic to the Americas, some of his colleagues were skeptical that this was a subject of significant scientific interest. "People used to find the topic of dust funny," he says.

His was a lonely enterprise, monitoring dust stations in Barbados and other pristine locations, analyzing and measuring what he could catch in his air filters. Eventually interest grew, however, in part because satellite photographs showed in ever greater clarity what Prospero and a few others were describing: giant plumes of particles, hundreds of kilometers wide, being swept off the African continent like sea spray from a massive storm and falling on the other side of the Atlantic. At the same time, interest in climate change grew, and it became clear that dust played a key role in modulating the earth's temperature.

"Now there are so many scientific papers coming out on dust, it's impossible to read them all," Prospero says. By one count, publications on Saharan dust doubled every four years from the early 1970s to 2001. Thomas E. Gill, an associate professor of geological sciences at the University of Texas at El Paso who helps to keep a database on dust, says he has a hard time keeping up. "You think it's an esoteric topic, but every week I see somewhere between 50 and 100 publications on dust in some shape or form."

What are all those studies telling us? The story of dust is actually about the challenges of trying to figure out what is happening to the planet we inhabit. It shows how an influence on one area of the earth's ecosystem can have outsize effects on other areas. "The more our scientific tools encourage us to get to one answer, the more they lead us to three more questions," says Robert J. Swap, a environmental studies professor at the University of Virginia. Swap, who co-wrote a seminal 1992 paper on African dust in the Amazon, says the study of dust leads to one conclusion: "We need to honor the complexity of nature."

Jeffrey Bartholet is a veteran foreign correspondent and former Washington bureau chief of *Newsweek*.

A way to understand that complexity is to follow a hypothetical handful of particles from the Sahara across the Atlantic. Along the way, and once our dust particles arrive at their next destinations (there are no final destinations), we can examine how they interact with the world around them.

We start in the Bodele because it is widely recognized as the dustiest place on earth. The broader Sahara and the nearby Sahel region also make their contributions: African dust is carried over much of the southern and eastern U.S. every summer and is responsible for 75 to 80 percent of the dust that falls over Florida. When it rains in Miami, and local residents clean a residue of reddish particles from their vehicles, they are wiping away a long-distance delivery from Africa. Walk across the islands of the Bahamas or the Florida Keys, and you will be hiking on African soil.

The earth emits an estimated two billion metric tons of dust a year, and more than half of it comes from African deserts and drylands. China emits dust that travels to Hawaii and western North America; Patagonia sends dust to Antarctica. Most of the dust that settles on Greenland comes from Asia, but when drought produced the American Dust Bowl of the 1930s, that dust also seems to have made its way to Greenland's glaciers.

Much of Africa's airborne dust takes a 6,400-kilometer ride on the westward trade winds across the Atlantic. By one estimate, roughly 40 million metric tons of dust, loaded with life-sustaining minerals, including iron and phosphorus, carpet the Amazon rain forest every year, and half of that amount may originate in the Bodele.

Before liftoff, the Bodele dust has been in a geologic waiting room. As each layer gets skimmed off, a new layer becomes exposed. The wind speed necessary to dislodge dust particles on the soil surface and to start them bouncing varies depending on surface and climatic conditions, but generally speaking, the threshold is in the range of four to 12 meters per second. As the particles start to jostle, they loosen others. The smallest ones float upward. Once airborne, the dust begins to mingle—first with other swirling particles from the Bodele, then with dust and pollution from elsewhere in Africa. Eventually it becomes part of a huge dust front moving across the Atlantic.

When I met with Prospero at his office at the University of Miami, he pulled up satellite photographs on his computer to show me this phenomenon and shook his head. "It's sort of a mess," he

COURTESY OF JACQUES DESCLOITRES *rapidfire.sci.gsfc.nasa.gov/MODIS Land Rapid Response Team, NASA GSFC (preceding pages)*

IN BRIEF

Although scientists have devoted much study to pollution, for many years they neglected the interrelatedness of natural dust and the atmosphere. Recently they have come to appreciate how dust influences climate and cloud formation—and the fertilization of oceans and rain forests. **Despite much research**, the effect of dust on the atmosphere is complex and poorly understood. Even the best supercomputers running the most sophisticated models do not provide a good picture.

Dirty ice: Members of Joseph R. McConnell's team take samples of ice in Greenland for analysis back in the lab (*above*). The ice contains particles that gathered in the snow over the centuries (*right*). The goal is to figure out what makes dust levels rise and fall.

said, pointing at plumes of various colors and origins over Africa and the Atlantic. "It's difficult to point your finger, in a quantitative sense, to what's going on there. It all just gets mixed up. The whole of North Africa is blowing away all the time."

Once in the air, dust that may have done nothing for millennia suddenly starts to modulate the earth's climate. It absorbs radiation from the sun, including some that is reflected off the earth, warming the atmosphere. And it reflects other radiation back into space, which has a cooling effect. What proportion of radiation gets absorbed or reflected depends, in turn, on the chemical composition, mineralogy and size of the dust, as well as on the wavelength of the light. For the most part, dust has a propensity to reflect short-wave radiation from space and to absorb long-wave radiation coming off the earth's surface. If the particles have mingled with soot, they will absorb even more heat.

Other factors also come into play. Dust traveling over darker areas, like the oceans, cools the planet because it reflects some light that would otherwise be absorbed on the surface. Yet dust traveling over light-colored areas like ice and sand tends to have a warming effect because it usually absorbs more light than the surface. If dust falls on snow or ice, it leads to more warming. "Any aerosol, any dust, any dirt will darken snow," says Charlie Zender, professor of earth system science at the University of California, Irvine. "If you walk through a snow field in the morning and put a little dirt on top of a small patch of snow, leave it there and come back in the afternoon, that part of snow will have sunken in." Several scientists I spoke with believe the overall impact of atmospheric dust is probably a cooling of the planet, but not nearly enough to compensate now for the warming effect of greenhouse gases.

Airborne dust influences climate in indirect ways, too. It has a vital part, for instance, in cloud formation. Moisture in the air does not form into droplets on its own. It needs to attach to particles. Scientists disagree on the extent to which dust acts as "condensation nuclei." Natalie Mahowald, a Cornell University professor who develops atmospheric models, firmly believes that both water and ice condense on dust. Paul Ginoux, who produces climate models at the Geophysical Fluid Dynamics Laboratory at NOAA, agrees that dust acts as a condenser for ice but believes water will condense only on dust that has been mixed with sulfates, mainly from pollution.

On at least one point, Mahowald and Ginoux concur: there are tremendous gaps in our knowledge about cloud formation. When large numbers of tiny particles are suspended in the atmosphere, they can help form big concentrations of water droplets, but because those droplets are so small, they are less likely to fall as rain. Clouds of small droplets, moreover, are brighter than clouds of large droplets—so they scatter more radiation back into space. If dust particles absorb heat, however, the moisture they attract will evaporate faster. The clouds will not last as long. "Dust can make precipitation more likely or less likely, depending on what the rest of the atmosphere is doing," Mahowald says. "It's even more complicated than you might think." Ginoux points out that even the best computer simulations do not give us a full picture: "We know the physical processes, but it's difficult to evaluate what's happening with any precision."

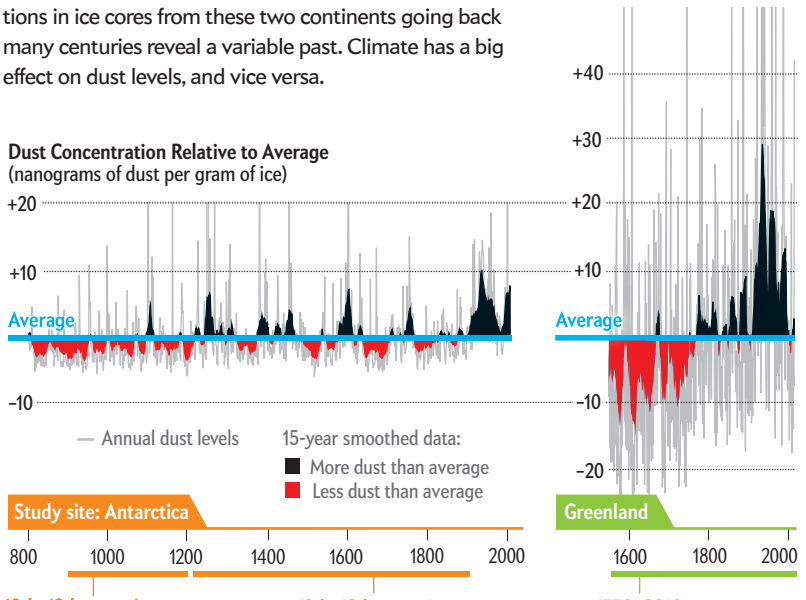
It is hard to overstate the importance of clouds to the earth's climate—and not just because they produce rain or snow. Roughly 60 percent of the earth's surface is covered with clouds at any given time. Small changes to the formation and properties of clouds could dramatically alter the role they play in reflecting light and heat back into space. By one estimate, a 5 percent increase in "short-wave cloud forcing" would cool the earth enough to compensate for all the increases in greenhouse gases that occurred between the years 1750 and 2000.

COURTESY OF DESERT RESEARCH INSTITUTE

PAST AND PRESENT

The Rise and Fall of Dust

When dust falls on ice in Greenland and Antarctica, it often is frozen into the geologic record. Dust concentrations in ice cores from these two continents going back many centuries reveal a variable past. Climate has a big effect on dust levels, and vice versa.



10th–13th centuries
The Medieval Climate Anomaly (a period of moderate warming and higher precipitation in the North Atlantic region) was characterized by lower levels of dust.

13th–19th centuries
More dust—with greater variability—accompanied a period of modest cooling and lower precipitation known as the Little Ice Age.

1550–2010
Trends in central Greenland dust levels during recent centuries are likely related to land-use changes and climate warming.

Of course, dust has been swirling around the globe for all of its existence. So why should it have any greater or lesser effect now than it has had before? Mahowald argues that, over much of the planet, more dust is in motion now than at other time in recent history. "It looks like we had about a doubling of dust over much of the planet in the 20th century," Mahowald says. "We don't know exactly what caused the 20th-century increase, but human activity could be fueling the change."

Joseph R. McConnell of the Desert Research Institute–Reno in Nevada has been working on precisely that question of cause and effect. To get answers, he analyzes the dust embedded in the ice of Greenland and Antarctica. He begins by taking ice cores, anywhere from 20 meters to three kilometers long, depending on how far back in time he wants to probe. Then he flies them to his lab. He has two $400,000 machines—high-resolution mass spectrometers—to measure the concentrations of elements found in the ice. These elements include aluminum and rare-earth elements such as cerium found in dust but not in sea salt, industrial pollution, or emissions from volcanoes and forest fires.

The machines work like this: glacial water from the ice cores is injected into a plasma that is as hot as the sun's surface—about 6,000 kelvins. "This vaporizes almost everything, and we count the ionized atoms of each leftover element based on their atomic mass and electrical charge," McConnell says. "It's extremely sensitive. Some elemental concentrations are as low as parts per quadrillion. We've applied it to shallow ice cores covering the recent centuries and just now are applying it to deep ice cores spanning the last ice age."

What McConnell is trying to measure is dust levels over time so that he can figure out what might have caused them to rise and fall. From his results it would seem that desertification and changes in land use in Patagonia (including the expansion of sheep farming in the early 20th century) correspond with a doubling in dust levels in Antarctica during that period. It might be tempting to argue for a simple process of cause and effect: overuse of land leads to desertification, which produces more dust, which then fuels climate change. McConnell warns, however, that "there are a lot of drivers of dust."

Climate itself is one of those drivers, but its role is not entirely clear. Rising temperatures, by reducing soil moisture and fueling desertification, might contribute to increasing levels of dust, which could be just a short-term phenomenon. Over the long term, dusty periods correlate with cooling. McConnell sees evidence that Antarctica was less dusty, for instance, between the 10th and 13th centuries—an era of moderate warming and higher precipitation in the North Atlantic region—and more dusty between the 13th and 19th centuries, a period of modest cooling and lower precipitation. His study of central Greenland ice records showed an increasing trend in dust levels over three centuries until the 1930s, followed by a mysterious decline.

BUT OUR HYPOTHETICAL PARTICLES TUMBLING AND SWIRLING OUT of Africa—part of the largest and most persistent migration of dust anywhere on the planet—do not just play a vital role in the atmosphere. They also act like an enormous spray of fertilizer over both the oceans and the land.

As they ride westward, many dust particles fall into the Atlantic. Here they perform a climate-regulating function that is different from what they do in the atmosphere but that also has a cooling effect: they provide iron, spurring the growth of phytoplankton, which consume carbon dioxide, die and take that carbon down to the deep, dark ocean depths. There the carbon remains isolated from the atmosphere for centuries.

The ocean contains nearly 85 percent of the carbon on the earth that is not held in rocks, and ocean phytoplankton are "responsible for ... a majority of all carbon sequestered over geologic time," says a 2011 paper in *Aeolian Research*. Yet whereas large areas of the ocean have high concentrations of the nutrients nitrogen and phosphorus, they also have shortages of iron, limiting the amount of plankton that can bloom. That is where

SOURCES: JOSEPH R. MCCONNELL *Desert Research Institute*; ZOE COURVILLE *Cold Regions Research and Engineering Laboratory*; AND NORWEGIAN-AMERICAN SCIENTIFIC TRAVERSE OF EAST ANTARCTICA RESEARCH TEAM

Graphic by Jen Christiansen

wind-borne dust comes in. African dust is high in iron content.

A few years ago there was so much excitement about the discovery of the important role of iron in the carbon cycle—and the indirect role of dust—that some scientists began to dream about ambitious geoengineering projects. The thinking went like this: in the large areas of the southern oceans and the northwestern Pacific called high-nutrient, low-chlorophyll zones, where plankton blooms are much reduced, we humans could just dump big loads of iron. Then plankton would bloom like crazy, consume carbon dioxide, die and sink to the ocean bottom. Good-bye, greenhouse gas problems.

It did not take long, though, to see the dangers in this approach. "There are many possible unintended consequences," Prospero says. These include a drastic change in the current species distribution of microorganisms in the water column. That is not necessarily a bad thing, but the impact is unpredictable; new ecosystems often are not as diverse and productive as those they displace. Also, if iron is dumped in zones that are deficient in iron but rich in other nutrients, the new plankton plumes will draw down to the depths not only carbon dioxide but also phosphorus and nitrogen. Those nutrients will not then be available elsewhere in the oceans where they are needed.

Other new knowledge further undermined the iron solution. "There's been a complete change in the way we see ocean biochemistry," Cornell's Mahowald says. "What we thought was going on 10 years ago is completely different from the way we see it now." One of the bigger revelations is that "not all dust is equal in terms of the iron it makes available." It turns out that acids in the atmosphere—from biomass burning and other pollution—interact with dust to make iron more soluble. So when we burn fuel and waste, we contribute to the production of available iron in the atmosphere and the oceans. "The amount of iron being deposited in the oceans may have already about doubled because of humans," Mahowald says. "At the same time, sedimentary iron in the ocean is a much larger amount than previously thought. There is much more iron coming off the ocean shelves. So atmospheric iron is less important than we thought it was."

For those particles that make it all the way across the Atlantic, the journey can take a week or more. It is common to see an African dust haze over Miami in the summer or to find a film of such particles on your vehicle after a rainstorm in the Amazon. That is how Swap of the University of Virginia got interested in the topic of dust transport back in the late 1980s. He was working in Brazil as a graduate student when he and others noticed that after days of rain, dust would continue collecting on their white Volkswagens. "We were 1,000 miles inland, where it would rain like hell, three to five inches a day," Swap recalls. "We'd look at our cars after a rain and find red dust. And we'd think, 'What's going on here?' "

THAT QUESTION WAS LINKED TO ANOTHER THAT HAD LONG festered about the Amazon. The basin consists of old soils continually battered by rains that probably should have drained out many of the key nutrients long ago. So how was the Amazon getting replenished? How did it remain so fertile? Some think it may replenish itself as plant matter decomposes. Others think that is unlikely and wonder how it became so fertile to begin with. "It's a very viable hypothesis that a lot of the fertility of the Amazon can be explained by the transport of African dust," says Daniel Muhs, a scientist at the U.S. Geological Survey. "How else does the Amazon support that unbelievable diversity of plants and animal species on such a hot, humid and old landscape, where the soils are highly leached?"

New studies have confirmed similar intercontinental dust deposits in other areas. Muhs took "geochemical fingerprints" of the soil on several islands in the Caribbean. "In some places, African dust is the sole source of the soils; in others, it's a partial source," he says. Some islands are made of limestone, coral reefs and sand, yet their topsoil is rich in unrelated clay and aluminum silicates. There are two possible sources, Muhs says: ash from a volcanically active part of the Caribbean or dust from Africa. In some places, including Barbados, the soils are composed of both. In others, like the Bahamas and the Florida Keys, it is almost all from Africa. "Our work on Barbados, with fossil reefs of different ages, indicates that the process [of African dust transport] has been going on for hundreds of thousands of years," Muhs says.

How long will the process continue? Here is the last thing you need to know about our traveling dust particles: not only do they have a profound effect on the earth's climate, but the earth's climate can also have a profound effect on them. "Dust is different from other aerosols because dust in the atmosphere—unlike man-made pollution—is dependent on climate itself," Prospero says. "If climate change affects wind velocity and rainfall, it can have an immense impact. Dust is extremely sensitive to small changes in wind and rain. It's the ultimate feedback loop."

Evidence of such relationships can be seen in ice core and other records. Glacial periods were much dustier than interglacial times. "But we're still trying to figure out the chicken and the egg of that," Muhs says. "Did glacial periods lead to more dust or more dust to glacial periods? There are a variety of feedbacks. It gets very complicated very quickly." That is what makes scientific solutions to climate change—dreams of a simple, elegant feat of bioengineering like the iron solution—so troublesome. "With all the feedbacks within feedbacks within feedbacks, what unexpected feedbacks might we have?" Muhs says. "We might solve one problem while creating another."

Prospero has already noted some unexpected weirdness going on. During the 1970s and 1980s dust concentrations at Barbados and Miami were highly correlated with drought and rainfall in North Africa: more drought, more dust. But all of that changed starting in the 1990s. "Now there is no correlation at all, and we don't know what's going on," Prospero says. "I am concerned and confused." He worries that dust might be yet another indicator that our complex earth systems could be getting out of whack, making predictions impossible and the future increasingly uncertain. SA

MORE TO EXPLORE

Environmental Characterization of Global Sources of Atmospheric Soil Dust Identified with the Nimbus 7 Total Ozone Mapping Spectrometer (TOMS) Absorbing Aerosol Product. Joseph M. Prospero et al. in *Reviews of Geophysics*, Vol. 40, No. 1; September 4, 2002.

Dust Cycle: An Emerging Core Theme in Earth System Science. Yaping Shao et al. in *Aeolian Research*, Vol. 2, No. 4, pages 181–204; March 2011.

The Dustiest Place on Earth. Web page for the BodEx field experiment in the Bodele Depression: www.rgs.org/OurWork/Grants/Grant+recipients/Example+projects/The+Dustiest+Place+of+Earth.htm

SCIENTIFIC AMERICAN ONLINE

To see more satellite photographs of atmospheric dust like the one that opens this article, visit ScientificAmerican.com/feb2012/dust

Kenneth F. Haynes is a professor of entomology at the University of Kentucky. His primary research interests are insect behavior and communication. The worldwide resurgence in bed bugs has led him and his students to investigations of these unusual insects.

PUBLIC HEALTH

Sleeping with the Enemy

Bed bugs are back. Can science stop them?

By Kenneth F. Haynes

THE ELDERLY MAN LIVED BY HIMSELF IN A LOW-income apartment near Cincinnati. But he was not alone. After dark the bed bugs would emerge from his recliner and tattered box-spring mattress to feed on his blood. Judging from the thousands of insects I found in his home, I would venture that it had been this way for many months. Imprisoned by poverty and infirmity, the man had nourished generations of these pests, enduring their bites night after night while their numbers swelled.

After largely disappearing for nearly 50 years thanks to the development of DDT and other broad-spectrum pesticides, the bed bug, *Cimex lectularius,* is making a disturbing comeback—and not just in crowded, urban locales. The parasite has infested upmarket hotels, college dorms, retail establishments, office buildings, theaters, hospitals, and the homes of rich and poor alike. Though widely dismissed as mere nuisances, bed bugs exact a toll that exceeds the itchy bites they may leave behind: in a 2010 survey

of more than 400 individuals living in bed bug–infested dwellings, 31 percent mentioned additional symptoms, ranging from sleeplessness to depression, that they attributed to bed bugs. And a study published in 2011 discovered MRSA bacteria—which cause severe skin lesions—in bed bugs, although much more research will be required to determine whether bed bugs contribute to the spread of MRSA. Bed bugs also cause significant economic losses, as when a hotel has to temporarily close rooms to combat an infestation. One public housing building in Ohio spent about $500,000 on bed bug control, culminating in fumigation of the entire building after more conventional approaches failed to make inroads into the problem.

To defeat these unwanted bedfellows, scientists have been endeavoring to figure out how they managed to crawl back into prominence. It appears that bed bugs have benefited from what my University of Kentucky colleague Michael Potter has called "a perfect storm" of factors, including the evolution of insecticide-resistance genes, shifts in control tactics for other urban pests, and changes in patterns of international travel and migration. The good news is that recent studies have suggested novel approaches to detecting incipient populations of the bloodsucking insects before they become full-blown infestations, and these studies have revealed aspects of bed bug biology that might be suitable targets for intervention.

GOOD NIGHT, SLEEP TIGHT

UNDERSTANDING HOW BED BUGS have come to plague us requires a basic knowledge of bed bug biology. The bugs are attracted to heat and carbon dioxide (and perhaps to body odors as well), which all humans give off. They live in groups in and around beds, hiding in nooks and crannies by day and emerging at night to feed on their sleeping hosts. An adult female lays about two eggs per day when she has access to regular blood meals and averages an estimated 150 to 500 eggs over her lifetime. Under ideal conditions, bed bugs can go six months or more without food. And they spread easily, walking quickly between adjacent rooms and hitchhiking on people's clothes, shoes and other belongings.

Humanity's struggle with bed bugs is long-standing. Archaeologists have recovered remains of the parasites dating back 3,500 years to the time of the Egyptian pharaohs. The roots of this relationship go far deeper than that, however. Some experts speculate that the ancestors of bed bugs were parasites of bats. They moved to humans, so the thinking goes, when people took up residence in caves. The relationship between our ancestors and bed bugs became cemented when we shed our nomadic ways in favor of permanent settlements. Still, in temperate latitudes, the onset of winter kept the pests in check. Sensitive to cold, their populations expanded in the warmer months and dwindled in the colder ones.

Before the advent of pesticides, our predecessors used every solution imaginable to reduce bed bug numbers, sometimes risking dangers or hardships that modern society would not permit. For example, a 1777 "vermin"-control manual suggested that gunpowder could be ignited in the crevices around the bed (I am not certain if this solution was one of vengeance or practical value). Alternatively, the right species of plants—namely, wormwood and hellebore—boiled with the "proper quantity of urine"—were said to do the job (or did it just force the occupant to seek a different place to sleep?). Arsenic, cyanide and other hazardous compounds were also deployed, with limited success. More commonly, people tackled the problem by intensively cleaning their homes—dousing the permanent parts of the bed with boiling water and kerosene while disposing of the straw mattress ticking. Temporary relief ensued.

As central heating of buildings became commonplace in Europe and the U.S., starting in the early 1900s, bed bugs began to flourish year-round. Only with the development of DDT did people finally get real relief from the bugs, starting in the 1940s. First used during World War II to protect U.S. armed forces from mosquitoes and lice, DDT turned out to excel at eliminating bed bugs, too. Its long-lasting efficacy meant that, unlike other treatments on the market, a single application was usually all it took. In a few years the pests had all but disappeared from countries in North America and western Europe and from other developed nations. Unfortunately, DDT and compounds like it also had a part in the near extinction of some predatory birds, among other serious environmental concerns, and they were pulled from store shelves in the U.S. in 1972.

Yet even in the absence of DDT, bed bugs did not begin to bounce back until around 2000. Scholars have proposed a number of reasons for this rally. Some have argued that escalating international travel from parts of the world where bed bugs were never under control has allowed the pests to reestablish themselves in areas that had once been cleared of the parasites, although the abruptness of the resurgence does not coincide with any major change in travel frequency. A more influential factor may have been the collapse of political barriers that restricted travel between the East and West, along with increases in the mobility of populations within countries.

A shift away from broad-spectrum insecticides other than DDT to much more focused and efficient baits and targeted sprays for roaches, ants and other urban pests could have also allowed bed bugs to slip through the cracks. Even the existence in many communities of affluence alongside poverty may play a role: when a perfectly nice-looking sofa ends up on the sidewalk because it has bed bugs, chances are it will find a home with someone in need. Insecticide resistance has contributed to the problem, too: bed bugs were among the earliest insects to evolve resistance to DDT, with the first cases found in Pearl Harbor just after World War II. (In fact, although some pest controllers advocate for the return of DDT to the bedroom, today's bed bugs are likely to be resistant to its effects.) And populations the world over have evolved resistance to the insecticides that replaced DDT. Together these forces, combined with the social stigma of bed bugs, which delays effective treatment, can ac-

IN BRIEF

After a decades-long reprieve, bed bugs have returned with a vengeance, plaguing rich and poor alike.

A confluence of factors ranging from the evolution of insecticide resistance to shifts in patterns of international travel seem to have fueled the parasite's comeback.

Scientists have recently identified several aspects of bed bug biology and behavior that could lead to novel ways of detecting and eradicating the pests.

COURTESY OF GRAHAM SNODGRASS *U.S. Army Public Health Command (preceding pages)*

CONTEXT

A Brief History of Bed Bugs

Bed bugs have plagued humans for thousands of years, leading to sometimes dangerous (and ineffective) eradication methods. Following a decades-long reprieve courtesy of DDT and other similar pesticides, bed bugs are booming once again.

3,500 years ago
Earliest archaeological evidence of bed bugs

1700s
Gunpowder is recommended for use against bed bugs

Early 1900s
Spread of central heating allows bed bugs to flourish year-round

1940s
Development of DDT brings first real relief from bed bugs

1972
DDT pulled from market because of environmental concerns

2000
Bed bugs begin to bounce back

count for the current bed bug pandemic.

With a track record of success going back thousands of years, bed bugs are daunting foes. But researchers are gaining on them. One priority is identifying better means of rooting out the insects early on. Because they are small and hide during the day, bed bugs are hard to find and reach. Reliably detecting their presence is key, as is verifying their absence following treatment. One of the simplest detection tools to hit the market recently is the ClimbUp Insect Interceptor, which consists of a shallow bowl with an outer moat (essentially two nested plastic bowls molded into one piece) designed to slip under the leg of a bed. The trap provides information about the source of the bugs: if bugs show up in the inner well, then the bed is a source; if they end up in the outer well, then they must have come from another part of the room. Such a tool might not detect a small population, though, or one that lives behind the headboard.

Another new kind of detection device taps into the bugs' mechanisms for locating human hosts. Traps that incorporate heat and carbon dioxide, along with other undisclosed attractants, are now on the market. A homemade trap made out of an inverted cat dish baited with slowly subliming carbon dioxide from dry ice is pretty effective, too. As with the double-bowl trap, however, these sometimes fail to reveal bed bugs at the early stages of invasion, when they are easiest to eliminate.

At present, nothing beats a well-trained dog when it comes to finding small, dispersed populations of bed bugs. Exactly what the dogs are picking up on remains uncertain, but it might include the bouquet of compounds that researchers at Simon Fraser University identified in 2008 as components of the chemical signals bed bugs use to aggregate. Aside from feeding, everything of consequence to a bed bug—mating, egg laying, development of the immature, and so forth—occurs in hidden harborages that they mark with their own feces, as well as volatile compounds that emanate from the bugs' bodies. These signals help colony mates find their way back to headquarters. The tendency of bed bugs to gather presumably benefits each individual, perhaps by elevating the humidity in its microhabitat. If we could mimic those aggregation signals, we could develop a simple trap that would allow people to test for the presence of the bugs. Such a trap, if unobtrusive, would no doubt appeal to hotels looking to discreetly monitor guest rooms for bed bugs.

STRANGE BEDFELLOWS

OF COURSE, DETECTING BED BUGS is only the first step. And eradicating them is far more difficult. Following careful inspection, exterminators typically use mattress and box-spring encasements to entomb the bugs that rest in these places. They may then vacuum, steam, freeze or dispense a fast-acting insecticide to eliminate bed bugs within view. They may also sprinkle insecticidal or desiccant powders in wall voids to kill bugs that crawl through these spaces and spray insecticides with residual activity that continue to kill insects that wander across treated surfaces for days, weeks or months. Yet even the most effective insecticides in the hands of the most knowledgeable professional usually require several applications over the course of a few weeks to eliminate infestations. These insecticides, available only to licensed exterminators, must be used according to strict guidelines designed to protect human health and the environment. Over-the-counter insecticides can be dangerous when misused and are often ineffective. Heating a room or a house with professional equipment to 50 degrees Celsius for four hours, however, is a nontoxic approach that has met with great success. With the exceptions of heat treatment and building-wide fumigation, though, getting rid of bed bugs demands the use of multiple tactics integrated judiciously.

Clearly, we need new ways of eliminating bed bugs once we find them. To that end, scientists around the world have been taking a close look at the unusual mating behavior of these insects in search of possible leads. Bed bug sex is a brutal affair. The males have a saberlike penis that they use to puncture the outer layer, or cuticle, of the female's abdomen—a form of mating descriptively termed traumatic insemination. The females have adaptations to these

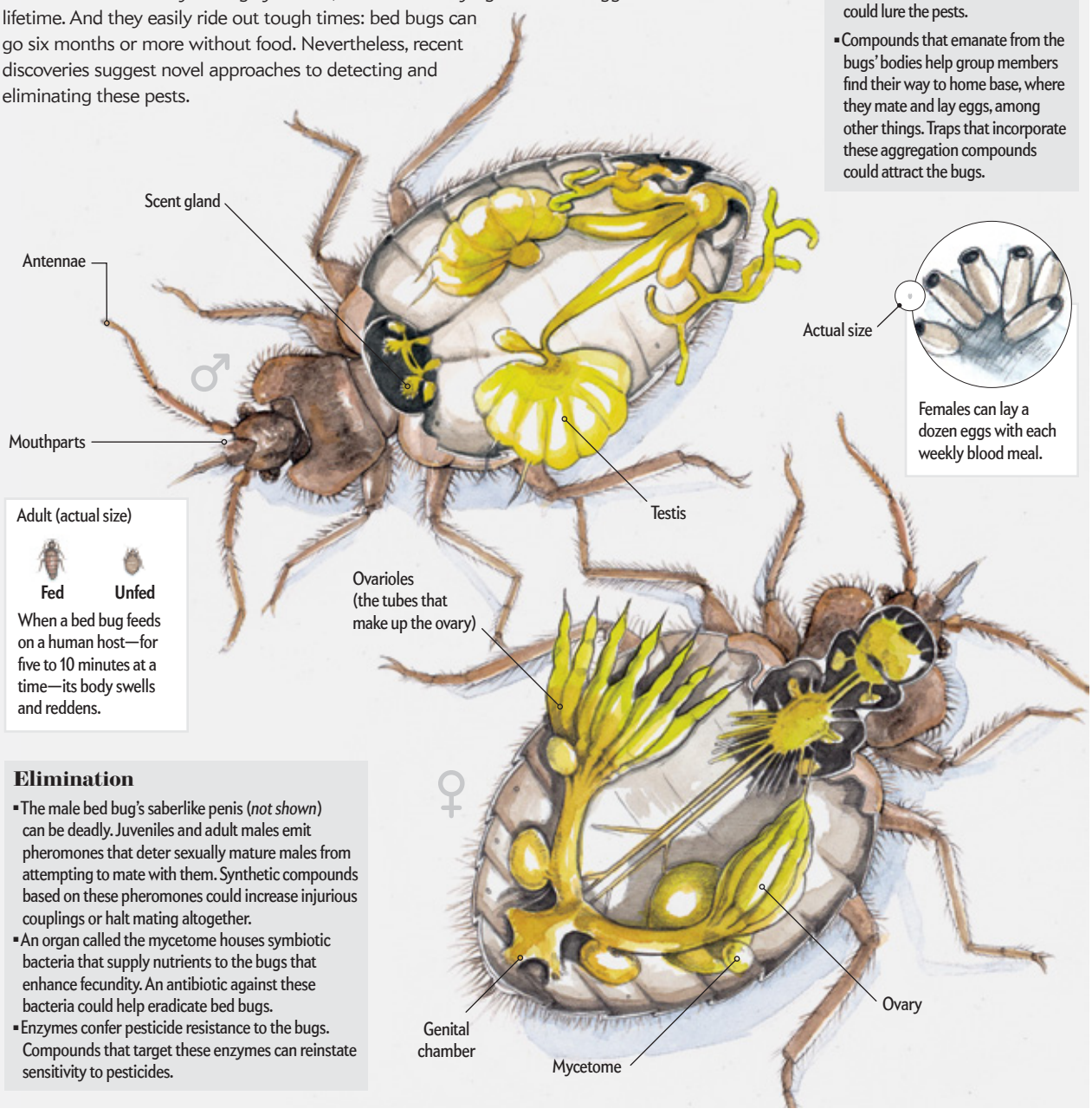
ALEX WILD *Corbis (bed bug)*; DAVE KING *Getty Images (gunpowder)*; CORBIS *(DDT)*

Know Thy Enemy

Bed bugs are formidable foes. Their small, flat bodies allow them to hide in the tiniest crevices to lie in wait until night falls and they can feed on their sleeping victims under cover of darkness. They are highly fecund, with females laying 150 to 500 eggs in their lifetime. And they easily ride out tough times: bed bugs can go six months or more without food. Nevertheless, recent discoveries suggest novel approaches to detecting and eliminating these pests.

Detection

- Heat sensors in antennae help bed bugs locate hosts. The bugs can also detect carbon dioxide. Traps that incorporate heat and carbon dioxide could lure the pests.
- Compounds that emanate from the bugs' bodies help group members find their way to home base, where they mate and lay eggs, among other things. Traps that incorporate these aggregation compounds could attract the bugs.



Elimination

- The male bed bug's saberlike penis (*not shown*) can be deadly. Juveniles and adult males emit pheromones that deter sexually mature males from attempting to mate with them. Synthetic compounds based on these pheromones could increase injurious couplings or halt mating altogether.
- An organ called the mycetome houses symbiotic bacteria that supply nutrients to the bugs that enhance fecundity. An antibiotic against these bacteria could help eradicate bed bugs.
- Enzymes confer pesticide resistance to the bugs. Compounds that target these enzymes can reinstate sensitivity to pesticides.

damaging copulations. A V-shaped groove in the abdomen called the ectospermalege channels the penetration so that the damage is less costly. Once inside the female's body cavity, the sperm and any accompanying pathogens encounter a barrier of blood cells loosely organized into an organ with presumed immune function—the mesospermalege. The sperm must migrate through the mesospermalege to a storage area near the base of each ovary. Yet even with these adaptations, my laboratory colonies of bed bugs drift to male predominance because of the injuries caused by multiple copulations. Without human intervention, the colonies would go extinct.

In the real world, the bed bugs carry on, probably because females disperse to escape damaging copulations. Why have bed bugs taken off on this costly evolutionary trajectory, whereas females of millions of other insect species have reproductive openings that males use to inseminate them without injury? My colleagues

Illustration by Mike Sudal

and I are exploring whether this mating behavior is a point of vulnerability.

Studies published in 2009 and 2010 by Rickard Ignell of the Swedish University of Agricultural Sciences Alnarp and his colleagues and by Camilla Ryne of Lund University in Sweden, respectively, revealed another intriguing bed bug adaptation to traumatic insemination that could prove useful to humans. Male bed bugs are not very discriminating in their initial sexual encounters. They pounce on other adult males, as well as large immature males and females. Such encounters could lead to life-threatening cuticular damage in these individuals because they lack the adaptations adult females have for sustaining punctures. The researchers found that to deflect these dangerous advances, nymphs and adult males release pheromones that tell the pouncer he is wasting his time and sperm. It does not take much of a leap to imagine manipulating these innate responses to our advantage. In theory, applying synthetic pheromones to bed bug refuges could discourage mating altogether or, if the bed bugs habituate to the odor, could result in costly mating mistakes of the kind that leads to the decline of captive bed bugs.

One more aspect of bed bug reproduction warrants mention. As in most sexually reproducing animals, male bed bugs have paired testes that manufacture sperm and a vas deferens that transfers sperm and accessory fluids to the female during copulation, and female bed bugs have ovaries that house eggs and oviducts through which those eggs are released. They also have an organ called the mycetome that contains symbiotic bacteria. When Takema Fukatsu of the National Institute of Advanced Industrial Science and Technology in Japan and his collaborators attempted to figure out what would happen to the viability of bed bugs rendered bacteria-free via antibiotics, they found that females from the bacteria-free colony had lower reproductive rates. Supplementing the females' blood diet with vitamin B restored their fecundity, indicating that the mycetome bacteria help to provide these nutrients.

It is tempting to speculate on the basis of this finding that scientists could treat the host with antibiotics and thus indirectly reach these bacteria, ultimately killing the bed bugs. Yet we need a much more specific solution. Using broad-spectrum antibiotics to treat a person who is not sick could lead to cascading problems. First, the good bacteria in our guts would be displaced, then antibiotic-resistant bacteria would eventually take over, and some of these bacteria would be human pathogens or would lead to our experiencing vitamin deficiencies. The bacteria in the mycetome are a target of opportunity, but we would need to design highly specific antibiotics that hit only these bacteria.

As for developing new insecticides, the future is uncertain. Over the past few decades people have relied heavily on insecticides based on compounds called pyrethroids to control bed bugs. Now the bugs are evolving resistance to pyrethroids—no surprise, given that reports of resistance to DDT emerged as early as the late 1940s. DDT and pyrethroids have a common mode of action that often translates into cross-resistance—that is, the development of resistance to one compound affords resistance to the other. My colleagues and I found a population of bed bugs in Cincinnati that was resistant by more than 10,000-fold to a commonly used pyrethroid called deltamethrin, meaning that it takes 10,000 times the dose to kill this strain of bed bugs compared with a naive, susceptible strain. We were startled to see the bugs trudge through a "snowdrift" of nearly pure deltamethrin and still live to feed another day, while their susceptible counterparts perished from exposure to nearly invisible traces of the stuff. They were also cross-resistant to DDT.

These Cincinnati die-hards are not unique: my team has detected insecticide-resistance genes in more than 85 percent of the bed bug populations across the country that we sampled. Our lab and others in the U.S. are just starting to identify mechanisms for this resistance. Two of my University of Kentucky colleagues, Fang Zhu and Subba Reddy Palli, have used genetic techniques to restore insecticide susceptibility to resistant strains of bed bugs. Their work suggests enzymes in resistant strains that operate to detoxify insecticides could be targets for human interference. Similarly, my research group has found that a compound well known to enhance insecticide toxicity by targeting that complex of enzymes renders our 10,000-fold-resistant population more susceptible to deltamethrin. The pest-control industry is already using commercial forms of the compound piperonyl butoxide to reinstate some level of bed bug sensitivity to pyrethroids. Researchers may soon be able to quickly identify the mode of resistance in any given bed bug population and then tailor an eradication strategy accordingly, selecting insecticides and synergists that would work on that particular group of pests.

Bed bugs are a nightmare, especially for those unable to afford effective countermeasures. Well-trained pest-control operators can conquer infestations with a combination of thorough inspections, knowledgeable use of available insecticides and other tactics, but their efforts are labor-intensive and expensive. For apartment dwellers and home owners, the best bet is to take commonsense measures to avoid bringing bed bugs home in the first place. For my part, when I return from a bed bug–infested apartment, I put my clothes through a cycle in the clothes dryer on the highest setting. Similarly, I might leave my suitcase in a hot car over a sweltering summer weekend rather than risk a home invasion after I travel: sustained exposure to 50 degrees C in every crevice of a suitcase will kill bed bugs. (Freezing bed bugs to death is a more difficult proposition because they can survive many hours of temperatures achieved by household freezers.)

It is unlikely that bed bugs will ever return to their recent status as a forgotten pest from our past. But by educating the public about bed bugs and exploring the insects' unique vulnerabilities, scientists can make inroads. Treating bed bugs as a public health concern and not a social stigma is a step society can take today. SA

MORE TO EXPLORE

Insecticide Resistance in the Bed Bug: A Factor in the Pest's Sudden Resurgence? A. Romero et al. in *Journal of Medical Entomology,* Vol. 44, No. 2, pages 175–178; March 2007.

Nymphs of the Common Bed Bug (*Cimex lectularius*) Produce Anti-aphrodisiac Defence against Conspecific Males. Vincent Harraca et al. in *BMC Biology,* Vol. 8, No. 121; 2010.

The History of Bed Bug Management—With Lessons from the Past. Michael F. Potter in *American Entomologist,* Vol. 57, No. 1, pages 14–25; Spring 2011.

SCIENTIFIC AMERICAN ONLINE

For a Q&A with the author on practical bed bug tips, visit ScientificAmerican.com/feb2012/bed-bugs

Ahoy! HMS *Foxglove* (*right*) was a British minesweeper that patrolled the South Pacific from 1915 to 1945.

CITIZEN SCIENCE

All Hands on Deck

Volunteers are combing through the logbooks of World War I–era ships to help researchers fill holes in the earth's climate record

By Kalee Thompson

NATIONAL ARCHIVES, ENGLAND (*ship and logbook*)

Illustration by Mark Weaver

Kalee Thompson is a freelance science writer and author of *Deadliest Sea: The Untold Story behind the Greatest Rescue in Coast Guard History* (William Morrow, 2011). She lives in Los Angeles.

KATHY WENDOLKOWSKI USED TO MAKE CANDY IN HER SPARE TIME. FOR THE past year and a half, this mother of three from Gaithersburg, Md., has been spending two to three hours a day on the Web site Old Weather (www.oldweather.org). There she transcribes temperature, pressure and wind-speed records from the logbooks of HMS *Foxglove,* a British minesweeper that patrolled the South Pacific in the years following World War I. It was a friend, a naval historian, who told her about the site soon after its launch in October 2010, Wendolkowski says. She quickly got hooked—not by the actual weather data but by the narrative of the *Foxglove*'s journey and crew, a story that played out alongside the thermometer readings in each day's logbook entries.

Old Weather is one of a handful of online endeavors that marshal volunteers to help researchers, relying on thousands of "citizen scientists" to comb through data that would otherwise be impractical to mine, explains British paleoclimatologist Philip Brohan, the project's lead scientist. Brohan, who estimates that it would take a professional transcriber 28 years to complete the work Old Weather volunteers finished in the project's first six months, says that those transcriptions are invaluable to researchers like him, who scrutinize data from the past to help predict what we will see in the future. "Every time there's a big storm, people ask, 'Would this have happened in the absence of human impact on the climate?' " Brohan says. "Is it new or unusual, or is it the sort of thing that's happened before? If we want to answer that question, we need to know how the weather has varied in the past."

Archives around the world contain expansive weather records from ships, scientific expeditions and colonial research stations, but extracting those data—which are often scrawled in archaic penmanship that is difficult for computers to read—has long been considered an all but impossible task. In 2009, however, Brohan met astronomer Chris Lintott, one of the founders of Galaxy Zoo, a pioneering online effort that, in its original incarnation, recruited Web surfers to classify hundreds of thousands of images of galaxies as either elliptical (football-shaped) or spiral (whirlpool-like). They both realized that the citizen science approach that had worked for astronomy could also be used for climate science. They secured funding from the British government, and Old Weather was born.

The site launched with 4,000 logbooks—about 250,000 ship days' worth of data—from 256 British Royal Navy vessels that sailed during and after World War I, a period chosen in part because of its scarcity of weather data (the war disrupted weather recording). Visitors to the site log in, select a ship and are shown a single page. They transcribe the data into neat pop-up boxes,

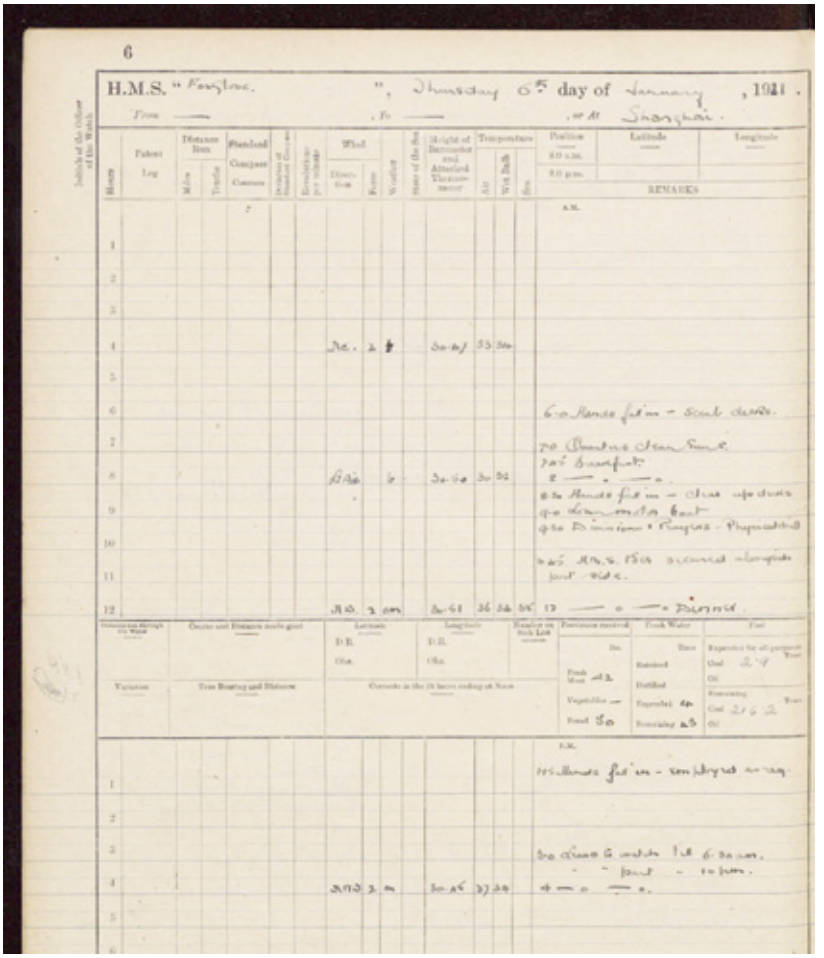
IN BRIEF

Citizen science projects marshal lay volunteers to help researchers carry out labor-intensive studies. Volunteers might report species sightings, assist in categorizing images or analyze data.

The Old Weather project is a collaboration among scientists, including British paleoclimatologist Philip Brohan, and thousands of nonexperts who are helping him plug holes in the planet's climate record.

Brohan's volunteers comb through the digitized logbooks of World War I–era ships, which would be difficult for a computer to read, and enter weather data into the project's Web site.

NOAA will add the collected information to its records in the U.S. A task that might have taken one professional transcriber 28 years took volunteers just six months to complete.



Decoding history: Kathy Wendolkowski has spent more than a year transcribing weather-related entries from HMS *Foxglove* logbooks like this one.

much like filling out an online form, click "finish" and, more often than not, go on to the next day's log. Each page is transcribed by three different users to cull and eliminate errors. The completed data set will be added to records kept by NOAA in the U.S. and made available to scientists worldwide. "If we have a comprehensive picture of the weather over the past 200 years, we can put current weather into context," Brohan says. "And we can test the big models we build to predict climate change in the future."

Although Old Weather models itself on earlier projects, such as Galaxy Zoo, the effort is far more complex for the individual user. Galaxy Zoo, for instance, originally required a volunteer to simply look at an image and click a button to classify a galaxy as spiral or elliptical, a task that a computer can accomplish with just 80 percent accuracy. Old Weather, on the other hand, asks users to record the date, the ship's location and seven different bits of weather data that have generally been recorded half a dozen times throughout the day. While the galaxy-labeling task may take just a few seconds, deciphering a page of a ship's log takes even an experienced transcriber two or three minutes—considered a long stretch in Web time. Luckily, there is also more to keep them drawn in. Brohan estimates that about 11,000 individual volunteers have contributed to Old Weather so far. Few of them are motivated by a concern about climate change; most are drawn by the stories of the ships. The site's designers capitalized on that pull by devising an incentive system by which users move up in rank, from cadet to lieutenant and, finally, to captain, depending on the number of pages they have transcribed. They created extended forums for users to discuss the goings-on of their ships (burials at sea and the 1918–1919 influenza epidemic are among dozens of discussion threads). And they partnered with the Web site Naval-History.net to make good use of the extensive non-weather-related information that the volunteers' transcriptions were turning up.

All of it was irresistible to Wendolkowski, who purposely chose an obscure ship she hoped other transcribers would pass by. "Everybody's going to go for the big battleships," she says. "I chose one that's just sort of puttering around." Wendolkowski started transcribing logbooks from mid-1921. By the spring she had worked her way through 1923 and become the *Foxglove*'s virtual captain. Wendolkowski has contacted experts at the British Embassy and at the nearby U.S. Naval Academy in Annapolis to help her translate antiquated acronyms and identify passing vessels she could not find in the historical record. Still, it is mostly the soccer and cricket matches, outings to the cinema, and the occasional man-overboard tragedy described in the narrative log that appears alongside the weather records that keep her logging in. That and the ranking system, which adds an element of competitiveness (another forum topic: obsession). "I'm number 92 on the list of transcribers," says Wendolkowski, who, despite completing close to 5,000 logbook entries, lost the *Foxglove*'s top job to another volunteer. "I want to move up that list."

She will have her chance. With the original logbooks nearly complete, the Old Weather team are adding hundreds of new logbooks, many from early Arctic expeditions. Forums on polar bear attacks and falls through the ice may soon follow. SA

NATIONAL ARCHIVES, ENGLAND (*logbook*); RALPH LEE HOPKINS *National Geographic Stock* (*whales*)

MORE TO EXPLORE

Citizen Science: People Power. Eric Hand in *Nature*; published online August 4, 2010. www.nature.com/news/2010/100804/full/466685a.html

Philip Brohan's climate-related publications: www.brohan.org/philip/publications

The Old Weather project: www.oldweather.org

Galaxy Zoo: Hubble. Citizen scientists view NASA Hubble Space Telescope images and help astronomers classify galaxies by shape: www.galaxyzoo.org

SCIENTIFIC AMERICAN ONLINE

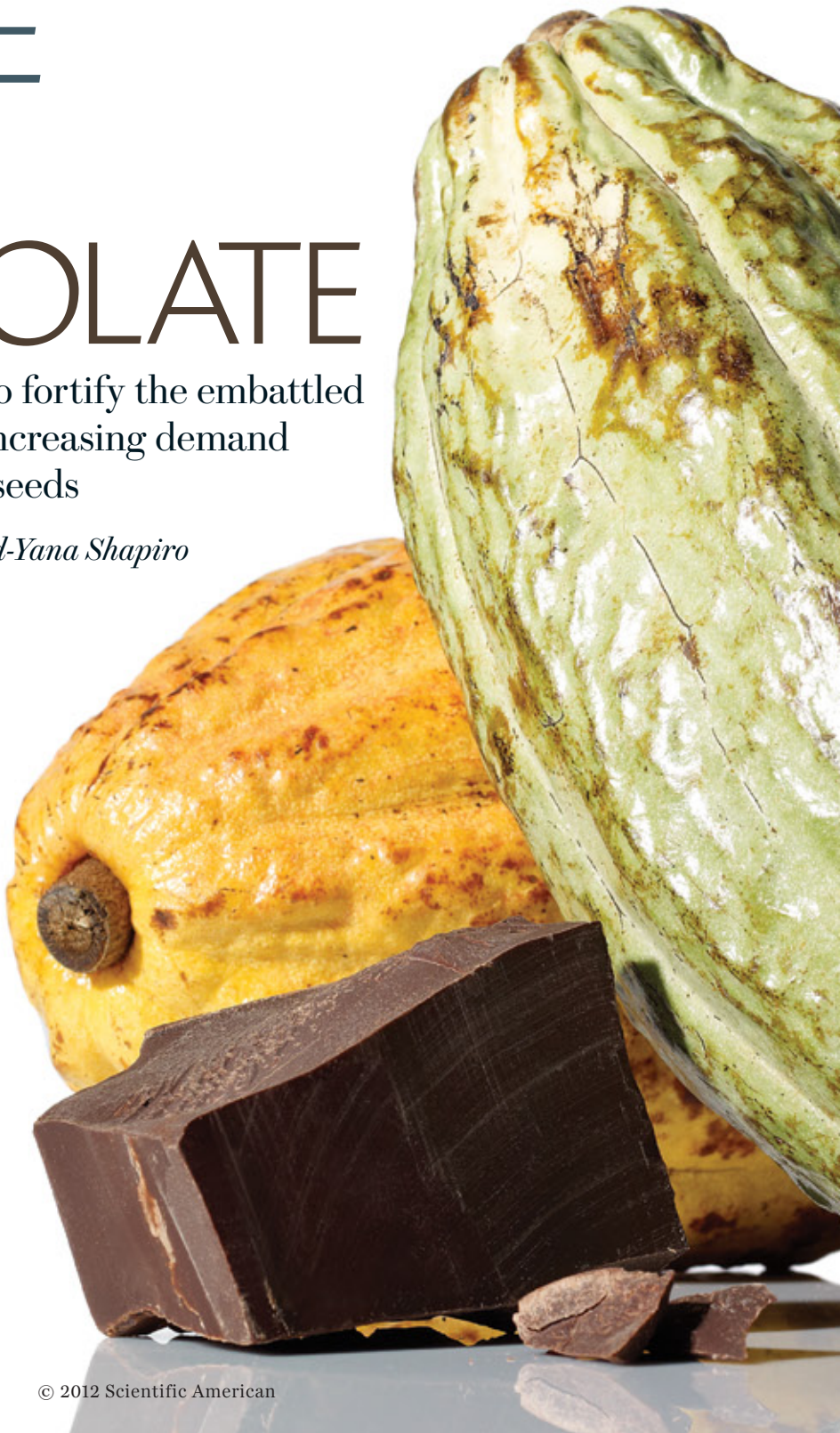
Scientific American is hosting its own citizen science project and has links to many others. The SA project, a partnership with Zooniverse, focuses on how pilot and killer whales communicate. Volunteers for the Whale Song Project (http://whale.fm) listen to and match whale calls online. This activity helps marine biologists understand the diversity of their sounds.

SUSTAINABLE AGRICULTURE

THE FUTURE OF CHOCOLATE

Researchers are racing to fortify the embattled cacao tree and to meet increasing demand for cocoa made from its seeds

By Harold Schmitz and Howard-Yana Shapiro



Photograph by Adam Voorhes

Harold Schmitz is chief science officer of Mars, Incorporated. A food scientist by training, Schmitz focuses on the food-production value chain and its influence on human and companion animal health and on ecological, environmental, social and cultural sustainability. He serves on the executive committee of the Government-University-Industry Research Roundtable at the National Academies.

Howard-Yana Shapiro is corporate staff officer of plant science and external research at Mars. Shapiro is also an adjunct professor of plant sciences at the University of California, Davis. He led the global effort to sequence the genome of *Theobroma cacao,* the cacao tree.

TO THE ANCIENT MAYANS, IT WAS THE FOOD OF THE GODS.

Nineteenth-century Cubans used it as an aphrodisiac. In the 20th century American culinary authority Fannie Farmer recommended its "stimulating effect" for "cases of enfeebled digestion." Throughout history people have prized cocoa—the defining ingredient of chocolate—a tradition that endures in our modern era. This Valentine's Day alone Americans will drop a projected $700 million on chocolate. Around the world people spend more than $90 billion a year on the treat. And with appetite on the rise thanks to expanding population size and growing numbers of people in the developing world who can afford chocolate, demand may outstrip supply in the near future.

All this cocoa production does more than feed our collective sweet tooth: the five million to six million farmers in the tropics who cultivate the cacao trees from which cocoa is produced rely on the sales of the seeds to feed themselves and their families. Workers extract the seeds (often called beans) from football-shaped pods and then ferment and dry them to form cocoa liquor, butter and powder. The livelihoods of another 40 million to 50 million depend on the long production road the cacao seeds travel from farm to candy on store shelves. In Ivory Coast, which produces 40 percent of the world's cocoa, such farming accounts for a full 15 percent of GDP and employs 5 percent of households.

"Many of these farmers use their cacao trees like ATM machines. They pick some pods and sell them to quickly raise cash for school fees or medical expenses. The trees play an absolutely critical role in rural life," observes Peter Läderach of the International Center for Tropical Agriculture, who led recent research into the effects of climate change on cacao farming in Ivory Coast and Ghana. Those countries, along with Nigeria and Cameroon, produce 70 percent of the world's cocoa supply.

But the delicate "chocolate tree," *Theobroma cacao,* is in peril. The tree has always been extremely susceptible to pests and fungal infections. In 1988, just six years after our company, Mars, Incorporated, established its Center for Cocoa Science in the thriving cacao-growing region of Bahia, Brazil, the fungal disease witches' broom was found in the area. The two of us watched as it reduced production by 80 percent, driving people whose families had grown cacao for generations to abandon their farms and move to city shantytowns—effectively destroying in a few short years a vast archive of cacao-farming knowledge built over centuries. Now another fungal disease, frosty pod rot, has spread throughout Latin America and may soon arrive in Brazil, where it could be even more devastating than witches' broom. And what would happen if witches' broom were introduced into West Africa, either by accident or in an act of bioterrorism?

Making matters worse, many farmers, particularly those in Africa, struggle to get access to the best seeds, fertilizers and fungicides, as well as the education to use them properly. Yields—and the income they generate—are thus only about a third of their potential or less. Even if disaster does not hit, farms will be hard-pressed to meet projected clamoring for cocoa: manufacturers reckon the industry currently produces around 3.7

IN BRIEF

Consumer demand for chocolate—which is derived from cocoa powder made from the seeds of the cacao tree—is on the rise.

But the cacao tree is under threat from pests, fungal infections, climate change, and farmers' lack of access to fertilizers and other products that enhance yields.

Researchers are working to bolster the fragile tree through selective breeding, farmer education, and novel planting, irrigation and pest-management techniques.

Black pod fungus infects the seed pods of a cacao tree in the Philippines (*top*). Planting cacao with other crops, such as coconut in Brazil, provides year-round income and food and increases the water-holding capacity of the crops (*bottom*).

COURTESY OF MARS, INCORPORATED

million metric tons of cocoa; they expect demand to reach four million metric tons by 2020.

In view of the challenges, we and others in the chocolate industry worry that without fast action on a number of fronts, cacao farming could slide into a downward spiral. To that end, researchers are now working to find ways to multiply yields sustainably. Some of the efforts involve nontraditional collaboration among farmers, corporations, universities and government agencies, including the U.S. Department of Agriculture. One such collaboration, led by Mars, has sequenced the cacao genome in an attempt to find ways to breed hardier trees. Whether these efforts will succeed in raising yields enough to save the livelihoods of farmers and meet the world's passion for chocolate remains to be determined, but we see some encouraging signs.

THE ASSAULT ON COCOA

PART OF THE PROBLEM facing cacao farmers, pressure to increase yields notwithstanding, is that the crop is hard to grow. The cacao tree originated in the upper Amazon, in what is now Ecuador, and was imported into the Mexican empire of the Olmec, who domesticated it and then sent it to the Mayans and Aztecs. Portuguese and Spanish sailors took the tree to colonies in Africa and Asia. Today the cacao tree still grows only in a narrow band within about 18 degrees north and south of the equator. It prefers rich, well-drained soils, which are often scarce in the tropics. And it requires heat and humidity, which tend to come with a host of fungal, viral and pest problems. Besides witches' broom and frosty pod rot in the Americas, other threats to the tree include cocoa swollen shoot virus in West Africa and a moth called the cocoa pod borer in Southeast Asia, the latter often costing $600 million in crop losses a year. Ghana's cacao trees suffer insect damage, black pod rot, water mold and the swollen shoot virus. Experts fear that these scourges are already attacking the healthier trees in neighboring Ivory Coast. We are concerned that Africa or Asia could suffer a Brazil-like collapse because of these threats.

The limited genetic variation of the tree does not help matters. Mars cacao geneticist Juan Carlos Motamayor and his collaborators found through genetic tracing that cacao contains 10 different major varieties, all of which belong to the same single species. Thus, although the similarity among strains means that growers can crossbreed them easily, it also means that the collected strains do not contain enough variation to provide much natural resilience to pests and disease; if one strain is genetically susceptible, chances are good they all will succumb. When farmers save their own seeds to plant new trees, this local inbreeding leaves the trees even more susceptible to pests and fungi.

Beyond the usual difficulties, growing conditions seem to be getting worse. Weather extremes such as floods, droughts and windstorms have always made farming in the tropics difficult. Climate change is beginning to intensify these extremes, which could worsen pest and disease infestation and disrupt water supplies. The 2007 report of the Intergovernmental Panel on Climate Change predicted that by 2020 yields in Africa from rain-fed crops—which make up the vast majority of African crops, including cacao—could be reduced by up to 50 percent in some countries. The same report predicted increases in temperature and associated decreases in freshwater in Amazonia by midcentury. Furthermore, Läderach's research on the effects of climate change in Ghana and Ivory Coast predicts that the ideal cacao-growing areas will shift to higher altitudes to compensate for rising temperatures. "The problem is that much of West Africa is relatively flat, and there is no 'uphill,'" he com-

mented in a September 2011 press release. Climate shifts could thus lead to drastic decreases in terrain suitable for cacao crops. In Indonesia, meanwhile, the annual monsoon rains are becoming more intense over shorter periods, often knocking the flowers off the cacao trees, thereby preventing pod formation.

Poverty exacerbates these challenges. In Ivory Coast and Ghana, internal movement of people of various ethnic origins and immigration from poorer, neighboring Burkina Faso have not only created tensions between richer and poorer people but also muddied property rights. In both countries, farmers hesitate to invest in trees that their children may not inherit, and many do not want to continue cacao farming unless tree productivity can be significantly improved. Young people are moving out of the cacao-growing areas, which translates to an increase in the average age of farmers and a decrease in their education levels. Unfortunately, the use of fertilizers, fungicides and pesticides—which could significantly boost crop production—is low or nonexistent in the region because farmers cannot afford them and do not know how to employ them effectively. Even if they could afford these tools, the remote locations of the farms, often accessible only via poorly maintained roads, mean governments and merchants have a hard time reaching farmers with these products and providing education on how best to use them.

SAVING CHOCOLATE

BECAUSE THE THREATS to cocoa production come from pests, disease, climate change and poverty, work must be done on all these issues to raise yields without tearing down rain forests to gain arable land. Abandoned land must be rehabilitated by enriching the soil with fertilizer and by planting trees and shrubs to control erosion. Whereas the average global yield is about 450 kilograms of cacao beans per hectare, crops tended using modern farming techniques could easily yield 1,500 kilograms or more per hectare. For many cacao farmers in developing nations, tripling their yields would mean the difference between a poverty-level income of $1 a day and a manageable $3 a day.

REGIONAL VARIATION

Global Efforts to Boost Cacao Crops

Cacao trees grow only in a slim band within 18 degrees north and south of the equator. The threats to cacao crops vary from region to region. Below are representative problems and possible solutions for imperiled cacao crops across the tropics.

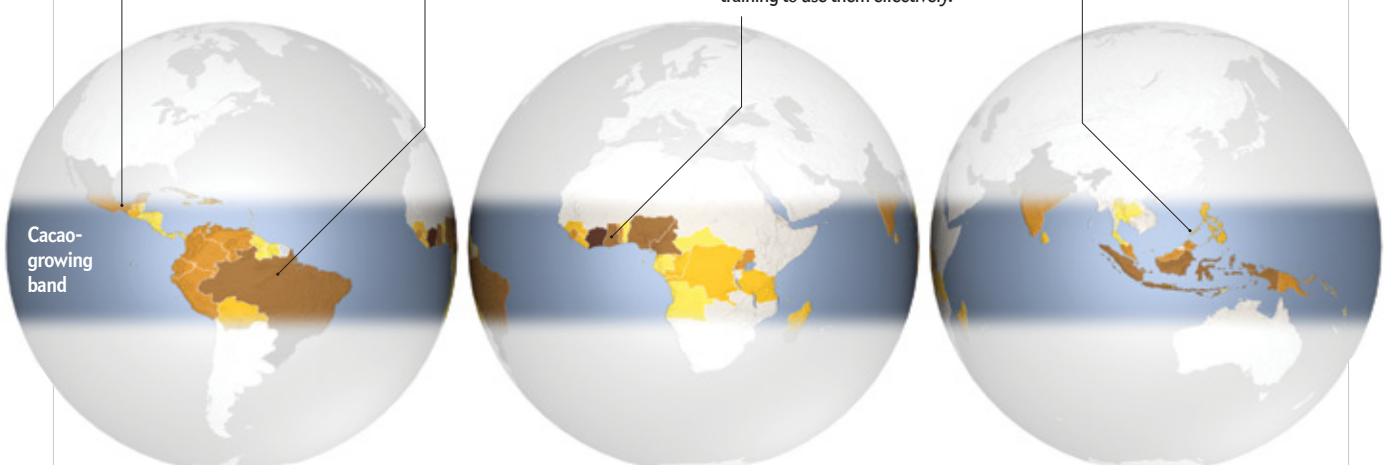
Threats

Frosty pod rot, a fungal disease that attacks cacao pods, has spread across Latin America and may soon enter Brazil.

Unreliable rainfall in Brazil could worsen in the face of climate change, subjecting cacao crops to damaging water shortages.

Poverty in Ghana and other parts of West Africa means that farmers cannot afford fertilizers, fungicides and pesticides—which could boost crop production—and do not have the training to use them effectively.

Cocoa pod borer, a moth whose larvae feed inside cacao pods and damage the seeds, can cause hundreds of millions of dollars in crop losses a year in Southeast Asia.



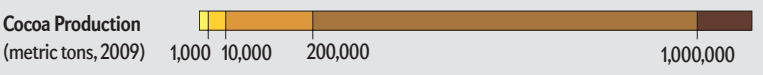
Solutions

Breed hardier trees. Using the cacao genome map, researchers have identified a gene variant that confers resistance to frosty pod rot. Farmers are grafting branches from resistant cultivars onto their trees.

Develop mixed agroforestry systems. Planting cacao trees among food crops, timber trees and fodder trees improves water-holding capacity throughout the system by varying the root structures in the tree matrix.

Help farmers help themselves. The Cocoa Livelihoods Program works to educate farmers, promote crop diversification and improve supply-chain efficiency.

Develop integrated pest-management techniques. Some farmers are no longer relying solely on pesticides, which can harm local biodiversity and are, for example, using natural foes of the pod borer to help control it.



SOURCE: UNITED NATIONS FOOD AND AGRICULTURE ORGANIZATION (*Cacao production in 2009*)

Graphic by George Retseck

Science took a critical step toward raising yields about two years ago, when researchers from Mars, the USDA's Agricultural Research Service (ARS), IBM and other institutions sequenced and analyzed the genome of the so-called Matina 1-6 variety of *T. cacao*, which many experts consider to be the progenitor of 96 percent or more of all the cacao grown in the world. We then made the results freely available to all—including Mars's competitors—over the Internet because we felt no single organization has the resources to, in a timely manner, do the breeding work needed to save the species from the various crises it faces. Cacao has not received the genetic attention paid to commodities such as rice, corn and wheat—attention that has dramatically improved yields for these crops. (Another consortium, led by the French agricultural research organization CIRAD, announced its sequencing of a different variety of cacao shortly after we released our sequence.)

To be effective, the molecular research on cacao taking place in labs in the developed world has to connect to what breeders are doing on the ground in the developing world. Mars and the ARS have thus, over the past decade, organized networks of cacao breeders in West Africa, Southeast Asia and Latin America. The breeders are using the cacao genome to discover where, among the world's cacao crops, disease resistance, enhanced yields, water and nutrient use efficiency, and climate change adaptability are to be found. Thanks to such collaborations, when Wilbert Phillips-Mora, a breeder in Costa Rica, found a cultivar that exhibited some resistance to frosty pod rot, he sent samples to the molecular biologists in the network, who were then able to use the genome map to identify the gene variant in the cultivar that confers resistance to the dread fungus. In subsequent breeding efforts, the breeders can quickly determine if new cultivars carry that trait or other useful traits for the next generation of cacao trees. Already farmers in Latin America are grafting parts of branches from these new plants to their trees.

Breeders have previously identified cultivars that resist witches' broom, but they do not produce high-quality cocoa. The new breeding work raises the prospect of mixing such desired attributes as resistance and quality in a single *T. cacao* cultivar through careful crossbreeding. In a similar vein, researchers have discovered a type of cacao resistant to Southeast Asia's vascular-streak dieback disease and are currently analyzing the genetic underpinnings of that trait. Cacao experts ultimately hope to breed trees that are resistant to other fungi and pests and that can endure the heat and water scarcity that often accompany climate change while preserving the quality of the cocoa beans. They also want to produce shorter trees. During harvest, farmers cut the cacao pods from the tree with knives on the ends of long poles. They take great care to not damage the site of pod growth. A shorter but equally or more productive tree would require fewer resources to generate the pods and be easier to harvest.

Yet even short, drought-tolerant trees still need some water. Eventually, no matter how efficient our cultivars, cacao growers will have to figure out how to irrigate more crops instead of relying on fickle rainfall. Farmers, scientists, aid agencies and foundations are trying different approaches to solving this problem across regions. Brazil is working on two radically different strategies. In the first, small farmers are trained to develop mixed agroforestry systems, in which cacao trees are planted among food crops, fodder trees and timber trees. These mixes improve water-holding capacity throughout the entire system by varying the root structures throughout the matrix of trees. The second strategy takes the opposite tack, creating large plantations of cacao trees in Bahia, Brazil, at higher altitude—out of the traditional pest and disease ranges—in the full sun and irrigating them with fertilizer-enriched water for maximum productivity. Vietnamese growers—some of whom are encountering falling water levels as a result of unsustainable groundwater use—are making reservoirs to collect rainwater for irrigating the cacao trees.

As is true for water supplies, each cacao-growing region of the world has its own set of challenges and organizations that are stepping up to tackle them. In early 2009 the World Cocoa Foundation (WCF) began a $40-million program, funded by the Bill & Melinda Gates Foundation and 16 companies, to improve the livelihoods of approximately 200,000 cacao farmers in five West and Central African countries. The five-year Cocoa Livelihoods Program works on enhancing farmer knowledge and competitiveness, improving productivity and quality, promoting crop diversification, and improving supply-chain efficiency. The program is based on a successful series of WCF field schools for African cacao farmers, themselves modeled on similar United Nations Food and Agriculture Organization farmer field schools. School facilitators found local farmer leaders to do much of the teaching, and aside from covering obvious topics such as disease management, pruning and harvesting, the schools tackled topics such as malaria, HIV/AIDS, farm safety and the avoidance of child labor. According to WCF president Bill Guyton, graduates increased their incomes by 23 to 55 percent.

In Southeast Asia, farmers tend to get the training they need because of better extension services. The main hurdle there is to develop integrated pest-management techniques to deal with the devastating pod borer—work that is just beginning. Such techniques include using pheromone-based traps and black ants (natural enemies of the pod borer) to control the moths and not relying solely on pesticides, which could damage the biodiversity in the region.

Tripling cacao yields sustainably is perfectly possible. Effective fertilizers, fungicides and training programs already exist, and scientists are beginning to develop cultivars resistant to some of the problems that have long dogged the cacao tree. But getting all these resources to poor, remote farmers so that they can become better off and better connected is a job too big for any single government, U.N. agency, company or project. Meeting that objective will take innovative, energetic coalitions. We are optimistic that a more secure future for chocolate and the vast social, cultural and ecological ecosystem it supports will come to pass, but it must be said that making cacao a truly sustainable crop will be a grand challenge indeed. SA

MORE TO EXPLORE

Chocolate: History, Culture, and Heritage. Edited by Louis Evan Grivetti and Howard-Yana Shapiro. Wiley, 2009.

Cacao Genome Database: **www.cacaogenomedb.org**

The Future of Chocolate on Earth: A View from Scientists on Mars: **www.youtube.com/watch?v=2BvTw5LtCis**

Securing Cocoa's Future: Rising to the Challenge of Cocoa Sustainability: **www.mars.com/cocoasustainability/home.aspx**

SCIENTIFIC AMERICAN ONLINE

For a timeline of chocolate history, visit **ScientificAmerican.com/feb2012/chocolate**

BRAIN SCIENCE

THE COLLISION SYNDROME

Football players diagnosed with Lou Gehrig's disease may suffer from the effect of repeated blows to the head, controversial new research says

By Jeffrey Bartholet

SCOTT CUNNINGHAM *Getty Images*

IN BRIEF

Kevin Turner, a former professional football player, suffered at least two concussions during his career and has been diagnosed with ALS, or Lou Gehrig's disease. Some scientists believe that he has a distinct type of ALS caused by repeated concussions and that other players have suffered a similar fate.

The findings, which stem from research connecting concussions to another brain disease, are controversial. Proponents compare their efforts to show a link between brain trauma and an ALS-like disease to the battle to prove a connection between smoking and lung cancer; others say that the science does not justify that analogy.

There is widespread agreement, however, that repeated blows to the head, such as those sustained during a football player's career, can result in brain damage.

KEVIN TURNER WAS A PREMIER ATHLETE IN THE NATIONAL Football League, a fullback who could run, catch and block. At 6' 1" and roughly 230 pounds, he was slightly undersized for his position, but he had tremendous thrust in his legs and used all of it to launch himself into players who were bigger than he was. He played for the New England Patriots from 1992 to 1994, then joined the Philadelphia Eagles, with whom he stayed until his abrupt retirement in 1999. Some called him "the Collision Expert"—a nickname he got because of the gouges he collected on his helmet.

Now Turner can't button his shirt. When we met recently at a California Pizza Kitchen in Birmingham, Ala., the first sign of physical impairment came when he put his small backpack into the booth where he would be sitting. His arm was Frankenstein-straight, and his shoulder was stiff as he swung the pack away from his body. Other issues soon became apparent. His fingers were curled up and his thumbs almost useless, so he drank from a glass by holding it in his palms. After he had trouble removing the little paper ring from his napkin, he took a furtive glance at the nearby tables before ducking his head down to rip it off with his teeth.

"I can't tell you how frustrating it is to open a box of cereal," the 42-year-old father of three told me as we left the restaurant. "Opening a box of cereal is an event." Turner needs someone to help him pull his pants on in the morning. His then 11-year-old daughter performed that duty the day I met him. She also helped him shave.

In 2010 Turner was diagnosed with amyotrophic lateral sclerosis (ALS), commonly known as Lou Gehrig's disease. Nobody knows what causes ALS. In 5 to 10 percent of cases, the disease is inherited; otherwise, it is a random death sentence. Its arrival is a mystery, and there is no cure.

Now a group of scientists in Boston believes that Turner, despite suffering symptoms of ALS, may not really have the disease. Around the same time he was diagnosed, these researchers discovered what they say could be a separate disorder with exactly the same clinical syndrome as ALS. It is also incurable. The only real difference is that this disease seems to have a clear cause: repeated blows to the head, like those that often occur on the football field.

The finding is hugely controversial. Many specialists in ALS have been critical of the science behind the new study and worry that it has confused their patients. They maintain that decades of research trying to find a link between head trauma and ALS have been inconclusive at best. They have been particularly incensed by the suggestion, made in press interviews, that Lou Gehrig might not have had Lou Gehrig's disease. In a letter to the editor of the *Journal of Neuropathology & Experimental Neurology,* more than a dozen doctors and researchers questioned the science in the findings and complained that "many patients have understandably been frightened and confused by these statements and are now wondering if their diagnoses are correct."

Ann McKee, a neuropathologist at Boston University and the Bedford VA Medical Center in Massachusetts, is the primary scientist behind the study. She says she regrets the controversy stirred up by the speculation regarding Gehrig but stands firmly behind the science. Her original study was based on three cases, and she now has five more, as well as three other suspected cases awaiting confirmation. McKee and her colleagues liken their battle to the one waged by scientists trying to show that smoking causes cancer. There has been a lot of resistance, but ultimately, they believe, they will prevail in showing that repetitive concussions cause a motor neuron disease with ALS-like symptoms.

Already findings about the potential for repetitive concussions to cause other forms of mental impairment have spurred the NFL to change some of its rules on flagrant hits to the head, and many states have passed legislation to ensure that young athletes do not return to the field too quickly after a concussion. Even some scientists critical of certain details in McKee's research, or the way in which it was presented to the press, believe her findings are significant. "The core observations of her work are very important," says Robert Brown, chair of neurology at the University of Massachusetts Medical School, "and the public policy implications are staggering."

HAVOC IN THE BRAIN

TO GRASP THE CONTROVERSY, it helps to first understand what happens inside the brain when someone suffers a concussion. Our current knowledge is based largely on animal models—experiments on rodents and cats—as well as the monitoring of human patients in intensive care with severe brain injuries and magnetic resonance imaging of people with mild concussions. Part of this picture is uncertain, but the science is improving. "Previously there was no way to get some of the necessary data without drilling a hole in somebody's head," says Christopher Giza, an associate professor of pediatric neurology and neurosurgery at the University of California, Los Angeles, who has done a review of the scientific literature. "We now have advanced imaging that has provided us with some of this information."

What is clear is that when the head, moving at significant speed, comes to an abrupt stop, the brain cells inside get stretched, squeezed and twisted. In their normal state, these cells function by transmitting electric current. A part of the cell called the axon acts somewhat like a wire, conducting current between the cells. Ions shift back and forth along the axons in a controlled fashion, transmitting messages from one part of the brain to the other and to the rest of the body. When a concussion occurs, however, the membranes of brain cells get damaged and the cells become leaky, Giza says. Ions rush in and out indiscriminately. As sodium and calcium rush in, potassium rushes out. The brain needs to restore balance.

When I asked Giza if he could compare this process to a car wreck, he said a submarine or boat accident would be a better analogy: leaks are springing everywhere, and emergency crews struggle to keep up. In the injured cells, microscopic pumps try to get the ions back in their proper places. The pumps require energy, however, and the stressed cells face an energy crisis. At the same time, other havoc is taking place. When ions rush in, they tend to destroy the scaffolding of the cell. "It's as if someone is in there with a saw, cutting through all the struts and supports," Giza says. Calcium inside the cell, moreover, can activate enzymes that can trigger the cell to destroy itself.

In severe cases, some brain cells simply break apart under the stress. In milder cases, which Giza calls "sublethal," there is an opportunity to recover. How long that recovery process takes is uncertain. In rats, it takes roughly a week to 10 days. But timescales are generally longer in humans than in lab rats, which have a life span of only about two years. A human brain may take longer to return to a normal, healthy state.

So what happens if, in the middle of the emergency recovery process, the brain suffers another concussion—or several more?

FROM CONCUSSIONS TO BRAIN DISEASE

IT HAS LONG BEEN CLEAR that multiple blows to the head can lead to mental impairment. Boxers refer to this breakdown as becoming punch-drunk. But it is only in the past decade that scientists have identified the problem in American football players. They have also been able to identify, on autopsy, pathological markers for the disease, now called chronic traumatic encephalopathy (CTE).

Some scientists still doubt or deny that former NFL players are suffering severe depression, memory loss, erratic or aggressive behavior, and early dementia because of repeated blows to the head. Yet a disturbing number of former NFL players have committed suicide or died after suffering mental disturbances, and many of them, worried that they have the disease, have arranged to donate their brain to science. One of the more recent was David Duerson, a former star safety with the Chicago Bears, who shot himself in the chest (not the head) and left instructions to give his brain to the NFL brain bank for study. As in many other cases, an autopsy determined that Duerson had CTE.

McKee is one of the scientists at the forefront of this research. She performed Duerson's brain autopsy and oversees a total brain bank of more than 100 donations, around 30 of them from former NFL players. Her morgue at the Bedford VA center has seven stainless-steel freezers loaded with frosty buckets of brain matter. When newly donated brains come in, McKee conducts autopsies and examines bits of brain tissue under a microscope. She looks mainly for abnormal deposits of two proteins: tau and TDP-43. The remaining brain matter is frozen and stored at –80 degrees Celsius (–112 degrees Fahrenheit) so it can be used for other research.

On a recent tour of the facility, McKee showed me two newly received brains. They looked like gelatinous hunks of coral or some other bottom-dwelling sea creature. Dressed in a blue vinyl smock and white rubber gloves, McKee turned one of the brains over and around in her hands, then delicately sliced off a piece the size of a fingernail and placed it in a plastic cassette. Bits of the tissue would later be stained for tau, TDP-43 and other markers. On the wall was a list of 28 regions of the brain that should be tested, but McKee said the actual list includes closer to 40 regions.

I learned from McKee that football players—not rocket scientists—tend to have bigger brains than the average Joe. "It's because they're bigger guys," McKee remarked. But the two brains here were not as big as they should have been. One was 1,120 grams (almost 40 ounces), when it should have been at least 1,350, and another—from a much older, retired player—was just 820 grams. She pointed out obvious defects, where a septum was missing and the amygdala was "almost nonexistent."

To identify CTE, however, McKee needs to look at stained tissue under a microscope. The buildup of tau within the brain cells is indicative of the disease. She notes that there is a correlation between the parts of the brain afflicted with abnormal tau and the psychological problems of the person before death. McKee finds abnormal tau in the frontal cortex, which is responsible for impulse control, judgment and the ability to multitask. She also finds it in a deep brain stem structure, the locus coeruleus, which is associated with depression. In later stages, tau is found in the amygdala, which has a role in impulse control, and in the hippocampus, which is important to forming and retaining memories.

When a concussion occurs, brain cells get damaged. A submarine accident would be a good analogy: leaks are springing everywhere.

After years of denial by the NFL and skepticism within the scientific community, CTE "is now gaining wide acceptance," McKee says. "We're definitely past the halfway mark. More and more people are coming around." Even the NFL has shifted its views, giving the Center for the Study of Traumatic Encephalophathy at Boston University, which McKee co-directs, $1 million for research.

McKee's more recent findings are an offshoot of this work and are even more controversial. She and her colleagues found that in about 13 percent of CTE cases studied, the deceased had also been diagnosed with ALS—a very high percentage. In the ordinary population, one in about 400 adults is likely to come down with the disease. In autopsies of these cases, McKee found the abnormal tau indicative of CTE but also an exaggerated amount of abnormal TDP-43 proteins, distributed in unusual patterns.

Under a microscope the TDP-43 appears like black lint or flea dust. The protein normally exists in the nucleus of brain cells, but when the cells suffer an axonal injury and become diseased, the proteins come out of the nucleus and build up in the cytoplasm. Abnormal TDP-43 is also found in ALS patients, but McKee says that in the brains she studied—where the subjects also had CTE—the pattern of TDP-43 distribution is distinct. She found TDP-43 deposits on the surface, around the ventricles and in the brain stem, a pattern atypical of ALS, she says. McKee and her team have given a new name to the disease: chronic traumatic encephalomyelopathy (CTEM).

McKee is clear that her research is far from complete. She does not understand, for instance, the precise role of the tau and TDP-43 proteins in causing the diseases or even if they have a role. "We still don't really understand it," she says. "The pathology has established that there is a problem, but it hasn't answered a lot of questions." Among them: Why do some people get symptoms of the diseases relatively quickly, whereas others take many years? Why do some people who suffer multiple concussions never have issues? Are some people more genetically susceptible to CTE and CTEM than others? The same or similar questions could apply to smoking and cancer, McKee and her colleagues say. Nobody now questions that smoking causes cancer.

A LEAP TOO FAR?

MANY ALS SPECIALISTS ARGUE that McKee and her co-workers have made broad claims that are not justified by the science. "There is a vast gap in our knowledge," says Stanley H. Appel, co-director of the Methodist Neurological Institute in Houston. "You don't know how many concussions it takes, what the risk factors are. You stop suffering concussions, and then, 10 or 15 years later, you have a condition that is devastating? This requires a lot of careful thought and investigation. I'm not critical of careful inquiry. I'm critical when I'm getting panicked calls from a dozen patients who think they may have been misdiagnosed."

One point Appel and McKee agree on is that ALS is a syndrome, not a single disease. Just as dementia is a big category of diseases, ALS is a category of clinical symptoms. In McKee's view, CTEM fits under the ALS umbrella—a distinct disorder caused by repetitive concussions. Appel thinks that is a "huge theoretical leap," unjustified by the published data.

Appel and others suspect that the brains McKee examined with motor neuron degeneration actually had two diseases: CTE and ALS. These critics point out that the strongest scientific studies trying to find a link between concussions and ALS have shown no such connection. "Is it possible that trauma leads to ALS?" Appel asks. "Of course. But top people have been studying that for 30 years and haven't been able to prove it."

Ordinary people may not factor in the nuances and fine points of the scientific process when they evaluate their own condition. They are likely to trust their memories—and their personal knowledge of their minds and bodies—to gauge what is happening to them. Kevin Turner and his family and friends feel certain that he has CTE and that he almost surely has CTEM as well. They are somewhat relieved, in a strange way, to have some explanation for what went wrong in Turner's life.

"I started to play football when I was five years old," Turner says. "I just really fell in love with the game. From when I was five until I was 31, that's what I did. I knew that when I got to be 60, I'd have bad knees and a bad back and neck. But nobody talked about the brain. They'd say, 'Hit with your forehead.' That was the only way I knew how to do it."

Turner can remember two times in his professional career when he suffered a severe concussion, once with the Patriots and once with the Eagles. After the second incident, he recalls that he played another quarter but could not remember or figure out what city he was playing in—was it Philadelphia or Green Bay? "But there may have been 100 times when my brain was rattled," he says. "What is a concussion? What are the criteria? When you hear bells ringing in your head? When you see spots? Or feel dizzy? There were many times, mostly in practice, when all of that happened."

DEALING WITH A DEATH SENTENCE

BY SEVERAL ACCOUNTS, Turner was a highly focused, well-organized kid, and that pattern continued into adulthood. "He was good and straight, always on time," says his University of Alabama roommate and friend, Craig Sanderson, who played wide receiver alongside Turner on the Alabama Crimson Tide. "When we were roommates, he had everything in its place." But now Sanderson's living room is evidence of the change that has overcome his friend in recent years. Turner sometimes lives with the Sanderson family, and his belongings—baskets of clothes, blankets, a box of football cards and other personal items—are strewn around the living room. "I've seen a distinct personality change," Sanderson says. "Kevin now has a really hard time taking a task from start to finish."

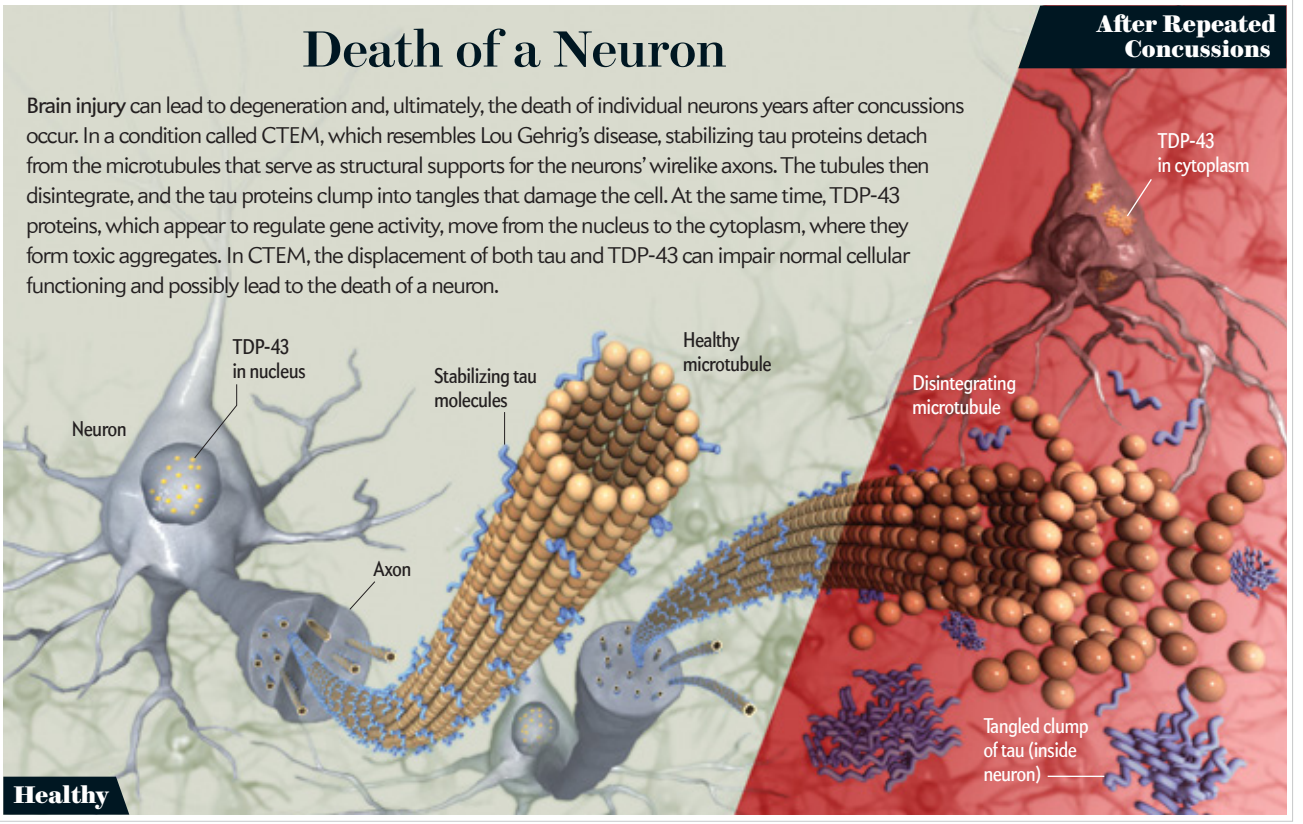
Both Sanderson and Turner's ex-wife, Joyce, say that he has suffered from depression. At first, they thought it was because he was retired from football and dealing with the lifestyle changes involved in returning to the ordinary world. Turner also suffered from a severe addiction to painkillers when he left the game. On top of that, his real estate business went bust. It is not hard to imagine that Turner's psychological problems—the depression, lack of focus—are connected to those difficulties. But his friends and family say the problems he has encountered are out of character, and now they have another explanation: his personal failures are typical of a significant number of ex-football players who, on autopsy, have a brain gummed up with tau. The behavioral and personality changes "can be considered psychological, but in reality, they're structural," McKee says.

"CTE really grabbed my attention because player after player I know had gone through many of the same problems as I had," says Turner, who has created a foundation to support research into the issue. "I still don't know that it's the reason for my troubles, but it's important to me to think that I'm not alone. At least 14 other guys have gone through similar things: addiction, divorce, bankruptcy. I was just in the special group that got ALS, too. But it gives me a little bit of solace that it wasn't just me turning into a loser overnight."

Abnormal tau can be identified only on autopsy, so nothing will be fully clear about Turner's case until then. He has arranged to donate his brain and spinal cord to McKee's research group. But he and his family feel confident about what the results will show.

Even so, Turner still loves the game of football. Both his sons play. Nolan is 14, and Cole is eight. (Turner nonetheless held his two sons out of football last autumn. He wants to be able to spend time with the boys while he still has use of his legs, and he wants his youngest son to avoid possible concussions at least until he gets to middle school.) They live with their mother in a modern brick house, with a trampoline and a skateboard ramp in the back driveway. "If they quit football, I'll be happy, but I have a hard time making them quit," says Turner, who retains a wry sense of humor about his predicament. "It's something that's been a big part of my life, and I can't just hate it. Just like my ex-wife: I have a hard time hating her."

Joyce Turner describes herself as angry over the whole sad situation. "He was this happy-go-lucky guy, and then he was depressed," she says. "He didn't want anyone to know he was suf-



fering. But he couldn't make a decision, couldn't get anything finished. It was like living with a fourth child or like a brother or best friend you're always angry at. Three years before the ALS diagnosis, he wanted to kill himself. He had some guns. He told me he wanted to kill himself because he just wasn't himself anymore. But he wouldn't because of the children.

"I hate what he has gone through, emotionally and physically, because of football. When he got knee injuries, he saw the best surgeons and the best physical therapists. But when he was getting his brains bashed around, he went right back into the game," she says. "It's like when we didn't know that smoking was bad for us."

Critics say the smoking analogy does not really hold when it comes to CTEM. Carmel Armon, chief of the neurology division at the Baystate Medical Center in Springfield, Mass., and professor of neurology at the Tufts University School of Medicine, believes that the data linking smoking to cancer, going back as far as 1950, are much more solid than the data presented by McKee and her colleagues on concussions and motor neuron disease. That evidence is poor, in Armon's opinion, and cannot be used to infer any association other than the chance coexistence of two diseases: CTE and ALS.

"There are many nuances that apply to data even when they are clear-cut," Armon says. For instance, tau and TDP-43 could be causal agents of brain disease, or they could be part of a response mechanism in the brain to fight the disease. Even if they are causal, they could be contributing to two different diseases. "The data don't support that CTE and CTEM are part of one continuum," Armon asserts.

Having said that, Armon adds that he has no doubt that concussions are bad for you. "It becomes a social question: Why does society encourage sports in which people are subject to multiple concussions?" he asks. "We used to have gladiators, and now we don't. No amount of scientific discussion is going to make it healthy to have multiple concussions."

McKee concurs on that point, but she also believes she can find remedies. Her work is aimed at a better understanding of the ways in which concussions lead to degeneration of the brain and may produce "enormous insight into potential therapeutic interventions," she says. For people like Kevin Turner and his family, it may be too late. But that is the only hope. SA

MORE TO EXPLORE

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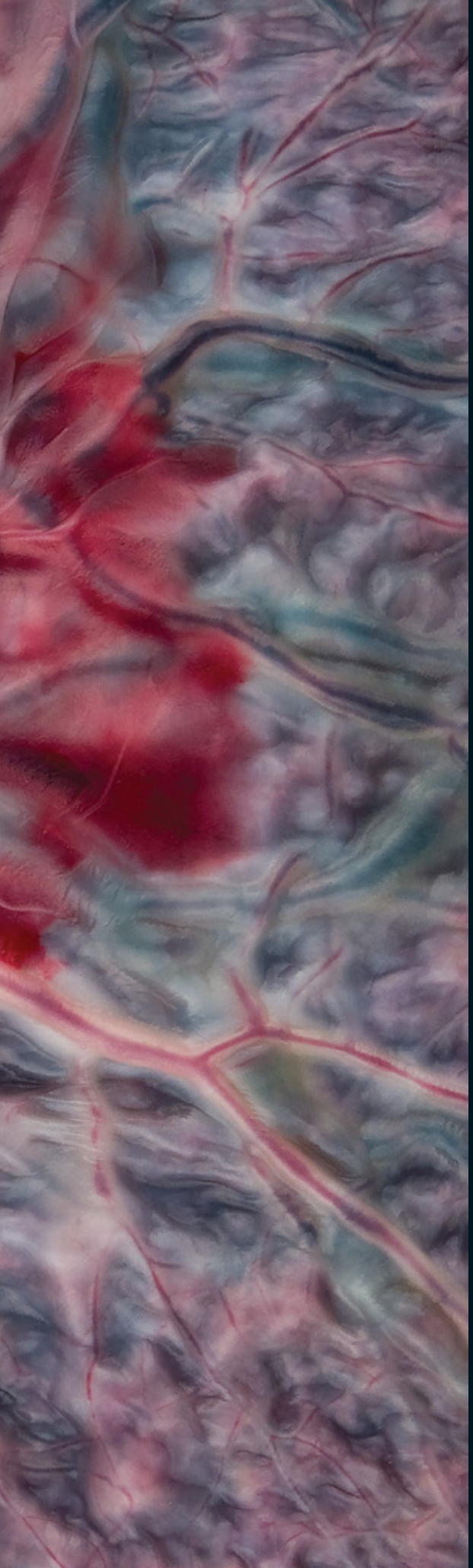
For a podcast interview with the author, visit ScientificAmerican.com/feb2012/brain-trauma

Illustration by Emily Cooper



ANATOMY

FETAL ARMOR

The placenta does more than nourish offspring in the womb—it actively shapes brain development

By Claudia Kalb

THE PLACENTA IS UNIQUE AMONG ORGANS—CRITICAL TO human life yet fleeting. In its short time of duty, it serves as a vital protective barrier to the fetus. The organ's blood vessels—which resemble tree roots in this image by Norman Barker, associate professor of pathology at the Johns Hopkins University School of Medicine—also deliver essential oxygen and nutrients from the mother to her developing baby. Still, the placenta has been vastly underappreciated. Scientists are taking a closer look and finding that it is much more than a simple conduit: it actively protects the fetus and shapes neurological development.

In a study published last summer, British researchers showed that when a mother mouse is deprived of food, the placenta takes over, breaking down its own tissue to nourish the fetal brain. Scientists at the University of Southern California's Zilkha Neurogenetic Institute (ZNI) and their colleagues, meanwhile, upended decades of biological dogma when they reported that it is the placenta—not the mother—that provides the hormone serotonin to the fetus's forebrain early in development. Because hormones play an essential role in brain wiring, even before they function as neurotransmitters in the brain, placental abnormalities could directly influence the risk of developing depression, anxiety and even autism. As a result, "we have to pay much closer attention to the health and welfare of the placenta," says Pat Levitt, director of the ZNI and the study's co-author.

Research into the placenta's influence on the developing brain is so new it has yet to be named. Anna Penn, a developmental neurobiologist and neonatologist at Stanford University, has dubbed it "neuroplacentology." Penn herself is studying the impact of placental hormones on fetal brain development after the 20th week of gestation. Her goal: to pinpoint how premature babies are affected by the loss of those hormones at delivery and, ultimately, to figure out a way to compensate for the deficit. The old thinking about the placenta is changing, Penn says, but there is still much to learn. SA

NORMAN BARKER

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BIOENGINEERING

The Brittle Star's Apprentice

Chemist Joanna Aizenberg mines the deep sea and the forest wetlands for nature's design secrets and uses them to fashion new materials that may change the world

Interview by Gareth Cook

IN BRIEF

who
JOANNA AIZENBERG

vocation | avocation
Runs a biomimetics lab

where
Harvard University

research focus
Takes inspiration from nature for designing new types of materials.

big picture
"What we do, then, is study interesting biological systems, but with the eyes of a physical scientist."

AMONG THE FIRST THINGS YOU NOTICE WHEN YOU STEP INTO THE CORNER office of Harvard University professor Joanna Aizenberg are the playthings. Behind her desk sit a sand dollar, an azure butterfly mounted in a box, a plastic stand with long fibers that erupt in color when a switch is pulled, and haphazard rows of toys. Especially numerous are the Rubik's cubes—the classic three-by-three, of course, but also ones with four, five, six and even seven mini cubes along each edge. An eight-year-old would be in heaven.

Playing with mathematical puzzles is more or less how Aizenberg, 52, spends her days. Nobody would challenge her seriousness, though. Born in a city near Ukraine's southwestern border, Aizenberg earned a degree in chemistry from Moscow State University and then, in 1991, fled the overt sexism and anti-Semitism of the Russian academy for a brilliant career in the West as a bioengineer, uncovering the design secrets of Mother Nature and using them in her work. She has a joint appointment at the Harvard School of Engineering and Applied Sciences, the Radcliffe Institute for Advanced Study and the Wyss Institute, a new, $125-million center

Photograph by Jared Leeds

at Harvard devoted to biologically inspired engineering.

Aizenberg approaches her research with a sense of play, crossing science's traditional disciplinary boundaries with the carefree gusto of a child. She is probably best known for her collaborations with biologists, discovering remarkable engineering principles in creatures hauled out of the marine abyss. But she also works (or perhaps, plays) with chemists and architects, physicists and toy designers.

Edited excerpts follow.

SCIENTIFIC AMERICAN: Why do you look to nature for inspiration?

AIZENBERG: Every time I look at a biological system I see an amazing new example of sophisticated design. There are so many interesting strategies that nature has evolved. Nature has created all these high-quality materials and devices that scientists are simply not aware of.

For example, there is the brittle star, which is a close relative of the starfish and sea urchin. It has a hard coating, and people assumed it was blind. But we found that part of its skeleton is coated with lenses—it can see through its shell. During the day it uses a dark pigment on the lenses to limit the light, and then at night it draws the pigment back into its body. It's like the brittle star is using sunglasses, and the lenses are better than we can make. This demonstrates an important principle: in biology, materials are often optimized for multiple functions. The shell has excellent mechanical properties because it is a skeleton, but it is also designed for optical performance. These are almost unrelated functions, from an engineering point of view, but this organism is able to combine them in a single structure.

What we do, then, is study interesting biological systems, but with the eyes of a physical scientist. This is an approach that will lead to new materials and to new devices that can change the world.

Can you tell me about your work on the deep-sea sponge?

It's amazing all around. It lives on the ocean floor, and it grows itself a skeleton made of glass. When people make glass, they do it at 2,000 degrees Celsius, but somehow these organisms synthesize glass fibers at ambient temperatures.

Then, at the sponge's base, where it is attached to the ocean floor, it has a crown of thin strands that behave like nearly perfect optical fibers, which guide light from one end to the other. We think that we invented optical fibers 60 years ago; nature created optical fibers—from the same material we use—half a billion years earlier.

But the sponge lives in darkness. Why would it create such a sophisticated fiber-optical system? It turns out that it lives symbiotically. Bioluminescent bacteria live on the sponge, and their light shines through the fibers. The crown of illuminated fibers acts like a beacon, attracting other life in the darkness. Then a pair of shrimp live inside the sponge—protected by this illuminated glass house, feeding on all the things that are attracted to the light. The waste from the shrimp then helps to feed the sponge. It's a complete system.

How did you find the sponge?

I was at a scientific conference in San Francisco, and I went to a gem shop. I am totally addicted to those stores. They had the sponge, lying in a very dark corner, with its crown of fibers all lit up. The entire thing was so beautiful. I picked it up, then did what I really love, which is to collaborate with marine biologists.

What do you think we can learn from this organism?

The deep-sea sponge offers us a lesson in improving the strength of inherently poor and fragile materials. Glass is fragile, but this sponge is not fragile at all; you can step on it, and nothing would happen.

The way nature achieves this is by combining different structural strategies, one on top of the other. It combines fibers to make a laminated material. These are built into struts, which are combined to form squares, and these squares are then surrounded by a glass-fiber cement. It's glass inside of glass inside of glass, but the sponge combines them to create a very strong material that overcomes glass's natural brittleness.

You can also look at the sponge as a green building, with a pattern of open windows on its surface. It makes me wonder, for example, whether you could make a skyscraper where every 10th floor was open so that energy could be harvested from the wind.

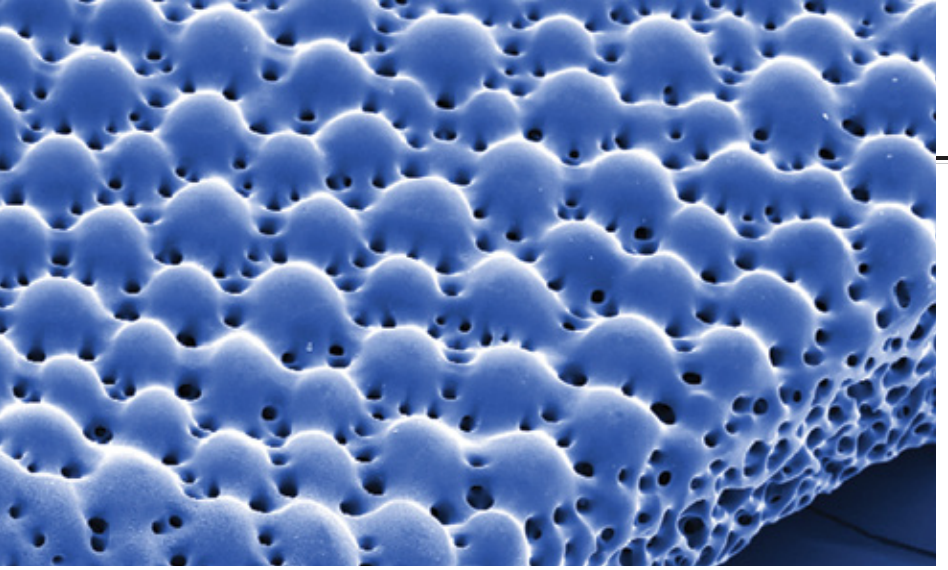
For engineers, what are the advantages of looking to nature, and what are the potential pitfalls?

Nature can show engineers the vast diversity of solutions for complex technological problems. Not all of them will be practical. One strategy inspired by nature might turn out to be so costly in terms of the materials or the energy needed that we can't use it. On the other hand, some natural solutions might be as good as what engineers do now, or a little bit worse, but much cheaper. So nature provides a whole range of interesting solutions to explore.

But we have to be careful. Nature has a very limited selection of materials. Biology doesn't have steel. We do. So I don't like to call my field "biomimetics," because I don't want to mimic biological structures. I would rather call it "bioinspired engineering" because what I'm doing is taking a concept from biological design, not the specific solution. I would not want to actually create a brittle star; I want to create a roof element that has lenses that collect light and that is mechanically stable. I'm not using the same materials as a brittle star, but I've stolen its strategy.

Why is nature so accomplished as an engineer?

Life is about function: it has to create robust solutions to the challenges it faces, whether it's how to divide, how to self-heal or how to produce things that will last. Nature also has a big advantage: millions and millions of years of evolution. We haven't had that time. The other thing is that in nature, there is no other option. It is survival of the fittest. If you are a bad engineer, you will be removed from the world. If you make a mistake, you die.



Biolenses: A brittle star, its skeleton made up of a honeycomb of natural lenses, is providing the inspiration for novel communications systems.

Did your parents influence your decision to become a scientist?

My father was a construction engineer who designed and built bridges and roads. My mother was a doctor who focused on infectious disease. They both inspired me, in many ways. My mother was in medical school in the 1950s [in the Soviet Union], when Stalin forbade any work on genetics, and she led a group of students that would meet in secret to study DNA. She was fearless, the most strong-willed person I have ever known.

When I was a child, I had polio, and my legs were paralyzed for a long time. My mother spent so much time talking to me, showing me the world I could see out of my window. "Look at how the trees grow, the shapes they make," she would say. "Look at the patterns the water makes as it rushes by." It was really wonderful.

How did you become interested in chemistry?

I know it sounds funny, but one of my favorite things to do as a child was solving mathematical problems. When I was in middle school, I earned a little money from a journal devising math problems for other students. When I arrived at Moscow State University, I met with people from the departments of mathematics, physics and chemistry. From these discussions I concluded that math is just math. Physics is just math plus physics. But the field of chemistry provides such breadth. And the more I have studied chemistry, the more I have come to feel that chemistry is the key science. It has branches going everywhere. It's an amazing place to be.

Does your work always start with some plant or animal that interests you, or do you ever set out with particular applications in mind?

My group has become interested in "wettability," which refers to how much a material attracts or repels liquids. What we'd like to do is to design surfaces with controlled wettability. For 15 years everybody has been looking to the lotus leaf for inspiration because water naturally flows right off it. But the community has realized that it's going to be extremely challenging to use the secrets of the lotus leaf in a practical material. The materials turn out to be too expensive and too sensitive to damage.

So we have turned to another natural model: the pitcher plant. The pitcher plant is carnivorous. It has an incredibly slippery surface. If an ant climbs on, it will just slide into the flower, where it is trapped and digested. Using this as inspiration, we have built a similarly slick surface. It could be used to coat the inside of oil pipelines, making the oil much easier to pump. For biomedical applications it would mean that blood would flow well, and no bacteria could build up anywhere. Another potential use is as a treatment for walls to resist graffiti. The paint would just slide right off. It would seriously irritate those artists.

What do you think we will see from materials science in the coming decades?

We know how to make strong materials. We know how to make optical materials. What we do not know how to do well is to manufacture materials that respond to the environment, that can automatically change their properties, that can self-heal, that can change appearance when necessary. We need materials that have reversible adaptive behavior.

For example, we have a material that could potentially be used for "smart" clothes. It naturally changes with the humidity, attracting moisture when it's extremely dry outside but repelling water when it's raining. You can imagine many applications for adaptive materials. If the weather were cold, then you'd want the windows to direct any available heat into the room. But on a hot summer day you'd want the same material to become reflective, keeping the room comfortable.

Creating these kinds of materials is the big challenge for the 21st century.

Having studied nature so much, do you look at it differently?

I would say so. I am really interested in how patterns are formed. So if I am walking on the beach, I keep looking at how the waves come in. Or I can spend all my time looking at the lines the receding waves leave behind. They make beautiful shapes. I might think about how the shapes are related to other beaches or to the size of the sand grains.

I truly love the ocean. The life there is so diverse and mind-blowing. And I'm convinced that every organism has something to teach us. SA

Gareth Cook *is a Pulitzer Prize–winning journalist at the* Boston Globe *and editor of the* Scientific American Mind *neuroscience blog Mind Matters.*

MORE TO EXPLORE

Harvard Portrait: Joanna Aizenberg. *Harvard Magazine,* page 59; July/August 2008. http://harvardmagazine.com/2008/07/joanna-aizenberg.html

Bioinspired Self-Repairing Slippery Surfaces with Pressure-Stable Omniphobicity. Tak-Sik Wong et al. in *Nature,* Vol. 477, pages 443–447; September 22, 2011.

The Aizenberg Biomineralization and Biomimetics Lab: http://aizenberglab.seas.harvard.edu/index.php

SCIENTIFIC AMERICAN ONLINE

To watch a video of Aizenberg's work, go to ScientificAmerican.com/feb2012/aizenberg

COURTESY OF JOANNA AIZENBERG

SCIENTIFIC AMERICAN™ Travel

BRIGHT HORIZONS™ 15

OCTOBER 25 – NOVEMBER 5, 2012 ✸ E. MEDITERRANEAN ✸ www.InsightCruises.com/sciam15

BEEN THERE, DONE THAT? ITALY, TURKEY, ISRAEL, AND GREECE have drawn explorers over the span of 5,000 years. Bright Horizons is heading in to experience the region through new eyes, new data, and new discoveries as classical cultures and cutting-edge science converge in the Eastern Mediterranean. Share in the new thinking required by a changing world on **Bright Horizons 15** aboard the Costa Mediterranea, roundtrip Genoa, Italy, October 25–November 5, 2012.

Face the challenges posed by conservation planning and wildfire management, guided by Dr. Yohay Carmel. Dive into discoveries in astro-particle physics with Dr. David Lunney. Glimpse the neuroscience behind sensory perception and visual illusions with Dr. Stephen Macnik and Dr. Susana Martinez-Conde. Focus on developments in the nature and maintenance of memory with Dr. Jeanette Norden. Take in evolving thought on humankind's emigration from Africa with Professor Chris Stringer.

Discover the possibilities in environmental and neuroscience, particle physics, and anthropology. Visit archaeological sites and imagine the finds to come. Soak in the Mediterranean lifestyle. Savor the cuisine of Genoa. If you're game for field trips, we've designed behind-the-scenes experiences to extend your fun, from the European Organization for Nuclear Research, known as CERN, in Geneva to fascinating Herodium in Palestine. Send your questions to concierge@insightcruises.com or call 650-787-5665. Please join us!

Cruise prices range from $1,299 for an Interior Stateroom to $4,499 for a Grand Suite, per person. (Cruise pricing is subject to change.) For those attending our Educational Program as well, there is a $1,475 fee. Government taxes, port fees, and Insight Cruises' service charge are $299 per person. Gratuities are $11 per person per day. **For more info please call 650-787-5665 or email us at concierge@insightcruises.com.**

NUCLEAR ASTROPHYSICS

Speaker: David Lunney, Ph.D.

A Hitchhiker's Guide to the Universe

An introduction to the formation and composition of the visible universe, emphasizing the synthesis of Earth's chemical elements in the stars. Discover the key reactions, the evolutionary process of nuclear systems, and the forces that shape ongoing debates in nuclear astrophysics.

Nuclear Cooking Class

Get cooking with a discussion of the physics behind element formation by fusion and capture reactions. Dr. Lunney will highlight the need to weigh ingredient atoms to precisely determine mass. Take a seat in a precise corner of the physics kitchen and feast on the latest on nucleosynthesis.

Weighing Single Atoms

The most precise balance known to man is an electromagnetic trap in which ionized atoms are made to dance, revealing their mass. We'll look at the basics of atomic mass measurement. Learn about current techniques of mass measurement, how these methods compare, and the diverse programs worldwide that use them. Glimpse the shape of the future of precision measurement.

Panning the Seafloor for Plutonium: Attack of the Deathstar

Long, long ago, not so far away, did an exploding supernova bathe our planet with its stellar innards? Explore the research, theories, and phenomena that suggest the role of a local supernova in the creation of the sun and its planetary system.

NEUROSCIENCE MEMORY

Speaker: Jeanette Norden, Ph.D.

How the Brain Works

Get the lay of the land in this introductory neuroscience session showing how the brain is divided into functional systems. A special emphasis will be on limbic and reticular systems, which underlie learning and memory, executive function, arousal, attention, and consciousness.

Memory and All That Jazz

Memory is among the most precious of human abilities. Find out what neuroscience has revealed about how we learn and remember. Pinpoint how different areas of the brain encode different types of information—from the phone number we need to remember for only a moment to the childhood memories we retain for a lifetime.

Losing your Memory

When we lose our memories, we lose a critical part of ourselves and our lives. Dr. Norden will introduce the many clinical conditions that can affect different types of learning and memory.

Use it or Lose it!

While memory can be lost under a wide variety of clinical conditions, most memory loss during aging is not due to strokes or neurodegenerative disease, but to lifestyle. Building evidence suggests that aging need not lead to significant memory loss. Find out how to keep your brain healthy as you age.

COGNITIVE NEUROSCIENCE

Speakers: Stephen Macknik, Ph.D. and Susana Martinez-Conde, Ph.D.

How the Brain Constructs the World We See

All understanding of life experiences is derived from brain processes, not necessarily the result of actual events. Neuroscientists are researching the cerebral processes underlying perception to understand our experience of the universe. Discover how the brain constructs, not reconstructs, the world we see.

Cognitive Neuroscience, cont.

Windows on the Mind

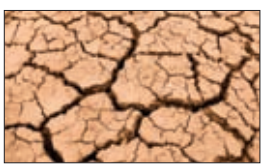
What's the connection behind eye movements and subliminal thought? Join Dr. Macknik and Dr. Martinez-Conde in a look at the latest neurobiology behind microsaccades, the involuntary eye movements that relate to perception and cognition. Learn how microsaccades suggest bias toward certain objects, their relationship to visual illusions, and the pressing questions spurring visual neurophysiologists onward.

Champions of Illusion

The study of visual illusions is critical to understanding the basic mechanisms of sensory perception and advancing cures for visual and neurological diseases. Connoisseurs of illusion, Dr. Macknik and Dr. Martinez-Conde produce the annual Best Illusion of the Year Contest. Study the most exciting novel illusions with them and learn what makes these brain tricks work.

Sleights of Mind

Magic fools us because humans have hardwired processes of attention and awareness that can be "hacked." A good magician employs the mind's own intrinsic properties. Magicians' insights, gained over centuries of informal experimentation, have led to new discoveries in the cognitive sciences, and reveal how our brains work in everyday situations. Get a front-row seat as the key connections between magic and the mind are unveiled!



CLIMATOLOGY

Speaker: Yohay Carmel, Ph.D.

Prioritizing Land for Nature Conservation: Theory and Practice

Forest clearing, climate change, and urban sprawl are transforming our planet at an accelerating rate. Conservation planning prescribes principles and practical solutions for selecting land for protection, assigning land for development, and minimizing the negative impact on nature. Taking a bird's-eye view of approaches to conservation, we'll put the hot topics and tough questions in perspective through an insightful discussion.

Facing a New Mega-Fire Reality

Worldwide, the area, number, and intensity of wildland fires has grown significantly in the past decade. Fire-protection strategies used in the past may not work in the future. Learn the roots and causes of wildfires and recent efforts to predict, manage, and mitigate fire risk. Gain food for thought about the complex interface between science and policy.

HUMAN EVOLUTION

Speaker: Chris Stringer, Ph.D.

Human Evolution: the Big Picture

Time-travel through 6 million years of human evolution, from the divergence from African apes to the emergence of humans. In 1871, Charles Darwin suggested that human evolution had begun in Africa. Learn how Darwin's ideas stand up to the latest discoveries, putting his tenets into context and perspective.

The First Humans

About 2 million years ago the first humans appeared in Africa, distinctly different from their more ancient African ancestors. Discover what drove their evolution and led to a spread from their evolutionary homeland to Asia and Europe. Explore current thinking on the early stages of human evolution.

The Neanderthals: Another Kind of Human

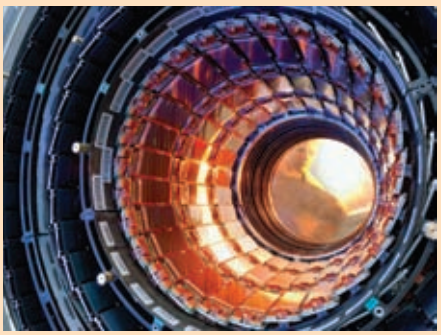
Our close relatives, the Neanderthals, evolved in parallel with *Homo sapiens.* Often depicted as bestial ape-men, in reality they walked upright as well as we do, and their brains were as large as ours. So how much like us were they? What was their fate? Track the evolution of the Neanderthals in light of the latest discoveries.

The Rise of *Homo Sapiens*

Modern humans are characterized by large brains and creativity. How did our species arise and spread across the world? How did we interact with other human species? We will examine theories about modern human origins, including Recent African Origin ("Out of Africa"), Assimilation, and Multiregional Evolution, and delve in to the origins of human behavioral traits.

SCIENTIFIC AMERICAN Travel HIGHLIGHTS

INSIDER'S TOUR OF CERN



Pre-cruise: October 22, 2012—From the tiniest constituents of matter to the immensity of the cosmos, discover the wonders of science and technology at CERN. Join Bright Horizons for a private full-day tour of this iconic nuclear-research facility.

Whether you lean toward concept or application, there's much to pique your curiosity. Discover the excitement of fundamental research and get an insider's look at the world's largest particle physics laboratory.

Our full-day tour will be led by a CERN physicist. We'll have an orientation, visit an accelerator and experiment, get a sense of the mechanics of the Large Hadron Collider (LHC), make a refueling stop for lunch, and have time to peruse exhibits and media on the history of CERN and the nature of its work.

This tour includes: Bus transfer from Geneva, Switzerland to our Genoa, Italy hotel (October 23) • 3 nights' hotel (October 20, 21, 22) • 3 full breakfasts (October 21, 22, 23) • Transfers to and from the hotel on tour day (October 22) • Lunch at CERN • Cocktail party following our CERN visit • Do-as-you-please day in Geneva, including transfers to and from downtown (October 21) • Transfer from airport to our Geneva hotel

The price is $899 per person (based on double occupancy). This trip is limited to 50 people. NOTE: CERN charges no entrance fee to visitors.

EPHESUS

November 1, 2012—Many civilizations have left their mark at Ephesus. It's a complex and many-splendored history, often oversimplified. Bright Horizons pulls together three important aspects of understanding Ephesus that are rarely presented together. You'll meander the Marble Road, visit the legendary latrines, check out the Library, and visit the political and commercial centers of the city. A visit to the Terrace Houses will enhance your picture of Roman-era Ephesus.

We'll take a break for Mediterranean cuisine in the Selcuk countryside, then visit the Ephesus Museum in Selcuk, where city excavation finds are showcased, and you'll get a fuller look at local history, from the Lydians to the Byzantines.

ATHENS

November 1, 2012—The Parthenon and its Acropolis setting are stunning, no doubt about it. Requiring no interpretation, they are ideal for a DIY Athens excursion. On the other hand, visiting the new Acropolis Museum and the National Archaeological Museum with a skilled guide who's on your wavelength adds immeasurably to the experience. We suggest you join Bright Horizons on a focused trip. You'll see the Parthenon frieze, exquisite sanctuary relics, and Archaic sculpture at the Acropolis Museum (as you can see from the picture, the museum sits just below the Acropolis).

Lunch is tucked away at a taverna favored by Athenian families. For dessert, we'll visit the richest array of Greek antiquities anywhere—at the National Archaeological Museum.

SCIENTIFIC AMERICAN™ Travel

BRIGHT HORIZONS™

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Discover an environment designed to engage your intense interest in science. Scientific American Travel feeds your curiosity, transports you to intriguing locations, and opens doors to new worlds.

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See the world through new eyes with Scientific American Travel. Converse with keen minds and sharp wits. Relax with a companion. Refresh body and soul. Make new friends among fellow citizens of science.

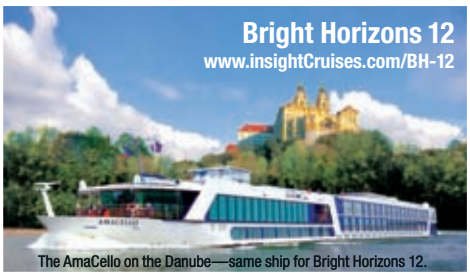
Join Scientific American Travel. Enjoy uncommon access to uncommon minds. Let us take care of the details so you can learn and have fun with peace of mind.

Cruise prices start at $959. For those attending our program, there is an additional program fee. Government taxes, port charges, and service fees are additional. All Bright Horizons programs and fees are subject to change.

For more info please call 650-787-5665 or email us at concierge@insightcruises.com

For information on more trips like this, please visit

scientificamerican.com/travel



The AmaCello on the Danube—same ship for Bright Horizons 12.

RHINE RIVER CRUISE

April 12–20, 2012

Curious how magic works? Ready to absorb the latest science, without distraction? Join Scientific American for current science and immersion into German culture and scenic beauty, on a river cruise sailing from Amsterdam, The Netherlands, to Basel, Switzerland on AMA Waterways's AmaCello, April 12–20, 2012. Particle physics, cognitive neuroscience, solar science, and alpine archaeology are on our itinerary, along with medieval German cities and Strasbourg, France.

Take a close look at sensory perception and visual illusions. Dig into medicine in the ancient world and the interplay of natural and physical sciences in archaeology. Illuminate the profound Sun-Earth connection. Capture evolving thought in subatomic physics. You can lose yourself in the rich intricacies of science while the AmaCello and its English-speaking staff provide gracious service, comfortable quarters, and superb regional cuisine.

Bright Horizons 12 offers distilled cutting-edge science and local brews together with long-awaited relaxation with good friends. You can add even more Aha! moments to your itinerary with an optional post-cruise excursion to CERN, or find your inner Parisian on an optional 1-, 2-, or 3-day post-cruise visit to the City of Lights.

Sampling of Topics

- PARTICLE PHYSICS
- SOLAR SCIENCE
- COGNITIVE NEUROSCIENCE
- ALPINE ARCHAEOLOGY

The cruise fare starts at $3,098 for a Category D cabin, per person. The Bright Horizons Program costs $1,195. Taxes and fees are $199 per person. Gratuities are €105.

ALASKA

June 8–15, 2012

What awaits you in Alaska on Bright Horizons 14? The Great Land and Scientific American present legacies and frontiers for your enjoyment. Based on Celebrity Cruises' m.s. Infinity, roundtrip Seattle June 8–15, 2012, we head up the Inside Passage and get the inside scoop on the Hubble Space Telescope, geospatial imaging, particle physics at CERN, and social psychology. Sail into a state of Native cultures, Gold Rush history, and rich, diverse habitats.

Powered by the midnight sun, surrounded by purple mountain majesty, explore the complex terrain of emotion and consciousness with Dr. John Cacioppo. Get details on the big picture of geospatial imaging with Dr. Murray Felsher. Catch up on particle physics at CERN with Dr. James Gillies. Get a firsthand account of life on the space station with astronaut Dr. Steven Hawley. Peer into the past and future of telescopic space exploration with Dr. Stephen Maran. Launch your Bright Horizons 14 fun with an optional pre-cruise sortie to the Museum of Flight in Seattle.

Connect to the science community on Bright Horizons 14. Inhale Alaska's unabashed outdoorsy spirit. Enjoy Native art and historic places. Sample unrivaled birdwatching. Glimpse bears on the beach and whales in the waves. Share glacier-watching and hot cocoa with a friend. Bring home the latest in the world of science.

Sampling of Topics

- PLANETARY SCIENCE
- COGNITIVE SCIENCE
- PARTICLE PHYSICS
- GEOSPATIAL IMAGING
- SPACE EXPLORATION

Cruise prices start at $959. The Bright Horizons Program costs $1,475. Government taxes and fees total $464 per person. Gratuities are $105 per person (a little more for Suite cabins).

For more info please call 650-787-5665
or email Concierge@InSightCruises.com

EAST MEDITERRANEAN

October 25 – November 5, 2012

Been there, done that? Think again! Italy, Turkey, Israel, and Greece have drawn explorers over the span of 5,000 years. Bright Horizons is heading in to experience the region through new eyes, new data, and new discoveries as Classical cultures and cutting-edge science converge in the Eastern Mediterranean. Share in the new thinking required by a changing world on Bright Horizons 15 aboard the Costa Mediterranea, roundtrip Genoa, Italy, October 25–November 5, 2012.

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Sampling of Topics

- NUCLEAR ASTROPHYSICS
- NEUROSCIENCE MEMORY
- COGNITIVE NEUROSCIENCE
- CLIMATOLOGY
- HUMAN EVOLUTION

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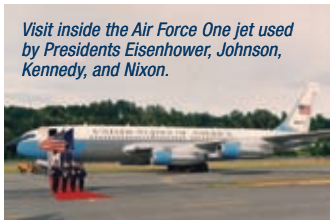
SCIENTIFIC AMERICAN Travel HIGHLIGHTS

INSIDER'S TOUR OF CERN

April 20, 2012 and October 22, 2012

From the tiniest constituents of matter to the immensity of the cosmos, discover the wonders of science and technology at CERN. Join Bright Horizons for a private, custom, full-day tour of this iconic facility. Whether you lean toward concept or application, there's much to pique your curiosity. Discover the excitement of fundamental research and get an insider's look at the world's largest particle physics laboratory. Our full day will be led by a CERN physicist. We'll have an orientation; visit an accelerator and experiment; get a sense of the mechanics of the Large Hadron Collider (LHC); make a refueling stop for lunch; and have time to peruse exhibits and media on the history of CERN and the nature of its work.



Visit inside the Air Force One jet used by Presidents Eisenhower, Johnson, Kennedy, and Nixon.

THE MUSEUM OF FLIGHT

June 7, 2012

If you love vapor trails in the wild blue yonder and the thrill of takeoff, join Insight Cruises in a day of fun and learning at the Museum of Flight at legendary Boeing Field near Seattle. Go behind the scenes with the Senior Curator. Explore The Boeing Company's original manufacturing plant. Get the big picture of aviation in the 3 million cubic-foot, six-story Great Gallery. An aviation historian will discuss the engineering and courage that took us from straight-wing planes to swept-wing jets. We'll do a refueling stop with a catered lunch provided by McCormick and Schmick's. After lunch, off we go into the Museum's Personal Courage Wing, followed by a talk on the development of aircraft carriers, and their technology and tactical use.

Please join us for an uplifting journey through aeronautical innovation. You may see the ubiquitous float planes of the great Northwest in a different perspective!

HAIFA & THE TECHNION

October 29, 2012

Perched on the Mediterranean, the Haifa region encapsules the ancient history and cutting-edge science, cultures, and beliefs that say "Israel." Get a context for Israel on a full-day visit that is equal parts cultural introduction and science field trip.

We start our day with a nod to the spiritual at the golden-domed Bahai Shrine, the world center of the Bahai faith renowned for 19 stunningly landscaped terrace gardens, and a UNESCO World Heritage site. Off next to the Technion, where Yohay Carmel, Ph.D., Professor of Civil and Environmental Engineering at the Technion (Israel Institute of Technology), along with some of his Technion associates, will direct our private tour of the Technion campus and research facilities.

ATHENS November 1, 2012

The Parthenon and its Acropolis setting are stunning, no doubt about it. They don't require interpretation, and compose the perfect DIY Athens excursion. On the other hand, visiting the new Acropolis Museum and the National Archaeological Museum with a skilled guide who's on your wavelength adds immeasurably to the experience. We suggest you join Bright Horizons on a focused trip. You'll see the Parthenon frieze, exquisite sanctuary relics, and Archaic sculpture at the Acropolis Museum (picture left; as you can see, the museum sits just below the Acropolis).

Lunch, of course, is tucked away at a taverna favored by Athenian families. For dessert, we'll visit the richest array of Greek antiquities anywhere—at the National Archaeological Museum.

CST# 2065380-40

For information on more trips like this, please visit
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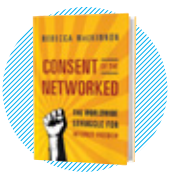
BOOKS

Science on Ice: Four Polar Expeditions

by Chris Linder. University of Chicago Press, 2011 ($40)

Frozen Planet: A World beyond Imagination

by Alastair Fothergill and Vanessa Berlowitz. Firefly Books, 2011 ($39.95)



Consent of the Networked

by Rebecca MacKinnon. Basic Books, 2012 ($26.99)

Armchair explorers can travel to the top and bottom of the earth with these coffee table books, each filled with glossy photos of the Arctic and Antarctica accompanied by narratives about the latest science from these regions. *Science on Ice* follows four groups of researchers who, among other projects, observe Adélie penguins, chart the floor of the Arctic Sea and trace the melting of Greenland's ice sheet. *Frozen Planet,* a companion to a forthcoming BBC Earth documentary, focuses on wildlife and describes how plants and animals are adapting to climate change.

In this timely and important book, journalist and scholar Rebecca MacKinnon asks who, exactly, is in charge of the Internet. Her grand tour of the ways countries, corporations and citizens fight to restrict what can and cannot happen online exposes a number of tensions that underlie our connected world. China, for instance, pioneered the practice of holding Web companies responsible for the content that their users post, which delegates the job of thought police to private corporations. The idea has spread to democracies, including the U.S., where

BY THE NUMBERS

5 MILLION

Approximate number of Adélie penguins that breed along Antarctica's coastline

SOURCE: Science on Ice

MUSEUMS

Geckos: Tails to Toepads. Museum of Science, Boston. Open until May 6. Spend time with more than 60 species of these highly adaptable lizards, known for their night vision, camouflage, sticky feet and, in at least one case, hang-gliding abilities. **www.mos.org**

Science in the City. Exploratorium, San Francisco. Tune in to this ongoing online media series, featuring videos about such subjects as pigeon science, cable cars, tattooing and battery corrosion. **www.exploratorium.edu**

It sticks: A lined leaf-tailed gecko.

a bill now before Congress would effectively require Internet service providers to monitor the material going to individuals' homes. No one elects these governors of the Net, but increasingly we're all living under their control. —*Michael Moyer*

The Kitchen as Laboratory: Reflections on the Science of Food and Cooking

edited by Cesar Vega, Job Ubbink and Erik van der Linden. Columbia University Press, 2012 ($29.95)

Top food scientists at such companies as Mars and Kraft, as well as in academia, explain the chemical interactions behind everyday dishes like grilled cheese sandwiches, chocolate chip cookies and hard-boiled eggs. They also explore broader questions: What, for instance, do we hear when we eat, and why are crunchy foods so pleasing? One essay addresses the organic food movement, reminding purists that some processed foods, such as enriched flour, have value for their added nutrients.

Design in Nature: How the Constructal Law Governs Evolution in Biology, Physics, Technology, and Social Organization

by Adrian Bejan and J. Peder Zane. Doubleday, 2012 ($27.95)

While listening to a speech in 1995, Duke University engineer Adrian Bejan hit on a unifying theory to explain the treelike shapes found in nature (lightning bolts, river deltas), as well as in man-made systems (corporate hierarchies): they facilitate movement. "The designs we see … are not the result of chance," he concludes. "They arise naturally, spontaneously, because they enhance access to flow in time."

Michael Shermer is publisher of *Skeptic* magazine (www.skeptic.com). His new book is *The Believing Brain*. Follow him on Twitter @michaelshermer

Lies We Tell Ourselves

How deception leads to self-deception

In Andrew Lloyd Webber's 1970 rock opera *Jesus Christ Superstar,* a skeptical Judas Iscariot questions with faux innocence ("Don't you get me wrong/I only want to know") the messiah's deific nature: "Jesus Christ Superstar/Do you think you're what they say you are?"

Although I am skeptical of Jesus' divine parentage, I believe he would have answered Judas's query in the affirmative. Why? Because of what the legendary evolutionary theorist Robert Trivers calls "the logic of deceit and self-deception" in his new book *The Folly of Fools* (Basic Books, 2011). Here's how it works: A selfish-gene model of evolution dictates that we should maximize our reproductive success through cunning and deceit. Yet the dynamics of game theory shows that if you are aware that other contestants in the game will also be employing similar strategies, it behooves you to feign transparency and honesty and lure them into complacency before you defect and grab the spoils. But if they are like you in anticipating such a shift in strategy, they might pull the same trick, which means you must be keenly sensitive to their deceptions and they of yours. Thus, we evolved the capacity for deception detection, which led to an arms race between deception and deception detection.

Deception gains a slight edge over deception detection when the interactions are few in number and among strangers. But if you spend enough time with your interlocutors, they may leak their true intent through behavioral tells. As Trivers notes, "When interactions are anonymous or infrequent, behavioral cues cannot be read against a background of known behavior, so more general attributes of lying must be used." He identifies three: *Nervousness.* "Because of the negative consequences of being detected, including being aggressed against … people are expected to be more nervous when lying." *Control.* "In response to concern over appearing nervous … people may exert control, trying to suppress behavior, with possible detectable side effects such as … a planned and rehearsed impression." *Cognitive load.* "Lying can be cognitively demanding. You must suppress the truth and construct a falsehood that is plausible on its face and … you must tell it in a convincing way and you must remember the story."

Cognitive load appears to play the biggest role. "Absent well-rehearsed lies, people who are lying have to think too hard, and this causes several effects," including overcontrol that leads to blinking and fidgeting less and using fewer hand gestures, longer pauses and higher-pitched voices. As Abraham Lincoln well advised, "You can fool some of the people all of the time and all of the people some of the time, but you cannot fool all of the people all of the time." Unless self-deception is involved. If you believe the lie, you are less likely to give off the normal cues of lying that others might perceive: deception and deception detection create self-deception.

Trivers's theory adds an evolutionary explanation to my own operant conditioning model to explain why psychics, mediums, cult leaders, and the like probably start off aware that a modicum of deception is involved in their craft (justified in the name of a higher cause). But as their followers positively reinforce their message, they come to believe their shtick ("maybe I really can read minds, tell the future, save humanity"). Trivers misses an opportunity to put a more positive spin on self-deception when it comes to the evolution of morality, however. As I argued in my 2004 book *The Science of Good and Evil* (Times Books), true morality evolved as a function of the fact that it is not enough to fake being a good person, because in our ancestral environments of small bands of hunter-gatherers in which everyone was either related to one another or knew one another intimately, faux morality would be unmasked. You actually have to be a good person by believing it yourself and acting accordingly.

By employing the logic of deception and self-deception, we can build a bottom-up theory for the evolution of emotions that control behavior judged good or evil by our fellow primates. In this understanding lies the foundation of a secular civil society. SA

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Illustration by Richard Mia

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The ROM is very expensive but at the same time it is the cheapest exercise a person can do. How can that be? More on that later.

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People cannot believe that our 4 minute cardio exercise is possible. The "experts" have that same (wrong) opinion. After watching our video, many people order a 30 day no obligation trial rental and 97% of them buy the ROM (stands for range of motion) machine at the end of the 30 day trial period. It sells itself.

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- 15 to 20 minutes stretching exercises.

The purchase of a ROM machine goes through several stages:

1. Total disbelief that the ROM can do all this in only 4 minutes a day.
2. Rhetorical (and sometimes hostile) questioning and ridicule.
3. Reading the ROM literature and reluctantly understanding it.
4. Taking a leap of faith and renting a ROM for a 30 day trial test in the home.
5. Being highly impressed by the health results and purchasing the ROM.
6. Becoming a ROM enthusiast and trying to persuade friends to buy one.
7. Being ignored and ridiculed by the friends who think you have lost your mind.
8. After a year of using the ROM your friends admiring your good shape.
9. You telling them (again) that you only exercise those 4 minutes per day.
10. Those friends reluctantly renting the ROM for a 30 day test trial in their home.

Then the above cycle repeats from point 5 on down.

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The ROM has been tested for over 8 weeks at USC's Department of Exercise Sciences. Conclusion: it gives the same or better cardiovascular benefit as does 20 to 45 minutes aerobic exercise. Another 8 week test was published in the Journal of the American College of Sports Medicine. The results speak for themselves.

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The machine is manufactured in Southern California with great attention to detail and quality. The machine is shipped in a custom wooden crate and comes fully assembled. A local delivery company will install the machine in the location of your choice. When they leave it is immediately ready for use.

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The ongoing search for fundamental farces

Steve Mirsky has been writing the Anti Gravity column since atmospheric carbon dioxide levels were about 358 parts per million. He also hosts the *Scientific American* podcast Science Talk.

When Animals Accidentally Attack

Every so often a critter takes a shot at making headlines

In journalism, there's what you call your dog-bites-man situation. Which is anything too common and expected to be a good story (unless the dog is one of those *Resident Evil* hellhounds, or the man is Cesar Millan). An example of a dog-bites-man science story is yet another confirmation of Einstein and relativity.

Then there's your more compelling man-bites-dog scenario. Which is something out of the ordinary (unless the man is competitive eater Takeru Kobayashi, and the dog is a Nathan's Famous with mustard and sauerkraut). An example of a man-bites-dog science story is the recent claim of neutrinos that move faster than light. Although this particular case might be more accurately called a man-claims-to-bite-dog-but-physicists-really-wanna-get-a-close-look-at-this-dog story.

Every so often, however, we are treated to a dog-shoots-man story. Which is when a dog shoots a man.

The latest dog-shoots-man incident occurred on November 27, when a Utah duck hunter left his 12-gauge shotgun unattended in his boat. The victim got out of the boat to adjust the decoys, at which time his dog allegedly stepped on the gun, causing it to discharge a literal butt-load of pellets—to add injury to insult, 27 pellets wound up in the man's buttocks.

Initial reports noted that neither the dog nor any ducks were injured. If the gun's safety was on, the dog would have had to disengage it, which would elevate this shooting from a crime of negligence to a crime of intent, if anybody was going to charge the man's-former-best-friend.

Sure, charging an animal with a crime seems loony now. But whether the dog meant to shoot could have been a major issue during the Middle Ages. As a Florida State University doctoral student named Jen Girgen pointed out in a 2003 monograph entitled *The Historical and Contemporary Prosecution and Punishment of Animals,* "when an animal caused physical injury or death to a human being, the animal was tried and punished by a judge in a secular court." In 1567 a French magistrate sentenced a pig to be hanged for killing a human. How did they know the pig did it? Somebody squealed.

The dog shooting case may be rare, but deer on the verge of becoming venison seem to even the score with hunters regularly, as evidenced by the results of an Internet search for "deer shoots hunter." A dead animal's reflexive kick that finds a trigger seems to be a common method of postmortem revenge, which can only be described as cold comfort.

Although we inkjet-stained wretches gravitate toward animal-shoots-human stories, I learned early on to be wary. I got my lesson back in 1992, when I heard a radio report about a Missouri man who was allegedly shot by a wild turkey. The story got repeated hundreds of times on radio stations and in newspapers after it was picked up by a wire service. The hunter was said to have shot a turkey, after which he tossed the bird and his gun into the trunk of his car. The hunter's son later opened up the trunk, and the turkey, merely stunned, thrashed around, clawed the trigger and shot the victim—well, the second victim—in the thigh.

Embarking on my own coverage of this important story, I called the Missouri Department of Conservation. At which point an agent told me that the turkey-did-it version "wasn't brought up until quite a bit after we took statements from the people involved. It almost boils down to a joke." He also strongly intimated that investigators suspected that the hunter's son was at fault. Which, if true, would have made for a stressful dinner at that house, as both turkey and wound got dressed.

Fortunately, the turkey hunter healed, the duck hunter will heal and the dog may heel. Which means their license fees can continue to support game management efforts and habitat maintenance. I just recommend hunting with a trusted human—if he sees your dog go for your gun, he can yell, "Duck!" SA

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Illustration by Matt Collins

February 1962

Error Codes

"Until quite recently the engineer who wanted to improve the quality of a communication channel concentrated his attention on reducing noise, or, to be more precise, on increasing the signal-to-noise ratio. The most direct way to achieve this is to increase the power of the signal. Within the past 15 years a host of new signal-processing devices—notably the electronic computer—have stimulated a different approach for transmitting signals with a minimum of error: the use of error-detecting codes. The principle underlying such codes has a long history. What is new is (1) a body of theory that tells the engineer how close the codes come to ideal performance and (2) techniques for constructing codes."

Hiding Nukes

"It appears increasingly doubtful that an atomic-weapons test of significant dimension can be concealed either underground or in outer space. A five-kiloton nuclear explosion in an underground salt cavern near Carlsbad, N.M., in December was clearly recorded by seismographs as far away as Tokyo, New York, Uppsala in Sweden and Sodankyla in Finland. The seismograph records included tracings of the 'first motion,' considered critical in distinguishing between earthquakes and underground explosions."

February 1912

Machine Replaces Muscle

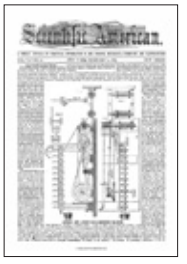
"Probably no agricultural development of the last decade is of more interest or greater significance than the rapid advance in the use of the traction engine. The coming of the gas tractor was the first step in making power farming universally possible. The old-time thresherman was little more than a stationary engineer. With the coming of the all-purpose tractor, his duties multiplied. Besides keeping his engine in trim, he had to learn to drive straight, avoid holes and obstructions, and above all to earn money for the owner of the outfit by keeping it eternally on the move. Out of the necessity has grown a new type—a farmer-engineer of high caliber, tersely termed a 'tractioneer.'"

Vickers Machine Gun

"Recently an improved type of the familiar Vickers light automatic rifle-caliber gun has made its appearance, and commands attention owing to its greater mobility and ingenious tripod. An appreciable reduction in weight has been also effected, for whereas the older weapon ready for use weighed 69 pounds, the new gun weighs only 36 pounds. This lessening of weight has been obtained by the use of high-class steel instead of gunmetal in the construction of all the parts."

This water-cooled machine gun was used extensively during World War I, which broke out two years later. For a look into our archives at the technology of weapons and warfare in 1912, see the slideshow at www.ScientificAmerican.com/feb2012/warfare

The tractioneer: A new breed of farmer-engineer ushering in the era of mechanized agriculture, 1912



February 1862

Does it Work for Shrapnel Wounds?

"The Committee on Military Affairs in the house of Representatives have under consideration the expediency of introducing the system of Samuel Hahnemann [homeopathy] into the army. It was agreed to authorize Mr. Dunn to report a bill instructing the Medical Bureau of the War Department to permit, under certain restrictions as to number and qualifications, the employment of graduates of regular Homeopathic colleges as army surgeons. This measure has been fought bitterly in committee, and has for its opponents the entire present medical force of the army. We understand that Gen. McClellan, who is a firm believer in homeopathy, is anxious to have the system tested in the army. Why not try it? It has thousands of firm believers in the country, and is rapidly gaining ground."

Salt and Slush

"The practice of salting the tracks of city railroads, whereby they have been kept in a state of cold slush during winter, has called forth the wisdom of various city magistrates and others in exposing the evils, or supposed evils, arising therefrom. The Common Council of Philadelphia called in scientific experts to give testimony. Professor Rand, of the Franklin Institute, did not believe there was any increase of mortality among children from catarrhal diseases since the use of salt upon the railroads. The difference between salt and no salt is, that with salt you may have only have one day's slush, where the slush would last a week without it."

SCIENTIFIC AMERICAN, VOL. CVI, NO. 6; FEBRUARY 10, 1912

How Science Degrees Stack Up

Female students, and management dreams, are changing the mix

Private firms may be experiencing a shortage of graduates in science, technology, engineering and math disciplines, but it's not for a lack of students. For many STEM disciplines, more undergraduate degrees are being awarded now than 10 or 20 years ago. More women are entering college, which in turn is changing the relative popularity of disciplines. (See the graphic for notes about specific trends.)

So what's behind the worker shortfall? Although the number of graduates and job openings match up fairly well, people with STEM degrees often choose jobs in other fields that pay more or have higher perceived status. "Biology students become doctors; math majors go into finance," says Nicole Smith, senior economist at the Georgetown University Center on Education and the Workforce. Others get M.B.A.s so they can take higher-salaried management positions, which makes it easier to pay off ever rising student debt.

—Mark Fischetti

SCIENTIFIC AMERICAN ONLINE
For a discussion about how to make STEM jobs more enticing, see ScientificAmerican.com/feb2012/graphic-science

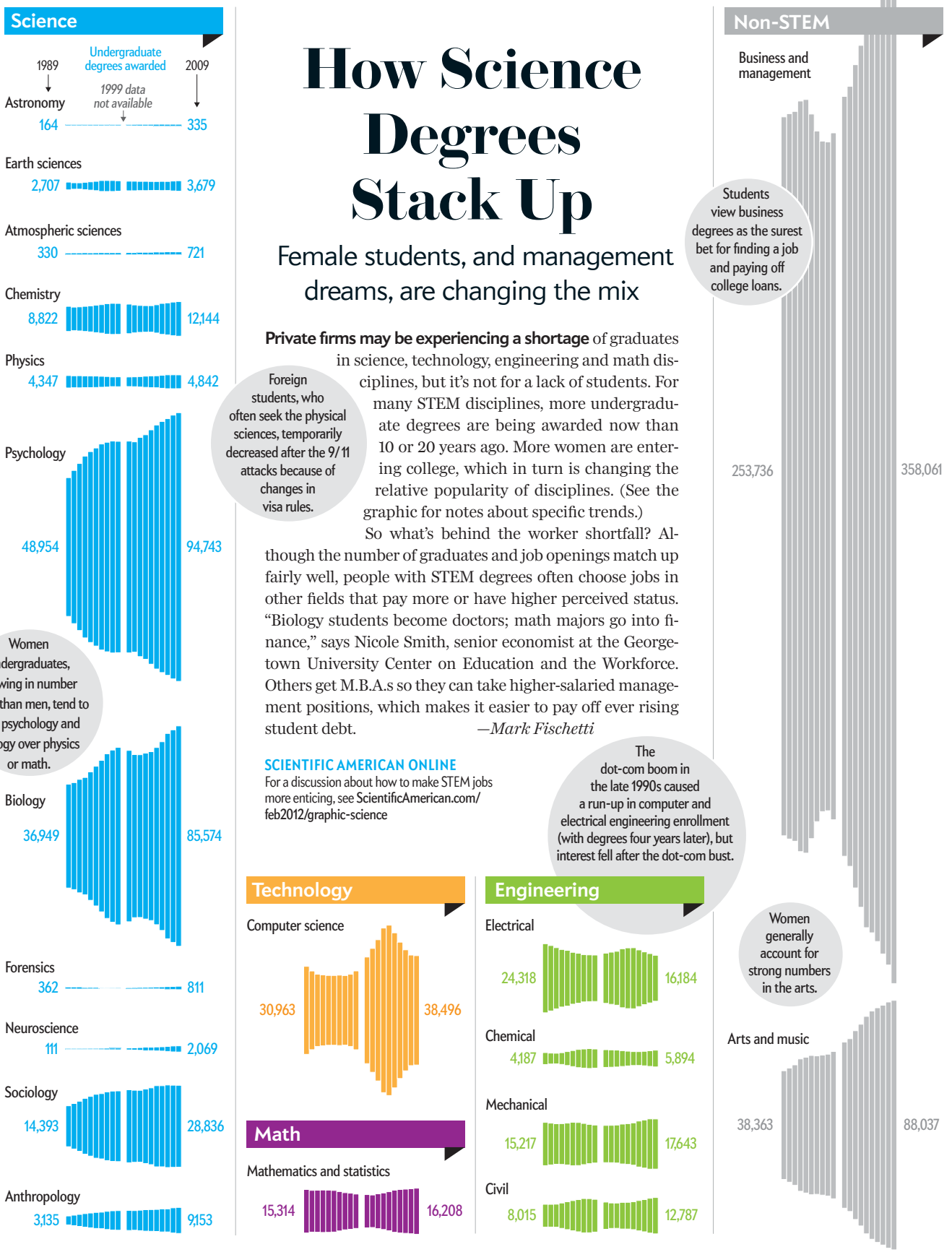
Foreign students, who often seek the physical sciences, temporarily decreased after the 9/11 attacks because of changes in visa rules.

Women undergraduates, growing in number faster than men, tend to take psychology and biology over physics or math.

The dot-com boom in the late 1990s caused a run-up in computer and electrical engineering enrollment (with degrees four years later), but interest fell after the dot-com bust.

Students view business degrees as the surest bet for finding a job and paying off college loans.

Women generally account for strong numbers in the arts.



SOURCE: NATIONAL SCIENCE FOUNDATION

Graphic by Nathan Yau

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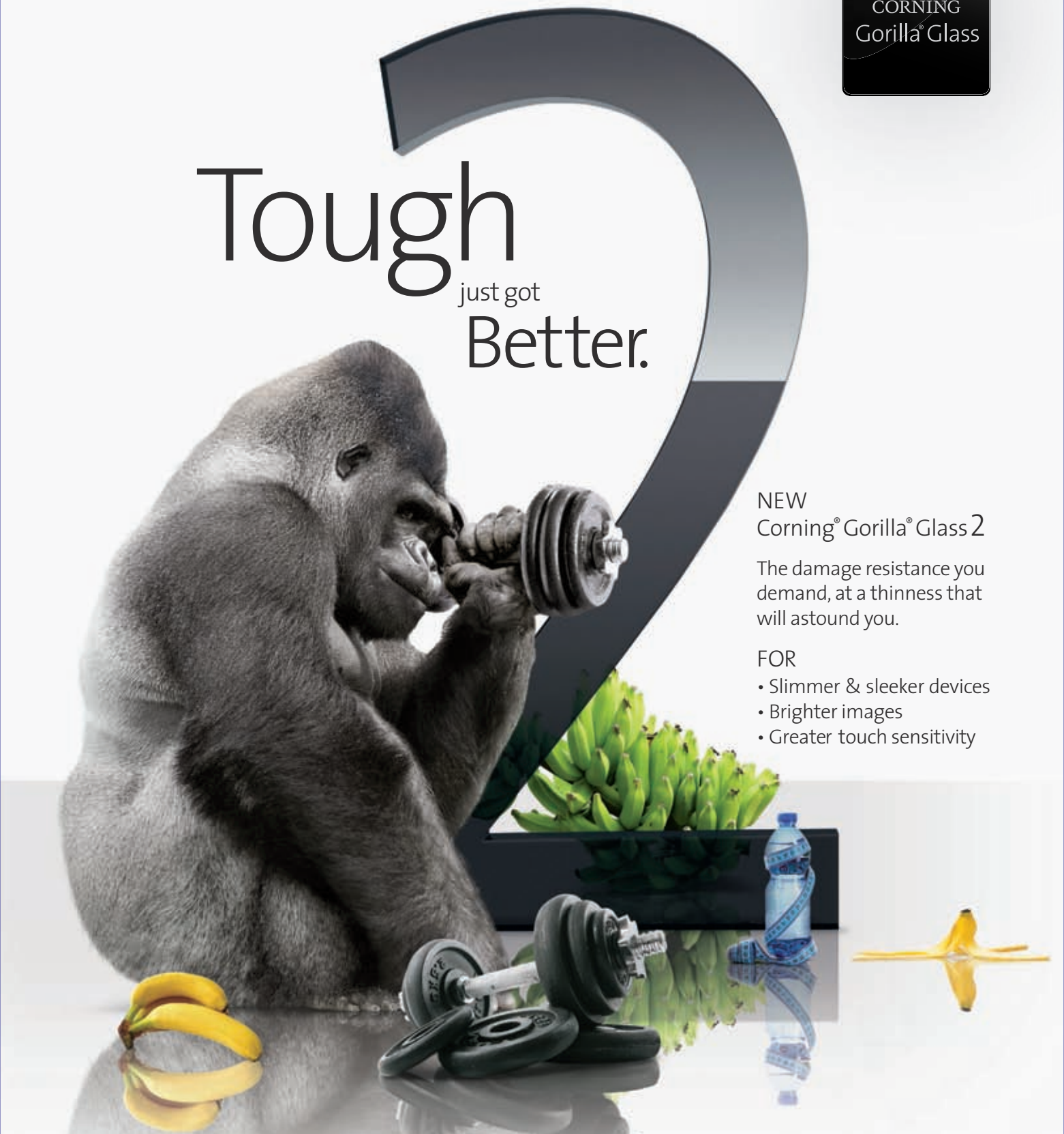

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