SCIENTIFIC AMERICAN

March 2011 ScientificAmerican.com

Planets
Mercury Up Close

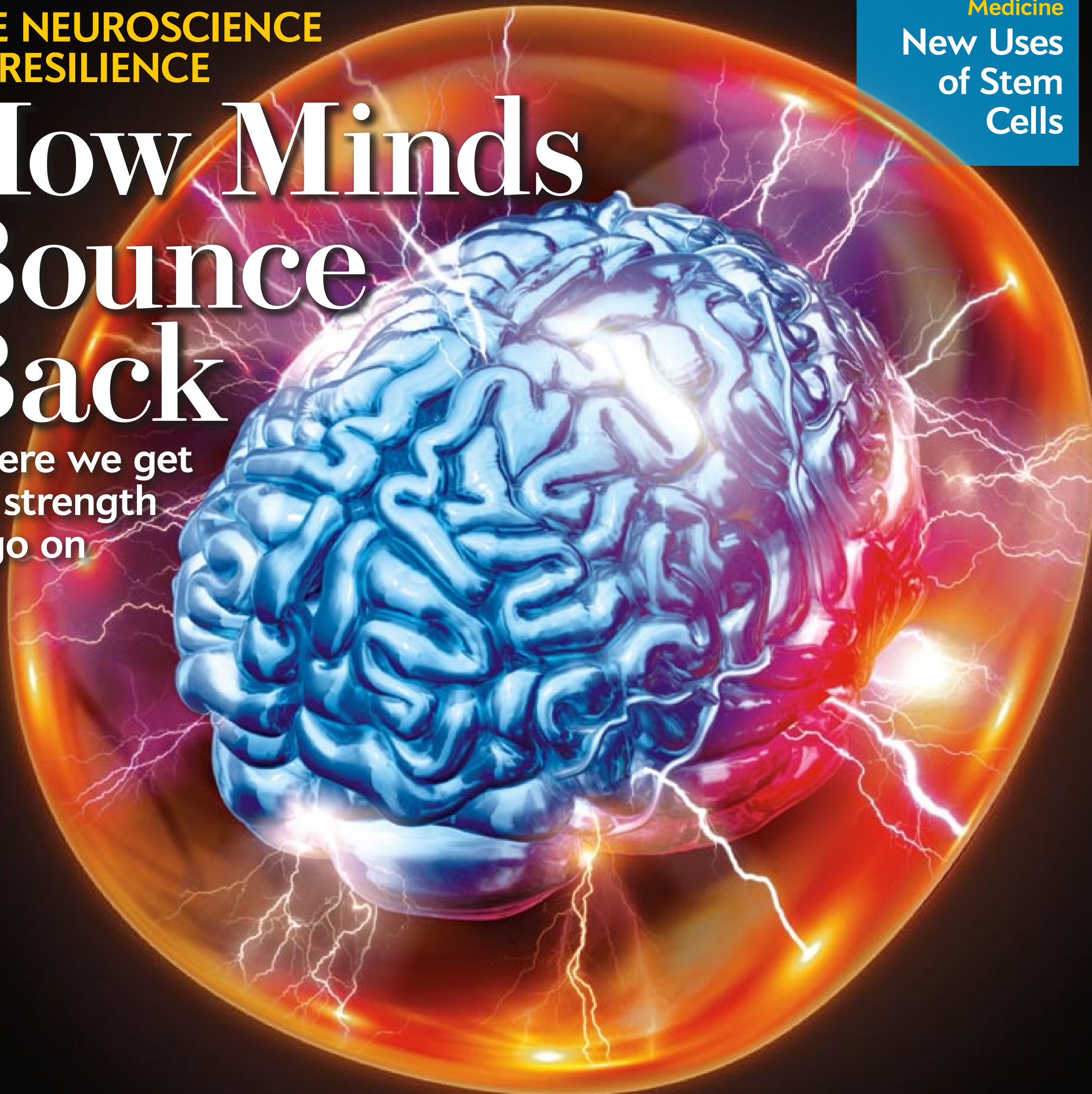
Dinosaurs
Ancient Mystery Solved

Medicine
New Uses of Stem Cells

THE NEUROSCIENCE OF RESILIENCE

How Minds Bounce Back

Where we get the strength to go on

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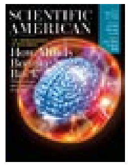
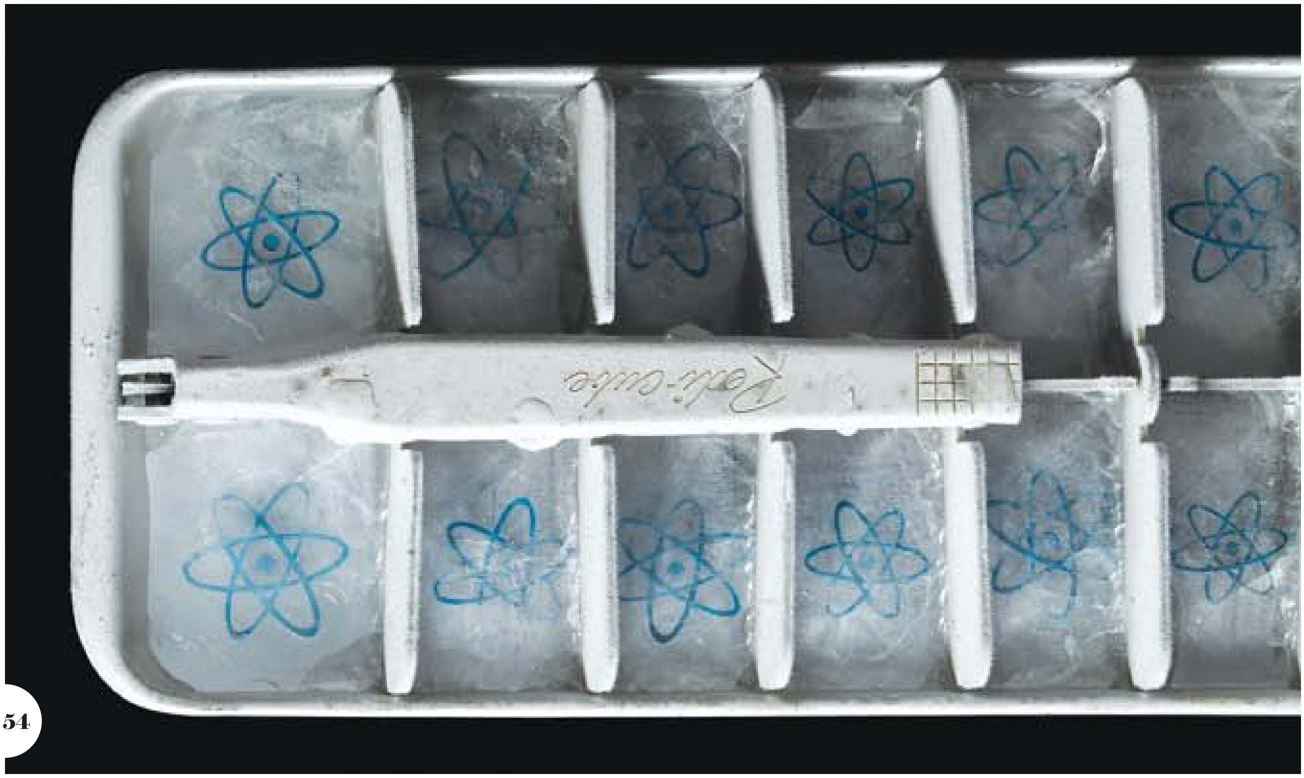
SCIENTIFIC AMERICAN

March 2011 Volume 304, Number 3

ON THE COVER



Psychological resilience—once considered rare—turns out to be the norm. We can withstand bereavement, natural disasters, terrorist attacks, usually emerging emotionally intact. Studies of the neurobiology and the psychology underlying resilience have begun to reveal the essentials of this attribute, which has allowed us to survive throughout the eons. Illustration by Kenn Brown, Mondolithic Studios.



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Photograph by Adam Voorhes

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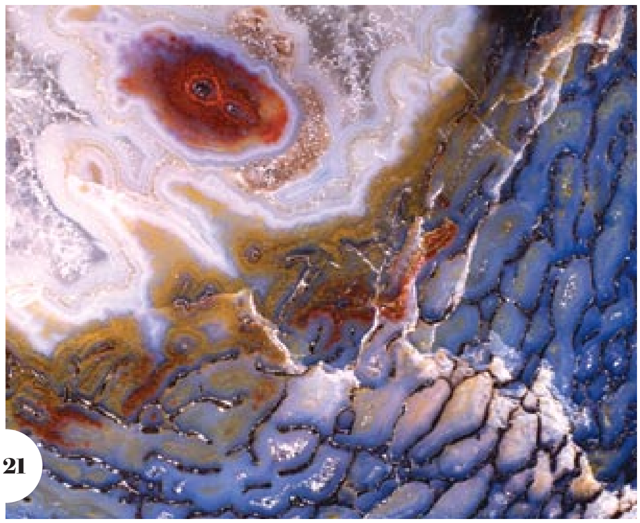

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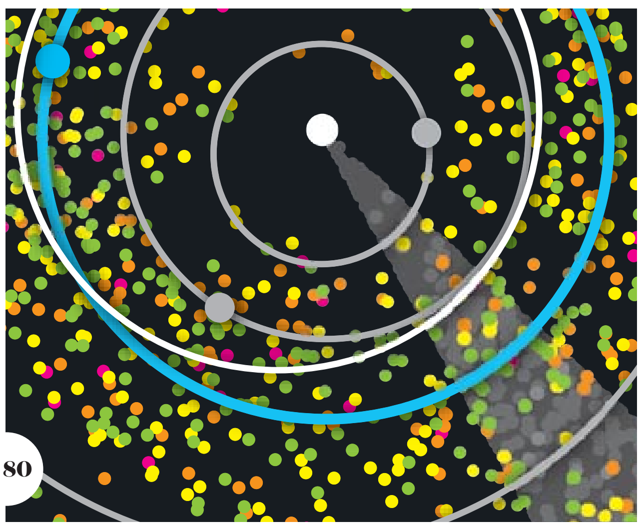

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SCIENTIFIC AMERICAN

DEPARTMENTS

ON THE WEB

"Science without Borders" inside the Beltway
The American Association for the Advancement of Science brings together researchers from countless disciplines and backgrounds. Appropriately enough, this year's meeting in Washington, D.C., was themed "Science without Borders."
Go to www.ScientificAmerican.com/mar2011/aaas

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

Spaces and Places

Among the topics that readers tell us they like best are those that explore inner space and outer space. In this issue, we've got both places covered—and others as well. The cover story, "The Neuroscience of True Grit," by Gary Stix, delves into the brain's astonishing power of resilience and recovery in the wake of mental trauma. After a tragedy such as the loss of a loved one or a terrorist attack, we naturally feel shock. But most of us soon begin to bounce back, restoring our mental balance and moving along with our lives. How do we do that? Researchers on both the brain science and behavioral sides have been getting a better picture of the process in recent years—and this understanding could help improve therapies in cases in which our built-in systems can't entirely do the job. Turn to page 28 for the full story.

As for outer space, we are finally getting a closer look at tiny Mercury, which orbits as close as 29 million miles from the sun. For those of us who remember the tantalizing glimpses from Mariner 10 in the mid-1970s, it's been a long wait. If all goes well, the MESSENGER spacecraft, which swung around the scorched planet in January, will settle into orbit March 18. In "Journey to the Innermost Planet," starting on page 34, Scott L. Murchie, Ronald J. Vervack, Jr., and Brian J. Anderson detail the fascinating findings from the flyby—which showed Mercury to be more active than suspected. I can't wait to learn what else the mission will reveal.

Back here on Earth, other feature articles look at the science of the near future and the distant past. Beginning on page 40, in "Diseases in a Dish," Stephen S. Hall explains a creative new use of stem cells made from adult tissues: modeling diseases in the lab, the better to improve drug development. And in "Dinosaur Death Trap," Paul C. Sereno solves a 90-million-year-old mystery about how a group of dinosaurs lived and died; go to page 70.

Here's a follow-up to something I mentioned last issue: students aged 13 to 18 can now enter the Google Science Fair: www.google.com/sciencefair. *Scientific American* is a participating partner, and I'm pleased to be among the judges of the anticipated 10,000 entries. Best wishes for success to all the young scientists. SA

Vinton G. Cerf, **Google's Internet evangelist, co-father of the Internet and *Scientific American* reader since 1957; geneticist and *National Geographic* Explorer-in-Residence Spencer Wells; and DiChristina at the Google Science Fair launch.**

ANDREW FEDERMAN

Illustration by Nick Higgins

editors@sciam.com

November 2010

CLIMATE AND HERESY

Michael D. Lemonick's "Climate Heretic" seems to suffer from a common misconception. Lemonick tends to avoid any distinction between skepticism and denial when referencing so-called climate skeptics. At the same time, he makes much of the rigidity so evident among some in the majority. Such portrayal does an injustice to serious proponents on all sides of the issue. To refer to all those in disagreement as "skeptics" implies that the vast majority of climate scientists then are credulous.

Skepticism—true skepticism, not the intractable bias characteristic of denial—is absolutely fundamental to the scientific method. I would submit that if but a single attribute can be said to characterize climate science in the hostile public policy milieu of recent years, it is surely skepticism.

Whatever their position on a topic or their bias toward a conclusion, true skeptics will ultimately follow the evidence where it leads. Deniers, on the other hand, interpret that same evidence only as it might support their foregone conclusions. The gulf between these mindsets is wide. In an age already rife with misinformation and scientific illiteracy, that difference should be acknowledged by scientists and journalists alike and at every opportunity.

DOM STASI
Studio City, Calif.

"True skepticism—not the intractable bias characteristic of denial—is absolutely fundamental to the scientific method."

DOM STASI *STUDIO CITY, CALIF.*

LEMONICK REPLIES: Those who do not accept the general scientific consensus on climate change span an enormous range, from people who have legitimate scientific disagreements on some of the details all the way to people who distort the facts to people who declare the whole thing a socialist plot (or, alternatively, a money-making scam). It is certainly inappropriate to lump them all together, and while my piece was not primarily focused on distinguishing between the different categories, I hope it did not create the impression that I consider skepticism and denial to be equivalent. I agree that true skepticism is an integral part of the scientific method—but want to emphasize that it is practiced by those who do accept the consensus, not just by those in opposition.

SHOPPING FOR DIESELS

Michael Moyer's "Window Shopping for Electric Cars" [Advances] got me doing just that, but I did not compare electric cars with other Japanese or U.S. cars. Rather I looked to German-made cars sold in the U.S.

I own a 2004 VW turbodiesel station wagon. On a recent 600-mile trip on the interstates, I averaged 52 miles per gallon. I am told the latest version of this model—which sells for only $16,000—would have made 57. Why would I want to buy a Toyota Prius when I can get two Jettas for the same money?

In Europe, about half of all new cars sold are now diesels, some of which are more fuel-efficient than a Prius. The irony is that both GM and Ford make respectable turbodiesels in Europe but declined to make any of them in North America, presumably because they feared the high EPA cleanliness standard that VW, Mercedes and BMW were able to meet. Surely it would make more sense for them to license clean diesel technology from VW and produce those cars here.

JOHN FITZHUGH MILLAR
Williamsburg, Va.

SCIENCE AND MUSIC

In David Biello's "Darwin Was a Punk" [Advances], Greg Graffin is quoted as saying that there are no good songs about science, but he ignores the work of Monty Python in their seminal "Galaxy Song." It may not appeal to Graffin's punk preferences, but not only is the song's science apparently plausible, it is also tuneful and the best song I know that begins and ends with the performer in a refrigerator.

NIGEL TAYLOR
New York City

THE EDITORS REPLY: Numerous readers reacted to Graffin's assertion by sending us great examples of science songs. In addition to Monty Python's immortal song, others include "Mammals" by the band They Might Be Giants, John Boswell's album "Science Is the Poetry of Reality" and many songs by Tom Lehrer. Presumably none of the songs satisfies Graffin's taste to qualify as "good."

DARK AND STILL

In "Dark Worlds," Jonathan Feng and Mark Trodden explain that the dark matter candidates called super-WIMPs interact only through gravity. That means they cannot undergo the type of collisions that dissipate energy (or hardly any collisions at all) the way ordinary particles do, primarily turning kinetic energy into electromagnetic energy, in the form of photons.

"When created, super-WIMPs would have been moving at a significant fraction of the speed of light," the authors write, adding that "they would have taken time to come to rest." In purely gravitational interactions, energy is nearly conserved. The only possible mechanism for individual super-WIMPs to lose kinetic energy is to convert a tiny bit of it into gravitational radiation. If super-WIMPs essentially cannot interact, how can they come to rest?

VAN SNYDER
La Crescenta, Calif.

FENG AND TRODDEN REPLY: If the universe were not expanding, super-WIMPs

would indeed have no way of slowing down. In an expanding universe, however, all matter comes to rest eventually, meaning that its motion ultimately is owed entirely to the expansion of the universe (technically, this means that it comes to rest in co-moving coordinates, which expand with the expansion of the universe). Thus, this is the sense in which super-WIMPs slow down. Incidentally, the same principle applies to the slowdown of WIMPs. The weak interactions that WIMPs possess (and super-WIMPs lack) do not have any appreciable impact on how long they take to come to rest or how well they seed galaxy formation.

HUMANS AND PARASITES

I read with interest in Mary Carmichael's "Halting the World's Most Lethal Parasite" the idea of vaccinating mosquitoes by using a human carrier to pass the vaccine on to the mosquito. Couldn't you use other mammals such as livestock instead, thereby eliminating the ethical dilemma of vaccinating people who will not directly benefit?

Paul Sidhu
Smethwick, U.K.

CARMICHAEL REPLIES: Vaccinating animals is an intriguing idea and one that is clearly more applicable for vector-borne diseases with nonhuman reservoirs (for example, vaccinating dogs to control both canine and human visceral leishmaniasis transmission). Still, the two major human malaria parasite species, Plasmodium falciparum *and* P. vivax, *are restricted in their "choice" of vertebrate host. Also, to reiterate one of the points made in the article, a vaccination campaign using only a malaria-transmission blocking vaccine (TBV) would indeed confer direct benefit to the immunized individual. The benefit is not immediate but simply delayed. No one is envisioning using TBV alone, however. It would most likely be used in combination with antimalarials and other vaccines.*

ERRATUM

In the "Vaccine Alternatives" box in "Halting the World's Most Lethal Parasite," the causative agent of malaria was incorrectly described as a virus; it is a parasite, as stated in the article.

LETTERS TO THE EDITOR

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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/mar2011

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Keep the Internet Fair

The government's net neutrality compromise fell flat. Here's a simple fix

The island of Key Biscayne, Fla., sits in the Atlantic Ocean 10 miles southeast of Miami. Its 10,000 residents depend on the Rickenbacker Causeway, a four-mile-long toll bridge connecting the island to the mainland, for all their supplies. Right now all vehicles passing through must pay a set toll—$1.50 for cars, $9.00 for three-axle cargo trucks, and so on. But what would happen if a bridge owner decided to charge a toll based not on the size of a vehicle but on the cargo it was carrying? He could let his brother's lumber-supply company through for free and make its chief competitor pay through the nose. He could force the Winn-Dixie grocery store to double its prices, pushing area residents to local restaurants. In short, the bridge owner would have the power to control everything that the residents of Key Biscayne have access to.

This is the essence of the widely discussed but little understood concept of "net neutrality." The bridge, in this case, represents the lines that carry the Internet to your home computer or smart phone. So far Internet service providers have for the most part treated all content equally. The worry is that, sensing a business opportunity, they might strike deals with certain content providers to deliver faster access for a fee or to block some information entirely. The worry isn't completely theoretical; Comcast recently told the company that delivers Netflix streaming videos that it needed to pay up if it wanted to access Comcast's customers. (Lost on no one was the fact that Netflix directly competes with Comcast's own video-on-demand service.)

To make matters worse, most Americans have only one choice of high-speed broadband provider; the most fortunate have two. Unhappy subscribers cannot just leave and get their Internet elsewhere. This effective monopoly leaves consumers with little protection from a provider that has the means to filter everything that they can buy, watch and read.

Internet service providers contend that they must retain the flexibility to manage their networks in the way they see fit—slowing or blocking some high-bandwidth applications to ensure reliable service for all. Network management is a serious concern, but it must not become a cover for policies that censor any content displeasing to the corporate gatekeeper.

The Federal Communications Commission approved a rule last December that was intended to ensure equal treatment of content providers. Yet while the FCC rule prohibits "unreasonable" discrimination of network traffic, it fails to spell out what unreasonable behavior entails. The ruling is vague in ways that only a Washington, D.C., lawyer could love; the only certainty it gives is of the tens of thousands of billable hours to be spent arguing over the meaning of "unreasonable" in federal court.

The fix, however, is simple. As the FCC goes about enforcing this ban on so-called unreasonable policies, it should clarify that the only kind of unreasonable discrimination is discrimination against particular applications.

What would this mean in practice? Instead of the "all you can eat" data plans of today, Internet service providers could sell customers access by the gigabyte. They could limit performance at peak times of the day to help balance network load or offer superfast plans at higher prices.

Internet service providers would not, however, be able to determine which applications go fast and which go slow. They would not be able to reach a deal with Facebook to speed up that site's page loads while slowing down LinkedIn. They could not put Skype calls through a bottleneck or throttle back all video-streaming sites, because these are all judgments based on application. This clarification gives Internet service providers the leeway they need to maintain healthy networks, as well as plenty of incentive to invest in advanced network infrastructure for those customers willing to pay for ultrahigh-speed service. But it takes away the power of Internet service providers to choose winners and losers. We can accept that a bridge owner can charge vehicles based on their size—$1.50 for cars, $9.00 for three-axle cargo trucks—but a democratic society can't abide discrimination based on content. SA

COMMENT ON THIS ARTICLE ONLINE
ScientificAmerican.com/mar2011

Illustration by Harry Campbell

Jonathan Zittrain is a professor of law and of computer science at Harvard University, where he co-founded the Berkman Center for Internet and Society. He is author of *The Future of the Internet—and How to Stop It* (Yale University Press, 2008).

Freedom and Anonymity

Fear of cyberattacks should not lead us to destroy what makes the Internet special

It's starting to get weird out there. When WikiLeaks released classified U.S. government documents in December, it sparked several rounds of online conflict. WikiLeaks became the target of denial-of-service attacks and lost the support of its hosting and payment providers, which inspired sympathizers to counterattack, briefly bringing down the sites of MasterCard and a few other companies. Sites related to the hackers were then attacked, and mirror sites sprang up claiming to host copies of the WikiLeaks documents—although some were said to carry viruses ready to take over the machines of those who downloaded the copies, for who knows what end. Months before, an FBI official said disruption of the Internet was the greatest active risk to the U.S. "other than a weapon of mass destruction or a bomb in one of our major cities."

Attacks on Internet sites and infrastructure, and the compromise of secure information, pose a particularly tricky problem because it is usually impossible to trace an attack back to its instigator. This "attribution problem" is so troublesome that some law-enforcement experts have called for a wholesale reworking of Internet architecture and protocols, such that every packet of data is engraved with the identity of its source. The idea is to make punishment, and therefore deterrence, possible. Unfortunately, such a reworking would also threaten what makes the Internet special, both technologically and socially.

The Internet works thanks to loose but trusted connections among its many constituent parts, with easy entry and exit for new Internet service providers or new forms of expanding access. That is not the case with, say, mobile phones, in which the telecom operator can tell which phone placed what call and to whom the phone is registered. Establishing this level of identity on the Internet is no small task, as we have seen with authoritarian regimes that have sought to limit anonymity. It would involve eliminating free and open Wi-Fi access points and other ways of sharing connections. Terminals in libraries and cybercafes would have to have verified sign-in rosters. Or worse, Internet access would have to be predicated on providing a special ID akin to a government-issued driver's license—perhaps in the form of a USB key. No key, no bits. To be sure, this step would not stop criminals and states wanting to act covertly but would force them to invest much more to achieve the anonymity that comes so naturally today.

The price to the rest of us would also be high. The Internet's distinct configuration may have made cyberattacks easy to launch, but it has also kindled the flame of freedom. One repressive state after another has been caught between the promise of economic advancement through abundant Internet access and the fear of empowering its citizens to express themselves freely. An Internet without the attribution problem would introduce a new issue: citizens could be readily identified and punished for their political activities.

We need better options for securing the Internet. Instead of looking primarily for top-down government intervention, we can enlist the operators and users themselves. For example, Web site operators could opt into a system of "mirror as you link." Whenever their servers render a page, they cache the contents of the link. Then, when someone tries to get to the site and can't, he or she can go back to the original linking site and digitally say, "I can't get that link you just directed me to. Would you mind telling me what was there?"

Such a system of mutual aid would draw on the same cooperative and voluntary instinct behind the development of the Internet itself. If I participate as a Web site, I will know that others linking to me will also mirror my material; we each help the other, not simply because it's the right thing to do, but because we each benefit, spreading the risk of attack and cushioning its impact among all of us. It's a NATO for cyberspace, except it would be an alliance of Web sites instead of states.

A mutual aid framework could also make the Internet secure in other ways. PCs can alert others not to run code that just sickened them, signaling health levels to others. Internet providers could also develop technologies to validate their relationships to one another and ferret out misleading data, the way Wikipedia volunteers can quickly act to roll back thousands of acts of vandalism a day.

We rightly fear our networks and devices being attacked—but we should not let this fear cause us to destroy what makes the Internet special. We have to become more involved and more subtle—and soon. SA

COMMENT ON THIS ARTICLE ONLINE
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ENVIRONMENT

Coal Fires Burning Bright

With promises to curb CO_2 emissions by 2020, China will need more than blackouts to get there

China has won international plaudits for its commitment to green goals. It has pledged to reduce carbon emissions by at least 40 percent per economic unit by 2020 and is also adding alternative energy sources such as wind farms and nuclear power plants faster than any other country.

But the nation is also in the midst of unprecedented economic growth—and an unprecedented surge in the use of energy, which for China means coal. The country burns more coal than the U.S., Europe and Japan combined, the main reason why it is now the world's largest emitter of greenhouse gases. "Will China's carbon dioxide emissions overwhelm the world?" asks Mark D. Levine, a senior staff scientist at Lawrence Berkeley National Laboratory who works in the country on energy-efficiency measures. "That's the question."

In China, growth is winning out over any push to go green. A recent reporting trip showed that one of the main problems is a combination of conflicting policies from the central government and a lack of commitment on the part of local officials. Here is where China is falling short:

CLEAN COAL Much like the U.S. government and power companies, Chinese officials say the technology to capture carbon dioxide at coal-fired power plants is simply too expensive to add. And coal technologies that might make such carbon capture and storage deep below the ground feasible, such as turning the coal into a gas before burning it, are not favored by at least some of those in charge. "[Gasified coal's] cost is no cheaper than nuclear power," says Zhang Guobao, vice chair of China's National Development and Reform Commission (NDRC), the government agency that sets Chinese energy and industrial policy. But unlike the U.S., China is continuing to build massive coal plants that will be pumping out greenhouse gases decades from now.

NEW ENERGY In a bid to reduce the country's reliance on coal, the NDRC has mandated that power companies generate at least 8 percent of their electricity from so-called new energy—such as nuclear power plants or wind turbines. But the wind is unreliable: in some provinces, it blows strongest in fall and winter, exactly when coal-fired power plants are most needed for their other output: heat. And while China is building nuclear power plants, the uranium-fueled reactors have not displaced any coal plants to date.

ENERGY EFFICIENCY Last November, when China appeared on the verge of exceeding the energy-efficiency targets set for the end of 2010, government officials imposed blackouts in some regions to make sure the country achieved its goal. That prompted factory owners to switch to back-up diesel generators, which still emit CO_2, to avoid fines for late deliveries of goods. China is willing to do "some very irrational things" to meet its efficiency goals, says Berkeley Lab's Levine.

The Chinese point to a double standard on the part of the U.S. "We have only developed our economy for three decades, and now we face great pressure [to clean up]. That is unfair," NDRC's Zhang says. He reaffirmed his commitment to expanding sources of alternative energy, but, he added, "for the foreseeable future, coal will continue to take up a big part of our energy mix." *—David Biello*

Up in smoke: Workers outside a coal plant in Dandong, China.

ANDY WONG AP Photo

FURTHER READINGS AND CITATIONS ScientificAmerican.com/mar2011/advances

PALEONTOLOGY

Bison vs. Mammoths

A scientist turns up new clues to the disappearance of North America's giant beavers, saber-toothed cats and other large mammals

Bear-size beavers, mammoths, horses, camels and saber-toothed cats used to roam North America, but by 11,000 years ago most such large mammals had died off. To this day, experts debate what caused this late Pleistocene extinction: climate change, overhunting by humans, disease—or something else? Eric Scott, curator of paleontology at the San Bernardino County Museum in Redlands, Calif., suggests it was something else: namely, the immigration of bison from Eurasia.

Armed with data from his own ongoing excavations as well as from those dating back as far as the 1800s, Scott says that bison appeared in North America as early as 220,000 years ago and spread across the continent throughout the remainder of the Pleistocene, a time when climate change had made food and water scarce. He first formally suggested the idea last spring in the journal *Quaternary International,* speculating that bison may have won enough battles for food and water during that time to share the blame with climate change as the major cause of the large mammal extinctions.

Scott's initial "aha!" moment came while excavating near the town of Murrieta, Calif., in the early 1990s. Years before, digging nearby in strata 760,000 years to 2.5 million years old, he had found no evidence of bison, only horses, and wondered: "What did horses think when bison showed up and ate their food?" So when his team excavated in late Pleistocene strata at Diamond Valley Lake near Murrieta, just miles away from where he had found no bison, and turned up fossils of bison and other mammals, he thought he might have an answer: "This brought home to me the idea that as bison immigrated into areas and their numbers grew, their effect on other large mammal populations might have reached tipping points." Scott is now collecting data from other parts of the U.S. to make sure the pattern he has observed in the Southwest holds up elsewhere.

Scott speculates that bison would have had multiple advantages over other large herbivores. For example, their multiple stomachs probably allowed them to extract maximum nutrition from their food. And they need not have won every battle they engaged in. Instead they might have, for example, malnourished nursing mothers just enough to cause population collapse. With no large herbivores to eat, dire wolves, American lions and other carnivores would have starved as well. —*Rebecca Coffey*

Foreign invader: Bison may have outcompeted other large mammals for resources.

Genius

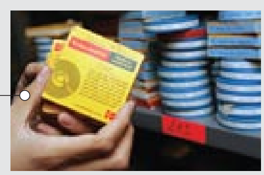
Researchers make progress on a new test that can pick up a single cancer cell in a sample of blood, potentially improving detection and treatment.

Evidence mounts that the U.S. and Israel are behind a computer worm that appears to have set back Iran's nuclear program.

The placebo effect works even when patients know they are receiving a placebo. Note to health insurers: cover sugar pills.

Women's emotional tears may contain a chemical that reduces male sexual arousal. "Not tonight, dear, I'm watching *Terms of Endearment.*"

Thousands of dead birds dropped from the skies in the U.S., Sweden and Italy in unrelated incidents. A sign of the apocalypse … or a slow news period?



The last rolls of Kodachrome film, beloved for its rich colors, were developed in a lab in Kansas. Its complex process and digital cameras spelled its doom.

Folly

—*George Hackett*

ERIC SCOTT *San Bernardino County Museum (bison skull);* TREVOR LUSH *Getty Images (test tubes);* CARLO A *Getty Images (woman crying);* ANGELO TURETTA *Redux Pictures (birds);* MARILYNN K. YEE *Redux Pictures (film)*

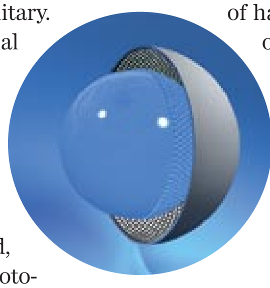
Wide-angle close-up: **A still-life shot with a gigapixel camera prototype shows zoom-ins of a New York City subway map (*1*), a dollar bill (*2*) and a fabric weave (*3*).**

COMPUTER SCIENCE

Can You See Me Now?

A camera with a unique, spherical lens may bring single-shot gigapixel cameras closer to reality

Imagine snapping a panoramic picture from the top of the Empire State Building, then zooming in on a speck to reveal a quarter lying on the sidewalk. That's the promise of single-shot gigapixel cameras—cameras that shoot images composed of at least one billion pixels, or picture elements. Apart from their obvious appeal to photographers, gigapixel images also hold tremendous potential for law enforcement and the military. Such high resolution would enable unmanned aerial vehicles to capture detail down to a license plate number while flying at altitudes too high to be spotted from the ground.



The Internet is already abuzz with sites, such as Google Earth, 360world.eu and GigaPan (created by Carnegie Mellon University, NASA and Google), that allow gigapixel digital photographs to be uploaded, viewed and shared across the Web. But these photographs actually consist of several megapixel-size images pieced together digitally. This is often accomplished using a long-lens digital single-lens reflex (SLR) camera placed atop a motorized mount. Software controls the movement of the camera, which captures a mosaic of hundreds or even thousands of images that, when placed together, create a single, high-resolution scene. The main drawback to this approach is that it can take up to several hours to complete the shoot, during which time lighting conditions may change and objects can move in and out of the frames.

Researchers are working to develop a camera that can take a gigapixel-quality image in a single snapshot. The U.S. Defense Advanced Research Projects Agency is investing $25 million over the next three and a half years into developing such compact devices. "We are no longer dealing with fixed installations or army tank units or missile silo units," says Ravi Athale, a consultant to DARPA on this program. "[Fighting terrorism requires] an awareness of what's going on in a wide area the size of a medium city." Current satellite images or those taken from drones are extremely high resolution but very narrow in view, like "looking through a soda straw," Athale says.

But today's camera-size digital processors and memory are unprepared to manage gigapixel images, which contain more than 1,000 times the amount of information of megapixel images. (A 10-gigapixel image would take up more than 30 gigabytes of hard drive space.) Oliver Cossairt and Shree K. Nayar of Columbia University's school of engineering, with funding from DARPA, have taken one promising approach: using computations to reduce such complexity. "Rather than thinking about it as capturing the final image, you're capturing information you would need to compute the final image," says Nayar, chair of Columbia's department of computer science.

In a paper to be presented at April's IEEE International Conference on Computational Photography in Pittsburgh, Cossairt and Nayar propose three compact gigapixel camera designs, two of which they built. Each relies on a unique ball-shaped lens that they selected for its simplicity—indeed, they built their first prototype around a crystal ball that they bought on New York City's Canal Street. Unlike flatter lenses, which lose resolution toward the edges, a sphere's perfect symmetry allows for uniform resolution. One of the Columbia lens designs resembles a fly's eye, with half the sphere covered in small, hexagonal relay lenses that transmit images to an array of sensors just above them.

Of course, any advanced imaging technology invites concerns over privacy. Christopher Hills, a security consultant with Securitas Security Services who also runs the site gigapixel360.com, acknowledges that a landscape gigapixel image of a city could be scrutinized to see into the windows of homes. "Still, if you were to go to your window, someone in another nearby building or on the street would be able to see you. That's why they make shades," Hills observes. *—Larry Greenemeier*

COMPUTER VISION LABORATORY, COLUMBIA UNIVERSITY

COMMENT AT ScientificAmerican.com/mar2011

MEDICINE

A Little Help from Their Friends

As more Americans sign up for health care, they'll be more likely to see nurses and physician assistants instead of doctors. That's a good thing

DAVID MUIR *Getty Images*

As health care reform rolls out over the next five years and millions of newly insured seek treatment, the shortage of general medicine doctors will only worsen. Many researchers anticipate that physician assistants (PAs) and nurse practitioners will step in to fill that gap. They are already on the front lines, handling more and more routine visits, and their numbers are expected to increase in the coming years. Researchers are finding that the presence of PAs and nurse practitioners at doctors' offices may help improve both the quality and availability of medical care.

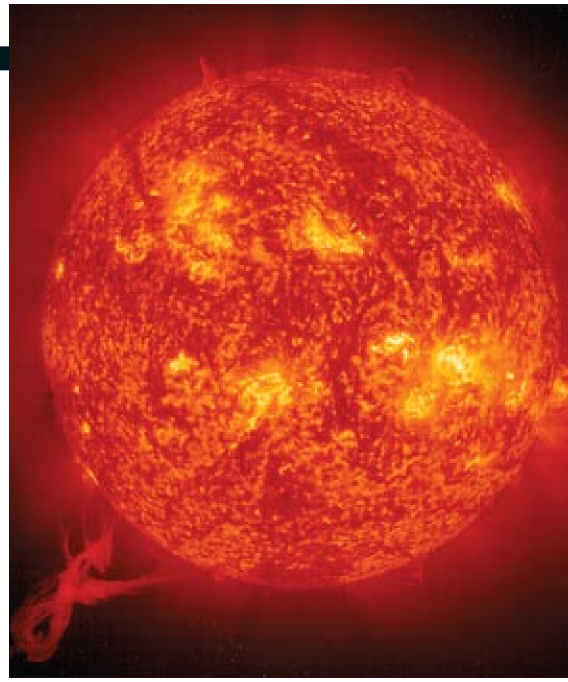
Today community health care clinics are twice as likely as private practices to employ PAs and nurse practitioners. Thanks in part to the PAs and nurses, one recent study published in the *Journal of Community Health* found, clinics were able to see a greater volume of patients and to remain open for longer hours. The clinics were also able to spend more time educating patients about their conditions—something that nurses and PAs were more likely to do than doctors. Clinics also employed an efficient division of labor, whereby PAs were deployed more to patients with acute conditions such as colds or minor injuries, and doctors treated more patients with chronic conditions. Right now who one sees at the doctor's office is too often dictated by scheduling convenience, rather than by how tricky one's case is, says Roderick Hooker, a health services researcher at the Lewin Group in Falls Church, Va., and co-author of the paper. As more PAs and nurses join private practices, community health clinics could be used as a model. With the flood of new patients, doctors will need all the help they can get.

—*Tia Ghose*

PHYSICIAN ASSISTANTS
Number in 2008: 74,800
Growth rate from 2004 to 2009: 29%
Average years of education: 18

NURSE PRACTITIONERS
Number in 2008: 158,348
Growth rate from 2004 to 2009: 39%
Average years of education: 18

REGISTERED NURSES
Number in 2008: 2,618,700
Growth rate from 2004 to 2009: 12%
Average years of education: 15



ASTROPHYSICS

Feeling the Heat

Short-lived fountains of plasma may explain why the sun's outer atmosphere is hotter than its surface

It is a question that has hounded solar physicists since the 1940s: Why is the outer layer of the sun's atmosphere, the region farthest from the heat-producing core, hotter than both the lower atmosphere and the sun's surface?

Experts have put forth various explanations, from sound waves or magnetic waves dissipating in the upper solar atmosphere, or corona, to short bursts of energy known as nanoflares that erupt as tangled magnetic field lines in the corona reconnect. Now observations from a new generation of sun-observing spacecraft are implicating a different mechanism, one that could provide the corona with a significant portion of its heat by continually delivering hot ionized gas, or plasma, to the upper atmosphere.

Spicules, which are short-lived fountains of plasma shooting up from the sun's chromosphere, or lower atmosphere, seem to play a role in heating the corona to searing temperatures at millions of degrees kelvins, investigators have found. Spicules, whose origins are somewhat mysterious, last just 100 seconds, rising from the chromosphere at speeds of 50 to 100 kilometers per second. As lead study author Bart De Pontieu of the Lockheed Martin Solar and Astrophysics Laboratory in Palo Alto, Calif., points out, that is fast enough to travel from San Francisco to London in minutes. De Pontieu and his colleagues reported their findings in the journal *Science*.

The group based its study on observations from NASA's new Solar Dynamics Observatory, launched in 2010, and the Japanese Hinode spacecraft, which began service in 2006. Both solar observatories can take detailed images of the sun every several seconds, the kind of quick-time observation needed to identify transient or rapidly changing phenomena.

As spicules measuring in the tens of thousands of degrees kelvins rise from the chromosphere, the researchers noticed, patches of the corona above flare up at one million to two million degrees.

The researchers do not yet know what launches the chromospheric plasma at such high speeds nor what heats it to the extreme temperatures it reaches in the corona. But the link between spicules and coronal heating holds promise for closing the books on a 70-year-old mystery, says Kenneth Phillips of University College London.

Although spicules seem to be important phenomena in certain regions of the sun, time will tell whether they deliver enough hot plasma on a global scale to explain the corona's tremendous heat, says James Klimchuk of the NASA Goddard Space Flight Center in Greenbelt, Md. Klimchuk calls the new observations "very exciting" but notes that his own preliminary calculations indicate that spicules provide only a small share of the hot plasma in the corona, leaving plenty of room for other, more conventional modes of coronal heating.

For his part, De Pontieu sounds a similar note of caution that the long-standing problem of the corona's temperature has yet to be conclusively resolved. "I think it's important to point out that we have not solved coronal heating, but we have provided a piece of the puzzle," he says. "We'll see down the line whether this proves to be a dominant process or simply a contributor." *—John Matson*

QUOTABLE

"We want to make cars with a feeling of individuality much like a Japanese mother does when she makes rice balls for her children."

—Akio Toyoda, president of Toyota Motor Corp., speaking to reporters at the 2011 North American International Auto Show in Detroit.

COURTESY OF SOHO/EIT CONSORTIUM/ESA/NASA

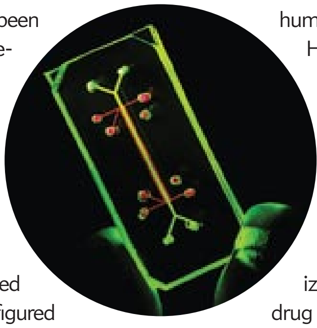
COMMENT AT ScientificAmerican.com/mar2011

BIOTECHNOLOGY

Organs-on-a-Chip

New devices may help bring drugs to market faster

One of the most challenging aspects of drug development is testing. Scientists are forced either to experiment on whole animals, which is expensive, raises ethical issues and may not predict effects in humans, or to perform tests on microscopic human cells found in tissue cultures, which have been altered to live forever and bear little relation to actual living, breathing people. But researchers are working on a new technique to help bridge that gap: microchips that simulate the activities and mechanics of entire organs and organ systems. These "organs on a chip," as they are called, are typically glass slides coated with human cells that have been configured to mimic a particular tissue or interface between tissues. Developers hope they could bring drugs to market more quickly and, in some circumstances, perhaps even eliminate the need for animal testing.



FELICE FRANKEL *Wyss Institute*

The chips are still in their early stages, but investigators are translating more and more body parts to the interface. Last summer bioengineers at Harvard University wrote in the journal *Science* that they had created a device that mimics a human lung: a porous membrane surrounded by human lung tissue cells, which breathes, distributes nutrients to cells and initiates immune responses. In November 2010 Japanese researchers announced online in *Analytical Chemistry* that they had built a chip that simultaneously tests how liver, intestine and breast cancer cells respond to cancer drugs, and in February 2010 scientists publishing in the *Proceedings of the National Academy of Sciences USA* developed a microscale replica of the human liver that allowed them to observe the entire life cycle of hepatitis C, a virus that is difficult to observe in cultured cells.

Pharmaceutical companies have expressed interest in the chips but are proceeding with caution. The main drawback, some say, is that the chips may not capture certain crucial aspects of living physiology the way whole animal tests do. "If you don't use as close to the total physiological system that you can, you're likely to run into troubles," like being surprised by side effects later on in clinical trials, says William Haseltine, founder and former chairman and CEO of Rockville, Md.-based Human Genome Sciences. Harvard researchers say the chips can provide hints about toxicity: for instance, the lung-on-a-chip initiated an immune response against silica nanoparticles, which are under investigation as possible drug-delivery vehicles.

Ultimately, the goal is to make chips that mimic more complex systems—perhaps even entire humans, says Donald Ingber, director of Harvard's Wyss Institute for Biologically Inspired Engineering and co-creator of the lung-on-a-chip. Scientists could build chips containing cells from patients with specific genetic mutations, which could predict drug responses in specific populations, as well as personalized chips that predict an individual's drug response. "Essentially this would be analogous to human clinical trial design, but all on inexpensive chips," Ingber says. "This is the whole point of bioinspired engineering. You don't have to re-create everything—you just have to get the salient features in." —*Melinda Wenner Moyer*

QUOTABLE

"The MMR scare was based not on bad science but on a deliberate fraud."

—Fiona Godlee, editor in chief of *BMJ* (*British Medical Journal*) on a report her journal published showing that the original paper linking the measles, mumps and rubella vaccine (MMR) with autism was based on falsified information.

SCIENTIST IN THE FIELD

Scrivener to the Stars

A Parisian astronomer tells how he became the unofficial record keeper of exoplanets and when we'll stop discovering new ones

LOUIE PSIHOYOS *Corbis*

What motivated you in 1995 to start the Extrasolar Planets Encyclopedia, which is a Web site that charts data on known and unconfirmed planets outside our solar system? I discovered the Web at the time, and I found it fantastic. I thought that the search for life in the universe is extremely important, and I wanted to make anything I could to encourage work on the search for life and other planets and possibly to unify the community.

PROFILE

NAME
Jean Schneider

TITLE
Astronomer, Paris Observatory

LOCATION
France

Back in 1995 there wasn't much to catalogue. Now there are hundreds of planets and more all the time. How much of your time does this occupy? It's become one hour every morning. The thing is to be regular. You have to keep up with the literature and with people sending information. At this point I know everybody in the astronomy world, so I know what is going on.

Late last year astronomers reported finding the 500th extrasolar planet. Why do you advise caution about celebrating such milestones? There are several reasons for that. First, there is no consensus on what is a planet and what is a brown dwarf [an object that is more massive than a planet but less massive than a star]. We don't know exactly where the planets stop and the brown dwarfs start. Second, there are always errors in measuring mass. But in my opinion, it is better to have a little bit too many objects than only those that are really well confirmed, because this catalogue is also a working tool to help astronomers around the world avoid missing an interesting candidate they can work on. Even so, I estimate that there have been only about five retracted planets, so that is 1 percent.

Still, the list of unconfirmed, controversial and retracted planets now numbers in the dozens. Do you ever get angry e-mails from astronomers about their planets being demoted? Almost never. In 15 years I have received perhaps five to 10 angry messages and hundreds of encouraging messages.

You've been keeping close watch on exoplanets for 15 years. Where do you see things headed in the coming years? I think the number of planets astronomers discover will increase until about 2030 and then begin to stop. Another step will start, which will be to characterize more and more closely these planets. Detect more and more molecules, investigate the climate of these planets, et cetera. Another thing we could eventually do is cartography of the planet—to make a multipixel image, to really see the continents. But this is in 2050.

Once we find habitable planets, how do we find out if they are inhabited? For me, the first priority is to make a spectroscopic investigation of the planets. That means to make an image of the planetary system and to measure the colors, if you want, of the planets in orbit to see what molecules are in the planets, what is the climate evolution around the orbit—to see seasons. For that we will need a direct imaging of the planetary system. This is the top priority. And it is too bad that the decadal survey did not go this way. [*Editors' note: The decadal survey is a report from the National Research Council that guides astronomy research.*]

—*John Matson*

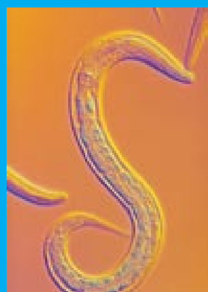
COMMENT AT ScientificAmerican.com/mar2011

NEUROSCIENCE

The Smallest Mind

Scientists use light to make worms start, stop and lay eggs

Researchers have come a step closer to gaining complete control over a mind, even if that mind is smaller than a grain of sand. A team at Harvard University has built a computerized system to manipulate worms—making them start and stop, giving them the sensation of being touched, and even prompting them to lay eggs—by stimulating their neurons individually with laser light, all while the worms are swimming freely in a petri dish. The technology may help neuroscientists for the first time gain a complete understanding of the workings of an animal's nervous system.



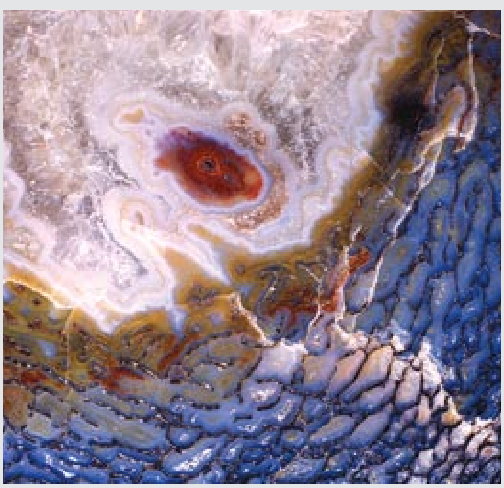
The worm in question, *Caenorhabditis elegans,* is one of the most extensively studied organisms in biology: investigators have completely mapped and classified its cells, including its 302 neurons and the 5,000 or so connections among them. But science still does not know exactly "how neurons work together in a network," says Andrew Leifer, a graduate student in biophysics at Harvard. For example, how does the worm coordinate its 100 or so muscles to relax and contract in a wave pattern as it swims?

To find out, Leifer and his collaborators genetically engineered the one-millimeter-long nematode worm to make particular cells in its body sensitive to light, a technique developed in recent years called optogenetics. Because the worm's body is transparent, sharply focused lasers, pointed with an accuracy of 30 microns, could turn on or suppress individual neurons with no need for electrodes or other invasive methods. Leifer placed a microscope on a custom-built stage to track the worm as it swam around in a dish. He also wrote software that analyzed the microscope's images to locate the target neurons, then pointed and fired the lasers accordingly. The journal *Nature Methods* published the results on its Web site (*Scientific American* is part of Nature Publishing Group).

Other teams have used optogenetics to control individual neurons on immobilized worms. But to understand the organism's physiology, Leifer says, it is necessary to manipulate it as it swims freely. He and his coworkers were able to show, for example, that during swimming, motor signals move down the body through muscle cells themselves as well as through nerve connections.

Leifer thinks the technique could someday help scientists create complete simulations of the organism's behavior. "We hope to be able to make a computational model of the entire nervous system," he says. In a way, that would be like "uploading a mind," though a rudimentary one. —*Davide Castelvecchi*

WHAT IS IT?



Boning up: *Is it art or science? Norman Barker is an expert on both. The associate professor of pathology and art as applied to medicine at Johns Hopkins University shot this cross section of a dinosaur bone at 15× magnification. The bone* (blue)*, from an unknown species, is about the size of a roll of duct tape and was found in the Morrison Formation on the Colorado Plateau, where fossils are common. The iron oxide* (red) *in the quartz-filled* (white) *sample could be part of the marrow or spongy bone, but Barker says "it could also be a tree root that grew and decomposed over the millions and millions of years it takes before the actual specimen becomes fossilized."*

—Ann Chin

SINCLAIR STAMMERS *Photo Researchers, Inc.* (worm); NORMAN BARKER (bone)

TECHNOLOGY

From iPhones to SciPhones

Scientists are developing iPhone apps that aid in research and that appeal to "citizen scientists" as well

1 BIRDSEYE
Developed by the Cornell Lab of Ornithology, BirdsEye has entries on hundreds of the most frequently seen North American bird species and includes images and bird sounds. It helps to guide avid watchers to birds in their area, based on sightings submitted online to eBird.org, a project of Cornell University and the National Audubon Society. Scientists use these observations to figure out the birds' range, movements and abundance.

2 MOLECULES
This app depicts 3-D models of compounds that users can manipulate with their fingers via touch screen. These are more than just pretty pictures—the 3-D structure of a molecule is often crucial to its function, so these models help researchers and amateurs see how they work. "You can show colleagues the structure of a protein wherever you want, such as over lunch," says Columbia University virologist Vincent Racaniello.

3 GEOLOGY
This line of apps from Integrity Logic covering 26 U.S. states provides maps with as many as 50 layers of information, including rock types and ages and the location of seismic faults and past earthquakes. Nonscientists find them helpful, too. Mushroom hunters have used the data on forest fires, as some types grow better after fires, says Integrity Logic founder Max Tardiveau.

4 TIMETREE
When did humans and chimps last share a common ancestor? Scan the tree of life to find out using TimeTree. The app, from scientists at the Arizona and Pennsylvania State universities, searches the massive databases at the National Center for Biotechnology Information, which hold information on more than 160,000 organisms. TimeTree returns answers on divergence times within seconds, including citations of scientific papers.

5 IVEGOT1
Do you want to spot alien invaders? Exotic wildlife such as Burmese pythons and Nile monitors are invading Florida and destroying the ecosystem. To help identify reptiles there, professionals and volunteers can rely on this app, which has photographs of species and data on their features, location, and status as native or exotic.

6 CHEMJUICE
Want to create your own database of molecules on the fly? With ChemJuice, just drag your finger across the touch screen to draw a chemical bond and tap the screen to delete an atom or bond or change its type. The app can also calculate molecular weight, formula and percent composition by element and e-mail the structure wherever you wish—handy for students and professionals. —*Charles Q. Choi*

ARCHAEOLOGY

She's 11, Going on 2,500

Museumgoers get their first glimpse of an average resident of ancient Greece

DNA from a mass grave found in Athens in the mid-1990s helped experts identify typhoid fever as a possible source of the plague that killed off one quarter of the city's population in the fifth century B.C. Now Manolis Papagrigorakis, the University of Athens orthodontist who published the typhoid discovery in 2006, has assisted in restoring the skull of an 11-year-old girl found in that same grave. Known as Myrtis, she is part of the exhibit "Myrtis: Face to Face with the Past" at the Archaeological Museum of Thessaloniki in Greece until March 13. Her reconstruction, the first of a layperson from ancient Greece, is described in the January issue of *Angle Orthodontist.*

Papagrigorakis worked with Oscar Nilsson, an expert on facial reconstruction, who applied a technique often used in forensics that proceeds muscle by muscle. The skull provided the scaffolding for many of the girl's features, and her full set of teeth guided her lips. Richard Neave, who reconstructed Philip II, father of Alexander the Great, is often asked what people looked like in ancient times. Myrtis shows the world, he says, that "people haven't changed." —*Alison McCook*

COURTESY OF APPLE (*iPhone*); YIORGOS KARAHALIS *Reuters* (*Myrtis*)

COMMENT AT ScientificAmerican.com/mar2011

FOOD

A New Spin on Cooking

Chefs are turning to lab equipment to perfect their consommés

RYAN MATTHEW SMITH *Modernist Cuisine LLC*

High-end restaurants have begun adding a new piece of equipment to the kitchen that until recently was found mainly in medical laboratories and university chemistry departments. The bigger versions look a bit like washing machines, but the spin cycle in these ultracentrifuges is a lot more powerful than that of any Maytag. They whirl vials around tens of thousands of times a minute, generating centrifugal forces up to 30,000 times as strong as Earth's gravity.

You might think that such crushing force would be enough to obliterate any foodstuff, but in fact the intense pseudogravity causes fluid foods such as purees—mixtures of liquids and solids of various kinds—to separate. For example, the meat of centrifuge-pureed tomatoes settles, along with bits of skin, in a compact puck at the bottom of the vial. The water in the tomato forms a clear layer in the middle, and the intensely flavorful oil floats above.

Chefs find centrifuges handy for several reasons. A centrifuge saves a cook time: a separation process, such as extracting the oil from a vegetable puree, that might take days under natural gravity finishes in mere minutes at 20,000 g. The results are also much more predictable than those obtained by natural settling. The biggest selling point for these culinary tools, however, is the amazingly clean division they produce among the components. Because the food emerges from the centrifuge separated into distinct strata, it is easy for the cook to then decant or scoop off the layers he or she wants to use.

In many foods, the high-speed spin concentrates the flavor molecules in a powerfully aromatic liquid layer that is ideal for cooking. A chef might use just the water and oil from a centrifuged tomato puree, for example, to make a consommé that has a brilliantly strong tomato flavor yet is perfectly clear. The cooks in our research kitchen at the Cooking Lab in Bellevue, Wash., have used the ultracentrifuge to make sweet and rich carotene butters from carrots. Indeed, centrifuges are great for spinning fat out of all kinds of vegetables and nuts; you can then use the purified fat to make constructed creams having consistencies similar to dairy cream but with dramatic and unexpected flavors—and because they are dairy-free, they are suitable for vegans to eat.

To make a soup or sauce that is transparent and smooth on the tongue, you must somehow remove solid particles that are larger than the tongue can discriminate: about seven microns (a mere 0.0003 inch) in size. Strainers, filters and other culinary tools can do this, with enough time and effort. But it's hard to beat the convenience of just pouring the mixture into a bottle, sticking it in the superspinner and pressing "start."

—W. Wayt Gibbs and Nathan Myhrvold

Myhrvold is author and Gibbs is editor of Modernist Cuisine: The Art and Science of Cooking, *scheduled for publication in March by the Cooking Lab.*

QUOTABLE

"There's a lot of snakes—and I mean a lot."

—Shane Muirhead, a resident of Rockhampton, Australia, on the floods that swept the northern and eastern parts of his country, affecting hundreds of thousands of people, wiping out vital food crops and bringing the mining industry to a halt.

Deborah Franklin is based in San Francisco and has reported on science and medicine for NPR, the *New York Times, Fortune* and *Health Magazine.*

Uninformed Consent

Technology can help individuals weigh the risks and benefits of an invasive medical procedure, experts say, but only if doctors and patients keep talking

Much of what happens to you in the hospital in the name of diagnosing and healing is invasive. Depending on what ails you, a doctor may need to ream out an artery to get more blood to your heart, or flood your body with a poison to kill cancerous cells, or saw through the bones of your leg to replace a crumbling hip or a worn-out knee. If a stranger came at you with a scalpel or syringe in a back alley, you would consider it assault and battery. But in a hospital most of us willingly schedule an appointment and pay big money to be precision-poked and carved because we trust our doctor's skill and knowledge and assume the alternatives—illness, incapacity or early death—are surely worse.

But how many patients truly understand the alternatives or the risks and benefits of the test or treatment they are undergoing? One of the guiding principles of modern health care is that, except in an emergency, doctors must get the patient's permission before the start of any invasive medical procedure. That "informed consent" is supposed to be based on an earlier conversation during which physicians make sure patients understand what the procedure will and will not do, along with its benefits and risks relative to other options.

Unfortunately, what typically happens in hospitals and clinics across the U.S. is far from ideal: On the way into surgery or some test or treatment, a nurse or technician slips the patient a clipboard of legalese to sign. In most cases, that piece of paper is either a vague permission slip acknowledging that the patient has been "informed" about the procedure, or it reads like a legal waiver—a laundry list of every single side effect and rare complication that could possibly go wrong. These badly written, hastily signed forms are meaningless or worse, health literacy experts say. Research consistently confirms that the flawed permission slips do not improve the patient's understanding or safety. Nor do they protect hospitals or doctors from misguided malpractice suits.

In hopes of filling the gap, a growing number of medical centers are now turning to technology—specifically, interactive computer programs that are designed to get beyond the one-size-fits-no-one consent form. These software solutions vary widely in approach and targeted audience. Some are aimed at doctors, others at patients. Some are meant to be reviewed with a health care provider during an office visit; others can be watched with family members at home. Health researchers still debate each approach's effectiveness. Rigorous outside testing of them has barely begun. But everyone lauds the goals these new approaches share. First, the programs aim to help make the discussion of the relative pros and cons of every invasive procedure—from angioplasty to tonsillectomy—more meaningful for the patient. Second, they aim to get doctors talking about benefits and risks much earlier in the diagnostic and treatment process so that patients can make truly informed choices about their own health care.

Strong evidence that traditional consent forms fail to inform patients or improve their care has been growing for more than a decade, says Harlan M. Krumholz of Yale University, who studies the ways the system goes wrong. One of the most telling nationwide investigations, he says, was a review published in 2000 of 540 forms collected from 157 randomly selected U.S. hospitals by a public health team led by Melissa M. Bottrell, then at New York University and now with the U.S. Department of Veterans Affairs. Its analysis revealed a haphazard mess: Some forms were short and vague; others were long and confusing. Many contained legalistic language that muddied the decision-making character of the consent process. Only about one in four of the forms went beyond a basic description of the procedure to include common risks, benefits and alternatives.

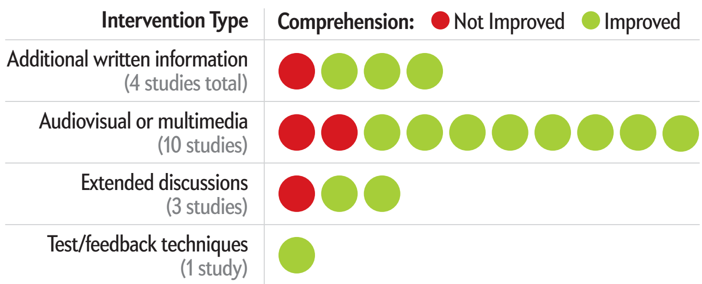
Illustration by Thomas Fuchs

In nearly 60 percent of the documents studied, protecting "against liability" was the rationale given for using the permission slips, according to the hospitals submitting the forms. Too often, Krumholz says, the informed consent process has deteriorated into "largely a risk management tool for hospitals—a way to try to avoid malpractice suits—instead of a way to promote good decisions. And that seems to me a real shame."

Often the forms do not achieve even that self-defensive aim, says attorney Jeffrey F. Driver, who advises Stanford University Medical Center on medical malpractice cases. For one thing, research suggests the legalistic tone of such forms irks patients and makes them suspicious of their doctor and the hospital, and that suspicion may increase the likelihood of a later suit. Plus there is good evidence that the long list of potential medical complications does nothing to help people distracted by illness or anxiety understand that even a medical procedure performed perfectly may still produce undesirable results, Driver says. His research showed that patients often sue because they mistakenly assume that a known complication of their procedure is the result of medical error. Lengthy forms only fueled such cases. "We realized what we needed was much better patient education up front," Driver says, "to make sure the patient's expectations of what could happen were similar to the doctor's."

Communication is essential no matter what the approach. Dean Schillinger, an internist and health literacy specialist at the University of California, San Francisco, and his colleagues recently published a review of 44 small studies of different programs aimed at improving the informed consent process. The key to enhancing patient understanding of risks and trade-offs, they found, was to have a high-quality discussion—whether prompted by a computer program or in response to a simply written printed explanation of pros, cons and alternatives. Anything that got patients to reiterate what they have learned in their own words significantly improved the consent process.

Improving the outcome: **Various efforts to change the informed consent process can lead to better results, according to a review of 44 studies. A closer look at the 18 highest-quality reports (*below*) determined that meaningful communication between clinicians and patients is vital to understanding the benefits and risks of invasive procedures.**



SOURCE: "INTERVENTIONS TO IMPROVE PATIENT COMPREHENSION IN INFORMED CONSENT FOR MEDICAL AND SURGICAL PROCEDURES: A SYSTEMATIC REVIEW," BY YAEL SCHENKER, ALICIA FERNANDEZ, REBECCA SUDORE AND DEAN SCHILLINGER, IN *MEDICAL DECISION MAKING*, PUBLISHED ONLINE MARCH 31, 2010

TWO NEW OPTIONS

One of the first decisions hospitals face when purchasing a technology-based system is whether they want to focus more on the physician's side of the informed consent process or the patient's side. In 2006 the Stanford Medical Center chose a patient-oriented product from a Chicago-based company, Emmi Solutions.

Patients log on to one of Emmi's online computer modules from the doctor's office or at home. All the programs are interactive and self-paced, typically taking about 30 minutes to complete, although they can be paused or reviewed. Nearly 200 frequently performed procedures—from colonoscopy to hip replacement—are covered. Doctors can enable the viewer to type a question to them or someone else on their staff and send it for a response in an online chat.

One of the audiovisual program's advantages over strictly paper-based forms is that it automatically checks for comprehension and flags certain items for deeper discussion. For example, the program keeps track of all questions raised by patients as well as every time they request more information. That list alerts the doctor to address the remaining concerns or confusion during the next appointment. Then, before the procedure, patients still sign a very brief written consent, signifying they have watched the interactive program and have had a discussion with their doctor. "Informed consent is the process, not the form," Driver says. "The piece of paper should just be a tickle to their memory about what's been discussed."

The ability to keep track of a patient's every click and screen view may also keep malpractice costs down. A would-be litigant dropped her malpractice charge against Stanford when she was shown that her pattern of computer clicks confirmed that she had actually looked at a screen shot describing that complication four times and discussed it with her doctor.

Meanwhile the Veterans Health Administration has chosen a different path, relying on software aimed at doctors. A program called iMedConsent, by Dialog Medical in Atlanta, allows the health team to quickly create consent forms and packets of educational materials tailored to each patient's needs. Doctors type the name of any of 2,200 medical conditions, treatments or procedures into the program, and a consent form specific to that condition or procedure pops up on the screen. Different parts of the online template detail the procedure's benefits, risks and alternatives in sixth-grade English or Spanish. The template also prompts doctors to discuss with patients their prognosis if they choose to have no treatment or procedure at all.

If more information is required, physicians can call up and print out educational brochures or illustrations from Dialog Medical's extensive online library. The patient and doctor can study the information together on the screen, or the patient can take it home to review it at his or her own pace with family members. Because the forms become part of the patient's electronic medical record, anyone on the health team throughout the VA system can easily check to see what sort of consent discussion occurred and answer any further questions.

U.C.S.F.'s Schillinger applauds any attempt to make the informed consent process "more than just a medical Miranda warning." But he is concerned that there has not been enough independent research to evaluate the effectiveness of various approaches to providing informed consent. Nevertheless, one thing is clear. True face-to-face interactions turn out to be the best medicine. ■

COMMENT ON THIS ARTICLE ONLINE
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Graphic by Jen Christiansen

David Pogue is the personal-technology columnist for the *New York Times* and host of the new science miniseries *Making Stuff* on PBS.

Gadget Politics

The truth behind what makes technology's true believers tick

I've been a consumer technology critic for over 10 years. During that time, hate mail has been part of my job every day.

In the early days I thought I understood it. Back then, it was all about Microsoft versus Apple. It was easy to see why people took sides: Apple was the underdog taking on an established giant. It was fun to root for one side or the other.

Today, though, there are fanboys and haters ready to attack every conceivable position in the tech world—"position," of course, meaning "company or product." Mention almost any big name, and you'll hit a raw nerve: iPhone. Android. Kindle. Canon. Nikon. Google. Facebook. And, of course, Apple or Microsoft.

We're not talking about civil disagreements, either. We're talking about name-calling, hair-pulling, toxic tantrums, featuring a whole new arsenal of modern-age putdowns (the suffix "-tard" is always popular). It's gadget hate speech.

At tech conferences, we columnists compare notes on the hostility of our hate mail. Doesn't matter if you think you're being evenhanded in the review; someone will flame you for it.

So when the Apple iPad debuted last year, I tried a crazy experiment: I wrote two reviews in the *New York Times* in a single column, taking opposite positions. One was for the fanboys—all positive. One was for the haters—all negative. Surely, I thought, this would satisfy everyone.

FOUR CLASSIC GADGET WARS
ScientificAmerican.com/mar2011/pogue

Incredibly, though, the stunt pleased nobody. The anti-Apple bloggers wrote about my "love letter" to the iPad; the fanboy bloggers foamed at the mouth about the "hatchet job" I'd written. Each side ignored half of the review!

Later, I learned that I was witnessing a well-documented cognitive bias: the hostile media effect. It says that people who hold strong opinions about an issue perceive media coverage of that issue to be biased against their opinions, regardless of how neutral the coverage may be. But that phenomenon usually applies in politics, not electronics. That could only mean one thing: that gadget brands have, in fact, become politicized.

What's going on here? Why do people work themselves into such a lather over their choice of phone, for heaven's sake?

First, tech companies these days work hard to link their products to style and image. Those colorful, silhouetted dancing iPod ads never mention a single feature—except how cool it makes you. The message seems to be, "You're not worthy if you don't buy one"—and suddenly, if someone disses your gadget, they're also dissing you as a person.

A second factor is that gadgets are expensive, and they quickly become obsolete. You become invested in the superiority of your purchase. People see you using it, judging your choice—so you defend your choice. Insult my gadget? You're insulting me.

The old Apple underdog phenomenon is still at play, too—but now in reverse. Apple is now the overlord of music players, tablet computers and app phones. Forget the 1997 Apple commercials that encouraged us to "Think different." Today if you buy Apple, you're not an iconoclast—you're a sheep. Those who once would have rooted for Apple the underdog now root against it.

For the same reason, Facebook and Google gain their own hater populations as they grow bigger and more prosperous. Size and success naturally stoke suspicion and cynicism.

But why gadgets? You don't encounter this degree of rabid partisanship among customers of rival clothing stores, insurance companies or banks, and those are large companies, too. And why now? I mean, you didn't hear about people in the 1950s flying into name-calling rages over their choice of toaster oven or gangs in the 1980s starting rumbles about brands of hair gel.

Easy: Because of the Internet effect. The kinds of people who peg their self-worth to their gadgets are precisely the kind of people who live online, where the standards for civility are very different from the real world's. When you're online, you're anonymous, so you don't experience the same impulse control you would if you were face-to-face with somebody.

Is there hope for a détente in the electronics wars? Not as long as nobody knows your real identity online, as long as the gadget mill cranks out new models twice a year, and the marketing machines make us believe that our self-worth depends on the brands we carry.

That's my opinion, anyway. And if you disagree with me, you're an idiot-tard. SA

Illustration by John Hersey

PSYCHOLOGY

THE NEUROSCIENCE OF TRUE GRIT

When tragedy strikes, most of us ultimately rebound surprisingly well. Where does such resilience come from?

By Gary Stix

IN FALL 2009 JEANNINE BROWN MILLER WAS DRIVING HOME WITH HER husband after a visit with her mother in Niagara Falls, N.Y. She came upon a police roadblock near the entrance to the Niagara University campus. Ambulance lights flashed up ahead. Miller knew her 17-year-old son, Jonathan, had been out in his car. Even though she couldn't make out what was happening clearly, something told her she should stop. She asked one of the emergency workers on the scene to check whether the car had the license plate "J Mill." A few minutes later a policeman and a chaplain approached, and she knew, even before they reached her, what they would say.

The loss of her son—the result of an undiagnosed medical problem that caused his sudden death even before his car rammed a tree—proved devastating. Time slowed to a crawl in the days immediately after Jonathan's death. "The first week was like an eternity," she says. "I lived minute by minute, not even hour by hour. I would just wake up and not think beyond what was in front of me."

IN BRIEF

Convention held that psychological resilience to life's stresses remained a fairly rare event, a product of lucky genes or good parenting.

Research into bereavement and natural disasters has found in recent years that the quality of resilience is, in fact, relatively commonplace.

People respond to the worst life has to offer with varied behaviors, some of which might be classified as narcissistic or dysfunctional in some other way.

But these behaviors—coping ugly, as one researcher calls it—ultimately help with adaptation in a crisis.

The question arises whether interventions to teach resilience—programs already instituted in schools and in the military—will really help if people cope naturally on their own.

PHOTOGRAPHED AT THE DEPARTMENT OF PSYCHOLOGY AND INSTITUTE FOR NEUROSCIENCE, UNIVERSITY OF TEXAS AT AUSTIN

Photograph by Adam Voorhes

Jeannine Brown Miller, who weathered her son's death in 2009, touches the tree into which Jonathan's car crashed.

Support came from multiple places, including her own personal decisions. Five hundred of Jonathan's classmates from Lewiston-Porter High School attended the wake and funeral, a demonstration of sentiment that helped to assuage the pain. She also found solace in her devout Catholic faith. After two weeks she returned to work as a human resources consultant. A couple of months after the accident she could visit the restaurant where she and her son had breakfasted the day he died. Support from the community never wavered. A ceremony honored Jonathan at the high school graduation, a Jonathan "J Mill" Miller Facebook page receives regular updates, and a local coffee shop serves "76" coffee in memory of his now retired football number. A year on she still cries every day, but she has found many ways to cope.

When the worst happens—a death in the family, a terrorist attack, an epidemic of virulent disease, paralyzing fear in the midst of battle—we experience a sense of profound shock and disorientation. Yet neuroscientists and psychologists who look back at the consequences of these horrific events have learned something surprising: most victims of tragedy soon begin to recover and ultimately emerge largely emotionally intact. Most of us demonstrate astonishing natural resilience to the worst that life throws our way.

The study of resilience is starting to uncover a series of underlying mechanisms through brain imaging and gene databases in addition to psychologists' traditional tools of social science questionnaires. After disaster strikes, biochemical, genetic and behavioral factors act together to restore our emotional equilibrium. Research seeks insights into the foundations of emotional strength—an understanding that may someday teach us what to do when the natural healing processes fail.

In the meantime, schools, the military and the corporate world are not waiting for a complete picture of genes, neurotransmitters and the rest before embarking on programs to inoculate against life's biggest stresses. In the absence of a definitive handbook on hardiness, a vigorous debate has emerged over whether any attempt to toy with what may be an innate quality may leave us worse off. The debate has special urgency now, as the U.S. Army begins a gargantuan training program to inculcate resilience in more than a million soldiers and their families, perhaps one of the largest psychological interventions ever undertaken by a single institution.

THE MECHANISMS OF RESILIENCE

SIGMUND FREUD had written in 1917 of the necessity of "grief work" in which we take back the emotional energy, or libido, as he called it, that had been invested in the now "non-existent object"—in other words, the deceased. This century-old view of the psyche as a plumbing system for channeling subliminal life forces prevailed, in the absence of evidence to the contrary, until recent decades. That is when psychologists and neurobiologists began to probe for alternative explanations.

One of the things they began to look at is the nature of resilience. The term "resilience" (from the Latin *re* for "back" and *salire* for "to leap") joined the psychological lexicon from the physical sciences. In a psychological sense, says University of California, Los Angeles, resilience researcher Christopher M. Layne, "it basically means that you spring back to functioning in a short period," like a steel beam, which bends under stress and returns afterward to where it started. Of course, no little metal strip in our heads acts as a thermostat that bends when our emotions run hot, triggering a neurochemical cascade that returns us to a set point of emotional equilibrium. Scientists have found that our biology is more complicated than the analogy from metallurgy.

Resilience begins at a primal level. If someone takes a swing at you, the hypothalamus—a relay station in the brain that links the nervous and endocrine systems—churns out a stress signal in the form of corticotropin-releasing hormone, which begins a chemical deluge telling you to put up your dukes or head for the hills. Your brain pulsates like a flashing light: fight or flight, fight or flight. Afterward, the biological typhoon subsides. If you are constantly called on to defend your turf, a set of stress hormones gush constantly. One of them, cortisol, produced by the adrenal glands near the kidneys, can actually damage brain cells in the hippocampus and amygdala, regions involved with memory and emotion. So you end up an emotional and physical wreck. Luckily, the vast majority of us have resilience on our side.

Stress hormones, aided by certain protective biochemicals, seem to switch off more readily in people who are resilient. In recent years scientists have discovered a number of biological signposts that indicate that a person might be capable of toughing it out. The list is long and involves chemicals such as DHEA (dehydroepiandrosterone), which lessens the effects of cortisol, and neuropeptide Y, which appears to, among other things, reduce anxiety by counteracting the effects of corticotropin-releasing hormone, released by the hypothalamus. In 2000 Dennis S. Charney and other researchers at the Yale University–affiliated VA Hospital in West Haven, Conn., found that under the intense stress of mock interrogations, U.S. soldiers with higher blood levels of neuropeptide Y performed better during the exercise. Later, in 2006, Rachel Yehuda and others at the Bronx Veterans Affairs Medical Center discovered that elevated levels of the chemical in combat veterans meant a lower risk of post-traumatic stress disorder.

Many biological pathways—chains of interacting proteins—contribute to something as multifaceted as resilience. So far, though, scientists have put together little more than a tantalizing collection of hints of the biological profile of the hardy soul. In May 2010 Eric J.

Photograph by John Hryniuk

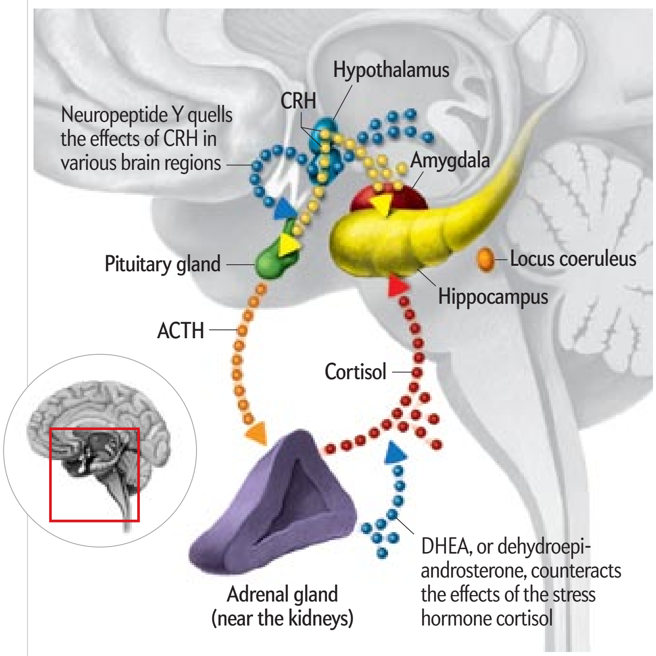
Nestler of Mount Sinai Medical Center and his colleagues reported, for instance, on a protein, called DeltaFosB, that appears to protect mice and possibly humans against stress induced from being alone and isolated or threatened by more aggressive mice. DeltaFosB acts as a molecular switch that turns on a whole set of genes (inducing production of the proteins they encode). It registered high levels in resilient rodents and was deficient in postmortem brain tissue of depressed patients. A drug that boosts DeltaFosB might protect against depression and bolster resilience more generally.

Still, it will be a while before an energy drink gets stoked with resilience powder. A pill that ups the brain's production of DeltaFosB might one day become a reality. For the time being, the work remains confined to rodents, as investigators explore the subtleties of a chemical that not only enables mice to nobly withstand the best efforts of laboratory researchers to scare them to death but may also, more ominously, play a role in the rewarding sensations of drug addiction.

RESILIENCE BOOSTERS

Toning Down the Brain's Alarm System

When faced with danger, the brain initiates a chemical cascade that primes you to put 'em up or run away. In turn, a series of chemicals in the brain can dampen this response, thereby promoting resilience to stress. One key chemical cycle begins when the hypothalamus releases corticotropin-releasing hormone (CRH), causing the pituitary gland to secrete adrenocorticotropin hormone (ACTH) into the bloodstream, which triggers the adrenal glands (near the kidneys) to release the hormone cortisol. Cortisol heightens the body's ability to respond to challenging situations, but too much can over time cause lasting damage. To help keep things in check, a series of chemicals (*two shown below*) dampens the stress response. Drugs or psychotherapy might stimulate production of these stress busters.



An array of other genes and proteins may contribute, but as with DeltaFosB, researchers must tread cautiously. The *5-HTT* gene, once thought to be a key "resilience gene," provides a cautionary tale of the pitfalls of a purely genetic approach. Nearly a decade ago a number of studies showed that people with the lengthier version of this gene seemed to resist depression more ably than those who had the shorter form—in other words, they were more resilient.

The gene made it big in 2006, when a *New York Times Magazine* article pointed to the imminent arrival of a commercial *5-HTT* test to assess resilience. This early optimism quickly faded into confusion (a common pattern in studies purporting to tie a complex behavior to a single gene). Two recent so-called meta-analyses of studies found that the evidence did not confirm a link between a variant of the *5-HTT* gene and depression induced by stressful life events. Another one did find a connection. If the gene is linked to resilience, the tie is likely a weak one. Ultimately, the psychobiology of resilience may lead to new drugs and more precise methods of assessing our adaptation to life stresses. For now, immediate insights into understanding the resilient self will come not from studying a gene or cell receptor but rather from performing old-fashioned face-to-face interviews with those immersed in personal crisis.

COPING UGLY

BEHAVIORAL SCIENTISTS have accumulated decades of data on both adults and children exposed to trauma. George A. Bonanno of Teachers College at Columbia University has devoted his career as a psychologist to documenting the varieties of resilient experience, focusing on our reactions to the death of a loved one and to what happens in the face of war, terror and disease. In every instance, he has found, most people adapt surprisingly well to whatever the world presents; life returns to a measure of normalcy in a matter of months. The theme of his research pervades the corner office in an aging building at Columbia. On the inner door, he has pasted a clipping from a German newspaper that profiled him with a headline: "S**t Happens, Bonanno Says."

Bonanno started researching how we respond emotionally to bereavement and other traumatic events in the early 1990s while at the University of California, San Francisco. In those days, the prevailing wisdom held that the loss of a close friend or relative left indelible emotional scars—and Freudian grief work or a similar tonic was needed to return the mourner to a normal routine. Bonanno and his colleagues approached the task with open minds. Yet, again and again during the experiments, they found no trace of psychic wounds, raising the prospect that psychological resilience prevails, that it was not just a rare occurrence in individuals blessed with propitious genes or gifted parents. This insight also raised the unsettling prospect that latter-day versions of grief work might end up producing more harm than good.

In one example of his work, Bonanno and his colleague Dacher Keltner analyzed facial expressions of people who had lost loved ones recently. The videos bore no hint of any permanent sorrow that needed extirpation. As expected, the videos revealed sadness but also anger and happiness. Time and again, a grief-stricken person's expression would change from dejection to laughter and back.

Were the guffaws genuine, the researchers wondered? They slowed down the video and looked for contraction of the orbicularis oculi muscles around the eyes—movements known as Du-

Illustration by Jen Christiansen

MARKO GEORGIEV *Getty Images*

Hurricane Katrina **tested the resilience of New Orleans residents.**

chenne expressions that confirm that laughs are what they seem, not just an artifact of a polite but insincere titter. The mourners, it turns out, exhibited the real thing. The same oscillation between sadness and mirth repeated itself in study after study.

What does it mean? Bonanno surmises that melancholy helps us with healing after a loss, but unrelenting grief, like clinical depression, is just too much to bear, overwhelming the mourner. So the wiring inside our heads prevents most of us from getting stuck in an inconsolable psychological state. If our emotions get either too hot or cold, a kind of internal sensor—call it a "resilience-stat"—returns us to equilibrium.

Bonanno expanded his studies beyond bereavement. At Catholic University and later Columbia, he interviewed survivors of sexual abuse, New Yorkers who had gone through the 9/11 attacks and Hong Kong residents who had lived through the SARS epidemic. Wherever he went, the story was the same: "Most of the people looked like they were coping just fine."

A familiar pattern emerged. In the immediate aftermath of death, disease or disaster, a third to two thirds of those surveyed experienced few, if any, symptoms that would merit classification as trauma: sleeping difficulties, hypervigilance or flashbacks, among other symptoms. Within six months the number that remained with these symptoms often fell to less than 10 percent.

Yet if most of these people did not confront lasting harm, what were they feeling? Had they escaped unscathed? It was difficult to know. The introduction of post-traumatic stress disorder into the *Diagnostic and Statistical Manual of Mental Disorders* in 1980 had tended to narrow psychologists' perspective. The framework established by the diagnostic manual tended to push researchers toward study of only groups who met the rote classification of post-traumatic stress disorder. The new trauma designation meant that patients who displayed symptoms of stress would get shoved into this diagnostic basket, even if they were ultimately capable of muddling through.

Bonanno began to inspect the feelings of those who had not sought psychological help. Subjects in social science research have notoriously distorted recollections of past events when they fill out questionnaires: when their worlds cave in, they may exaggerate how bad things are or remember them as overly catastrophic. To compensate, Bonanno began to do so-called prospective studies in which he would follow groups of varied ages before some of the individuals in those groups would die, a technique that helped to eliminate what psychologists label recall bias. He also began to use a sophisticated statistical technique—latent growth mixture modeling—that enabled him to delineate more precisely the specific type of reactions people experienced following trauma.

Similar to the earlier laughter studies, these more incisive looks at the bereavement process captured a wide range of responses that did not fit neatly into categorizations used to designate healthy adaptation. The messiness of it all prompted Bonanno to label the less classic responses "coping ugly." Some people engaged in "self-enhancing bias"—inflated perceptions of who they were and how they acted, behavior that, in other circumstances, may have bordered on narcissism. For the mourner, these slight distortions may have served to avoid rumination: Could I have done something different to prevent this from happening?

Ego boosting was not the only strategy. Others repressed negative thoughts and emotions—and some just convinced themselves that they could handle whatever came their way. Still others laughed and smiled their way through, even though many psychologists would consider this an unhealthy form of denial. Bonanno found that coping ugly served not only the bereaved but also Bosnian civilians in Sarajevo in the aftermath of the Balkan conflict and witnesses of the 9/11 attack on the World Trade Center Towers. The people were similar to Fred Johnson, who coped his way through the aftermath of Hurricane Katrina.

Johnson, 57, a lifelong New Orleans resident responded to Katrina by helping with the posthurricane rescue at the Superdome. The lines snaking from the stadium to board buses leaving the city furnished a disquieting spectacle. Some parents were so distraught as they emerged from the stadium that they tried to hand their young children to the rescuers. Others had soiled themselves. Aghast when he first witnessed the scene, Johnson lost it. He moved away from the entrance of the giant structure and burst into tears. The whole thing was just too much. Then a few minutes later he stopped, and what he calls his "governor" kicked in. Johnson explains: "When I become overwhelmed, I think my process is this. I'm going to cry about it, I'm going to dry my eyes and then I'm going back to work, but I'm not going to keep crying, crying, crying. I think that's my governor. That's how I keep my sanity."

Bonanno's work has won acclaim, but not everyone remains convinced that resilience is as innate as his studies suggest. Some colleagues claim that he defines the term too broadly. Bonanno acknowledges that adversity in childhood can lead to more lasting consequences than transient emotions that arise after a death in the family or a natural disaster. Yet the reactions of most adults, whether to a job loss or a tidal wave, reveal that the ability to rebound remains the norm throughout adult life.

BE ALL THAT YOU CAN BE

IF RESILIENCE PREVAILS as the status quo for virtually all of us, what about the 10 percent or so who, in the face of emotional trauma, will fail to bounce back and instead become mired in anxiety and depression? Is it possible to train them to bear up better? The jury is still out, but the evidence at hand suggests caution. Psychologists and aid workers who descend on a disaster scene have often intervened with a technique called critical incident stress debriefing. It requires individuals or a group to talk about their experiences to rid themselves cathartically of nascent trauma symptoms. Victims of the Columbine High School shootings and the Oklahoma City bombing went through debriefings.

Several studies over more than 15 years have shown the technique is not effective and might cause harm. Sometimes one frazzled person in a group session can infect panic in others, making things worse for most of the participants. After the 2004 Indian Ocean tsunami, the World Health Organization warned against debriefings because they might prompt some victims to feel more unsettled. The experience with debriefings raises questions about newer attempts to inculcate resilience by mustering techniques from the armamentarium of positive psychology.

The positive psychology movement had its formal coming-out ceremony in 1998, when Martin E. P. Seligman, a professor at the University of Pennsylvania, advocated at the annual meeting of the American Psychological Association that mental illness should not be the sole preoccupation of his discipline. Seligman came to positive psychology from his discovery that dogs went into a state of abject submission—what he called "learned helplessness"—after exposure to electrical shocks. Seligman took inspiration from that research to explore the prospect of clinical interventions that accomplish the polar opposite: encouraging optimism, well-being and, yes, resilience in patients.

MORE ABOUT RESILIENCE TRAINING
Scientific American.com/mar2011/resil-training

Seligman became instrumental in launching the Penn Resiliency Program two decades ago, which has proved its worth, particularly among school-age children. Drawing from theories of depression, the training involves techniques such as the mental reframing used by cognitive-behavioral psychologists to get patients to revise thoughts in a more positive light. Evaluations of the program through at least 21 controlled studies in 2,400 children ages eight to 15 showed success in preventing depression and anxiety.

Now the U.S. Army is scaling similar methods to more than one million soldiers and their families, in what it labels as likely the "largest deliberate psychological intervention" ever attempted. The $125-million, five-year program already has 800,000 soldiers working with an online "global assessment tool," a psychological test that measures emotional and spiritual well-being, among other factors, and taking training courses to enhance "fitness" in various aspects of emotional resilience. Each month 150 soldiers come to the University of Pennsylvania to learn how to teach resiliency to others in the military. Ultimately, Seligman foresees the data gathered from these programs going into a huge database of psychological and health statistics, which civilian researchers will mine for resilience studies. "This is science taken to a level that psychology's never had before," Seligman says.

The program got off to a rushed start: Army Chief of Staff William Casey was anxious to help rank-and-file soldiers who faced repeated deployments. No pilot studies attempted to probe whether a program that had worked for teenagers would carry over to a soldier facing a third tour in Iraq. As the program progresses, researchers will measure whether soldiers better withstand the stresses of military life. "Even though we're building this in midair, it's still being rigorously evaluated," Seligman observes.

Bonanno, for one, has pointed to the lack of evidence for the effectiveness of the program—and in light of the checkered history of previous interventions, he wonders whether more harm than good might result. He has collaborated on an unpublished study that tracked over 11 years some 160,000 soldiers throughout the military, half of whom had at least one deployment to Iraq or Afghanistan. Nearly 85 percent who went were deemed resilient, judged by an absence of trauma symptoms, and only 4 to 6 percent had diagnoses of post-traumatic stress disorder. "If most people are resilient, as they seem to be in all the studies we've done, what happens to those people if you give them stress-inoculation training?" Bonanno asks. "Can you make them less resilient? That's a question that I think is imperative to answer."

The entire military has not embraced universal resilience training. William P. Nash, a physician formerly charged with overseeing stress-monitoring programs for the U.S. Marines, says there is little evidence for prophylactic resilience training. He compares the situation in the military to professional football. No matter how much players train during, the week, they still get bruised and battered on Sundays. "You can never prevent bad things from happening," Nash says. "In the same way, you can't prevent people from getting damaged by stress."

Can anything be done to promote a person's ability to cope in the face of adversity? Arming people beforehand may or may not work. Sophisticated drug therapies are years away. After a disaster, the most experienced investigators—psychologists and other health professionals from the National Center for PTSD—have developed an approach designed to encourage a person's own coping abilities rather than introspective delving into psychopathological reactions. "If someone is okay, you're acknowledging that they're okay," says Patricia Watson, who helped to originate this technique. Psychological First Aid, its formal name, recognizes that many handle things well on their own: it focuses first on the practical. Food and shelter take precedence, but victims also learn about help available and how to monitor their own progress. After 9/11, some of those who had been near the World Trade Center thought anxiety and depression were to be expected three months after the calamity, and so they ignored the kind of help available for those with more than just passing symptoms. "People ended up suffering longer than they had to because they thought this was just normal," Watson says. For victims of full-fledged post-traumatic stress disorder, various psychiatric drugs as well as cognitive-behavioral therapy that exposes a patient to the source of stress have shown some success.

The new science of resilience shows that one size does not fit all in coming to terms with what befalls us. Sometimes the worst does happen, but our innate capacity to bounce back means that most of the time things turn out all right. SA

Gary Stix *is senior writer at* Scientific American.

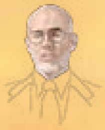
MORE TO EXPLORE

The Other Side of Sadness: What the New Science of Bereavement Tells Us about Life after Loss. George A. Bonanno. Basic Books, 2009.

Flourish: A Visionary New Understanding of Happiness and Well-being. Martin E. P. Seligman. Free Press, 2011.

Scott L. Murchie got interested in rocks because there were so many of them outside his family's house in New England. Now a geologist at the Johns Hopkins University Applied Physics Laboratory (APL), he analyzes the spectrum of reflected sunlight to work out the structure and history of planetary crusts.

Ronald J. Vervack, Jr., also at APL, traces his lifelong interest in planetary science to a four-inch telescope his grandparents gave him for Christmas. Having never really grown up, Vervack is fascinated by all things planetary, studying atmospheres, comets and asteroids at a variety of wavelengths.



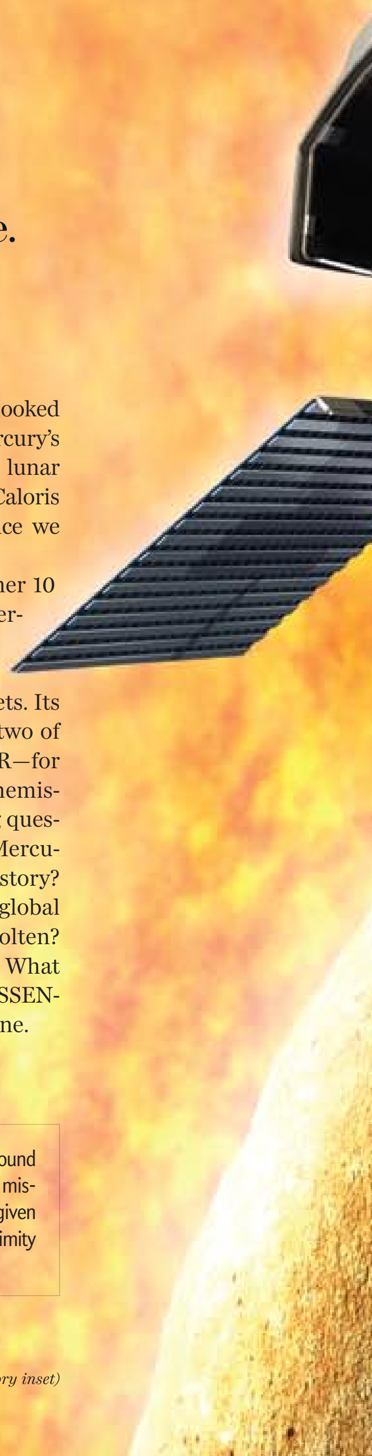
Brian J. Anderson, at APL, too, specializes in planetary magnetic fields, magnetospheres and space plasmas. In his free time, he sings in community choruses. "Singing was my first love," he says, "but my natural aptitude was for science. So now I support my musical life with this amazing research career."

SPACE SCIENCE

Journey to the Innermost Planet

Mercury has never been orbited by a spacecraft before. That will change this month

By Scott L. Murchie, Ronald J. Vervack, Jr., and Brian J. Anderson



THE OLD JOKE GOES THAT THE ONLY THING worse than finding a worm in an apple is finding half a worm. Planetary scientists had a similar feeling on March 29, 1974, when the Mariner 10 space probe flew by Mercury and gave humanity its first good look at this tiny inferno of a world. It discovered, among other features, one of the largest impact basins in the solar system, later named Caloris. Yet its pictures captured only half the basin; the other half remained cloaked in darkness. In fact, between this visit and the second and third flybys later in 1974 and in 1975, Mariner 10 imaged less than half the planet's surface.

It was not until 34 years later that we finally saw the entire basin illuminated, and it was even more impressive than the early images suggested. On January 14, 2008, the MESSENGER spacecraft swung by Mercury, and the first image it transmitted to Earth was very nearly centered on Caloris. When our colleague Nancy Chabot showed the image to the team, everyone cheered—but only briefly, because then we launched into an intense discussion of what exactly we were seeing. It looked like a negative image of the moon. Although Mercury's cratered surface was reminiscent of the moon's, lunar basins have dark, lava-filled interiors, whereas Caloris was filled with light-colored plains—a difference we have yet to fully understand.

INSIDE MESSENGER
ScientificAmerican.com/mar2011/mercury

This month MESSENGER does what Mariner 10 was unable to: it will enter into orbit around Mercury to study the planet in depth, rather than just catching fleeting glimpses during flybys. Mercury is the least explored of the inner planets. Its landforms and brightness variations are only two of its mysteries. Launched in 2004, MESSENGER—for MErcury Surface, Space ENvironment, GEochemistry, and Ranging—is designed to answer six big questions: What is the composition of Mercury's surface? What is its geologic history? How can such a small planet have a global magnetic field? Is its metallic core molten? What are the radar-bright patches at the poles? What processes govern the tenuous atmosphere? MESSENGER should finish what Mariner 10 left half-done.

IN BRIEF

Mercury baffles scientists. Only half again as large as the moon, it has Earth-like features such as a global magnetic field. Its surface is heavily cratered yet has signs of comparatively young geologic activity.

In 2008 and 2009 NASA's MESSENGER space probe made the first flybys of Mercury since the mid-1970s. It captured images of a hemisphere never before seen in detail and saw unexpectedly turbulent plasma activity.

On March 18 it finally enters into orbit around Mercury and begins a one-year orbital mission. Just getting there has been hard, given the planet's high orbital speed and proximity to the sun.

Illustrations by Don Foley (MESSENGER) and Jen Christiansen (trajectory inset)

GETTING TO MERCURY

Descent to Hades

One reason it took three decades to follow up the Mariner 10 mission is that getting to Mercury and surviving there are technologically challenging. A spacecraft on a direct path from Earth falls into the sun's gravitational field and accelerates to almost 13 kilometers per second faster than Mercury's orbital velocity. A conventional rocket engine could not slow the spacecraft enough to be captured into orbit by the planet's gravity. In terms of energy, Mercury is harder to reach than Jupiter, even though Jupiter is much farther away.

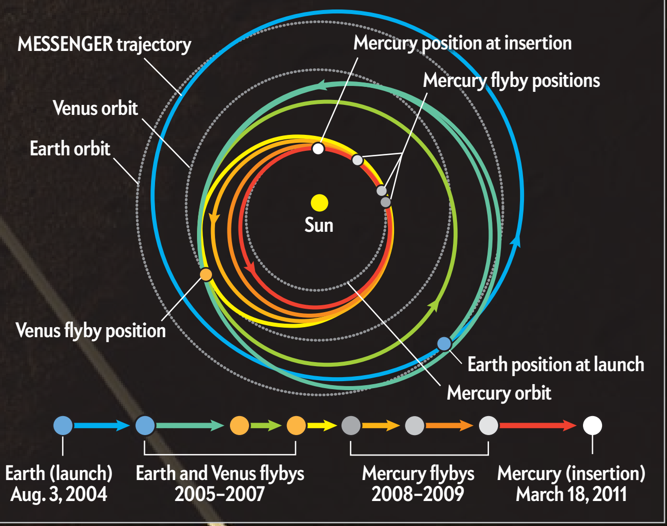
To pull it off, MESSENGER made one flyby of Earth, two of Venus and three of Mercury itself. Each time, some of the spacecraft's momentum was transferred to the planet. This procedure is the same as the gravitational slingshot effect used to propel spacecraft to the outer planets, except that the trajectory was designed to slow rather than speed up the spacecraft. Over six and a half years the sequence of flybys shed 11 kilometers per second.

MESSENGER's main rocket engine completed the task. The spacecraft is built like a flying gas tank, with a minimal and lightweight structure built around propellant tanks (1). At launch the total spacecraft mass was 1,100 kilograms, and more than half of that, 600 kilograms, was fuel.

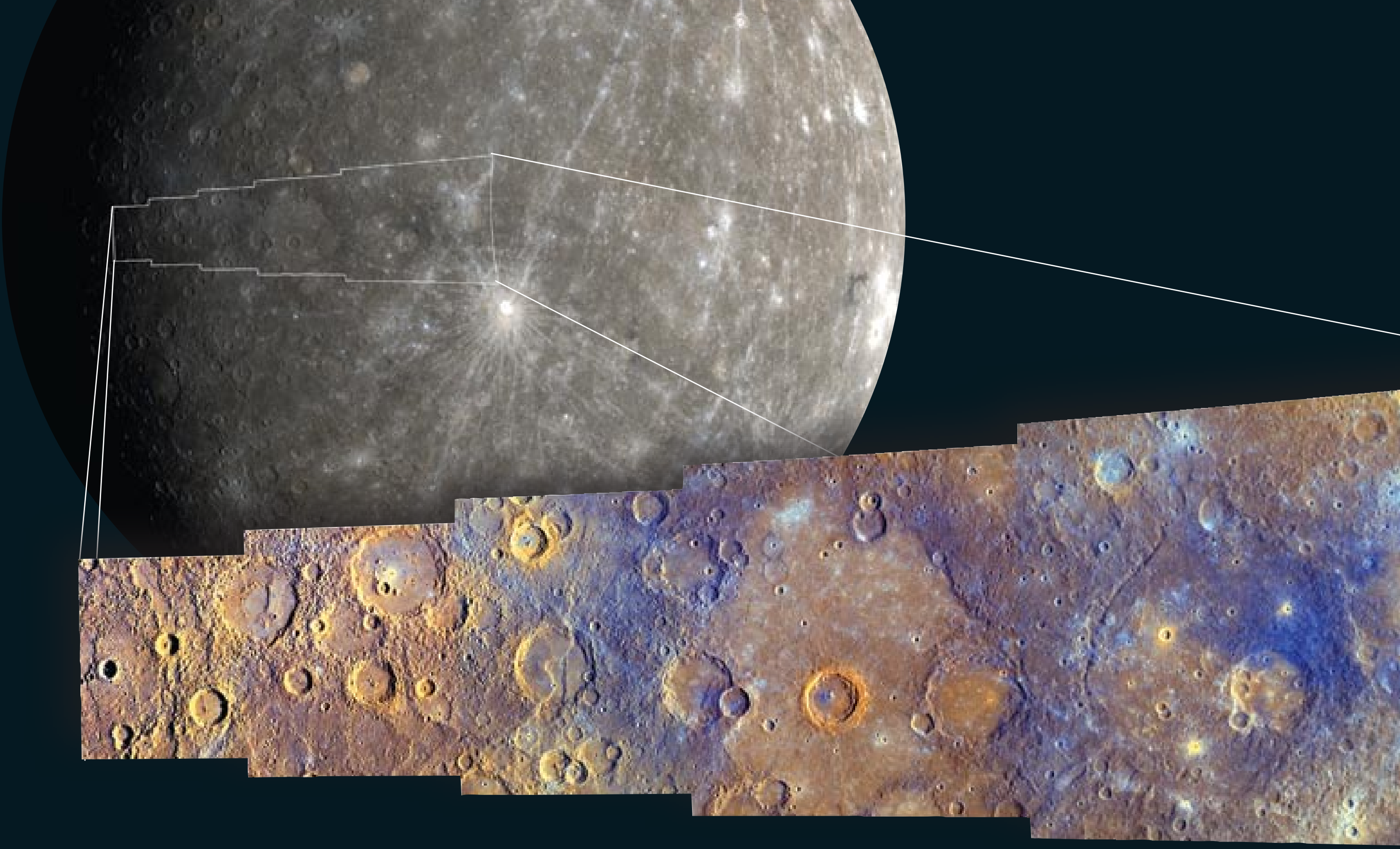
Getting there was only half the fun. At Mercury the sun is up to 11 times brighter than at Earth, and the surface of the planet reaches temperatures high enough to melt zinc. The spacecraft hides behind a sunshade (2) woven from ceramic fibers. The solar panels (3), of course, have to protrude beyond the sunshade, and even though the panels are designed to operate at high temperatures, we have to tilt them at a steep angle so that they absorb only a small fraction of the sunlight and do not overheat.

The scientific instruments must expose themselves to the surface. To withstand the roasting, the camera (4) sits on 400 grams of paraffin. When the spacecraft is low in its orbit, the paraffin melts, absorbing heat; when the spacecraft is at high altitude or over the night side, the paraffin refreezes for the next pass.

Yet another challenge is that Mercury rotates on its axis very slowly. A solar day on Mercury—sunrise to sunrise—lasts 176 Earth days. Many sites will be visible at their ideal viewing geometries for just a few short periods during the one-Earth-year mission.



SOURCES: NASA/JOHNS HOPKINS UNIVERSITY APPLIED PHYSICS LABORATORY/CARNEGIE INSTITUTION OF WASHINGTON



CRUST

Not as Dead as It Looks

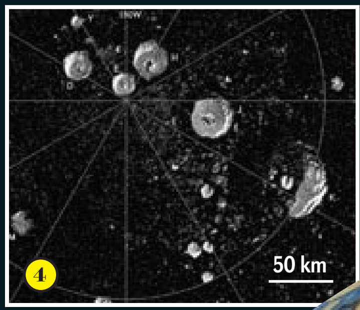
Prior to Mariner 10, some scientists expected Mercury to be as geologically dead as Earth's moon. Geologic activity grinds to a halt when a planet or satellite loses its internal heat, and size determines how fast that happens; smaller objects have larger surface areas in relation to their volume and therefore cool off faster. Because Mercury is only half again larger than the moon, its geologic history should have been similar. Mariner called this wisdom into question when it returned images of vast plains that appeared to be volcanic. But it was hard to tell. From afar, the Cayley Plains on the moon, too, looked like an unusual volcanic plain—but when *Apollo 16* astronauts landed there, all they found was debris ejected from an impact basin.

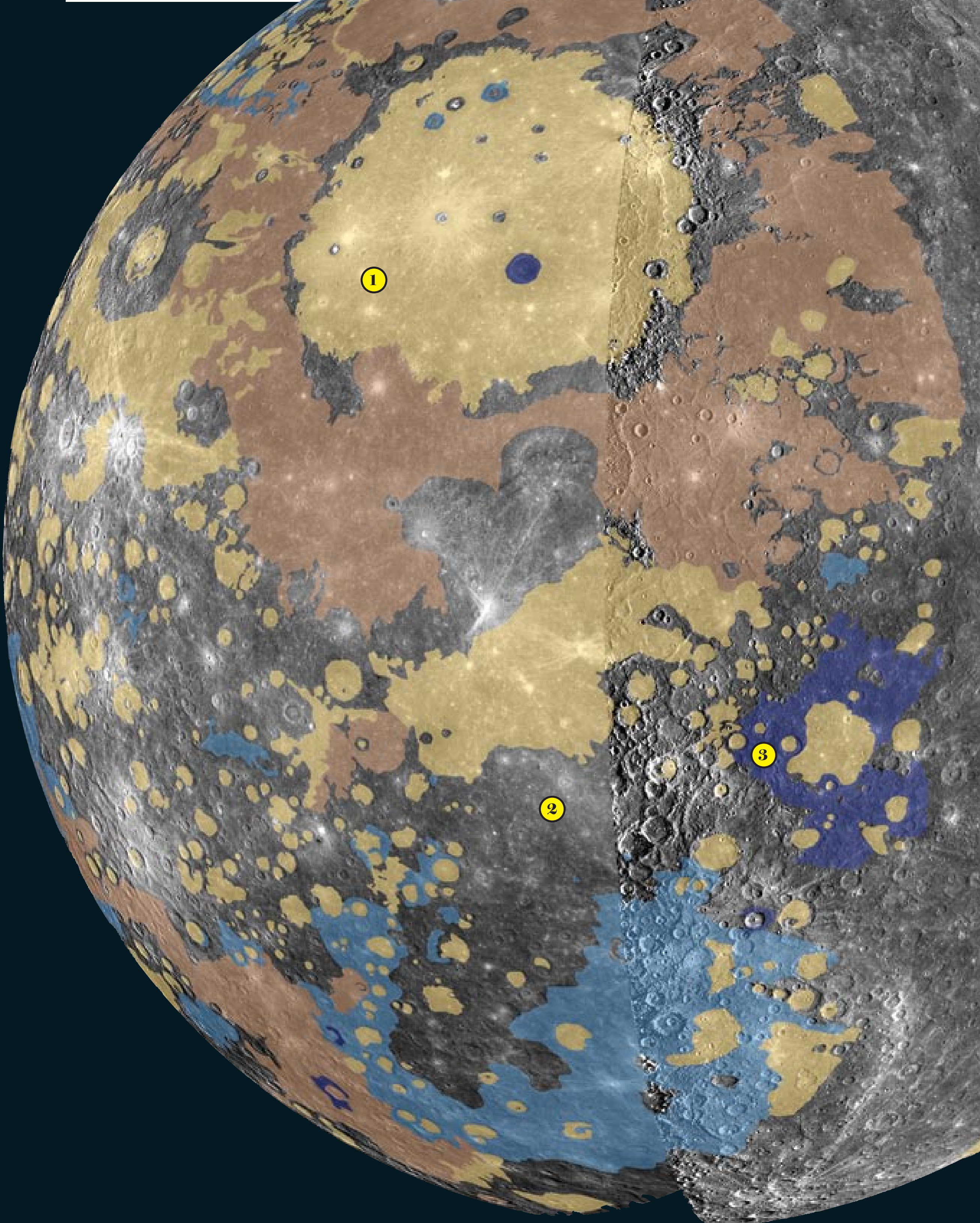
We never thought MESSENGER would settle the question as quickly as it did. It has seen clear evidence for lavas of various colors and composition, as well as for past pyroclastic eruptions like those at Mount St. Helens. Computer enhancement of the color variations (*in images above*) brings out these relations. Distinctly colored smooth material fills low areas inside craters. Smaller, younger craters have excavated multicolored materials from a range of depths in the crust. These images suggest that the upper few kilometers of Mercury's crust consist of layered volcanic deposits.

Tracing the boundaries of terrain with similar landforms and colors, mission scientists have made the first new MESSENGER-era map of Mercury's geology (*at right*). About 40 percent of the surface—including the interior of the Caloris impact basin (1)—consists of smooth plains, many of which are probably volcanic (*shades of brown on map*). Gray areas between the smooth plains are more cratered and may be older (2). A notable difference from the moon and Mars is how smooth plains are distributed. The moon's are concentrated on the near side, facing Earth; Mars's are mostly in the northern hemisphere and on a volcanic plateau. Mercury's are found all over the planet. The youngest may be just one billion years old, relatively new by lunar and Martian standards.

Scientists continue to puzzle over relatively blue regions that cover 15 percent of the surface, such as Tolstoj basin (3). These may contain iron- and titanium-bearing oxides that impacts have dredged up from great depth, or they may be the very oldest volcanic materials poking up above younger lighter-colored lavas.

The images MESSENGER takes from orbit will have three or more times better resolution than these flyby images, and instruments that had short times to operate during the flybys will finally begin to send back their highest-quality data. The Gamma-Ray and Neutron Spectrometer, for example, will follow up a discovery made in the 1990s from ground-based radar observations: the polar regions contain highly radar-reflective materials, possibly water ice (4). Ice seems like the last thing you would expect to find on a scorching planet, but perpetually shadowed regions near the poles could be sufficiently frigid to capture any wisps of water vapor from impacting comets or water-rich meteoroids.





SOURCES: NASA/JOHNS HOPKINS UNIVERSITY APPLIED PHYSICS LABORATORY/ARIZONA STATE UNIVERSITY/CARNEGIE INSTITUTION OF WASHINGTON; JOHN HARMON *Arecibo Observatory* (ice)

A Magnetic Mystery

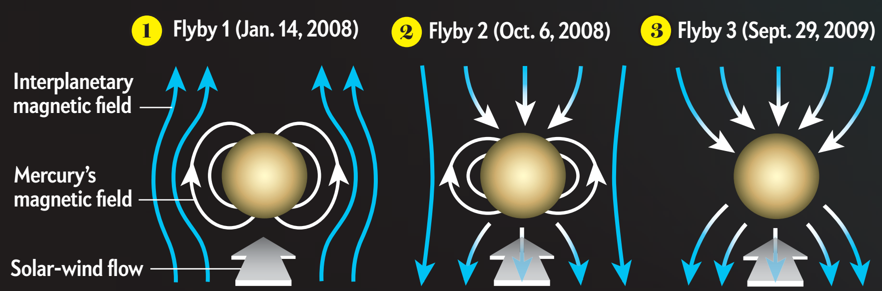
By tracking Mariner 10's trajectory, scientists measured Mercury's gravitational field and refined the estimate of its density. The value is oddly high, about 5.3 grams per cubic centimeter, compared with 4.4 for Earth, 3.3 for the moon and 3 for an average rock. (These values all correct for self-compaction caused by gravity, so that we can compare the intrinsic material properties.) Underneath the rocky veneer of Mercury must be a dense core dominated by iron. Earth also has an iron-rich core, but in relation to the planet's mass, Mercury's is twice as large. Perhaps Mercury once had a thicker rock layer and impacts stripped it off, or perhaps the material from which Mercury formed, by virtue of being so close to the sun, was rich in iron.

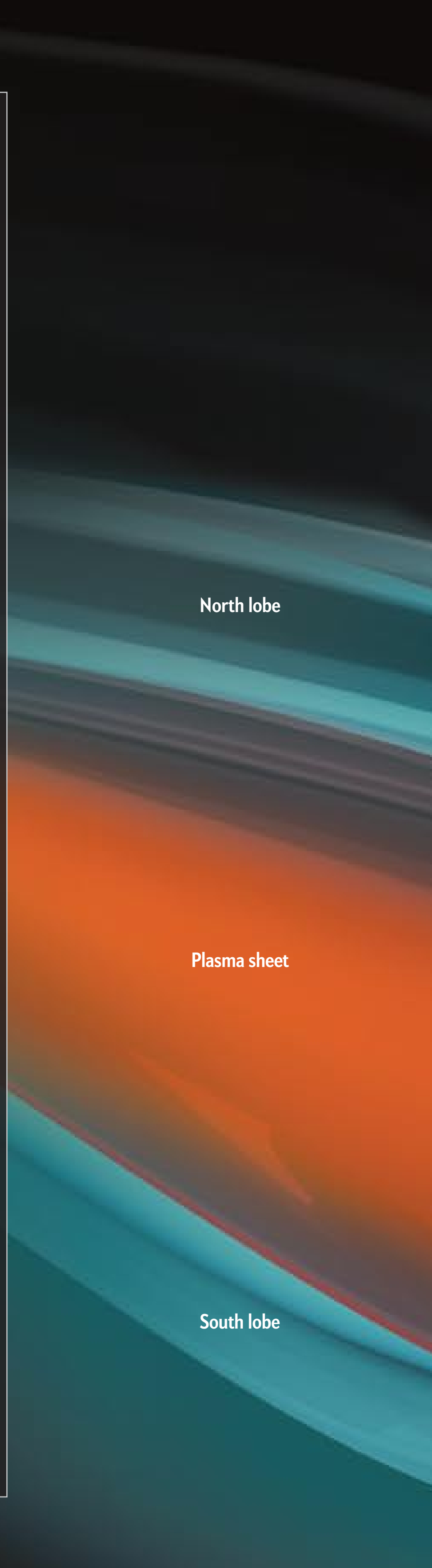
The large core surely is related to one of Mariner 10's most startling discoveries: a global magnetic field. The field is mainly dipolar, like that of a bar magnet. Although the field at the surface is only about 1 percent as strong as Earth's, it is remarkable that Mercury has a dipole field at all. No other solid-surfaced body in the solar system besides Earth and Jupiter's moon Ganymede does.

Earth's field is generated by circulating molten iron in the outer core, a "planetary dynamo." Mercury's field, as well as subtleties of how the planet changes its spin rate in the course of each revolution about the sun, indicates that the outer core has not completely solidified, even though Mercury's size suggests it should have. Mercury somehow evaded the fate of Mars, which had a global field early in its history and lost it. Figuring out why is a major goal of MESSENGER.

Apart from indicating what is happening within the planet, the magnetic field makes for some wild plasma physics around Mercury. The field deflects the solar wind, the stream of charged particles emanating from the sun, and creates a volume surrounding the planet dominated by Mercury's magnetic field rather than the interplanetary magnetic field carried by the wind. Mariner 10 detected bursts of energetic particles similar to those associated with Earth's dazzling auroral displays.

MESSENGER has found that the magnetosphere keeps changing. At the time of the first flyby, the interplanetary field pointed north, so that it was aligned with the planet's equatorial magnetic field (1). The magnetosphere was quiescent. At MESSENGER's second visit, the interplanetary field happened to be pointing southward, opposite to the direction of Mercury's magnetic field at the equator. Magnetic fields aligned in opposite directions can splice together in a phenomenon known as reconnection (2), which releases large amounts of energy and injects plasmas from each region into the other—in this case, jetting solar-wind plasma into Mercury's magnetosphere. MESSENGER measured a rate of magnetic reconnection 10 times stronger than that observed near Earth. On the third flyby, the observations suggested that the planetary field lines were profoundly distorted, alternately being linked entirely to the solar wind (3) and then, five minutes later, linking normally between the northern and southern hemispheres. Under such powerful dynamics, a compass needle would be of little use to navigate on the surface, because it would flip direction every few minutes. What else might Mercury's magnetosphere be capable of?





MORE TO EXPLORE

The Evolution of Mercury's Crust: A Global Perspective from MESSENGER. Brett W. Denevi et al. in *Science,* Vol. 324, pages 613–618; May 1, 2009.

The Magnetic Field of Mercury. Brian J. Anderson et al. in *Space Science Reviews,* Vol. 152, Nos. 1–4, pages 307–339; May 2010.

Mercury's Complex Exosphere: Results from MESSENGER's Third Flyby. Ronald J. Vervack, Jr., et al. in *Science,* Vol. 329, pages 672–675; August 6, 2010.

Illustrations by Don Foley (Mercury), Jen Christiansen (magnetic field inset), and Ronald J. Vervack, Jr. (exosphere inset)

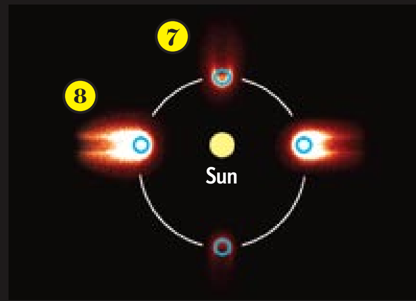
A Slow-Motion Strobe Light

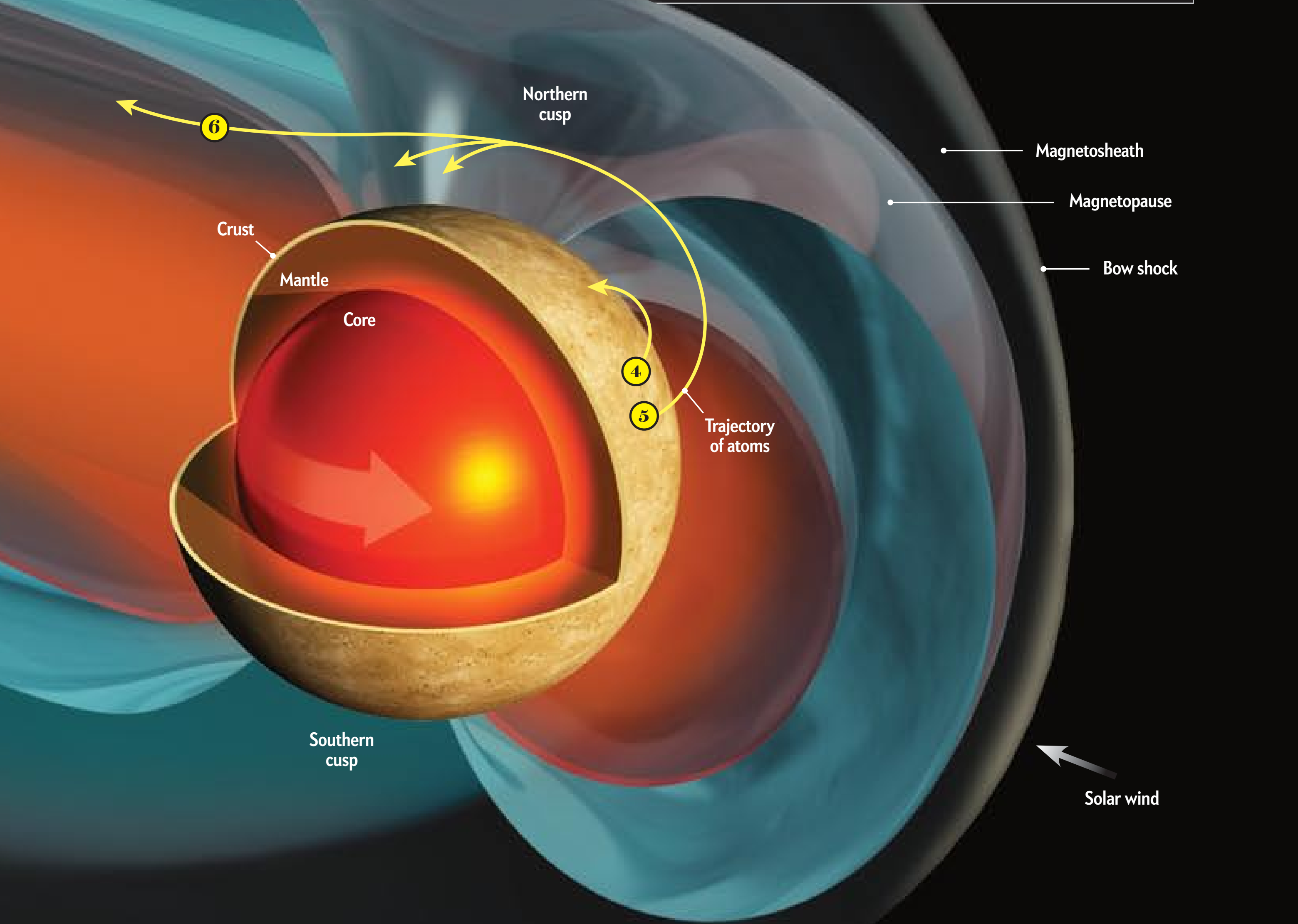
Mercury does not have a traditional atmosphere in the sense of a thick blanket of air, but it does have an exosphere: an "atmosphere" so tenuous that atoms can bounce across the surface like billiard balls without colliding with one another. The atoms come from the surface via several processes. Sunlight knocks them out of mineral crystals and evaporates volatile elements such as sodium; ions from the solar wind bombard minerals and eject atoms from them; and the steady hail of micrometeoroids vaporizes surface materials. Processes involving sunlight are fairly low in energy, and the atoms they eject generally fall back to the surface (4).

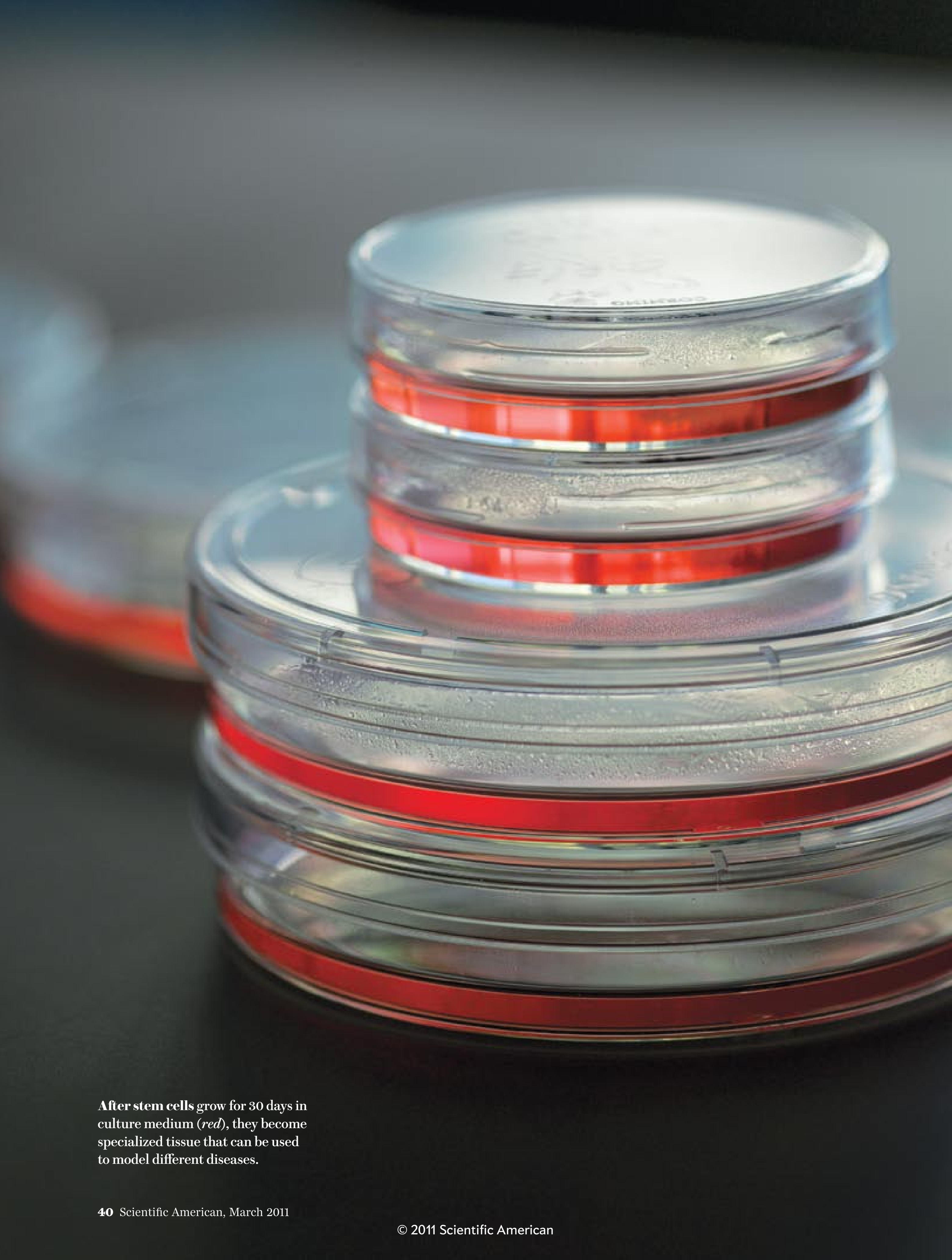
The solar wind and micrometeoroid bombardment are more violent, and the atoms they expel remain aloft longer (5). Some, especially sodium, can form a cometlike tail as solar radiation pushes them away from the sun and the planet (6).

Through a fascinating combination of effects, the exosphere pulses slowly in brightness twice per Mercury orbit. The reason is that the elements making up the exosphere absorb sunlight at certain wavelengths and then emit some of that energy back at the same wavelengths. These elements are also present in the outer layers of the sun, however, where they absorb the wavelengths that stimulate exospheric emissions. But sometimes the required sunlight reaches Mercury after all, because the planet's orbit is highly elliptical; when the planet is accelerating away from or toward the sun, the Doppler effect shifts the solar spectrum, so that more light of the requisite wavelengths reaches the exosphere and causes it to glow more brightly. Thus, when Mercury is closest to or farthest from the sun, the exosphere is barely visible (7). At intermediate points in its orbit, it is bright (8).

Over the coming year MESSENGER will watch as the exosphere goes through its orbital cycles. If past experience is any guide, Mercury will exhibit new phenomena that have yet to be imagined.







After stem cells grow for 30 days in culture medium (*red*), they become specialized tissue that can be used to model different diseases.

MEDICINE

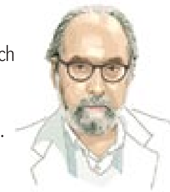
diseases in a dish

A creative use of stem cells made from adult tissues may hasten drug development for debilitating diseases

By Stephen S. Hall

Photographs by Grant Delin

Stephen S. Hall described the early history of stem cell research in the award-winning *Merchants of Immortality* (Houghton Mifflin, 2003). His most recent book, *Wisdom: From Philosophy to Neuroscience* (Vintage), will be issued in paperback in March.



On June 26, 2007, Wendy Chung, director of clinical genetics at Columbia University, drove to the New York City borough of Queens with a delicate request for the Croatian matriarchs of a star-crossed family. She asked the two sisters, one 82 and the other 89, if they would donate some of their skin cells for an ambitious, highly uncertain experiment that, if it succeeded, promised a double payoff. One, it might accelerate the search for treatments for the incurable disease that ran in their family. Two, it might establish a valuable new use for stem cells: unspecialized cells able to give rise to many different kinds of cells in the body. "We had a very nice lunch and literally went back to the house and took the biopsies," Chung remembers. As they sat around the dining-room table, the elderly sisters were "very happy sticking out their arms," recalls the daughter of the 82-year-old woman. The younger sister told Chung: "I get it. Go right ahead."

The sisters suffered from amyotrophic lateral sclerosis (ALS), a degenerative and slowly paralyzing nerve disorder that is also known as Lou Gehrig's disease, after the Yankee slugger who was told he had it in 1939 and died two years later. The 89-year-old showed few signs of the disease, whereas her 82-year-old sister had trouble walking and swallowing.

Although most cases of ALS are not hereditary, the disorder has struck multiple members of this particular family. Affected members inherited a mutation that has been linked to a more slowly progressing form of the disease than the one that attacks most other people with the condition. Chung had been tracking the disorder across several generations of the family in Europe and the U.S. "Lou Gehrig's disease is not a pretty way to die," she says. "Every time family members would get together at funerals, people in the younger generation would be looking around and asking, 'Am I going to be next?'"

It took Chung just a couple minutes to perform the actual "punch biopsy"—two quick nips of flesh, each three millimeters in diameter, from the inner arm. Eventually the sisters' cells, along with skin samples from dozens of other ALS patients and healthy volunteers who similarly donated bits of tissue, were chemically induced to become a form of stem cell known as an induced pluripotent stem cell and were then reprogrammed to become nerve cells. Specifically, they were induced to become motor neurons, the nerve cells that directly or indirectly control the muscles of the body and are adversely affected by ALS. The resulting tissue cultures exhibited the same molecular defects that gave rise to ALS in their human donors. In other words, the investigators had, to an astonishing extent, re-created the disease in a petri dish.

With these cells in hand, they could begin to study exactly what goes wrong in the nerve cells of ALS patients and could start to screen potential drugs for useful effects on the diseased cells. This use of stem cells is new and contrasts with so far disappointingly slow progress in efforts to use stem cells as therapies. If successful, the disease-in-a-dish concept could speed up researchers' understanding of many different diseases and lead to faster, more efficient screening of potential drug therapies, because scientists can test potential drugs in these custom-made cultures for both therapeutic efficacy and toxicity. In addition to the ALS work, the induced stem cells are currently being used experimentally to model dozens of illnesses, including sickle cell anemia, many other blood disorders and Parkinson's disease. Researchers in Germany, for example, have created cardiac cells that beat irregularly, mimicking various heart arrhythmias. Pharmaceutical companies, long wary of stem cell science as a commercial enterprise, are starting to show greater interest because the disease-in-a-dish approach complements the traditional strengths of industrial drug discovery.

The first fruit of the ALS experiment was published in 2008. As in most cases of innovation, success depended not only on the soundness of the idea but on the right mix of people pursuing it. In this case, the cast of characters, in addition to Chung, included Lee L. Rubin, a refugee from the biotech industry who

IN BRIEF

Still waiting: Stem cells from embryos hold promise for treating incurable conditions; however, investigators have not so far made much progress in deriving therapies from stem cells.

A new idea: Rather than focusing on treatments, a few researchers think stem cells are better suited—for now—to help screen for drugs and to investigate how different diseases damage the body.

Creative approach: Until recently, the stem cells needed to pursue this idea were made using embryos. But in 2007 scientists managed to reprogram adult human cells into stem cells.

Customized stem cells: Researchers are using these reprogrammed cells to re-create various diseases in a petri dish. Then they can test potential drugs against the refashioned tissue samples.

became head of translational medicine at the Harvard Stem Cell Institute, and Kevin C. Eggan, a tireless young stem cell scientist from Harvard, who was collaborating with Christopher E. Henderson and other motor neuron experts at Columbia.

A NEW ROLE FOR STEM CELLS

THE STEM CELLS used in these studies should not be confused with embryonic stem cells—the kind derived from early embryos. A dozen years ago James A. Thomson and his colleagues at the University of Wisconsin–Madison electrified the world with the news that they had created human embryonic stem cells in a lab for the first time. These primordial cells had the biological endurance to renew themselves forever and the versatility to turn into any cell type in the body. The possibility of using stem cells to create made-to-order transplants for everything from Parkinson's to diabetes tantalized doctors, researchers, the public at large and, most of all, patients with incurable conditions.

But two harsh realities awaited. First, a loud public debate over the ethics of stem cell science politicized the science and slowed research; the technology posed moral questions because human embryos had to be destroyed to harvest the embryonic stem cells. That debate culminated in President George W. Bush's announcement in August 2001 that the National Institutes of Health would restrict funding support to research using only a few existing embryonic stem cell lines, which effectively impeded the generation of additional stem cells, including the disease-specific cell lines. In response, prominent research groups at Harvard, Columbia and Stanford universities, along with patient advocacy groups such as Project ALS and the New York Stem Cell Foundation, created separate, "nonpresidential" labs to pursue research with private funding. In 2009 the Obama administration relaxed the rules governing stem cell research, but a federal court ruling in 2010 banned grant support from the National Institutes of Health once again and plunged the field into scientific uncertainty and funding chaos.

The second problem was scientific. As Valerie Estess, scientific director of Project ALS, recalls it, there was a mad rush to test the idea that specialized cells derived from stem cells could simply be transplanted into sick people (or animals) as cellular therapies to cure a host of diseases. "The big dream," she explains, "was to derive motor neurons from stem cells, and then you would put them in the brain or spinal cord, and the patients would just get up and start dancing the Watusi." But it did not work out that way in repeated animal experiments. "From beginning to end," Estess says, "these experiments were failures."

In 2002 Thomas M. Jessell, Hynek Wichterle and their team at Columbia published a landmark paper in the journal *Cell,* spelling out the ingredients and procedure for nudging embryonic stem cells down a biological pathway to form motor neurons. One researcher who saw in that work promise for a different use of stem cells was Rubin. Elfin and enthusiastic, Rubin had trained in neuroscience and served as research and chief scientific officer of a Massachusetts biotech company called Curis. He realized that creating a disease in a dish offered a potentially revolutionary way to discover drugs. And unlike a lot of academic scientists, he knew something about drug discovery. During a previous stint in biotech, he worked on a molecule that ultimately became the billion-dollar multiple sclerosis drug Tysabri.

After hearing the results of Jessell and Wichterle's research, Rubin drafted a business plan for a new kind of stem cell institute, "one that focused," he says, "not on cell therapy—which all stem cell biologists were interested in—but on using stem cells to discover drugs." At the time, venture capitalists wanted nothing to do with the idea. So Rubin nursed the idea along at Curis, working on spinal muscular atrophy, a childhood motor neuron disease that has a similar pathology to ALS. When Curis decided to drop the project in 2006, he quit biotech and moved to the Harvard Stem Cell Institute to pursue the disease-in-a-dish idea.

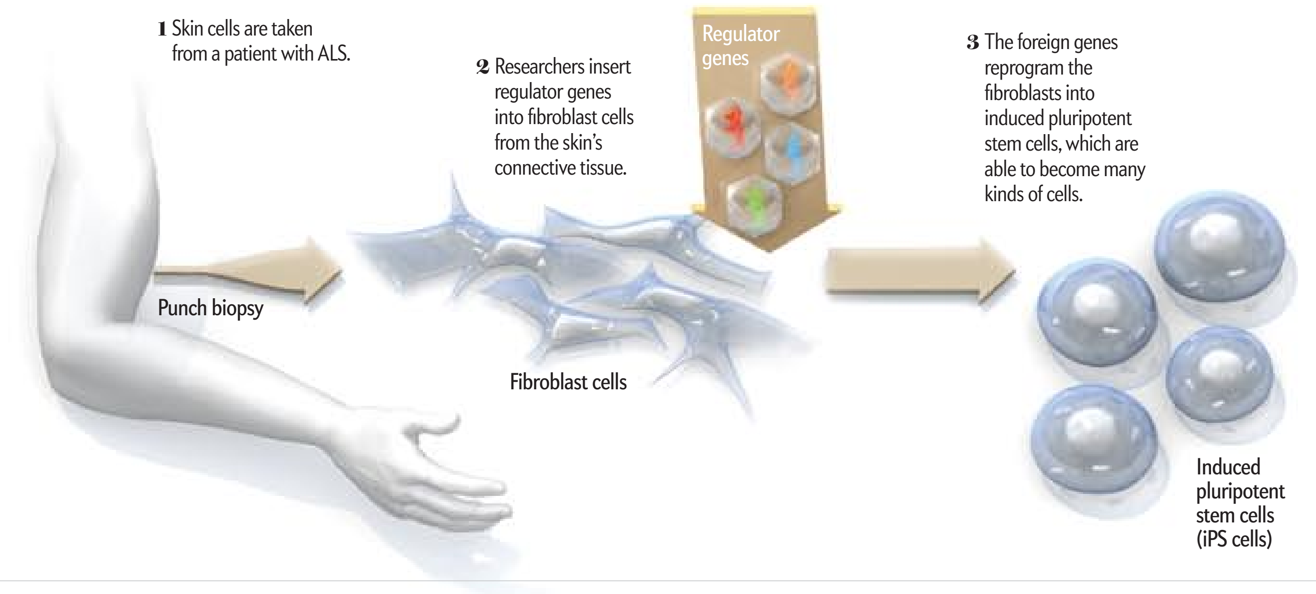
Shortly afterward, a Japanese biologist named Shinya Yamanaka disclosed a technique that would ultimately transform both stem cell biology and stem cell politics. At a scientific meeting at Whistler, B.C., in March 2006, the Kyoto University scientist described a procedure by which biologists could take ordinary adult mammalian cells and "reprogram" them. In essence, Yamanaka had biochemically reset the adult cells back to an embryoniclike or stemlike state without needing to use or destroy an embryo. He called the cells "induced pluripotent stem cells," or iPS cells. A year later both Yamanaka and Wisconsin's Thomson separately reported that they had created iPS cells from human tissue [see "Your Inner Healers," by Konrad Hochedlinger; SCIENTIFIC AMERICAN, May 2010].

One of the people sitting in the audience that day in Whistler

Cold storage: Biopsies and stem cells are preserved in liquid nitrogen.

New Uses for Old Skin

Using techniques pioneered in Japan, researchers from Harvard and Columbia universities extract skin tissue from adults (*below*), isolate specialized cells called fibroblasts from the sample, then gently coax them with genes and chemicals to become nerve cells.



was Eggan, who was a cellular reprogramming expert at Harvard. In fact, he had already embarked on his own version of the disease-in-a-dish idea, launching several projects to take an adult cell and biochemically coax it back into an embryolike state, allow it to replicate, and harvest stem cells from the resulting colony. He was trying to make embryolike cells the "old-fashioned" way, however, by applying the same cloning technique that produced Dolly the sheep. Eggan would take the nucleus out of an adult cell, such as a skin cell, and implant it into an unfertilized egg whose own nucleus had been removed. Cloning, however, was terribly inefficient and also terribly controversial if you planned to reprogram human cells—not least because you had to find women willing to donate their egg cells for the procedure.

Using Yamanaka's approach, however, Eggan and his team finally got the iPS technique to work in a test run with human cells in the summer of 2007. Everything else was already in place to try the disease-in-a-dish concept. Chung and her Columbia colleagues, for example, had collected cells from the two Croatian sisters and other ALS patients in anticipation that they would be used in Eggan's cloning experiments. With private funding, Project ALS had created a special laboratory near Columbia where researchers had been stockpiling cell lines from patients (including the elderly sisters) for months. Suddenly, the iPS approach offered a better chance of success. "That was complete kismet, that we had begun to collect human skin cells with a very different experiment in mind," says Estess of Project ALS.

The headliner among all those first ALS cell lines was the one from the younger, sicker Croatian sister, identified as patient A29. The skin cells of both sisters were successfully reprogrammed into nerve cells, but the age and degree of illness in patient A29 demonstrated that the iPS technique could be used to create cells that reflected a serious, lifelong disease. "We chose those samples because those were the oldest people in our study," Eggan says. "We wanted to prove the point that you could reprogram cells even from a very, very, very, very old person who'd been sick for some length of time. They were a special case."

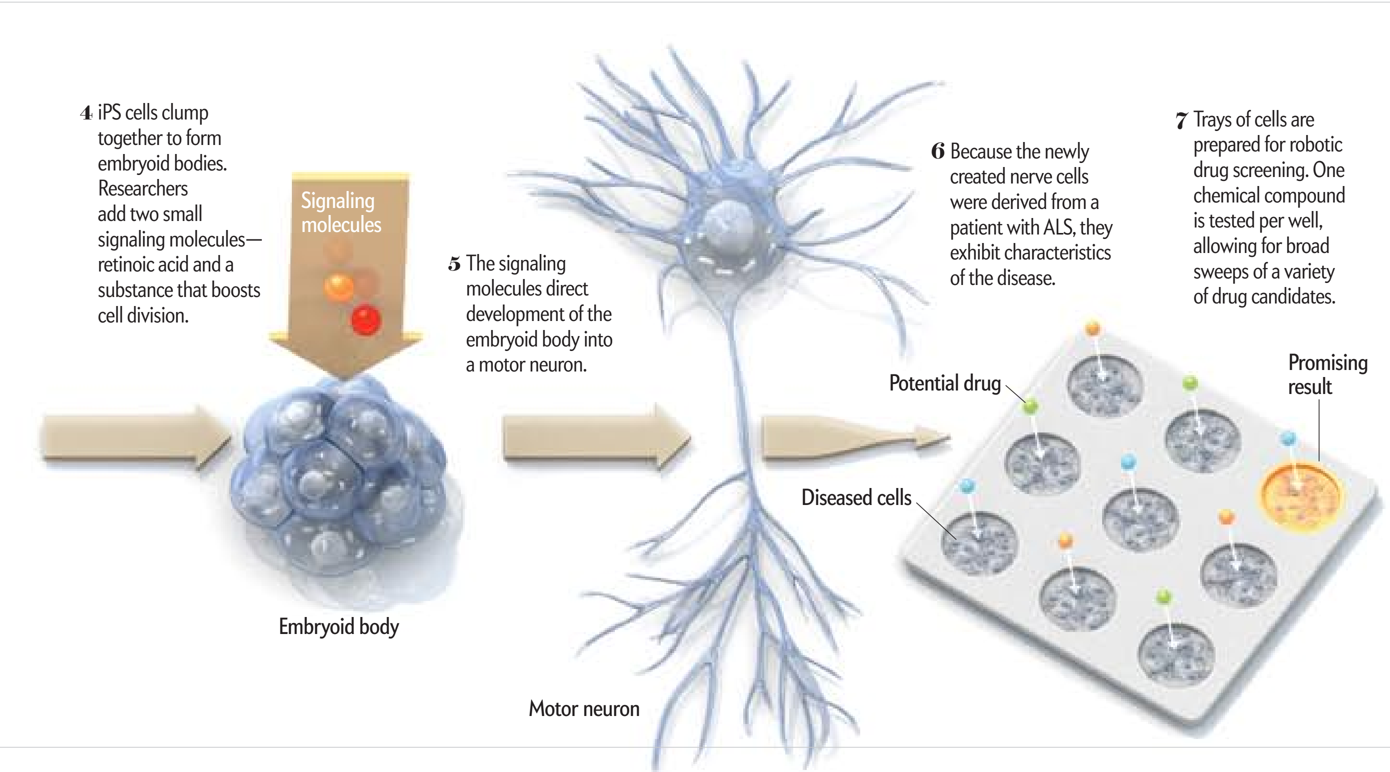
The results appeared in the August 29, 2008, issue of *Science* and were hailed in the press as a scientific milestone. The idea of using stem cells to create a disease in a dish promised experimental access to cells that were otherwise difficult or impossible to obtain—the motor neurons characteristic of ALS and spinal muscular atrophy, brain cells in many neurodegenerative disorders, and pancreatic cells typical of juvenile diabetes.

MADE-TO-ORDER STEM CELLS

IN THE PAST TWO YEARS the Columbia-Harvard collaboration has produced no fewer than 30 ALS-specific human cell lines, with more on the way. Many of these cell lines capture unique mutations found in people with unusually severe cases of ALS. More important, the disease-in-a-dish approach is beginning to deliver on its potential, providing insights into the nature of motor neuron disease. Using cells from the two sisters, for example, researchers have identified molecular pathways that seem to be involved in the death of motor neurons, which occurs when these cells are poisoned by another class of neurons known as astrocytes. With both motor neurons and astrocytes in a dish, scientists are now searching for potential therapeutic compounds that can either block the toxic activity of astrocytes or enhance the survival of motor neurons.

In January 2010, for example, researchers at the Project ALS lab began a preliminary screen of about 2,000 compounds in ALS motor neurons from humans, looking to see if any of the molecules would prolong the survival of nerve cells that contain the mutated ALS gene. This initial pilot program reflects a novel approach to drug screening: the ALS researchers began by testing compounds that have already been approved by the Food

Illustration by Bryan Christie



and Drug Administration for other illnesses. The hope is that researchers might get lucky and find a molecule, already tested and proved safe in humans, that could be rapidly repurposed for motor neuron disease. Pursuing a parallel track at Harvard, Rubin has identified almost two dozen small molecules that interact with one of the newly identified pathways and enhance the survival of motor neurons. The Spinal Muscular Atrophy Foundation is currently testing one of the molecules in an animal model of spinal muscular atrophy.

Perhaps an equally telling indicator that iPS cells offer a promising approach to drug discovery is the fact that Rubin is no longer banging his head against the door of pharmaceutical companies. Since the Columbia and Harvard researchers established the principle of a disease in a dish—that neurons with the genetic makeup of those in a diseased person can be produced—with patient A 29 in the summer of 2008, pharmaceutical companies have been banging on Rubin's door. Without naming specific companies for confidentiality reasons, he says, "I would say that of the major pharmaceutical companies, all of them have become interested in this approach now." The excitement has spilled over into biotech: many of the researchers in the motor neuron disease-in-a-dish story, including Eggan and Rubin, have become involved in a California-based biotechnology company called iPierian, which is one of several startups, including Cellular Dynamics International and Fate Therapeutics, that are adapting iPS technology for drug discovery.

MORE ON IPS CELLS
ScientificAmerican.com/mar2011/ips

Meanwhile more and more stem cell researchers are pursuing the disease-in-a-dish concept. Shortly after the ALS publication in 2008, a separate group of researchers at the Harvard Stem Cell Institute reported using the iPS technique to create disease-in-a-dish cells from patients with juvenile diabetes, Parkinson's and other disorders. And in late 2008 researchers at Wisconsin, led by Clive N. Svendsen (who has since moved to Cedars-Sinai Medical Center in Los Angeles), created motor neurons in a dish from a patient with spinal muscular atrophy.

When I asked researchers at Columbia and Harvard if the two Croatian sisters were aware of the research that grew out of their donated cells, no one seemed to know at first. But I eventually learned that the sisters are still alive, according to the daughter of patient A29, who agreed to speak as long as her name and those of family members remained anonymous. The older sister, now 93, remains essentially free of symptoms of ALS; indeed, according to her niece, she still "lives by herself, walks everywhere, shops, cooks, sweeps and cleans." The younger sister, patient A29, turned 85 last June; despite her ALS, she can move "slowly and weakly" and is "grateful" to have had the opportunity to help.

Still, the family's cruel burden never seems far away and underscores the urgency felt by those who might benefit from the new stem cell approach to finding drugs. "I am relatively young," says patient A29's daughter, who herself was diagnosed with ALS in 2002. "We are afraid that the onset of the disease is becoming earlier as the generations go along. We feel a little like"—she pauses as she speaks, to gather herself and her inevitably grim thoughts—"it's a race against time. I myself have a teenage daughter, and it just weighs so heavily on the mind and heart." SA

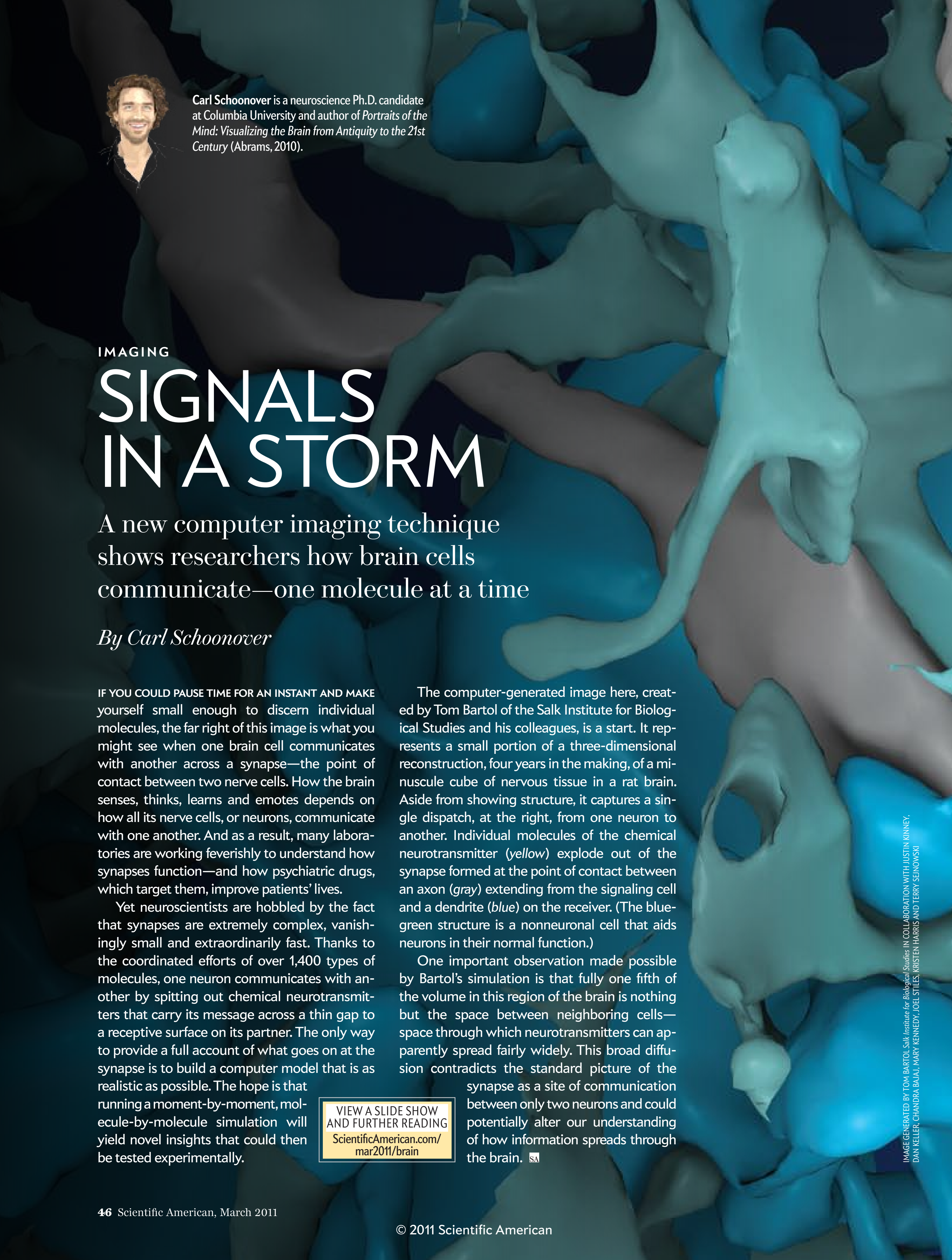
MORE TO EXPLORE

Induced Pluripotent Stem Cells Generated from Patients with ALS Can Be Differentiated into Motor Neurons. John T. Dimos et al. in *Science*, Vol. 321, pages 1218–1221; August 29, 2008.

Study Says Brain Trauma Can Mimic A.L.S. Alan Schwarz in *New York Times*, August 17, 2010.

iPS Cells: A Promising New Platform for Drug Discovery. George Daley in Children's Hospital Boston's science and clinical innovation blog, September 23, 2010: http://vectorblog.org/ips-cells-a-promising-new-platform-for-drug-discovery

Diseases in a Dish Take Off. Gretchen Vogel in *Science*, Vol. 330, pages 1172–1173; November 26, 2010.



Carl Schoonover is a neuroscience Ph.D. candidate at Columbia University and author of *Portraits of the Mind: Visualizing the Brain from Antiquity to the 21st Century* (Abrams, 2010).

IMAGING

SIGNALS IN A STORM

A new computer imaging technique shows researchers how brain cells communicate—one molecule at a time

By Carl Schoonover

IF YOU COULD PAUSE TIME FOR AN INSTANT AND MAKE yourself small enough to discern individual molecules, the far right of this image is what you might see when one brain cell communicates with another across a synapse—the point of contact between two nerve cells. How the brain senses, thinks, learns and emotes depends on how all its nerve cells, or neurons, communicate with one another. And as a result, many laboratories are working feverishly to understand how synapses function—and how psychiatric drugs, which target them, improve patients' lives.

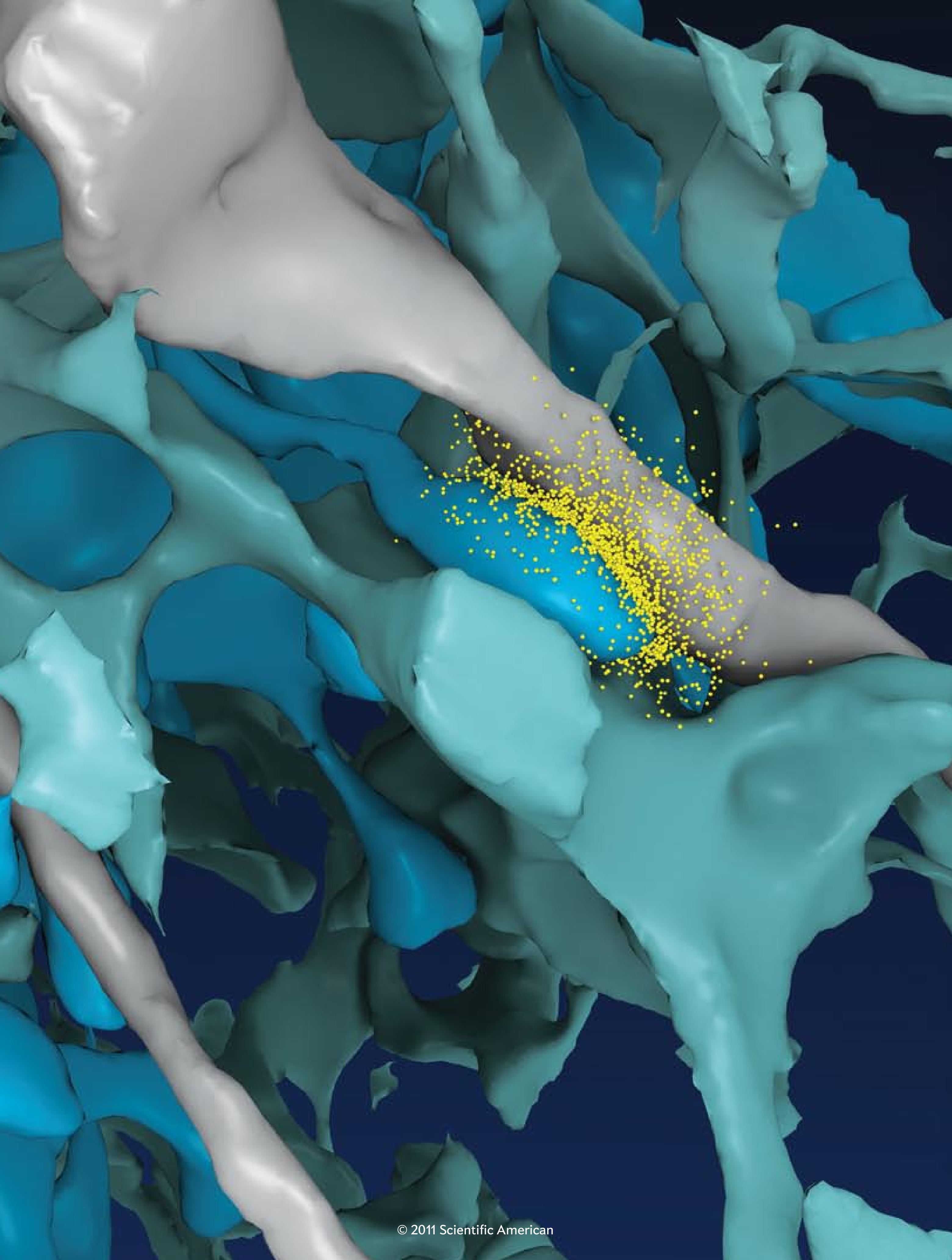
Yet neuroscientists are hobbled by the fact that synapses are extremely complex, vanishingly small and extraordinarily fast. Thanks to the coordinated efforts of over 1,400 types of molecules, one neuron communicates with another by spitting out chemical neurotransmitters that carry its message across a thin gap to a receptive surface on its partner. The only way to provide a full account of what goes on at the synapse is to build a computer model that is as realistic as possible. The hope is that running a moment-by-moment, molecule-by-molecule simulation will yield novel insights that could then be tested experimentally.

The computer-generated image here, created by Tom Bartol of the Salk Institute for Biological Studies and his colleagues, is a start. It represents a small portion of a three-dimensional reconstruction, four years in the making, of a minuscule cube of nervous tissue in a rat brain. Aside from showing structure, it captures a single dispatch, at the right, from one neuron to another. Individual molecules of the chemical neurotransmitter (*yellow*) explode out of the synapse formed at the point of contact between an axon (*gray*) extending from the signaling cell and a dendrite (*blue*) on the receiver. (The blue-green structure is a nonneuronal cell that aids neurons in their normal function.)

One important observation made possible by Bartol's simulation is that fully one fifth of the volume in this region of the brain is nothing but the space between neighboring cells—space through which neurotransmitters can apparently spread fairly widely. This broad diffusion contradicts the standard picture of the synapse as a site of communication between only two neurons and could potentially alter our understanding of how information spreads through the brain. SA

VIEW A SLIDE SHOW AND FURTHER READING
ScientificAmerican.com/mar2011/brain

IMAGE GENERATED BY TOM BARTOL, *Salk Institute for Biological Studies* IN COLLABORATION WITH JUSTIN KINNEY, DAN KELLER, CHANDRA BAJAJ, MARY KENNEDY, JOEL STILES, KRISTEN HARRIS AND TERRY SEJNOWSKI



ARCHAEOLOGY

PUTTING STONEHENGE IN ITS PLACE

An increasingly accepted view holds that the great stone circle may have been just part of a much larger ceremonial landscape

By William Underhill

William Underhill is a journalist living in England. He has contributed to a wide range of newspapers and magazines, including *Newsweek*, the *Economist*, the *Guardian* and the *Daily Telegraph*. He has a particular enthusiasm for British history.

WITH THE CLICK OF A MOUSE, ARCHAEOLOGIST Vince Gaffney proudly summons up a vision of an ancient landscape. Amid the clutter of his office at the University of Birmingham in England, the 52-year-old professor of landscape archaeology is displaying early results of a virtual excavation at Britain's best-known prehistoric monument. On the screen: a giant ring of wood posts that may have stood roughly 1,000 yards northwest of Stonehenge, a timber twin of its grander neighbor. In 2010 Gaffney began a three-year project heading an international team that will probe the surrounding countryside in one more attempt to unravel the site's mysteries, this time with the aid of the very latest technology. The first reward came quickly. Within just two weeks the team, armed with high-powered magnetometers and ground-penetrating radar, discovered traces of that putative timber ring—possibly the most important find on the site in half a century.

Gaffney's is one of many recent discoveries that have scientists rethinking Stonehenge. The recovery of new materials, along with the reanalysis of earlier finds using modern archaeological techniques, has led to a steady flow of new information. Advances in carbon dating mean experts can provide a more accurate chronology. More sophisticated chemical analysis of human remains allows archaeologists to identify the likely origin of the earliest visitors to the site. The pace is quickening. Radar devices can turn out data at a rate inconceivable even

IN BRIEF

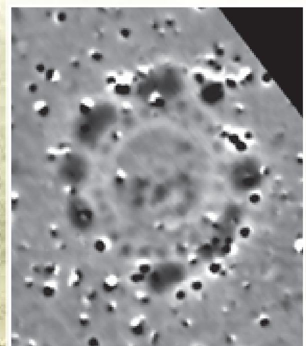
Scholars have speculated about Stonehenge's purpose for centuries. **Traditionally** their interpretations focused on the great stone circle itself. But recent discoveries have underscored that Stonehenge was never a stand-alone structure. **Rather it appears** to have been the centerpiece of a far more expansive ritual setting—a revelation that has spawned new theories about the monument's true function.

PRECEDING PAGES: TOM NAGY *Gallery Stock*; THIS PAGE: COURTESY OF UNIVERSITY OF BIRMINGHAM (*magnetometer scan*)

FINDINGS

Lay of the Land

In recent years archaeologists have discovered several major structures in the vicinity of Stonehenge that have spawned new ideas about how Neolithic people used the landscape. A leading theory holds that the builders of the famous stone circle lived in a settlement at Durrington Walls while they erected the monument and then returned there for seasonal celebrations at a timber counterpart of Stonehenge called the Southern Circle. Opposite this domain of the living was the domain of the dead, comprising Stonehenge and perhaps other monuments. The deceased may have been transported down the river Avon to Bluehenge, where they were then cremated before embarking on the last leg of their journey, along the Avenue, to their final resting place at Stonehenge.



Below the Surface
In 2010 researchers using magnetometers to scan the area around Stonehenge reported that they had detected traces of what appears to be a timber henge some 1,000 yards from the stone circle itself. In the magnetometry reading at the left, a ring of pits marks the spot where the timber posts may have stood.

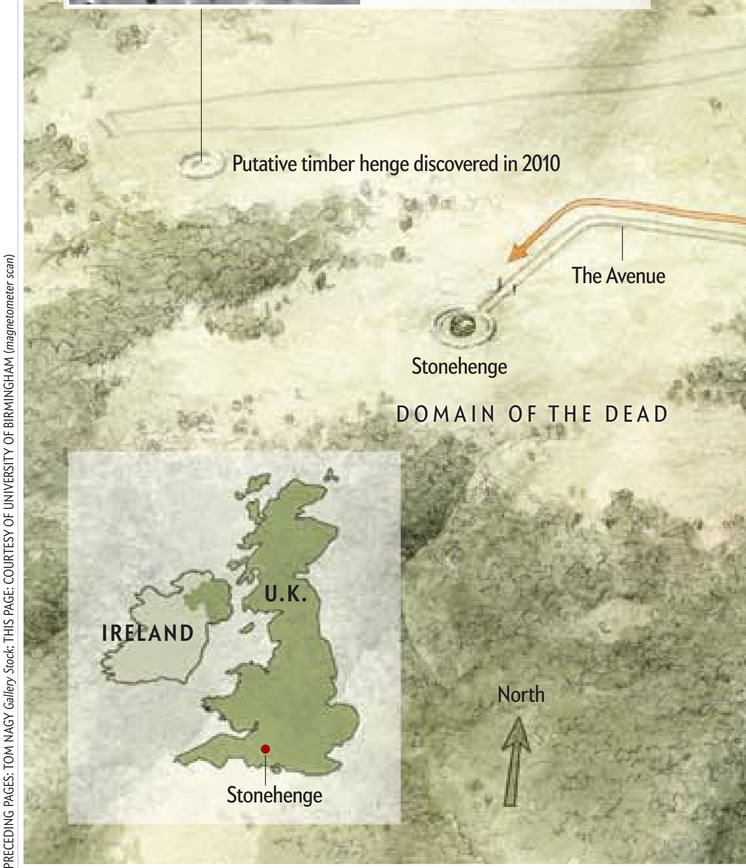


Illustration by Richard Schlecht

Stonehenge circa 1600 B.C.

Stonehenge started off as a circular ditch and bank around 5,000 years ago, possibly surrounding a ring of timber posts. Over the next 1,000 years builders brought in and arranged the giant stones. The structure is imagined here as it was around 3,600 years ago. Standing on rising ground on Salisbury Plain, its stones aligned with the rising sun on the summer solstice.

Woodhenge

Aerial photography revealed the site of a structure called Woodhenge in 1925. It may have had a roof, as reconstructed above, or been an open structure. Although Woodhenge was erected centuries after Stonehenge and Durrington Walls, it hints at what the older timber henges excavated within the past few years might have looked like on completion. The Southern Circle located within Durrington Walls, for example, was about the same size as Woodhenge. Oriented to mark sunset on the summer solstice, the Southern Circle is the mirror image of Stonehenge a few years ago. (Gaffney's equipment collected as much data in two days at Stonehenge as he managed in three years at a previous site.) And with more data come fresh ideas. New evidence is now emerging to bolster a front-running theory: Stonehenge never stood in majestic isolation. Says Gaffney: "It was just part of a much wider ritual landscape."

AN ENDURING ENIGMA

SCHOLARS HAVE BEEN STRUGGLING to unscramble the significance of Stonehenge since the 17th century. Almost every generation has thrown up its own solutions to the big questions of who built the monument, how and why. At different times, its function has been described as an astronomical observatory, a burial place for the great, a temple for Druid priests of the Iron Age, and more. Before scientists assigned credit for its construction to Neolithic humans, the list of possible builders included the Romans, the Danes and Merlin the magician.

Trouble is, telltale signs of the builders are frustratingly scarce—a smattering of charcoal from their fires, stone chippings, cattle bones, arrowheads and the occasional antler pick. All that is known for certain is a broad outline of the chronology. A circular ditch and bank, possibly surrounding a circle of timber posts, appeared around 3,000 B.C., and over the next 1,000 years the monument gradually took its final shape. On the outside: a ring of sarsens—huge blocks of sandstone probably dragged to the site from quarries in the Marlborough Downs 18 miles away. On the inside: arrangements of smaller bluestones, somehow transported 150 miles from the mountains of southern Wales, and one more horseshoe of giant sarsen slabs. The placement of the stones appears to have been significant, aligning the central axis with the rising sun at dawn on the summer solstice and sunset at midwinter.

Since the construction, much has happened to confuse the archaeologist's task. Stonehenge's early builders appear to have changed the arrangement of the bluestones. Some have vanished altogether. Today only around half of the total—originally 80 or so—remain. The messy habits of the 20th century have not helped. Gaffney's magnetometers pick up the debris—scraps of metal and bottle tops—dropped by the crowds at the music festivals of the 1970s and 1980s. That is not to mention the spectral outline of trenches dug when the land was used as a military training ground in World War I or the problems caused by the casual approach of the earliest archaeologists who allowed evidence to disappear. The designation of Stonehenge as a World Heritage Site in 1986 helped to protect the monument and its environs, but it also limited the scope for archaeological digging.

> Parker Pearson posits that Stonehenge had its own wood counterpart, the two monuments forming a single spectacular ceremonial site linked to the worship of the ancestors and the sun.

CRADLE TO GRAVE

THE IDEA OF STONEHENGE as the focal point of a much wider ritual landscape is not new—one glance at a map shows a rich scattering of tombs, some predating Stonehenge, across the surrounding countryside. And aerial photography revealed the site of a timber henge called Woodhenge as far back as 1925. But slowly the evidence is accumulating that allows archaeologists to speculate on how the ceremonies that governed life and death might have fitted together.

A few years before Gaffney's team picked up the latest circle of timber posts, other excavations in the greater Stonehenge area had already begun to yield hints of a bigger picture. In 2007 archaeologist Mike Parker Pearson of the University of Sheffield in England and his team from the Stonehenge Riverside Project, which includes some of the country's leading archaeologists, announced discovery of the remains of a vast prehistoric settlement, possibly the largest in Britain, at Durrington Walls, a massive man-made enclosure just two miles northeast of the monument itself. The smart application of soil chemistry—think nitrogen or phosphorus levels—yielded a mass of information about how its residents might have organized their homes, from where the cooking took place to where they slept. (Bed-wetting babies leave their mark even after millennia through traces of urine.) And hyperaccurate carbon dating suggested that the village was occupied for less than 45 years, leading Parker Pearson and his collaborators to speculate that this was where the builders of Stonehenge once lived, moving on after their work was complete.

Just as important, the team had excavated traces of another henge, prior to Gaffney's: a concentric ring of timber posts dubbed the Southern Circle that was apparently aligned to mark sunset at the summer solstice—the mirror image of the arrangement at Stonehenge. Parker Pearson posits that Stonehenge had its own wood counterpart, the two monuments forming a single spectacular ceremonial site linked to the worship of the ancestors and the sun. "This is evidence that clarifies the site's true purpose," he asserts. "We have found that Stonehenge was just half of a larger complex."

Each half, he believes, had its own symbolic role. Most likely, the great ring at Stonehenge represented the domain of the dead, a lasting monument to the ancestors, whereas the Southern Circle was the opposite: a secular place where the living came first as builders of the stone circle and later for seasonal celebrations. Inspiration for this interpretation came partly from a colleague of Parker Pearson's from Madagascar who saw similarities with practices at home where wood dwellings are matched by stone buildings for the dead. Tests on animal bones found at Durrington Walls offer some backing for the theory, suggesting that cattle were brought from many miles away in southern England, perhaps to be eaten at ritual feasts. Further evidence came in 2009, when the Stonehenge Riverside Project uncovered the site of a circle of 25 bluestones two miles from the monument (and the same distance from Durrington Walls), beside the river Avon—a site quickly dubbed Bluehenge. The stone slabs were gone, possibly taken to Stonehenge itself, but left behind were fragments of the distinctive blue rock and, more important, traces of charcoal suggesting the structure was erected around 5,000 years ago. Perhaps, Parker Pearson surmises, Bluehenge was a place of cremation, a sacred site where the dead began the final journey to Stonehenge.

Certainly the bluestones held a special meaning for Neolithic humans—why else would they have stood at the very center of Stonehenge protected by the bigger sarsen monoliths?—and one more theory now places them at the heart of the entire Stone-

COURTESY OF WESSEX ARCHAEOLOGY

Seeking a cure? **Chemical analysis of the remains of a teenage boy found near Stonehenge seems to indicate that he came from the Mediterranean—one of several discoveries suggesting that the site was a place of healing, rather than a monument to death.**

henge story while also assigning yet another role to Stonehenge. Evidence collected in a 2008 dig at Stonehenge itself—the first within the circle for 40 years—supports the idea that Stonehenge was mainly a place of healing, a destination for the sick who traveled hundreds of miles in the hope of a cure. "Like a great medieval cathedral, all sorts of things would have happened at Stonehenge, but its principal draw was as a sacred place of healing," asserts Timothy Darvill of Bournemouth University in England, who conducted the 2008 excavation with Geoff Wainwright, former president of the Society of Antiquaries in London.

CURATIVE POWERS

DARVILL AND WAINWRIGHT'S THEORY could help explain the stupendous efforts undertaken to transport the massive slabs of bluestone—each weighing up to four tons—some 150 miles from their source in the Preseli Hills in South Wales all the way to southern England. (Not so difficult as it might seem: a team of students demonstrated last fall how the slabs might have been rolled across the ground on small stone balls. Experts devised the test after finding such balls close to a similar stone circle in Scotland.) It could also explain why so many of the bluestones are now missing. In the course of his 2008 excavation, Darvill found plenty of tiny flakes apparently deliberately chipped off the larger blocks, perhaps for use as talismans. Maybe whole stones were shipped off for use elsewhere.

TIMELINE OF STONEHENGE DISCOVERIES AND THEORIES
ScientificAmerican.com/mar2011/underhill

But the dead, not the stones, provide the most telling support for Stonehenge's past as a prehistoric equivalent of Lourdes, the Catholic shrine in France famed for its supposedly miraculous healings. In 2002 archaeologists excavating a building site three miles from Stonehenge at Amesbury reported that they had turned up the grave of a Bronze Age male, buried around 2,300 B.C., with a rich assortment of treasures. Studies of the skeleton, dubbed the Amesbury Archer for the archery gear that accompanied his remains, showed he had lost one knee, and infection had entered his bones. And intriguingly, analyses of his tooth chemistry revealed a blend of strontium isotopes that suggested his original home was far away in the Alps (tooth enamel forms in a child's earliest years, storing a chemical record of where an individual was raised). Maybe he had crossed to England seeking a cure or at least relief from pain at the already fabled Stonehenge. Indeed, excavations at many of the tombs buried nearby have turned up remains of individuals who seem to have suffered serious injury. One likely interpretation is that the Amesbury Archer was one of a stream of visitors hoping for relief at Stonehenge.

Recent isotope analysis of tooth enamel from a grave found in nearby Boscombe in 2003 suggests that the archer was not the only visitor from afar. Seven of the grave's occupants may have spent part of their early lives in Wales, the source of the bluestones. And last year Jane Evans of the British Geological Survey reported that similar tests on the remains of a teenager discovered nearby in 2005 appear to suggest that he came from a warmer, Mediterranean climate, although there are still question marks over the interpretation of the data.

The Lourdes theory, like all Stonehenge theories, has it doubters. The strongest argument against it is that there is insufficient evidence to back the idea that a disproportionate number of human remains found in the area show signs of trauma. Substantiating that point would require a far larger sample of bones. Yet even if further discoveries do indeed bolster the Lourdes hypothesis, they will not necessarily weaken Parker Pearson's case, because the theories are not mutually incompatible. No doubt over the course of 5,000 years people used the site for different purposes and regarded it in different ways.

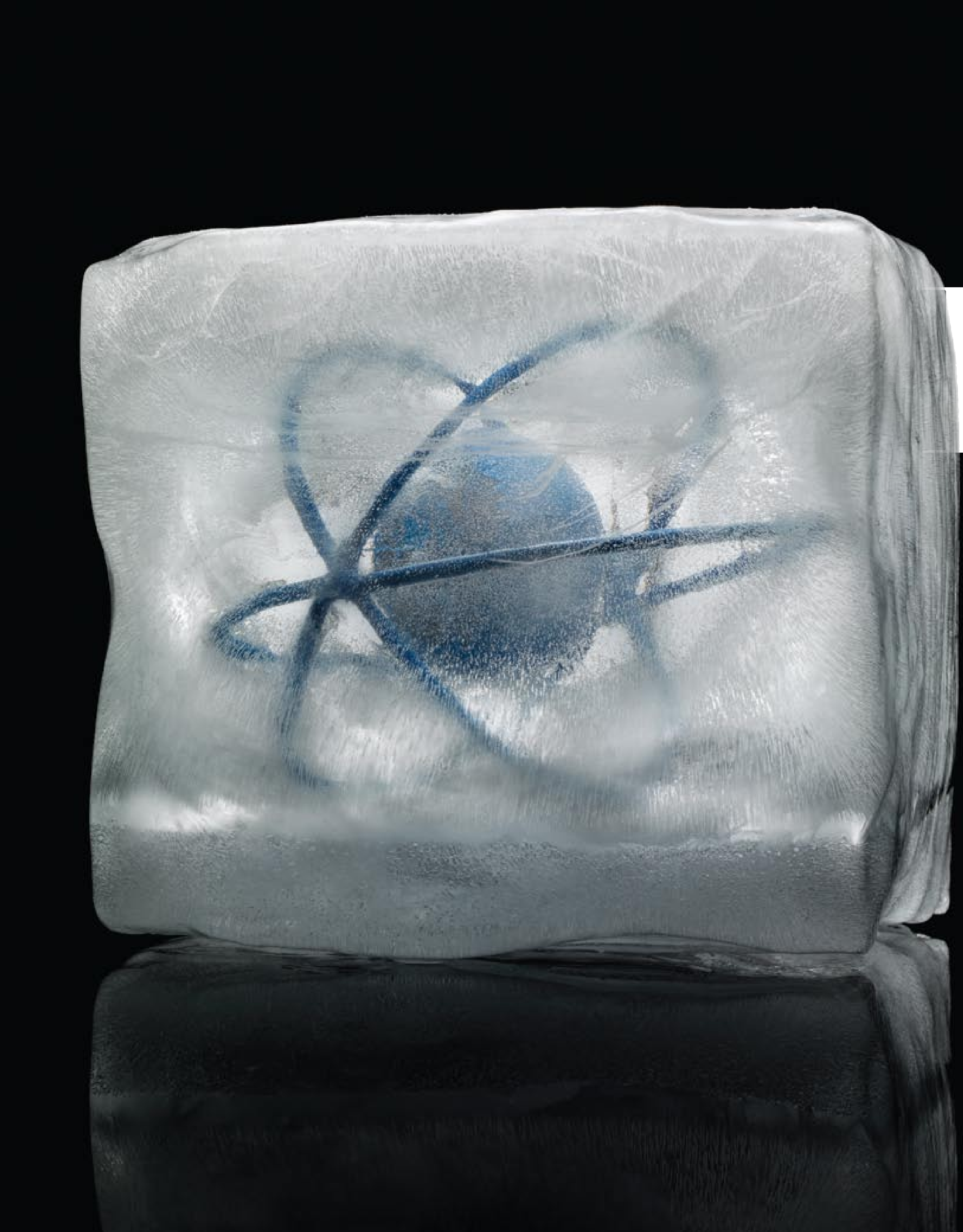
Despite all the new finds, much about Stonehenge remains a mystery. The peoples of the Stone Age have left scant clues as to their beliefs or how they lived their lives. But archaeologists, equipped with new technology, will not abandon the challenge. This year English Heritage, the state body that controls the site, hopes to conduct a laser scan of the stones, searching for telltale scratch marks and graffiti. And Parker Pearson is analyzing animal bones found at Durrington Walls as part of the Feeding Stonehenge project, looking exactly at how the people who built the stone circle lived, what they ate and where they came from. Meanwhile Gaffney's own high-tech trawl, covering more than five square miles, will in time yield the first comprehensive picture of what lies underneath the soil. More revelations seem certain to come. Stonehenge, Gaffney says, appears to be part of a "complex multitude of monuments." Complex but perhaps not impervious to scientific scrutiny. SA

MORE TO EXPLORE

Stonehenge Excavations 2008. Timothy Darvill and Geoffrey Wainwright in *The Antiquaries Journal,* Vol. 89, pages 1–19. Published online April 21, 2009.

Who Was Buried at Stonehenge? Mike Parker Pearson et al. in *Antiquity,* Vol. 83, No. 319, pages 23–39; March 2009.

The UNESCO World Heritage Center's Web site about Stonehenge: **http://whc.unesco.org/en/list/373**



Mark G. Raizen holds the Sid W. Richardson Foundation Regents Chair in Physics at the University of Texas at Austin, where he also earned his Ph.D. His interests include optical trapping and quantum entanglement. As a toddler, Raizen got to meet physicist Leo Szilard, who was a patient of his father, a cardiologist, and who explained why Maxwell's demons do not violate the laws of thermodynamics.

PHYSICS

DEMONS ENTROPY AND THE QUEST FOR ABSOLUTE ZERO

A 19th-century thought experiment has turned into a real technique for reaching ultralow temperatures, paving the way to new scientific discoveries as well as to useful applications

By Mark G. Raizen

IN BRIEF

Traditional methods for cooling gases to close to absolute zero work only with a few of the elements.

Two novel techniques together can cool down atoms of virtually any element, even some molecules.

One of the techniques, which appears to break the second law of thermodynamics, is a physical realization of a celebrated 1800s thought experiment called Maxwell's demon.

Applications range from studying the properties of elementary particles without expensive accelerators to separating isotopes for their use in medicine and research.

Photograph by Adam Voorhes

A

s you read these words, the air's molecules are zipping around you at 2,000 miles per hour, faster than a speeding bullet, and bombarding you from all sides. Meanwhile the atoms and molecules that make up your body incessantly tumble, vibrate or collide with one another. Nothing in nature is ever perfectly still, and the faster things go, the more energy they carry; the collective energy of atoms and molecules is what we call, and feel as, heat.

Even though total stillness, corresponding to the temperature of absolute zero, is physically impossible, scientists have edged ever closer to that ultimate limit. In such extreme realms, weird quantum effects begin to manifest themselves and to produce new and unusual states of matter. In particular, cooling gaseous clouds of atoms—as opposed to matter in the liquid or solid state—to a small fraction of a degree above absolute zero has enabled researchers to observe matter particles behaving as waves, to create the most precise measuring instruments in history, and to build the most accurate atomic clocks.

The drawback of these atom-cooling techniques is that they are applicable to only a few of the elements in the periodic table, limiting their usefulness. For example, hydrogen, the simplest of all atoms, was for a long time extremely challenging to cool. Now, however, my research group has demonstrated a new cooling method that works on most elements and on many types of molecules as well.

My inspiration: James Clerk Maxwell's Victorian-era thought experiment. This great Scottish physicist theorized the possibility of a "demon" that seemed able to violate the rules of thermodynamics.

The newfound capability will open directions in basic research and lead to a wide range of practical uses. For example, variants on the technique may lead to processes for purifying rare isotopes that have important uses in medicine and in basic research. Another spin-off might be an increase in the precision of nanoscale fabrication methods that are used to make computer chips. On the science side, cooling atoms and molecules may enable researchers to explore the no-man's-zone between quantum physics and ordinary chemistry or to uncover possible differences in behavior between matter and antimatter. And supercooling hydrogen and its isotopes could help small laboratories to answer questions in fundamental physics of the type that have traditionally required huge experiments such as those at particle accelerators.

RACING BULLETS

Stopping and manipulating atoms and molecules is no easy feat. In a typical experiment, researchers begin by producing a rarefied gas of a certain chemical element by heating up a solid or vaporizing one with a laser. The gas must then be slowed, confined in a vacuum chamber and kept away from its walls.

I started out with a time-honored trick. More than 40 years ago chemists found out that at a pressure of several atmospheres, gas escaping through a small hole into a vacuum undergoes significant cooling as it expands. Remarkably these "supersonic beams" are nearly monoenergetic, meaning that the speeds of molecules will all be very close to the average: for example, if a beam comes out at 2,000 miles per hour, molecules in it will deviate from that speed by at most 20 mph. By comparison, air molecules at room temperature, with an average speed of 2,000 mph, can have speeds anywhere between 0 and 4,000 mph. What that means, from the thermodynamic point of view, is that the beam, despite having a substantial amount of energy, is extremely cold. Think of it this way: an observer traveling with the beam at 2,000 mph would see molecules moving so slow that the beam's temperature would be just one 100th of a degree above absolute zero!

I realized that if my collaborators and I could slow down and stop such a beam while preserving the small spread in velocity, we could end up with a rather cold bunch of atoms that we could then trap and cool down even further.

To achieve that goal, my group started working with supersonic beams in 2004, together with Uzi Even, a chemist at Tel Aviv University. Our first attempt was to build a rotor with blades moving, at their edges, at half the speed as the supersonic gas beam. We aimed pulses from the beam at the rotor's receding blades in such a way that the beam's velocity would precisely cancel out with that of the blades. When the gas atoms bounced off the rotor, the rotor took all the kinetic energy out of them, just as a receding tennis racket can bring a ball to rest.

That setup, however, was difficult to work with because it required extreme fine-tuning. Robert Hebner, director of the Center for Electromechanics at the University of Texas at Austin, suggested a different design: bounce the gas off the back of a projectile as the projectile races down a coilgun. A coilgun is an experimental weapon that pushes magnetized projectiles out the barrel of a gun with magnetic fields rather than gunpowder. It works by accelerating the bullet through a series of wire coils that have electric current running through them, creating magnetic fields. The bullet, which is essentially a bar magnet, is attracted to the center of the coil it is passing through. An approaching bullet is thus accelerated by attractive forces. Once the bullet passes the center, on the other hand, the forces would start to pull it back and thus slow it down to its original speed. But the current in each coil is switched off precisely at the moment the projectile crosses its center, so that the magnetic forces always push the projectile in the right direction—down the barrel.

I quickly realized that we could apply Hebner's idea but get rid of the bullet altogether. Instead we would use the same principle on the beam itself, though in reverse: rather than accelerating a bullet, the coils of the gun would act in this case directly on the gas molecules, bringing them to rest [*see box on opposite page*]. The trick is possible because most atoms have at least a small amount of magnetism, and all do when their electrons are put in an excited state. Many types of molecules are magnetic, too.

We built the new device and tested it first on excited neon atoms and then on oxygen molecules. We succeeded in stopping both species. Unbeknownst to us, a group working in Zurich led by Frederic Merkt independently developed the same idea and succeeded in stopping atomic hydrogen at roughly the same time we conducted our own experiments. Several groups around the world have now built their own atomic coilguns, which are ultimately very simple and robust devices, based on ordinary copper wire, off-the shelf capacitors and transistors.

Once we succeeded in stopping atoms in this way, it was relatively straightforward to trap them in static magnetic fields. The more difficult problem was to find a way to cool them further. Although 0.01 kelvin (one 100th of a degree above absolute zero) sounds chilly, it is still very far from the limits reached by other techniques. We needed to find a way to go lower.

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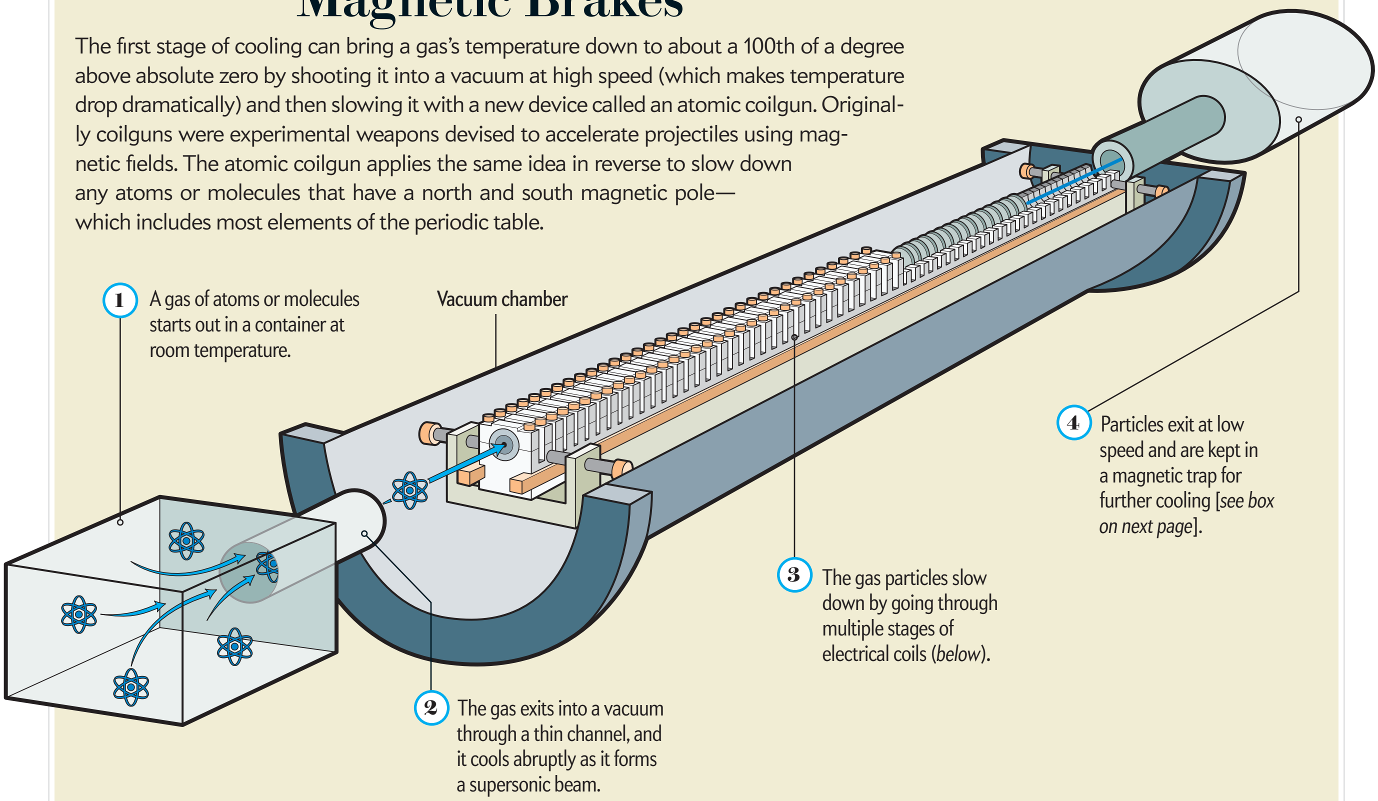
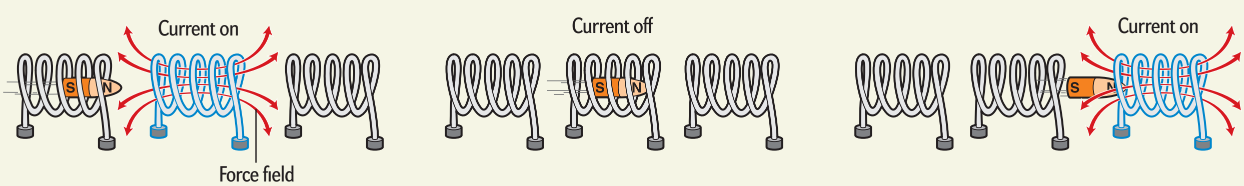
STAGE ONE OF COOLING

Magnetic Brakes

The first stage of cooling can bring a gas's temperature down to about a 100th of a degree above absolute zero by shooting it into a vacuum at high speed (which makes temperature drop dramatically) and then slowing it with a new device called an atomic coilgun. Originally coilguns were experimental weapons devised to accelerate projectiles using magnetic fields. The atomic coilgun applies the same idea in reverse to slow down any atoms or molecules that have a north and south magnetic pole—which includes most elements of the periodic table.



How the Reverse Coilgun Works



ONE-WAY ROADS

I WAS THINKING ABOUT general cooling methods well before anyone thought about atomic coilguns, but for a long time I did not see a solution. The technique of laser cooling, which was invented in the 1980s, has been extremely successful—resulting in the creation of a state of matter called Bose-Einstein condensates and in the award of two Nobel Prizes in Physics in 1997 and 2001. But the range of applicability of laser cooling is mostly limited to the atoms in the first column of the periodic table, such as sodium or potassium, because those are easy to switch between a ground state and a single excited state, as required by the technique. Another method I considered was evaporative cooling, which relies on skimming off the hot atoms, leaving the cooler ones behind (the same principle by which sweat cools us off as it evaporates from our skin). But without the aid of laser cooling, it is very hard to get to high-enough density to kick off evaporation in the first place.

In February 2004 I visited Princeton University and talked with Nathaniel J. Fisch, a plasma physicist. He told me about an idea he had just developed: how to drive an electric current of electrons in a plasma—a gas of electrons and positive ions—with a scheme that causes electrons to go in one direction and not the other. I wondered if we could accomplish something similar with atoms or molecules: build a "gate" that lets atoms through in one direction but not the other.

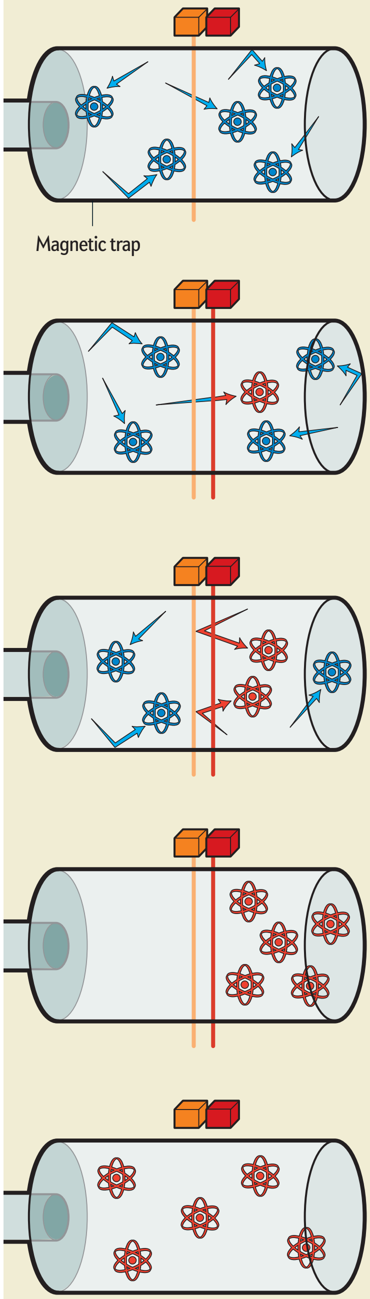
Leaving aside for a moment the technical issue of how to actually build a one-way gate, let me first explain why such a device might help cool down a gas. The first step would be to reduce the

Illustration by Brown Bird Design

STAGE TWO OF COOLING

Devilishly Cool

After an atomic coilgun or some other device has cooled a gas to hundredths of a degree above absolute zero, the serious freeze can begin, down to millionths of a degree or lower. The new technique of single-photon cooling achieves that feat using a one-way gate inspired by a 19th-century thought experiment. The idea is to first let the gate concentrate atoms into a smaller volume (but without raising their temperature) and then allow them to expand to the original volume (which brings their temperature down).



1. Atoms in a given initial state (*blue*) are held in a magnetic trap. A laser that affects those atoms only when they are in a second state is switched on (*orange*).

2. A second laser beam (*red*) switches atoms from their blue state to a second stable state (*red atom*) when they hit it.

3. Atoms in the red state bounce back when they hit the orange laser and so are forced to stay on the trap's right side.

4. All atoms eventually cross the second laser, turning red and ending up on the right side. They are at the same temperature as they started but in a smaller volume.

5. The atoms are allowed to slowly expand back to their original volume. As the gas expands, it cools down.

volume of the gas without raising its temperature. Suppose a gate separates a container into two volumes. Gas atoms bounce around the container randomly and sooner or later end up flying toward the gate. If the gate lets them through in only one direction, say, from left to right, eventually all atoms will concentrate on the right side of the container. Crucially the atoms' velocities do not change in the process, so the gas will be at the same temperature at which it started. (Thermodynamically this procedure is completely different from compressing the gas into the right half of the volume, which would accelerate the atoms and thus raise temperature.)

The second step would be to let the gas expand back to its original volume. When a gas expands, its temperature decreases, which is why spray cans get cold during use. So the end result would be a gas with the original volume but lower temperature.

The problem that long befuddled physicists is that such atom-sorting gates would seem to violate the laws of physics. In its compressed state, the gas has lower entropy, which is a measure of the amount of disorder in a system. But according to the second law of thermodynamics, it is impossible to lower the entropy of a system without expending energy and producing more entropy elsewhere.

This paradox has been a topic of controversy ever since James Clerk Maxwell's thought experiment in 1871, in which an "intelligent being with deft hands" could see the coming and going of particles and open or close a gate appropriately. This hypothetical creature became known as Maxwell's demon and appeared to violate the second law of thermodynamics because it could lower the entropy of the gas while expending a negligible amount of energy. After many years, in 1929, Leo Szilard resolved the paradox. He proposed that the demon collects information every time that the trap door is opened. This information, he argued, carries entropy, which exactly balances the entropy decrease of the gas, thereby "saving" the second law. (Szilard was ahead of his time: in later decades the concept that information has real physical meaning arguably kicked off modern information science.)

All thinking around Maxwell's dilemma, including Szilard's solution, was purely speculative, and for many decades it seemed destined to stay that way. My colleagues and I, however, created the first physical realization of Maxwell's thought experiment the way Maxwell thought it up. (Other recent experiments have done something conceptually similar but with nanomachines rather than gates for a gas.) And we used it to cool atoms to temperatures as low as 15 millionths of a kelvin.

As we shall see, the device we built clarifies how Maxwell's demon can exist in practice, as well as why Szilard's insight—that information plays a crucial role—was correct.

For the one-way gate to work, I reasoned, the atoms in the gas must have two different states (possible configurations of orbiting electrons) that are both of low energy and thus stable. Let us call the two states blue and red. The atoms are suspended in a container that is cut across the middle by a laser beam. The beam is tuned to a wavelength that makes red atoms bounce back when they approach it, so that it acts in essence as a closed gate. Initially all atoms are blue and thus can fly through the laser barrier unimpeded. But just to the right of the barrier beam, atoms are hit by a second laser, this one tuned so that atoms turn from blue to red by scattering a single photon. Now the atoms, being red, are repelled by the barrier beam and thus cannot go through the gate and back to the left side. Eventually all the atoms gather up on the right side, and the left side remains empty.

Illustration by Brown Bird Design

We first demonstrated our gate with atomic rubidium in early 2008. We called our method single-photon cooling to distinguish it from the earlier laser cooling, which required many photons to cool each atom.

Single-photon cooling demonstrates the idea of Maxwell's demon, a being that appears to violate the second law of thermodynamics.

Meanwhile, unbeknownst to me, Gonzalo Muga of the University of Bilbao in Spain, together with his collaborator Andreas Ruschhaupt (now at Leibniz University in Hannover, Germany), independently developed a similar concept. Since then, Muga, Ruschhaupt and I have worked out some of the theoretical aspects of the gate. In a joint paper that appeared in 2006, we pointed out that when an atom scatters one photon, the photon carries away with it information about that atom—and thus a tiny quantum of entropy. Moreover, whereas the original photon was part of an orderly train of photons (the laser beam), the scattered photons go off in random directions. The photons thus become more disordered, and we showed that the corresponding increase in the entropy of the light exactly balanced the entropy reduction of the atoms because they get confined by the one-way gate. Therefore, single-photon cooling works as a Maxwell demon in the very sense envisioned by Leo Szilard in 1929. The demon, in this case, is particularly simple and efficient: a laser beam that induces an irreversible process by scattering a single photon. Such a demon is certainly neither an intelligent being nor a computer and does not need to make decisions based on the information coming from the atoms. The fact that the information is available and can in principle be collected is enough.

FRONTIERS OF TRAPPING AND COOLING

THE CONTROL OF ATOMIC and molecular motion opens new directions in science. Chemists have long dreamed of trapping and cooling molecules to study chemical reactions in the quantum regime. The coilgun works on any magnetic molecule and complements a method that uses electric rather than magnetic forces to slow down any molecule that is electrically polarized. If the molecules are small enough, single-photon cooling should then be able to bring temperatures down low enough that quantum phenomena start to dominate. For example, molecules turn into stretched-out waves that can chemically react over much larger distances than usual and with no need for the kinetic energy that fuels ordinary reactions. Several groups are now pursuing this direction.

Another major advantage of single-photon cooling is that it works on hydrogen—and on its isotopes deuterium (with a neutron in addition to the single proton in the nucleus) and tritium (with two neutrons). In the late 1990s Dan Kleppner and Thomas J. Greytak of the Massachusetts Institute of Technology were able, through heroic efforts, to trap and cool hydrogen using cryogenic methods and evaporative cooling, but they never did the same with the other isotopes. Further progress hinged on new methods to trap and cool hydrogen isotopes in a relatively simple apparatus. Single-photon cooling is perfectly suited to trapping and cooling of all three isotopes of hydrogen. One goal will be to push the current limits of ultrahigh-precision spectroscopy, another important application of cool atoms.

Trapping and cooling of tritium may make it possible to measure the mass of neutrinos, the most abundant of the known elementary particles in the universe, and thus to better understand the particles' gravitational effects on the evolution of the cosmos. Tritium is radioactive, and it transmutes into helium 3 when one of its neutrons decays into a proton, an electron and an antineutrino, the antimatter counterpart of a neutrino. By measuring the energy of the electron, which shoots out as beta radiation, physicists could determine the energy that went missing with the antineutrino—which would fly through the apparatus undetected—and thus the antineutrino's mass; physicists expect the mass of neutrinos to be the same as that of antineutrinos.

The same methods will also work for trapping and cooling antihydrogen, the antimatter equivalent of hydrogen. Antihydrogen has only recently been created at CERN, the particle physics lab near Geneva, and is extremely delicate to handle because antimatter vanishes into a flash of energy as soon as it comes into contact with matter. In this case, the supersonic beam method cannot be used as the starting point. Instead a beam of antihydrogen could be generated by launching antiprotons through a positron cloud and then stopped and cooled with our Maxwell demon. Experiments with antihydrogen will be able to answer the simple question: Does antimatter fall the same way as matter? In other words, does gravity act the same way on all objects of the same mass?

The new techniques of atomic coilgun and single-photon cooling could also have important practical applications. Isotopes from most of the periodic table of elements are still separated using a device called a calutron, invented by Ernest Lawrence during the Manhattan Project. Calutrons separate the isotopes, which have slightly different masses, by an electric field, essentially like a large mass spectrometer. The only active calutron program right now is in Russia and is quite inefficient. A Maxwell demon concept similar to the one that works in cooling could be used to separate isotopes in a beam and would be more efficient than calutrons. This method can produce small quantities of isotopes, such as calcium 48 or ytterbium 168, that are relevant to medicine and basic research but poses no risk for nuclear proliferation because it is practical only for isolating very small amounts of an isotope.

Another spin-off we are pursuing is to build structures on the nanometer scale. Instead of using magnetic fields to slow atoms down, one could let the fields focus atom beams like a lens focuses light, but with a resolution of just one nanometer or better. Such beams could then deposit atoms to create smaller details than is now possible with optical lithography, the golden standard of computer-chip fabrication. The ability to create nanoscale structures in this bottom-up fashion, rather than by the top-down approaches that are more common in nanoscience, will start a new field that I call atomoscience.

Absolute zero may be as unattainable as ever, but there is still much to be discovered—and to be gained—on the path that leads there. SA

MORE TO EXPLORE

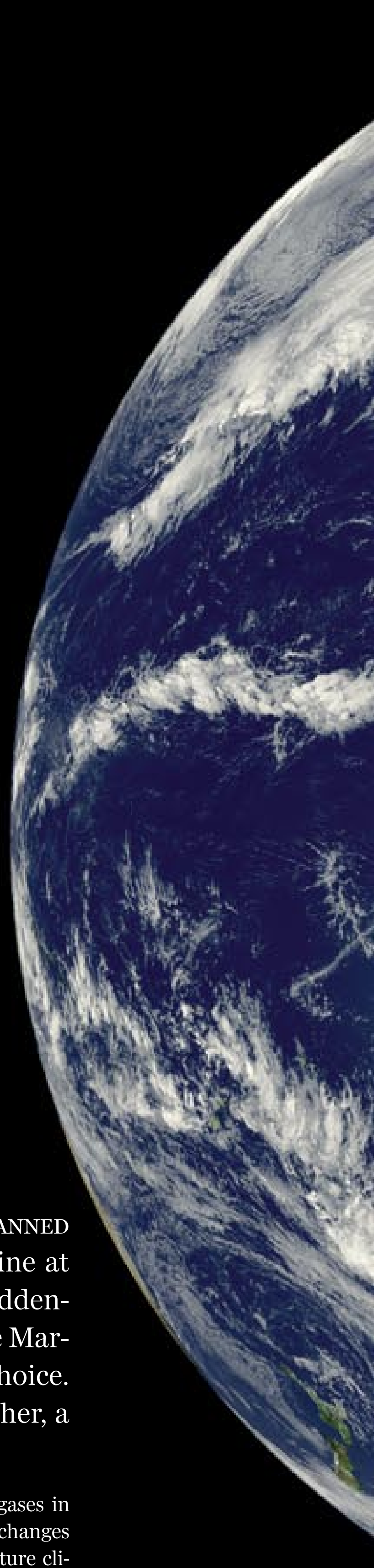
The Spectroscopy of Supercooled Gases. Donald H. Levy in *Scientific American*, Vol. 250, No. 2, pages 96–109; February 1984.

Demons, Engines and the Second Law. Charles H. Bennett in *Scientific American*, Vol. 257, No. 5, pages 108–116; November 1987.

Laser Trapping of Neutral Particles. Steven Chu in *Scientific American*, Vol. 266, No. 2, pages 70–76; February 1992.

Julian P. Sachs is an associate professor of oceanography at the University of Washington. His laboratory focuses on developing and applying molecular and isotopic techniques to decipher climate, geochemical and biochemical processes over the past 2,000 years.

Conor L. Myhrvold, a geoscience major at Princeton University, was a fieldwork assistant and photographer for Sachs on recent expeditions.



CLIMATE CHANGE

A Shifting Band of Rain

By mapping equatorial rainfall since A.D. 800, scientists have figured out how tropical weather may change through 2100

By Julian P. Sachs and Conor L. Myhrvold

THE FIRST INDICATION THAT OUR EXPEDITION WAS NOT GOING AS PLANNED was the abrupt sputter and stop of the boat's inboard engine at 2 A.M. The sound of silence had never been less peaceful. Suddenly, crossing the open ocean in a small fishing vessel from the Marshall Islands in the North Pacific Ocean seemed an unwise choice. A journey to a scientific frontier had led us to a different frontier altogether, a vast darkness punctuated by the occasional lapping wave.

We are climate scientists, and our voyage (which ended safely) was one of many intended to help us do what at first glance seems impossible: reconstruct rainfall history back in time, across an ocean. By tracing that history, we can gain a better understanding of how the ongoing buildup of greenhouse gases in the atmosphere, rising air temperatures and changes in tropical precipitation are likely to alter future climate patterns. We have traveled far and wide to numerous islands across the Pacific Ocean.

IN BRIEF

The tropical rain band that wraps the globe north of the equator migrates as atmospheric temperature changes, altering rainfall patterns worldwide.

Data from sediments in Pacific Island lakes show that the band is at 3°N to 10°N, as far north as it has ever been in at least 1,200 years.

At current warming rates, the band could shift north by five degrees by 2100, drying out farmland for millions of people in Ecuador, Colombia and elsewhere.

Multiyear drought conditions in the southwestern U.S. could persist as that area becomes more like the semiarid region of northern Mexico.

Some present-day climate patterns are well known, such as the El Niño and La Niña circulations in the Pacific. A lesser known but equally important pattern is the primary precipitation feature on the planet: a band of heavy rainfall that circles the globe in the tropics and migrates north or south seasonally with the angle of the sun. The area in which it moves is known as the Intertropical Convergence Zone (ITCZ).

Any change in the earth's temperature, as a result of incoming solar radiation or greenhouse gases, can affect the rain band, which provides the precipitation that feeds equatorial agriculture. The band also plays a central role in the monsoons of Asia, Africa and India and the large convection cells that transport heat from the equator toward the poles. The frequency and intensity of El Niño and La Niña events and the strength and duration of hurricane seasons in the Pacific and Atlantic can all be influenced by variations in the band's position. Changes in rainfall resulting from a permanent shift of the band would dramatically alter the equatorial environment, with effects reaching worldwide. And we have good reason to believe the band is shifting.

Until recently, climate scientists did not know whether the current annual range of the band's midline—from 3°N to 10°N latitude over the Pacific Ocean—was its historical range. But now field measurements from latitudes bracketing the ITCZ have allowed our colleagues and us to define how the band has moved over the past 1,200 years. A large shift of five degrees northward—about 550 kilometers—occurred from about 400 years ago until today. Discovery of that shift led us to a startling realization: small increases in the greenhouse effect can fundamentally alter tropical rainfall. We can now predict where the ITCZ will move through 2100 as the atmosphere warms further. We can also predict whether rainfall may rise or fall across the world's equatorial zones, the probable effects across higher latitudes in Asia, Central America and the U.S. southern tier, and what those changes might mean for weather and food production. Some places are likely to benefit, but many others, we fear, will face dry times.

MEDIEVAL UNKNOWN

UNTIL WE BEGAN mapping rainfall history, scientists had little data about where the ITCZ had been during the past millennium. The band hovers near the equator, but it can be tens or hundreds of kilometers wide, depending on local conditions and seasonal sunshine. Because the zone is highly pronounced over the Pacific, that region is ideal for tracking its movement. And because the rain band girds the earth, Pacific trends indicate global changes.

Scientists can profile the sun's strength from isotopes such as carbon 14 in tree rings and beryllium 10 in ice cores and can reconstruct the historic profile of worldwide greenhouse gases from air bubbles trapped in tubular cores of ice extracted from polar regions. By comparing solar output and greenhouse gas levels with the ITCZ's position over centuries, we can infer how tropical rainfall might change in the 21st century in response to rising greenhouse gas emissions.

Clever investigators have identified many different indicators of global temperature during the past millennium. Two periods stand out. Around A.D. 800, global temperatures were similar to those in the late 1800s. Temperatures then rose during the Medieval Warm Period (A.D. 800–1200), reaching levels similar to 20th-century temperatures. They gradually settled and fell during the Little Ice Age (A.D. 1400–1850). In the past two decades the sun's output has remained essentially constant, yet both temperature and levels of carbon dioxide—the most abundant man-made greenhouse gas—have become significantly higher than at any point in the past 1,200 years.

Atmospheric scientists knew few specifics about past tropical climate, however, when we began our work. Seafloor sediments, which can provide exquisite records of climate on multithousand-year timescales, accumulate too slowly to record much information about the past 1,000 years. Many corals produce annual bands, but the creatures rarely live longer than 300 years, providing no records from 300 to 1,000 years ago.

Mapping rainfall would allow us to fill in the missing information about the ITCZ's position over the past millennium. Usually determining rainfall once it has hit the ocean is a lost cause. But small islands scattered across the Pacific have enclosed lakes and ponds that can reveal the history. In the past six years we have collected dozens of sediment cores from the bottoms

IN THE LAB

Algae: Rain Gauge of the Ages

Algae obtain all their hydrogen from the water in which they live. By measuring the two stable isotopes of hydrogen—deuterium and protium—in the lipids of algae that are preserved in sediment underneath tropical lakes, we can infer the amount of rainfall that occurred when they lived.

The deuterium/protium (D/H) ratio of many algae has a linear relation with the D/H ratio of the water. The water ratio, in turn, reflects the rate of precipitation relative to evaporation in a lake's area. Within the tropical rain band region, where rainfall is frequent and heavy, the D/H ratio of lake and seawater is low. Outside the region, where evaporation can exceed precipitation, the D/H ratio is high. So we can use the varying D/H ratios of algal lipids found deeper and deeper in sediment to infer past rainfall.

Fortunately for us, algae also adjust the D/H ratio of their lipids in response to salinity. Special conditions on Christmas Island created a natural experiment for us to calibrate this response. The island hosts a series of ponds that have similar temperatures, light levels, nutrient levels and water D/H ratios, yet they differ widely in their salinities. We found that as the salinity increased so did the D/H ratio of lipids produced by cyanobacteria, in a linear fashion. Because the salinity of saltwater ponds decreases when rain is abundant and increases when it is dry, the salinity effect on lipid D/H acts in the same direction as the rainfall amount effect, making lipid D/H ratios sensitive gauges of hydrologic change.

These results, alone, are like geeks at the prom: they need dates! A sediment's age is determined by two radioactive isotopes, carbon 14 and lead 210, which have half-lives of 5,730 and 22.3 years, respectively. By comparing the hydrogen isotope ratios at various dates, we have reconstructed the series of precipitation changes going back 1,200 years. *—J.P.S. and C.L.M.*

PRECEDING PAGES: COURTESY OF NOAA-NASA GOES PROJECT of such waters in some of the most remote, exotic Pacific islands. The locations span a range of latitudes above, below and within the current band and fully across the Pacific. We can define where the rain band was during a given time period by pinpointing places that experienced intense rainfalls in that period at various latitudes. Simultaneous rainfall increases and decreases, northward or southward, indicate a common, oceanwide shift in the band.

Fieldwork is an adventure fraught with setbacks, equipment issues, language barriers and difficulty getting to the sediment-coring locations. For example, by the time we arrived in the capital city of Majuro, the local airline, Air Marshall Islands (affectionately known to locals as "Air Maybe"), had two broken planes in its fleet of two. The two-day trip mentioned earlier to test a local entrepreneur's modified fishing boat that looked alarmingly unseaworthy ended when the engines died on our overnight return from a neighboring atoll.

A sediment core pulled from a lake bottom on Lib Island holds preserved algae that reveal past rainfall. Trees prove handy for keeping a core vertical as thin sections are cut for the lab.

To retrieve an undisturbed sediment core, we push, pound and screw long tubes into a lake's bottom. Just about every site we have cored has a unique sediment sequence. Sometimes we find bright-red gelatinous layers several meters thick made up of cyanobacteria, as in the Washington Island lake. Other times the sediment is brown mud rich in hydrogen sulfide (read: it stinks!), containing mangrove leaf fragments and the occasional layer of bivalve shells, as in Palau.

As we slog through mud on foot and row across shallow water, we push a long pole into the sediment to test depths and to see whether obstacles lurk. It is not unusual to abort a core attempt because it hits rocks, ancient coral, sand or roots.

Because the rate of sediment deposition is highly variable, we do not know how deep we need to go. Generally speaking, one meter of sediment stretches back at least several hundred years: nine meters of sediment from Washington Island, for example, spanned 3,200 years. When possible, we try to hit "bedrock" at the bottom of a core: deposited sand, coral or volcanic rock marking the time when the lake first began accumulating sediment, so that we can obtain the most complete record of the historical climate.

THE SECRET LIES IN LIPIDS

RECONSTRUCTING RAINFALL is our goal, but we have to measure the ecosystem's characteristics in the present climate to know what the same measurements of the past environment reveal about the past climate. We therefore collect water samples at different depths to determine the chemical composition and hydrogen isotope ratio of the water, as well as traits of the algal and microbial populations. We trap phytoplankton, zooplankton and microbes on fine, glass-fiber filters, then immediately store them on ice so we can later analyze their lipid composition. Vegetation samples are collected from the immediate vicinity to evaluate their lipids, too.

After we carefully raise the cores out of the lake bottom, we have to get the samples back to the lab without disturbing the sediment. To avoid mixing a core's layers, we painstakingly "section" the uppermost sediments that are particularly soft into one-centimeter slices and store each slice in labeled plastic bags.

Once we have sectioned cores on site, we journey back to Seattle to our lab at the University of Washington, hauling stacks of ice chests filled with sediment and water and long cardboard boxes filled with the segments of cores that did not require bagging. By measuring the two stable isotopes of hydrogen in the lipids of algae preserved in successively deeper layers of sediment, and dating the samples back in time, we can infer the amount of rainfall that occurred when the flora lived [*see box on opposite page*].

WET REGIONS BECOME DRY

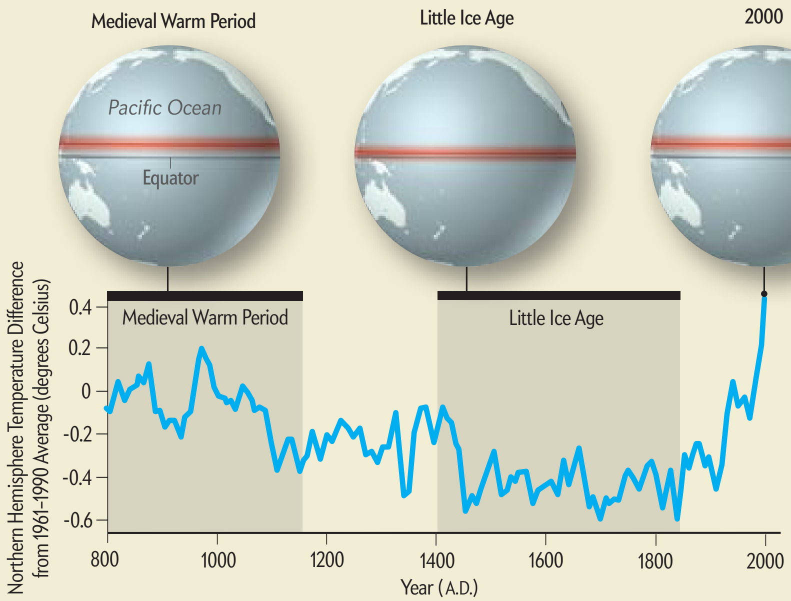
OVER SUCCESSIVE YEARS we have added more data to an increasingly accurate map that pinpoints the ITCZ's historical locations, and we continually update it with our latest results. Although our findings from the most recent expedition—to Kosrae in Micronesia—will take a few more months to analyze, the results from many trips, combined with data from colleagues, indicate that small changes in atmospheric heat were accompanied by large changes in tropical rainfall during the Little Ice Age, drying previously wet regions such as Palau and bringing abundant rain to previously arid regions such as the Galápagos Islands. When solar energy reaching the top of the atmosphere decreased by just two tenths of a percent for about 100 years, the ITCZ migrated south toward the equator by 500 kilometers.

COURTESY OF CONOR L. MYHRVOLD

As Temperature Rises, So Does the Rain Band

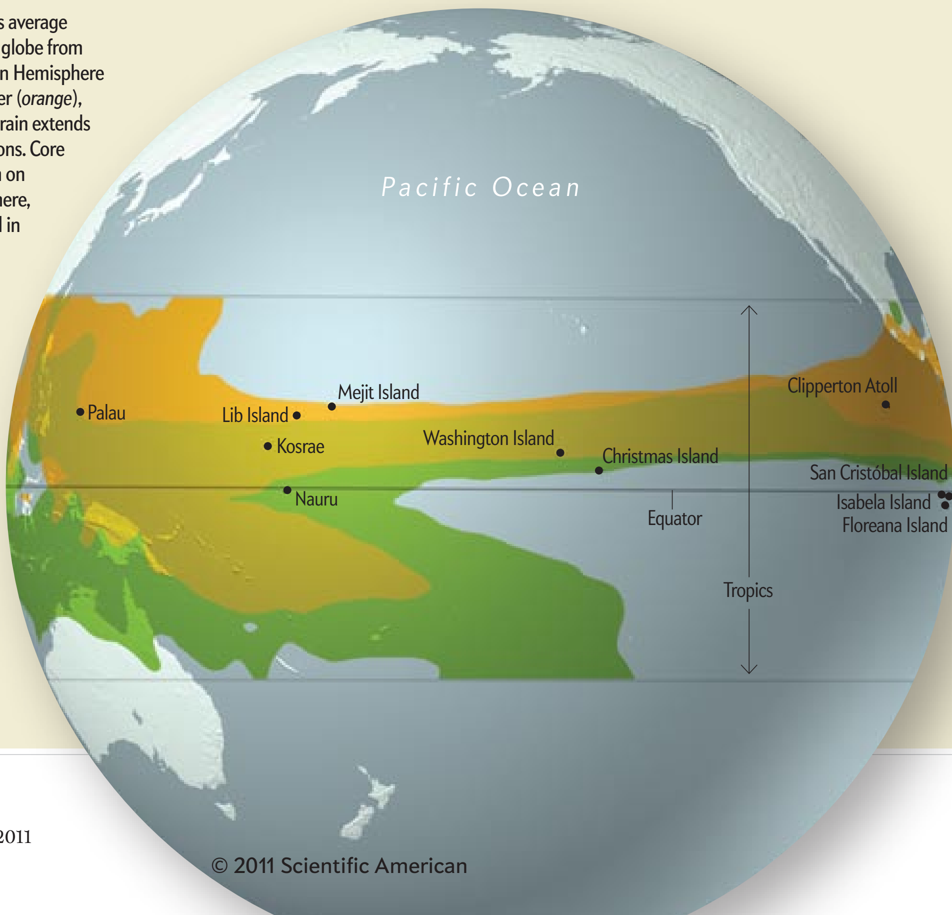
The Intertropical Convergence Zone (*red*), which circles the earth, is formed by opposing trade winds that create low pressure above equatorial water heated by the sun. The water evaporates, rises and condenses as rain—lots of it. The low pressure also creates adjacent, massive high-pressure cells that circulate atmospheric heat toward higher latitudes, driving weather systems there.

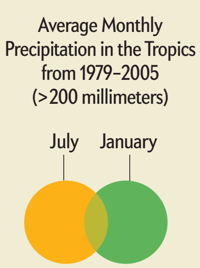
Elevated Northern Hemisphere temperatures moved the rain band north during the Medieval Warm Period (*left*); cooler temperatures shifted it south during the Little Ice Age. Today the band is as far north as it has ever been in the past 1,200 years. The projected rise in global greenhouses gases could bump it another five degrees northward by 2100.



Implications: If the rain band travels another five degrees north, hundreds of millions of people near the equator would be left in its dry wake. Subsistence agriculture, coffee and banana crops, and tropical biodiversity would wither in places such as Ecuador, Colombia, northern Indonesia and Thailand. Locations in the band for the first time would receive much more rain, including Guam and El Salvador. Serious drought in the southwestern U.S. would likely become the new normal pattern.

Seasonal swing: The rain band's average latitude of 7°N varies across the globe from roughly 3°N during the Northern Hemisphere winter (*green*) to 10°N in summer (*orange*), stoked by the sun's heat. Heavy rain extends beyond the band in certain regions. Core samples of lake sediments taken on islands, including some shown here, reveal where and when rains fell in the past, indicating the band's position over time.





SOURCES: NOAA (*precipitation*); "PROXY-BASED RECONSTRUCTIONS OF HEMISPHERIC AND GLOBAL SURFACE TEMPERATURE VARIATIONS OVER THE PAST TWO MILLENNIA," BY M. E. MANN ET AL., IN *PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES USA*, VOL. 105, NO. 36; SEPTEMBER 2, 2008 (*temperature curve*)

That sensitivity does not bode well for our future. The Intergovernmental Panel on Climate Change projects that because of primarily tailpipe and smokestack emissions, the atmospheric carbon dioxide concentration will rise to double preindustrial levels by midcentury and triple by 2100, causing an increase in atmospheric heating two to three times larger than changes that occurred at the end of the Little Ice Age from increased sunlight alone.

During the Little Ice Age the rain band's midline remained south of 5°N. Today it hovers between 3°N and 10°N. Recent increases in greenhouse gases threaten to move the band's center another five degrees northward—550 kilometers—by 2100. This new location (8°N to 15°N) would significantly change the intensity of rainfall in many regions [*see box on opposite page*].

Evidence for potential changes comes from our findings on the islands. Washington Island, located at 5°N, now receives three meters of rain a year, but 400 years ago it received less than one meter of rain and experienced more intense evaporation. Conversely, the highlands of San Cristóbal Island at 1°S in the desertlike Galápagos archipelago were substantially wetter during the Little Ice Age.

Evidence from archaeologists is also helpful. They have concluded that on islands across Indonesia and the South Pacific, a marked increase in the construction of fortifications coincided with the last large southward shift in the ITCZ's position. The bulk of fortifications—stone structures to fend off intrusions from neighboring societies—were built from the onset to the end of the Little Ice Age. As the rain band moved south, islands left in its northern wake dried out, perhaps forcing inhabitants to flee to more southern islands, raising fears of invasion among local peoples there.

Today desalination technology and shipping ease strict dependence on rainfall, but a move of the rain band five degrees further north would endanger the hundreds of millions of people who live near the equator and depend on subsistence agriculture, not to mention tropical biodiversity. Most nations in the current range are developing nations. They are likely to experience great population increases during this century and are unlikely to have the resources to successfully adapt. Rainfall declines, on one hand, and flooding, on the other, across decades or even a few years would reduce crop yields, leading to localized food shortages, political unrest and ultimately geographic displacement.

Areas directly in the ITCZ for the first time (10°N to 15°N), such as El Salvador and Manila in the Philippines, would receive more rain annually and would become more humid. Regions no longer under the rain band's direct influence (3°N to 8°N) would receive less rain and become more arid. Whether this drying effect would be countered in certain places by the strength of the Asian and Indian monsoons is subject to debate.

SLIDE SHOW OF PACIFIC RAINFALL RESEARCH
ScientificAmerican.com/mar2011/sachs

LESS COFFEE, FEWER BANANAS

OVERALL, WET AREAS in northern Indonesia, Malaysia, the Philippines, Micronesia, Thailand and Cambodia would miss a good portion of the ITCZ rains they now receive. Crop varieties ideal for today's growing conditions would no longer thrive. For example, coffee plants, much like vineyards, need a lot of rain at the beginning of the growing season and require more than 1.8 meters in total to develop suitable beans.

In Central America, Ecuador and Colombia would be left in the ITCZ's wake and become drier. Colombia's increased urbanization may help it cope because its economy is no longer as highly dependent on agriculture. Colombia, however, is the world's third-largest coffee producer, and as in Indonesia, less precipitation could affect long-term coffee yields. Most growing regions for the bean, which are below 8°N latitude, would likely suffer by the mid- to late 21st century. Productive areas in the south and along the coast are most at risk because they will be the farthest from the rain band.

The future of Ecuador's banana industry may be bleak. Good bananas require warm temperatures and 2 to 2.5 meters of annual rainfall, but Ecuador is already well below the current ITCZ and barely meeting the minimum precipitation threshold. A shift would likely decrease rainfall to a meter a year or less by 2100, shutting down the country's banana industry. A large drop in banana yield can happen quite fast. In the Philippines at the beginning of 2010, roughly half of the plantations produced small and underweight bananas that were useless commercially, because of an abnormal dry season.

Subsistence agriculture would also be affected in all the aforementioned locations. Even if people gravitate toward cities, a lack of regional food sources is a recipe for disaster.

If the band continues migrating north at the average rate it has been over the past 400 years, substantial rainfall changes in the continental U.S. are likely, too. Some changes may have already begun. The southwestern U.S. is enduring a severe multiyear drought that is likely to represent the new normal pattern in the 21st century should greenhouse gas levels continue to rise apace. Higher temperatures, and a continuing northward shift of the rain band, threaten to shift the subtropical dry zone that lies to its north, which currently stretches across northern Mexico, into this part of the country.

Scientists are unclear whether a northward shift would affect the frequency or size of hurricanes or monsoons. We also have yet to determine any possible effects on the patterns of El Niño and La Niña.

BETTER MODELS COMING

MORE WORK needs to be done before alarm bells can be sounded with confidence. Computer-based climate models have not accurately reproduced past and present rainfall patterns in the tropics. If modelers can use data from sediment cores and other sources to produce patterns that more closely approximate those that are known, the world could have greater confidence in their projections of future rainfall. This type of experiment is being pursued by our colleagues at the University of Washington and elsewhere.

We will continue to study sediments from tropical islands in the ITCZ, and to its north and south, to more precisely define the rain band's position throughout the past millennium and to predict where it will be in generations to come. SA

MORE TO EXPLORE

Proxy-Based Reconstructions of Hemispheric and Global Surface Temperature Variations over the Past Two Millennia. Michael E. Mann et al. in *Proceedings of the National Academy of Sciences USA,* Vol. 105, No. 36, pages 13252–13257; September 2, 2008.

Southward Movement of the Pacific Intertropical Convergence Zone AD 1400–1850. Julian P. Sachs et al. in *Nature Geoscience,* Vol. 2, No. 7, pages 519–525; July 2009.

Paleoclimates and the Emergence of Fortifications in the Tropical Pacific Islands. Julie S. Field and Peter V. Lape in *Journal of Anthropological Archaeology,* Vol. 29, No. 1, pages 113–124; March 2010.

Paleoclimate research at the Sachs Lab: **http://faculty.washington.edu/jsachs**

Illustration by George Retseck (globes) and Jen Christiansen (graph)

PUBLIC HEALTH

Not Just an Illness of the Rich

Recent global health campaigns have focused on HIV, tuberculosis and malaria. Tackling the growing threat from cancer, says medical anthropologist Paul Farmer, could improve health care more broadly

Interview by Mary Carmichael

By 2020, 15 million people worldwide will have cancer and nine million of them will be living in developing countries, according to World Health Organization estimates. Harvard University physician and medical anthropologist Paul Farmer is determined to ensure that prediction doesn't come true. Farmer, a pioneer in global health, has a history of tackling big problems. His Ph.D. dissertation on HIV in Haiti ran to 1,000 pages, leading Harvard to impose a cap. Since then, as co-founder of the nonprofit Partners In Health, he has brought medical treatments, from basic primary care to antiretroviral therapies for AIDS, to millions of the world's poor.

Farmer's work—chronicled in the Tracy Kidder best seller *Mountains beyond Mountains* and in his own books—has inspired governments and global agencies to do likewise. Recently he has focused his attention on cancer in the developing world, where the disease is increasingly common and costly treatments are often hard to come by. In the medical journal the *Lancet* last October, he and a team of other leaders from the Global Task Force on Expanded Access to Cancer Care and Control in Developing Countries announced an ambitious, multipronged plan to increase these countries' access to cancer medical resources—by raising money, driving down the cost of drugs, and figuring out new ways to get those drugs to patients in need. Science writer Mary Carmichael spoke with Farmer at his office in Boston. Excerpts follow.

Scientific American: What does it mean to say that cancer is on the rise in developing nations? Is it part of a worldwide pattern?

FARMER: Incidence is hard to measure, and "cancer" epidemiology isn't the same in, say, Jordan as it is in Burundi because, for one thing, Jordan has more medical resources. But there are some general trends. In 1970, 15 percent of cancer diagnoses were in developing countries. That number was 56 percent by 2008. And the death rates are almost 50 percent greater in low-income countries than in those with high incomes. I don't like the term "lifestyle," but some of the risk factors for cancer such as exposure to viruses and pollutants or toxic chemicals are more widely prevalent, and that increases the incidence. Also, in a lot of countries life expectancy is going up. What that

IN BRIEF

Nearly two thirds of the 7.6 million cancer deaths worldwide occur in low- and middle-income countries, but a mere 5 percent of the world's cancer resources are spent on patients there.

Global health pioneer Paul Farmer and his group Partners In Health have joined a global task force that wants to marshal support for cancer care and treatment in these countries.

Partners In Health has begun to develop programs in Malawi, Haiti and Rwanda, which collaborate with Harvard-affiliated teaching hospitals to provide a full range of care to patients in these resource-poor settings.

Photograph by Christopher Churchill

means is that if you're treating drug-resistant tuberculosis or HIV, now you can get people to survive for decades, but that gives them more time to die of a malignancy.

One reason cancer is on the rise is that other causes of death are declining?
Yes. One of the points in our recent *Lancet* piece is that we really need to integrate cancer prevention and care by marshaling various preventives, diagnostics and therapeutics. Instead of having different programs regarded as radically separate, the more you can bring them together, the more bang you'll get for the buck. That's true of all efforts to strengthen health systems. But with cancer, the need to integrate is especially clear, because there's not just one way to approach the disease. Some types can be prevented with vaccines, such as some liver and cervical cancers, certain head and neck cancers, et cetera. Others are curable with chemotherapy or radiation or surgery. And others, you can palliate for discomfort. So you need to get different institutional players in medicine involved. You also need to make sure cancer care is part of national health insurance programs for the poor, as it already is in Mexico and Colombia.

Paul Farmer began his crusading work in the public health arena in Haiti in the 1980s. He is now targeting cancer care.

MARK L. ROSENBERG *The Task Force for Global Health*

Do you think cancer has been ignored in the developing world? It seems like infectious diseases—HIV, TB, malaria—get more attention.
If you go back to 2003, there really were not any programs to diagnose and treat AIDS either and very few for tuberculosis and malaria. The U.S. President's Emergency Plan for AIDS Relief had been proposed, but it hadn't actually rolled out. And with the Global Fund to Fight AIDS, Tuberculosis and Malaria, one of the first grants went to Haiti, and that didn't come in until 2003. So that's very recent history—AIDS, tuberculosis and malaria weren't on the map either. Poor people's problems in general just were not on the map.

Why not? And what put them there?
The 1990s was in my view a decade of terribly low expectations in global health. I think people had started thinking that the number of public health interventions possible in a given nation-state was related directly to the GDP of that nation-state. What that meant is that you'd hear things like, "Haiti's so poor that we really can't afford to waste resources on anything that isn't cheap."

But then AIDS shows up, and it's a transnational phenomenon. So to have strategies that are only focused on what's available in one country when the diseases go back and forth—it's crazy, right? And by the turn of the millennium, AIDS, tuberculosis and malaria were killing six million people a year, almost entirely in places where there weren't enough resources. Then new media really made everybody feel like they were on the same planet, so suddenly you would have people Skyping from Haiti to Harvard. That's when the Bill & Melinda Gates Foundation and the Global Fund and the President's Emergency Plan, the largest financial commitment any country had ever made to fighting a single disease, came into play, and that changed the landscape radically, but again, that was only in the past few years.

Cancer was a problem then, too. Why wasn't it part of the global health agenda in the early 2000s?
It should have been. But I do think it was good to focus on some of the other burdens of disease and gaps in treatment because, after all, AIDS, tuberculosis and malaria were all neglected. If you said, "Let's have a global fund to fight diseases and poverty"—well, we've tried that before, and it didn't work so well. I think there was something really compelling about the U.S. President's Emergency Plan for AIDS Relief focused on one disease. Still, when there's perceived scarcity of resources, you do get people saying, "All the attention's focused on AIDS. None of it's focused on 'fill in the blank.'" But that kind of competitiveness over resources is not great. Let's not make the same mistake again and again and again. We shouldn't assume that in a resource-poor setting you're only going to have enough money to do a good job on a few things.

Can you harness the competition among diseases for the good?
I think you can. That's what this global cancer task force is trying to do, in a sense to say, "Okay, we'll focus on cancer," knowing that we also have to work on strengthening health systems overall and on vaccines, diagnostics, chemotherapy and palliative care. The complexity of cancer means that people are working together, and we're trying to use this integrative approach of revamping the whole health system.

What public health interventions will be the most effective in preventing cancer?
Cervical cancer is one malignancy that we could probably almost wipe out because of new preventives, better early detection and treatments, and I wouldn't have said that 10 years ago.

Because we didn't have the Gardasil vaccine 10 years ago?
We didn't. Of course, HPV [human papillomavirus] is sexually transmitted, so you can imagine all of these other primary preventions: so-called safe sex or delayed onset of sexual activity. But humans being humans means that the vaccine is better. Now, maybe the variants of the virus that are not covered by the vaccine could become dominant: we don't know. And of course, the vaccine doesn't protect against other sexually transmitted diseases. But it's something. We start with that. This is a malignancy that really affects poor women, and now we've got something that's going to prevent a big fraction of the cases.

What comes next?
Screening. You can use acetic acid to look at the cervix, and if you see lesions in situ, they can be removed with cryotherapy. They can be burnt out. That's curative. And after that, of course, you have patients who could have more radical surgery that would be curative, and finally you have patients who couldn't be cured and need other kinds of therapies, like radiation to palliate their symptoms.

How available are those treatments in the developing world?
Not widely. I had a patient 12 years ago who had metastatic cervical cancer, and she had to go to get radiation therapy in the Dominican Republic because there was none in Haiti. But she did get it, and I just saw her a couple of weeks ago. The question is, if the treatments aren't available, are we going to use that as the beginning of a discussion or the end of one?

So what's available right now in the kind of places I work? You start with nothing. If you go to a capital city anywhere in Africa, even the poorest one, you're always going to find an oncologist or hematologist. But we go to rural areas. What tends to happen is that if you put together decent health care infrastructure in these rural areas, people actually come there from the cities looking for care, because they're poor. They get referred by the private hematologists and oncologists, who say, "I can't help you, but I hear these people out in the boondocks are providing cancer diagnosis and care." When we started working in rural Africa, we knew this would happen, because we had gone through it in Haiti. We became the provider of last resort. In northern Rwanda, there were 500,000 people without a district hospital. So, with the Ministry of Health, we built a hospital. We've also tried to get diagnoses made with the help of a Harvard teaching hospital, the Brigham and Women's Hospital. They're doing all the pathology for us for free.

ADDITIONAL RESOURCES
ScientificAmerican.com/mar2011/farmer

You send samples back and forth?
Yes, so with a solid tumor, you just do a biopsy—which we can easily do at any of these sites—send it back, get the diagnosis at the Brigham, and then the Dana-Farber Cancer Institute gets us the chemo, which we deliver in Rwanda with the help of pediatricians and general practitioners and nurses who are there. We've been using this model in Malawi, Haiti and Rwanda.

That's extraordinary, to think that someone in a rural area in Rwanda is getting treated by one of the best cancer centers in the world.
I think it is. We hope that other providers in the field see this and stop saying, "Oh, we can't do this. It's Africa. You can't treat cancer there."

Could other hospitals develop this kind of partnership?
Every hospital in America has a pathology department and a chemo program. You don't need them all to do it, but the academic medical centers should be doing this.

You also need to train people on the ground, right?
One of the lessons we learned in Haiti, trying to treat tuberculosis, is that if you want to get people to adhere to treatment, you have to work with community health workers. I remember originally we thought, "We've got the doctors, we've got the nurses, we've got the lab, we've got the microscope," and patients were still dying. And so we had to figure out, what is the delivery problem here? What we discovered is even if you can afford doctors and nurses, you still need community health workers, because they're in the villages with their neighbors. And of course, the problem was it was a chronic illness and the patients have to stay on the meds. Community health workers could encourage them to take the medications and also help with daily tasks that patients needed.

You also need community health workers for palliative care at the end of life, which is a focus of your cancer work. Obviously, there's no reason that someone in Africa shouldn't have it if someone here has it. Do you get resistance to the idea?
In a sense, given the sad fact that all humans are mortal, all care is palliative. But what's interesting to me as a medical anthropologist is the way some of these terms get perverted. In a place where you have no effective therapy, the "palliative care" term was abused a bit, because the idea was: we can't treat the cancer or the AIDS, so we'll just give palliative care. And I think that was a mistake. People should've said, we should be doing our best job of treatment and doing palliative care.

But people with painful malignancies, oh, yeah, they need palliation in Haiti just as much as they do at Harvard. And pain management is not a really expensive proposition. It's very difficult to manage narcotics, that's true. You have to make sure the drugs are working without too many side effects, and you also have to make sure they aren't being stolen and sold on the street.

It's not always that the drugs themselves are so expensive. And again, yes, cancer care is expensive, but is that the end of the conversation or the beginning? Because if it's the beginning, we can then say, "How do we drive down costs?" And that's one of the focuses of the task force.

You spend so much time working on policy. Do you still see patients, too?
I'm actually going down tomorrow to Haiti to see a patient, a 25-year-old kid. He had these pulmonary lesions that everybody assumed—correctly—were tuberculosis, but then it turned out he also had lymphoma. I started seeing him about half a year ago, and we got the diagnosis made at the Brigham and then the chemo from the Dana-Farber, and he actually just left the hospital. Believe it or not, his name is Victory.

Is he cured?
I think so. He did six cycles of chemo, and he's certainly cured of his TB. I'm hoping to see him tomorrow. He went home, but not too far from the hospital. So I can probably dig him up. Not out of the ground, thank God. SA

Mary Carmichael *is a senior writer at* Newsweek *covering health and science and is currently a Knight Science Journalism Fellow at M.I.T.*

MORE TO EXPLORE

Expansion of Cancer Care and Control in Countries of Low and Middle Income: A Call to Action. Paul Farmer et al. in *Lancet,* Vol. 376, pages 1186–1193; October 2, 2010.

Cancer Control in Developing Countries: Using Health Data and Health Services Research to Measure and Improve Access, Quality and Efficiency. Timothy P. Hanna and Alfred C. T. Kangolle in *BMC International Health and Human Rights,* Vol. 10, No. 24; October 13, 2010.

Paul C. Sereno is a paleontologist based at the University of Chicago. He has led expeditions to five continents and discovered over two dozen new species of dinosaur. He is also co-founder of Project Exploration, a science outreach organization for urban youth.

PALEONTOLOGY

DINOSAUR DEATH TRAP

On a trip to the Gobi Desert, a team of fossil hunters unearths a death scene that reveals new clues about how dinosaurs lived

By Paul C. Sereno

"ANOTHER SKELETON WITH A PERFECT SKULL!" I SHOUTED TO THE TEAM, ALL OF whom were face down on the quarry floor exposing other skeletons. In the years I had spent as a paleontologist, never had I seen anything like this. Our team of fossil hunters had been prospecting for only 15 days in the Gobi Desert of Inner Mongolia, but already we had uncovered a veritable graveyard of intact fossils.

Over the next few weeks we would apply chisel, pickax and bulldozer to the site, digging up more than a dozen examples of an ostrichlike dinosaur that was to become one of the most well known in the dinosaur world. But the story would soon grow far richer than a simple body count of fossil bones, as intact and well preserved as they might be. This group of individuals would reveal how these dinosaurs interacted with one another, how their society was built, as well as the circumstances surrounding their gruesome and untimely deaths. We were just beginning to uncover the first clues of this 90-million-year-old murder mystery. Little did I know that what we were about to learn

IN BRIEF

An expedition in the Gobi Desert of Inner Mongolia turns up evidence of a 90-million-year-old graveyard, including the remains of more than a dozen fossilized ostrichlike dinosaurs.

Evidence at the site points to a unique and rare conclusion: the dinosaur fossils were not deposited at the site over millennia. Instead the dinosaurs all met their fate at the same time.

By studying this mass grave, researchers have learned about the structure of dinosaur society, the ways in which these creatures interacted, and the division of labor among adults and juveniles.

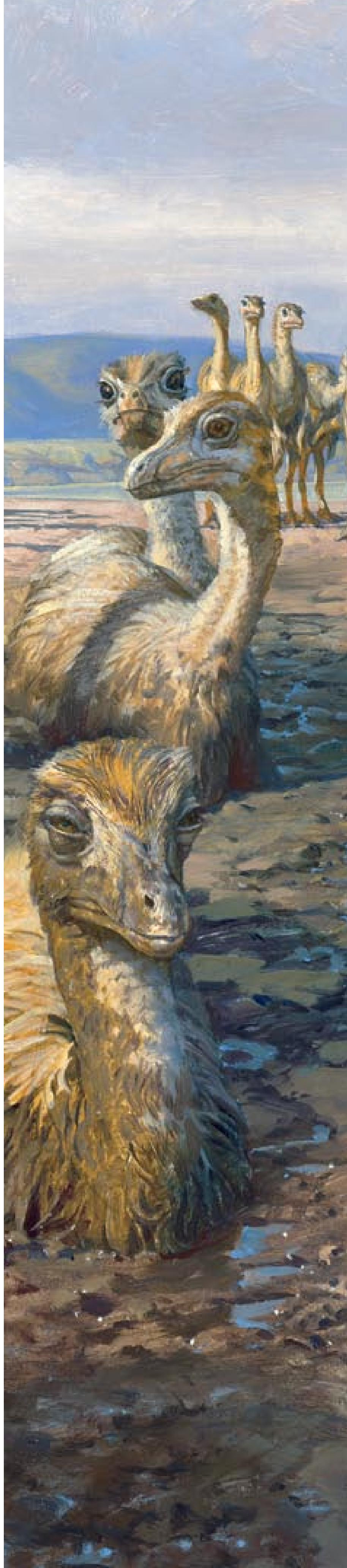


Illustration by James Gurney


GURNEY

would end up making this the richest site for a single dinosaur species I had ever encountered.

THE LURE OF THE GOBI

AMERICANS INEVITABLY associate dinosaur discovery in the Gobi with Roy Chapman Andrews, the swashbuckling expedition leader from the American Museum of Natural History in New York City. In the 1920s Andrews ventured into the desert regions of Outer Mongolia and returned to great fanfare with the first known dinosaur eggs and the sickle-clawed wonder *Velociraptor*. Andrews was not the only explorer combing the desert, however. At around the same time, Swedish explorer Sven Hedin was recovering unprecedented fossils from the southern half of the Gobi in Inner Mongolia, a region that is now part of China.

In the intervening years, scientists searching near Hedin's sites have uncovered dinosaur egg nests with brooding parents and sickle-clawed raptors that rival the best discoveries in Outer Mongolia. Yet scholars and public attention have favored Outer Mongolia; as a result, scores of international fossil expeditions have crisscrossed the area since it opened to the West more than a decade ago. In contrast, Inner Mongolia has remained relatively untouched.

I was a 27-year-old graduate student in geology in the middle of an around-the-world tour when I first visited Inner Mongolia in 1984—the first year that China allowed foreign tourists to travel in the country without an escort. After I arrived in the capital city of Hohhot by coal-powered steam locomotive, I visited the museum in the center of what was then a one-story town. Outside, dinosaur-age rock stretched for hundreds of kilometers west, flanking the fabled Silk Road linking the Mongolian steppe with the heart of Central Asia. When I returned to Beijing, I met with Zhao Xijin, a professor at the Institute of Vertebrate Paleontology and Paleoanthropology and one of China's most accomplished fossil hunters, who had at the time already been responsible for discovering more than a dozen new species. We discussed exploring the area together at some time in the future. Some 16 years later the timing and circumstances finally aligned.

In 2000 I returned to Hohhot with Zhao to arrange the logistics of a major dig in the area. We stepped from the train onto the platform in Hohhot and were greeted by Tan Lin, a geologist and director of the Long Hao Institute for Stratigraphic Paleontology in Hohhot. Looking much younger that his 60 years, Tan energetically laid out the details of vehicles and supplies needed for a Gobi expedition the following spring. Fortunately, we would have no problem finding suitable expedition vehicles in Hohhot. The one-story town I knew had been replaced by a bustling metropolis with wide boulevards lined with flashing neon signs.

Tan suggested we revisit sites made famous by the fossil discoveries of Hedin and later expeditions. Certainly more fossils were there to be discovered. But I had other ideas. "Anywhere no one has been" was my refrain. Eventually the pull of the unknown won the day, and we decided to set out on the Silk Road in the spring, heading to the remote western reaches of the Gobi.

THE FIRST CLUES

BY MID-APRIL 2001 our 16-person crew composed of American, French, Chinese and Mongolian fossil hunters had gathered in Hohhot. We divided ourselves among four field vehicles and a truck packed with tons of supplies for the 700-kilometer trip along the banks of the Huang He (Yellow River) and out into the desert.

We set up our first base camp not far from the tiny outpost of Suhongtu. The Gobi wind battered our iron-framed Chinese army tents, spraying a coat of silt and dust on everything inside. Hair soon stood erect as if gelled. Showers were out of the question, given the shortage of water and profound chill.

Every day we set out to hunt for fossils. Team members would walk for miles over the uneven terrain, searching for interesting finds that might be peeking out of the rock. With fossil hunting, it's good to be lucky, but it's better to be blessed with the "nose"—a natural talent for sniffing out fossils.

Montana State University paleontologist Dave Varricchio spotted the first major find—a three-toed footprint on the underside of a low ledge of rock. That footprint, notable for its short side toes, was small for a dinosaur, though bigger than his hand. We deduced that it was likely made by a large ornithomimid, or "bird mimic." Soon we would have no doubt about what made the print.

The area surrounding the camp was Late Cretaceous in age—about 90 million years old—according to a Chinese geology map printed some 25 years earlier. Besides the footprint, our finds were limited to bones of small dinosaurs found before in the Gobi, and so we moved into a broad valley nearby where fossils were more plentiful. Soon team members were poking at several finds, including what was likely a primitive duckbill skull poking out of the surface. Another fossil appeared to belong to a small sauropod, the four-legged plant eaters that often grow to enormous size.

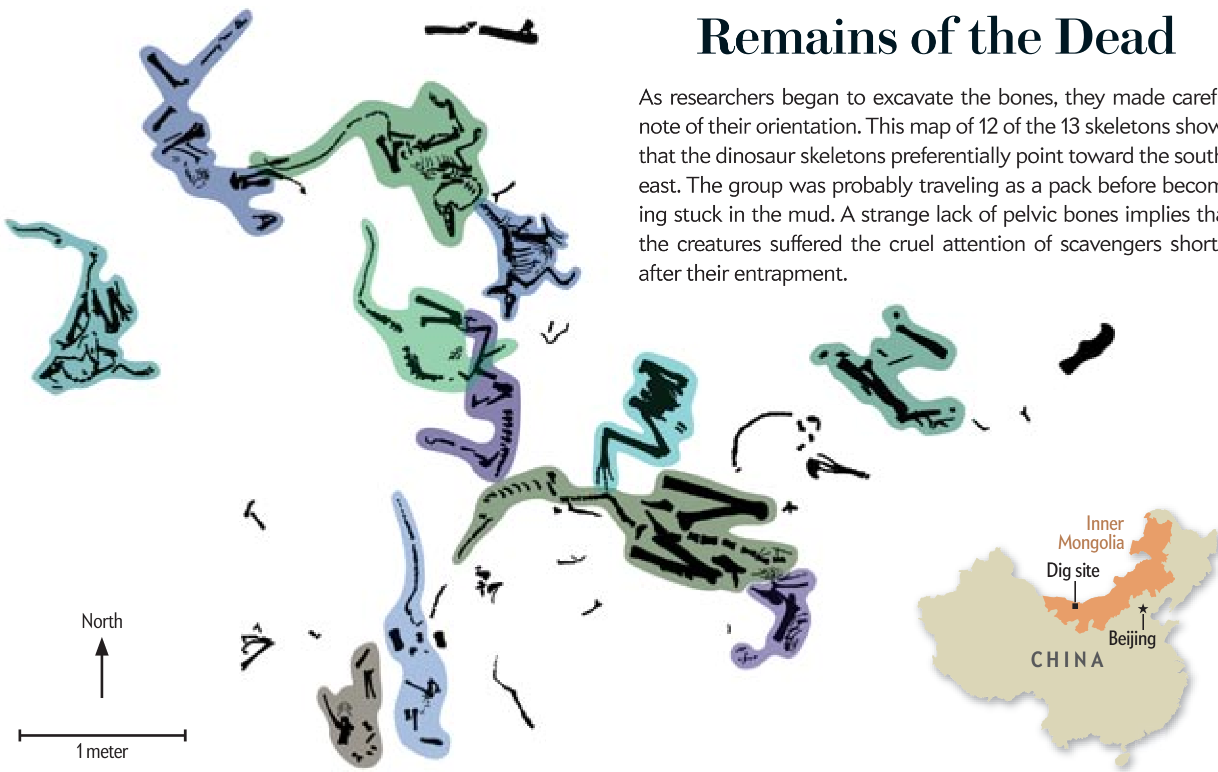
The most interesting site was a vertical wall of layered red and blue rock that was peppered with the leg bones of several relatively small dinosaurs. This was not a natural wall. Hewn by chisel and pick, it was the


MIKE HETTWER

Speed the plow: **Without this bulldozer, on loan from a nearby Chinese army base, the excavation would have taken months, not weeks.**

Remains of the Dead

As researchers began to excavate the bones, they made careful note of their orientation. This map of 12 of the 13 skeletons shows that the dinosaur skeletons preferentially point toward the southeast. The group was probably traveling as a pack before becoming stuck in the mud. A strange lack of pelvic bones implies that the creatures suffered the cruel attention of scavengers shortly after their entrapment.



FROM "MUD-TRAPPED HERD CAPTURES EVIDENCE OF DISTINCTIVE DINOSAUR SOCIALITY," BY DAVID J. VARRICCHIO ET AL., IN *ACTA PALAEONTOLOGICA POLONICA*, VOL. 53, NO. 4; 2008 *(bone map)*

back wall of a fossil quarry. Someone had been there before us.

Tan explained that this site was originally found in 1978 during a mapping survey by a geologist and former classmate of his. "Look here," he said, pointing to a small bone symbol on the geology map. Using this map, Tan had guided a joint Chinese-Japanese-Mongolian expedition to this site four years earlier in 1997. Running short of time and materials, they had collected multiple skeletons but stopped before the excavation was complete.

In my backpack was a paper from 1999 on a new ornithomimid from the Gobi by a young Japanese paleontologist, Yoshitsugu Kobayashi, who at the time was a graduate student at Southern Methodist University. I now realized that the paper was based on finds from the quarry before me. Kobayashi and his colleagues had noted the presence of many fossils as well as their exquisite preservation; some fossils even included stomach stones—pebbles that ancient sauropods (and modern-day alligators, seals and birds) ingest to help grind food and aid digestion. In 2003 Kobayashi would name this dinosaur *Sinornithomimus dongi*. Yet mysteries remained: Why were so many fossils preserved in one small area? Did they all die at the same time or over millennia? And if they did all perish at once, how?

The quarry was located at the base of a small, rocky hill in a desolate windswept region of the Gobi. The horizon had turned gray brown—an early warning of an approaching dust storm. In the desert, these warnings are best measured in minutes, not hours. We raced for the field vehicles, hoping to dash back to camp while we could still navigate by the tracks we left on the way there. Within minutes the wind began to sling sheets of sand, dulling the paint on the lower reaches of our trucks.

The pore-filling dust and bone-chilling cold was offset at day's end by the camp cook, who regularly served seven-course meals for dinner—always a different seven from the night before. Fortunately, the camp was located not far from an army outpost, giving us access to fresh vegetables. Chinese cuisine, to my palate, is the best the world over. Equally renowned is Chinese beer, which we downed by the quart that season in celebration of our luck racking up noteworthy finds.

THE DEATH TRAP

WE RETURNED to that valley every day for the next few weeks, many of us devoted to unraveling the mystery of the ornithomimid quarry. One skeleton led to another, as our tools pushed the back wall of the quarry deeper into the hill. Others studied and sampled the cliff face, compiling a detailed log of the rocks entombing the graveyard.

When multiple individuals of a single species are preserved in one place, a paleontologist must ask whether that assemblage is natural—that is, was it a family group or herd congregating, as it might on a given day, only to be caught dead in its tracks? Most bone accumulations of a single species are not so interesting. Rather they are composed of unrelated individuals that, over some unknown length of time, died near a water hole or were washed in by a flood.

If we quickly bagged the remaining skeletons, the most interesting part of the story—how all these dinosaurs died—would be lost forever. Clues to the cause, circumstances and timing of death do not reside solely in the bones themselves but also in the position of skeletons, in the presence of tooth marks or splintered bone, and in the character of the sediment that is laid down before, during and after death. A crime scene, not a pa-

Map by XNR Productions (China)

leontologist's trophy trove, is how we must view such a quarry.

We soon came to believe that these animals all met their fate at the same time. The skeletons were not randomly distributed—all the bones seemed to point in the same direction. That could have been the result of a flood or a river carrying multiple sets of bones to the same place, but we could not find any evidence that the bones were moved in this way. All the skeletons were intact.

In addition, the thin-layered red and blue rock of the cliff face implied that the area used to consist of fine-grained mud and silt. We found spots in the infilled mud cracks, suggesting that the area went through wet and dry periods. Tiny, flat shells of freshwater creatures called conchostracans blanketed some of the skeletons, the flotsam from an expanding lake. Near the skeletons the mud was nearly pure, lacking the worm burrows and roots of a soil that supported plant life. All in all, the rock surrounding the skeletons suggested the ebb and flow of an ancient lake—an oasis in an otherwise dry area.

A collection of fossils such as this was unheard of—it was (and remains to this day) the only known Pompeii-like sampling of a dinosaur species. As the quarrying operation continued, we spent many hours musing on death scenarios. Perhaps these dinosaurs perished from a nearby volcano or succumbed to a flash flood? "Perhaps they just got stuck in the mud?" team member Gabrielle Lyon suggested, while outlining with a jeweler's needle the clenched digits of the foot of a fallen dinosaur. To me, the idea of a mud trap seemed a bit far-fetched. Though an experienced excavator, Lyon was an educator, not a paleontologist or geologist. Modern animals such as cows sometimes die near water holes—the large beasts get mired up to their kneecaps in mud and ultimately die of thirst, exposure and starvation. Yet it is extremely rare for entire herds to die this way (although sometimes it does happen to wild horses, noted Varricchio, the expedition's expert on taphonomy—the science of death and dying).

RECONSTRUCTING THE DEATH TRAP
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As we dug, more clues began to accumulate. Dave spotted V-shaped patterns on the cliff face near the horizon preserving the skeletons. The layers of mud were deformed downward, as if pulled by the passage of a thin object such as the claw on a dinosaur's toe. Was this evidence of a lethal dance in mud?

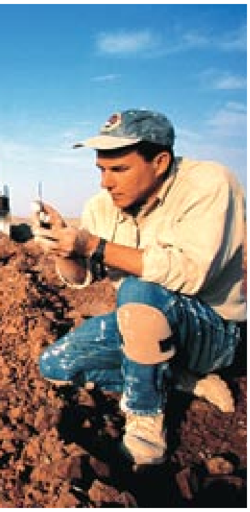
Unfortunately, we were not going to be able to dig for much longer. Our ornithomimid quarry was angling downward into the hill, getting more difficult to extract by the day. A complete excavation using the tools we had available would take months, if not years. Fortunately, we were soon to learn that in China, anything is possible.

On our day off we traveled out to the Chinese army outpost, where we were challenged to a game of basketball by the recruits. Professors Tan and Zhao watched from the sidelines, noticing the impressive heavy equipment parked nearby. Having befriended the soldiers during the basketball game, we took our case to officials at the base that evening, helped along with mind-numbing rounds of *baijiu,* a spirit that euphemistically translates to "white wine," even though it is served by the shot. A few days later a giant bulldozer arrived at the site.

As the blade trimmed off the top of the hill a few centimeters at a time, we followed in its wake, searching for fossils above the graveyard. "Stop!" shouted Jeff Wilson, who was hunched over a block tipped up by the monstrous blade. A paleontologist at the University of Michigan at Ann Arbor, Wilson had spotted some jaws and teeth. We picked through the tailings to each side of the last pass until we found all the missing pieces. Locked in that concretion just one human body length above the graveyard was a 45-centimeter skull of an unknown predator.

By the fourth day at the quarry, the bulldozer had removed the entire hill, its blade just above the graveyard. We resumed excavation until we unearthed the last of 13 individuals. Skeletons usually collapse on a flat surface to be buried in mere centime-

MIKE HETTWER



Scenes from a dig (*from left*): Dave Varricchio searches for small bones; the author takes a pickax to the tough Gobi rock; the team sorts through the tailings left in the bulldozer's wake; the team takes refuge from a sandstorm; a *Sinornithomimus* arm is found encased in rock.

ters of sediment, but as we chipped the mudstone from the main horizon containing the skeletons, the hind legs of several dinosaurs plunged deep into the mud. Some of the otherwise perfectly preserved skeletons were missing hipbones. These individuals looked as if they were trapped in mud, only to suffer the attention of ancient scavengers.

It was just what we would expect if a herd of dinosaurs on the move all became stuck on the same muddy shore. Lyon's hypothesis, drawn from the panic she must have sensed in the bones, was emerging as the most likely death scenario.

IN LIFE AND DEATH

BACK AT THE UNIVERSITY OF CHICAGO, members of my research team cleaned the skeletons one by one under the microscope, revealing a remarkable level of preservation. Not only were stomach stones preserved, but they seemed to retain the shape of the gizzard where they once pulverized plants. We also discovered a thin film of black carbon coating either side of the gizzard. The black material was the remains of the dinosaurs' last meal.

Additional evidence helped to confirm one of our hunches from the excavation. In the desert we had noticed that all the skeletons in the quarry were immature. At a field site the best way to measure a dinosaur's age is to examine the individual bones that constitute the backbone. Every vertebrae is made of a spool-shaped bone (the centrum) below and a curved structure (the neural arch) above. If these two parts are fully fused, the backbone is no longer growing, and the dinosaur is mature. All skeletons collected at Suhongtu had vertebrae preserved as two parts.

Yet this feature provided only a crude estimate of the dinosaurs' ages. Back at Chicago, we sliced bones into thin sections to count their annual growth rings as you would a tree. We learned that the skeletons ranged from one to seven years of age, with most ranging between one and two years old. This pattern told us two things. First, it meant that *Sinornithomimus* must have required about 10 years to reach maturity. And second, we realized that the herd at Suhongtu was a band of adolescents—dinosaur teenagers cruising in a pack.

With this realization we could put together the full history of the dinosaurs—not just the way they died, but the way they *lived* as well. Paleontologists have speculated about the social habits of half-grown dinosaurs, but the herd at Suhongtu provides the best evidence to date. Because maturation took about a decade in *Sinornithomimus,* juveniles had plenty of opportunities to congregate. Adults were busy with a range of activities during the breeding season—courtship, nest building, nest defense, brooding, and nurturing of hatchlings. Juveniles seem to have wandered about, fending for themselves as they went.

This particular group had met an untimely end. To a passing herd, the mud trap would have looked like many other areas along the lake's edge—mud that might record a footprint rather than swallow a foot. A central pair of skeletons most dramatically captures the 90-million-year-old tragedy. These two animals lay hopelessly trapped, their bodies collapsed sideways on the surface, one on top of the other, their feet deeply anchored in mud. Their skeletons were exceptionally complete except for their hipbones, which must have been pulled off by hungry scavengers. An isolated hipbone helped to confirm that scenario, the central portion of its blade crushed under the weight of an intruder's toe.

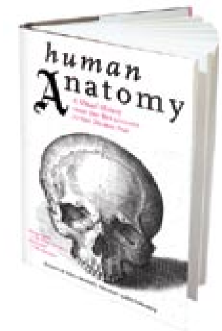
Then the water level rose, at least briefly, gently sealing in mud the graveyard and its tale of woe. SA

MORE TO EXPLORE

Herbivorous Diet in an Ornithomimid Dinosaur. Y. Kobayashi, J. C. Lu, Z. M. Dong, R. Barsbold, Y. Azuma and Y. Tomida in *Nature,* Vol. 402, pages 480–481; December 2, 1999.

Mud-Trapped Herd Captures Evidence of Distinctive Dinosaur Sociality. D. J. Varricchio, P. C. Sereno, X. Zhao, L. Tan, J. A. Wilson and G. H. Lyon in *Acta Palaeontologica Polonica,* Vol. 53, No. 4, pages 567–578; 2008.

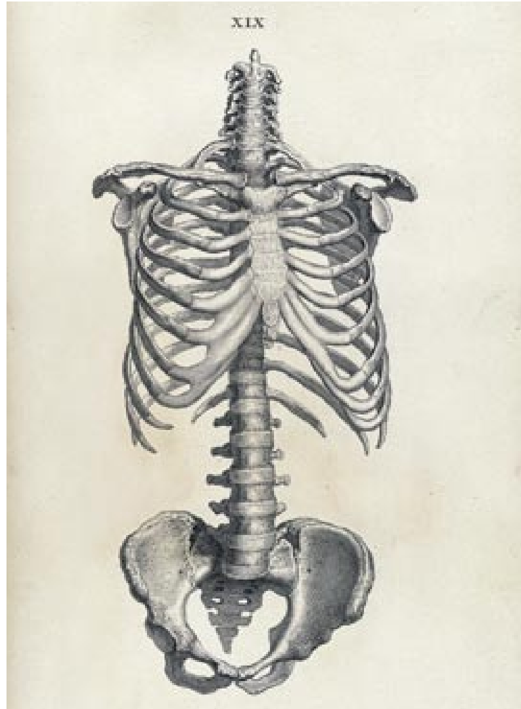
Project Exploration Dinosaur Expedition 2001: **www.projectexploration.org/mongolia**



Human Anatomy: A Visual History from the Renaissance to the Digital Age

by Benjamin A. Rifkin and Michael J. Ackerman.
Biographies by Judith Folkenberg. Abrams, 2011 ($16.95)

From Leonardo da Vinci's exquisite pen-and-ink drawings of the human skeleton to the digital Visible Human Project in its three-dimensional glory, this fascinating book, now in paperback, documents more than 500 years of anatomical illustration in living color.



Engraving by William Cheselden, 1733

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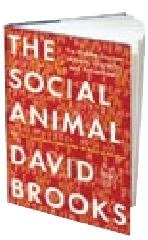
Spacesuit: Fashioning Apollo

by Nicholas de Monchaux. MIT Press, 2011 ($34.95)

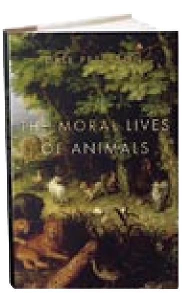
Talk about haute couture. In 1968 Playtex, the bra and girdle manufacturer, beat out a slew of military-industrial companies to win the contract to design and hand-sew the space suit for the 1969 Apollo mission to the moon. Nicholas de Monchaux of the University of California, Berkeley, delves into the history and enduring impact of the 21-layer garment in this well-illustrated volume.



The Social Animal: The Hidden Sources of Love, Character and Achievement

by David Brooks. Random House, 2011 ($27)

New York Times columnist David Brooks invents two characters, Harold and Erica, to illustrate recent scientific discoveries about human nature and the quest for success, following their paths from birth to old age.



The Moral Lives of Animals

by Dale Peterson. Bloomsbury Press, 2011 ($26)

Cooperative hyenas, scorekeeping impalas, heroic rats—humans are not the only creatures with a code of ethics. Dale Peterson of Tufts University argues that animals across many species exhibit behaviors that reveal evolutionary continuity between us and them. The rules and values *Homo sapiens* shares with other species provide a basis for Peterson to speculate about the future of our relationship with our fellow fauna.

ALSO NOTABLE

Deep Future: The Next 100,000 Years of Life on Earth, by Curt Stager. St. Martin's Press, 2011 ($25.99)

Discoverers of the Universe: William and Caroline Herschel, by Michael Hoskin. Princeton University Press, 2011 ($29.95)

Alone Together: Why We Expect More from Technology and Less from Each Other, by Sherry Turkle. Basic Books, 2011 ($28.95)

Blood Work: A Tale of Medicine and Murder in the Scientific Revolution, by Holly Tucker. W. W. Norton, 2011 ($25.95)

The Tribal Imagination: Civilization and the Savage Mind, by Robin Fox. Harvard University Press, 2011 ($29.95)

The Ragged Edge of the World: Encounters at the Frontier Where Modernity, Wildlands, and Indigenous Peoples Meet, by Eugene Linden. Viking, 2011 ($26.95)

Once and Future Giants: What Ice Age Extinctions Tell Us about the Fate of Earth's Largest Animals, by Sharon Levy. Oxford University Press, 2011 ($24.95)

Moonwalking with Einstein: The Art and Science of Remembering Everything, by Joshua Foer. Penguin Press, 2011 ($26.95)

Lab Coats in Hollywood: Science, Scientists, and Cinema, by David A. Kirby. MIT Press, 2011 ($27.95)

The Quiet World: Saving Alaska's Wilderness Kingdom, by Douglas Brinkley. HarperCollins, 2011 ($29.99)

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

Financial Flimflam

Why economic experts' predictions fail

In December 2010 I appeared on John Stossel's television special on skepticism on *Fox Business News,* during which I debunked numerous pseudoscientific beliefs. Stossel added his own skepticism of possible financial pseudoscience in the form of active investment fund managers who claim that they can consistently beat the market. In a dramatic visual demonstration, Stossel threw 30 darts into a page of stocks and compared their performance since January 1, 2010, with stock picks of the 10 largest managed funds. Results: Dartboard, a 31 percent increase; managed funds, a 9.5 percent increase.

Admitting that he got lucky because of his limited sample size, Stossel explained that had he thrown enough darts to fully represent the market he would have generated a 12 percent increase—the market average—a full 2.5 percentage points higher than the 10 largest managed funds average increase. As Princeton University economist Burton G. Malkiel elaborated on the show, over the past decade "more than two thirds of actively managed funds were beaten by a simple low-cost indexed fund [for example, a mutual fund invested in a large number of stocks], and the active funds that win in one period aren't the same ones who win in the next period."

Stossel cited a study in the journal *Economics and Portfolio Strategy* that tracked 452 managed funds from 1990 to 2009, finding that only 13 beat the market average. Equating managed fund directors to "snake-oil salesmen," Malkiel said that Wall Street is selling Main Street on the belief that experts can consistently time the market and make accurate predictions of when to buy and sell. They can't. No one can. Not even professional economists and not even for large-scale market indicators. As economics Nobel laureate Paul Samuelson long ago noted in a 1966 *Newsweek* column: "Commentators quote economic studies alleging that market downturns predicted four out of the last five recessions. That is an understatement. Wall Street indexes predicted nine out of the last five recessions!"

Even in a given tech area, where you might expect a greater level of specific expertise, economic forecasters fumble. On December 22, 2010, for example, the *Wall Street Journal* ran a piece on how the great hedge fund financier T. Boone Pickens (chair of BP Capital Management) just abandoned his "Pickens Plan" of investing in wind energy. Pickens invested $2 billion based on his prediction that the price of natural gas would stay high. It didn't, plummeting as the drilling industry's ability to unlock methane from shale beds improved, a turn of events even an expert such as Pickens failed to see.

Why are experts (along with us nonexperts) so bad at making predictions? The world is a messy, complex and contingent place with countless intervening variables and confounding factors, which our brains are not equipped to evaluate. We evolved the capacity to make snap decisions based on short-term predictions, not rational analysis about long-term investments, and so we deceive ourselves into thinking that experts can foresee the future. This self-deception among professional prognosticators was investigated by University of California, Berkeley, professor Philip E. Tetlock, as reported in his 2005 book *Expert Political Judgment.* After testing 284 experts in political science, economics, history and journalism in a staggering 82,361 predictions about the future, Tetlock concluded that they did little better than "a dart-throwing chimpanzee."

There was one significant factor in greater prediction success, however, and that was cognitive style: "foxes" who know a little about many things do better than "hedgehogs" who know a lot about one area of expertise. Low scorers, Tetlock wrote, were "thinkers who 'know one big thing,' aggressively extend the explanatory reach of that one big thing into new domains, display bristly impatience with those who 'do not get it,' and express considerable confidence that they are already pretty proficient forecasters." High scorers in the study were "thinkers who know many small things (tricks of their trade), are skeptical of grand schemes, see explanation and prediction not as deductive exercises but rather as exercises in flexible 'ad hocery' that require stitching together diverse sources of information, and are rather diffident about their own forecasting prowess."

Being deeply knowledgeable on one subject narrows focus and increases confidence but also blurs the value of dissenting views and transforms data collection into belief confirmation. One way to avoid being wrong is to be skeptical whenever you catch yourself making predictions based on reducing complex phenomena into one overarching scheme. This type of cognitive trap is why I don't make predictions and why I never will. SA

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Illustration by Juliette Borda

The ongoing search for fundamental farces

Steve Mirsky has been writing the Anti Gravity column for 100 years, within an order of magnitude. He also hosts the *Scientific American* podcast Science Talk.

The Future Is Now

Herbert Hoover was president when some big thinkers thought about today

As an understocked purveyor of large dried fruit might say, we're out of big dates for a while. The Orwellian 1984 came and went, we partied like it was 1999, the most ominous monoliths in 2001 turned out to be ideological and the Clarkesque follow-up of 2010 recently ended without interplanetary incident. We have another five centuries before we judge the prescience of Zager and Evans, if we are still alive.

We are thus left with 2011, a seemingly nondescript little year—except that the *New York Times* saw fit to publish predictions about it back in 1931. That year marked the *Times*'s 80th anniversary, so the editors thought it made sense to ask intellectual luminaries of the time to gaze into a future an equal period away, which, if you do the math right and don't engage in any major Gregorian-style calendar recalibrations, gives you 2011.

(I'm indebted to the law firm of Gallivan, White & Boyd and their "Abnormal Use: An Unreasonably Dangerous Products Liability Blog" for bringing this whole four-score-and-no-more business to my attention. Faced with a mass tort or catastrophic loss claim? Call Gallivan, White & Boyd. But not during a thunderstorm. And not while you're driving. And don't hold the phone too close to your head.)

The *Times* recruited Henry Ford, perhaps on the premise that the man who said "history is more or less bunk" would have more generous thoughts about contemplation of the future. Ford wrote, "To make an eighty-year forecast may be an interesting exercise … but its principal interest will probably be for the people eighty years on, who will measure our estimates against the accomplished fact." Bingo.

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The newspaper also published the musings of a couple of major physicists, Arthur H. Compton and Robert A. Millikan. Compton won the Nobel Prize in 1927 for his discovery of "Compton scattering," which usually describes the behavior of x-ray and gamma-ray photons when they hit matter but which can also refer to the reaction of politicians in the California city of Compton upon the arrival of corruption investigators.

Compton wrote that "communication by printed and spoken word and television [will be] much more common than at present, so that the whole earth will be one great neighborhood." What the great thinker did not predict was that the entire neighborhood would be transfixed by competitions involving second-rate singers, third-rate dancers and 400-pound dieters. Fortunately, the mass communications system also evolved an escape mechanism, namely, yet another viewing of the video of the sensational dramatic prairie dog (often taxonomically miscategorized as a dramatic chipmunk).

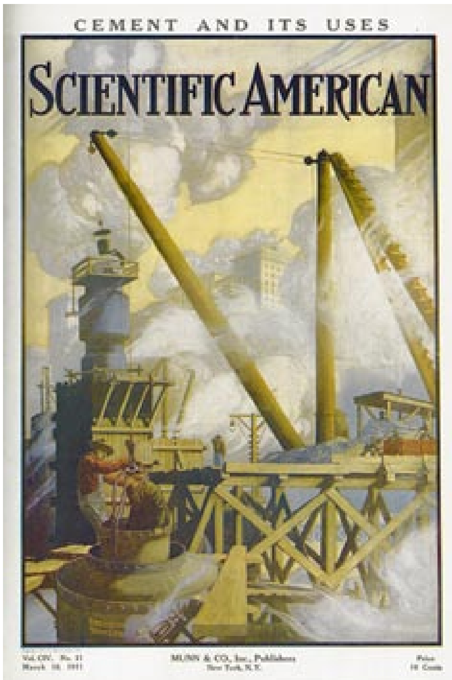
Millikan, winner of the 1923 Nobel Prize in Physics, achieved everlasting fame for the oil-drop experiment, his brilliant determination of the charge of the electron. Not to be confused with Alfred, Lord Tennyson's earlier determination of "The Charge of the Light Brigade."

"The task," Millikan wrote, "of learning to substitute stored solar energy for muscular energy—the great underlying cause of most of the changes in man's activities and living conditions—has been learned within the past eighty years and will never need to be learned over again."

For Millikan, "stored solar energy" must have meant fossil fuel, a tank of which today could be exchanged for enough cash for what was then a down payment on a 1931 Ford Model A. Fossil fuels, of course, are just aged and tenderized organisms that long ago converted sunlight into energy or fed on organisms capable of converting sunlight into energy. In essence, substituting stored solar energy for muscular energy means that we can drive up a hill rather than having to walk up the hill. Or, to make the point clearer to many members of Congress, we can be driven up a hill rather than having litter bearers carry us up the hill.

What Millikan did not foresee was the dire need to learn how to quickly and efficiently store that solar energy in the first place. Because with China and India poised to put tens of millions of new fossil-fuel-powered cars on the road, the stuff coming out of all those exhausts is going to make it hard to see the top of the hill. And it's going to be unusually warm up there, too. SA

Illustration by Matt Collins



March 1911

Concrete for Construction

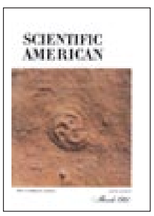
"About fifteen years ago serious attempts were made to combine steel and concrete by molding the one into the other in such a way that the resulting product would possess a high resistance not merely to compressive but to bending and tensional stresses. A vast amount of experimental work was done, out of which has sprung our modern reinforced concrete. Not only is concrete found to be available for practically every form of construction [*see illustration at left*] which hitherto has been built in brick or stone, but it has now invaded the field which was supposed to be peculiarly reserved for iron and steel."

Atmosphere of Venus

"Venus is nearly as large as the earth and, as it is much nearer the sun, its temperature must be higher than that of the earth. The average temperature is estimated to be about 140 degrees F. Various phenomena appear to indicate that the planet is surrounded by a comparatively dense and cloudy atmosphere which, indeed, is apparently seen as a luminous border, in the transits of Venus over the sun's disk, which occur once or twice in a century. This dense atmosphere strongly reflects the sun's rays and thus prevents the surface of the planet from attaining a temperature too elevated for highly organized life. The planet would be regarded as habitable."

Reinforced concrete builds a skyline for the American city, 1911

SCIENTIFIC AMERICAN, VOL. CIV, NO. 11; MARCH 18, 1911



March 1961

Food for Climate Skeptics

"The frigid winter now ending may be, unhappily, no fluke. The warming trend that had dominated world climate during most of the years since 1880 appears to have come to an end. Murray Mitchell, Jr., of the U.S. Weather Bureau reported that mean annual temperatures have dropped in both Northern and Southern hemispheres by 0.2 degree Fahrenheit since the early 1940s. In many areas climatic conditions have already returned to those that prevailed in the 1920s. The downturn has allayed fears about the 'greenhouse effect,' in which a rising concentration of carbon dioxide in the atmosphere, due to increased use of fossil fuels, was supposed to be trapping more and more solar energy. But the reasons for the cooling are unknown."

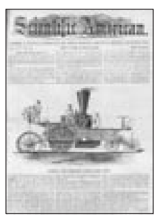
Daytime temperatures had fallen during the 1940s and 1950s as an aerosol haze created by industrial pollution reflected sunlight.

Gravity

"If a future experiment should demonstrate that antiparticles have a negative gravitational mass, it will deliver a mortal blow to the entire relativistic theory of gravity by disproving the principle of equivalence.

An antiapple might fall up in a true gravitational field, but it could hardly do so in Einstein's accelerated spaceship. If it did, an outside observer would see it moving at twice the acceleration of the ship, with no force at all acting on it. The discovery of antigravity would thus force upon us a choice between Newton's law of inertia and Einstein's equivalence principle. The author earnestly hopes that this will not come to pass. —George Gamow"

Full article is at www.ScientificAmerican.com/mar2011/gamow



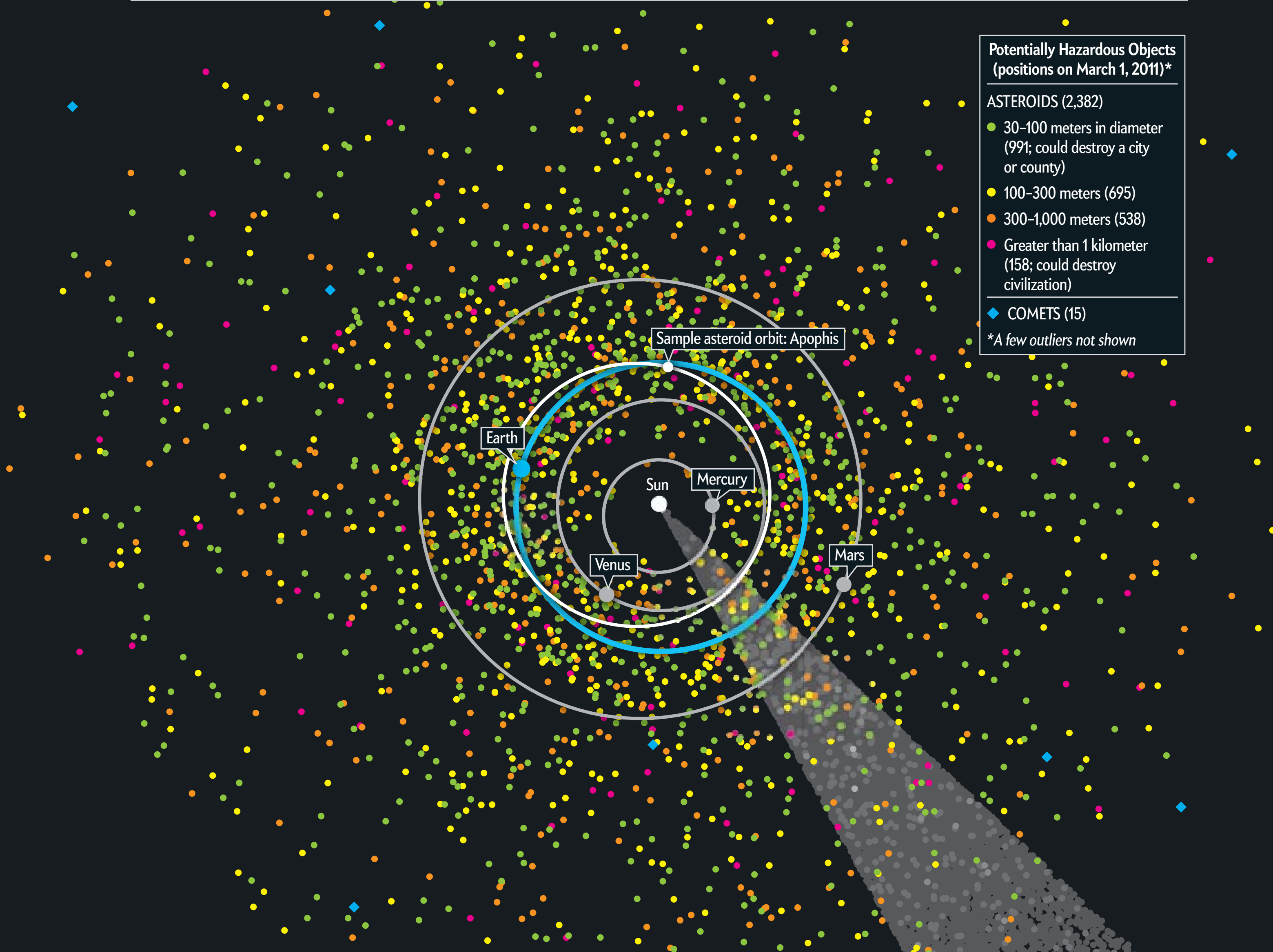
March 1861

Drudgery of the Needle

"At the present moment some 650,000 females are employed in the United Kingdom as milliners, dressmakers, seamstresses and shirtmakers; and their labor being manual, they are, on an average, the most enslaved, most dependent, and most unhappy of the industrial classes. Half a million sewing machines are much needed amongst them. Their introduction would double their wages. Nor is there any danger that this market for female labor will be overcrowded, at least for several generations. Men must eventually resign the monotonous drudgery of hand-sewing to machines that are wrought or attended to by women. Three fourths of the journeymen and apprentice tailors now in Great Britain—50,000 able-bodied men—could well be spared to man the navy, or engage in some more suitable employment than handling the needle."

Fun with Sparks

"In some of the furnace-heated houses of this city, the air is so dry that it is a common amusement of the children to light the gas by a spark of electricity from their fingers. By rubbing the feet along the carpet the body becomes so charged with the electric fluid, that, on approaching the finger to the gas-burner, a spark is drawn forth sufficient to light the gas." SA



Death by Asteroid

What we don't know could hurt us

Researchers have identified more than 2,300 asteroids and comets that are big enough to cause considerable damage on Earth and could possibly hit us. These "potentially hazardous objects" look ominous on the flat plot here, but because they travel in three-dimensional orbits, the perfect timing needed to intersect Earth makes the likelihood of collision remote. The symbol sizes shown also deceive; each object is many thousands of times as small as Earth.

NASA is concerned nonetheless. Scientists estimate that they have found fewer than 1 percent of the projectiles. "We are discovering them at a rapid clip, but the population is very large," says Donald K. Yeomans, manager of the Near Earth Object Program Office at NASA's Jet Propulsion Laboratory. A NASA advisory group says that for $250 million to $300 million annually over 10 years, the space agency could inventory the objects and develop and test technologies that could alter a worrisome asteroid's trajectory. One option: ram it with a massive spacecraft to knock it off course.

—*Mark Fischetti*

SEE ASTEROID ORBITS
ScientificAmerican.com/mar2011/graphic-science

Graphic and research by Paul Chodas, NASA Jet Propulsion Laboratory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