EVOLUTION
New Life for
ANCIENT DNA

ATMOSPHERIC SCIENCE
How Clouds Spew
GAMMA RAYS AND ANTIMATTER

NEUROSCIENCE
The Roots of
JOY IN THE BRAIN

SCIENTIFIC AMERICAN

August 2012
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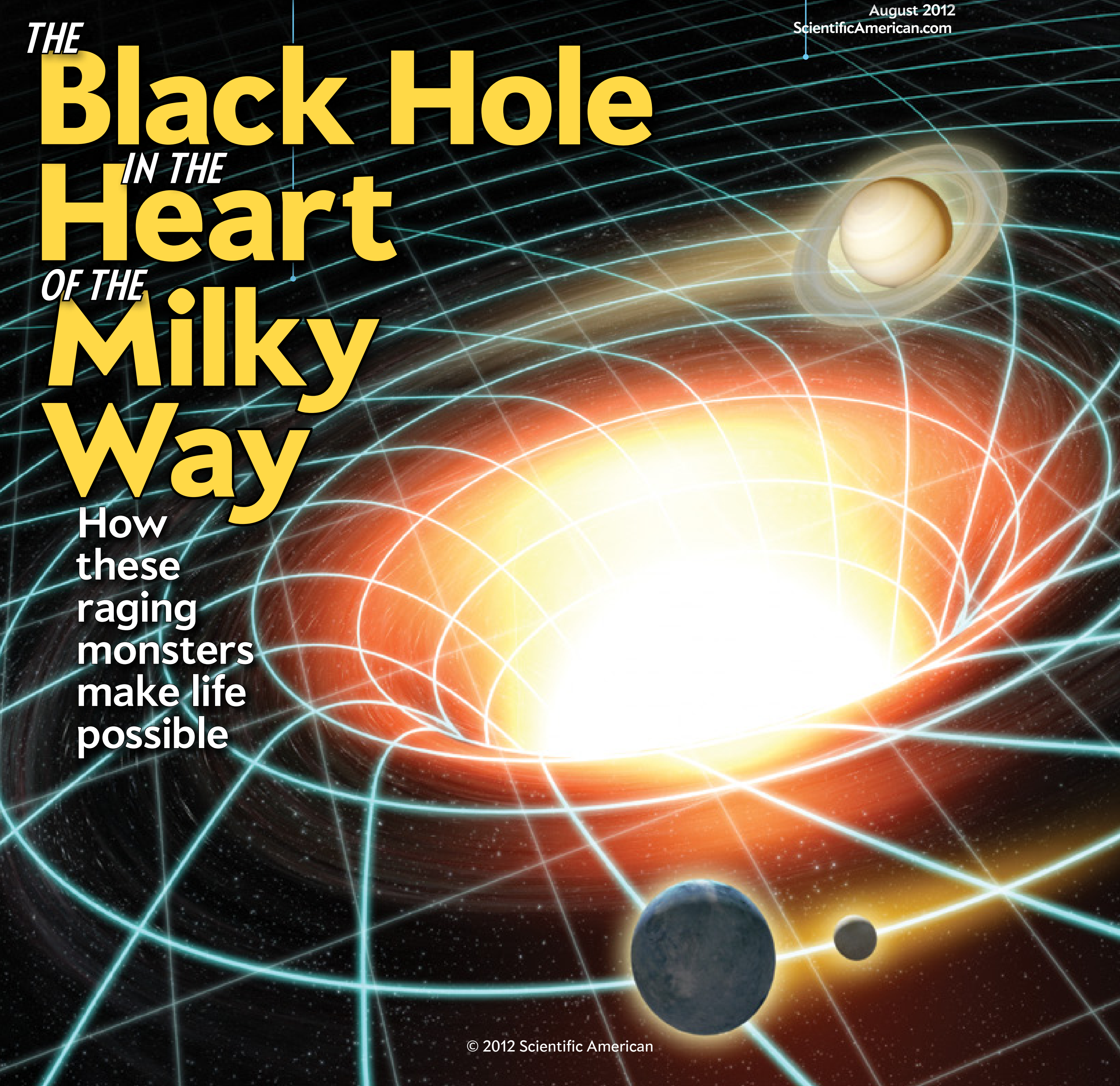
THE Black Hole IN THE Heart OF THE Milky Way

How these raging monsters make life possible



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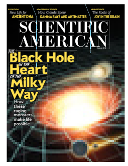
SCIENTIFIC AMERICAN

August 2012 Volume 307, Number 2

ON THE COVER



Black holes suck in matter, but they also cause some of the material swirling around them to zoom off at close to the speed of light across far distances in the galaxy, where it affects stars and planets. The matter strewn by the Milky Way's black hole apparently even accounts in some ways for life on Earth. Image by Kenn Brown, Mondolithic Studios.

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JAMES BALOG

FEATURES

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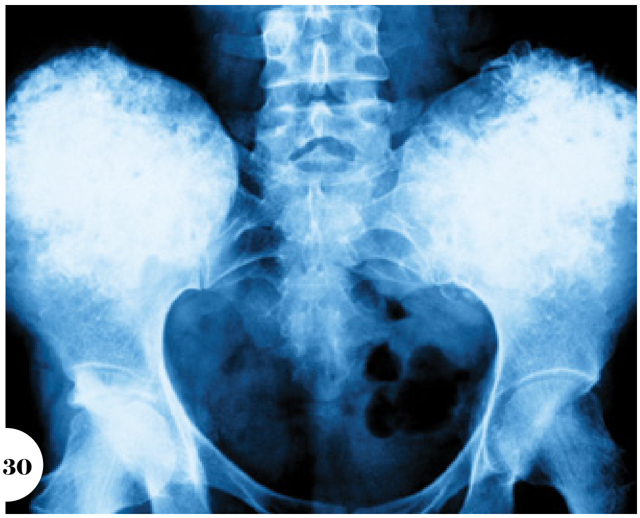

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SCIENTIFIC AMERICAN

DEPARTMENTS

ON THE WEB

The Science of the Olympics
As competitors from around the world face off in London, we take an in-depth look at sports psychology, the limits of human performance, and the tactics—both legal and illicit—today's athletes use to gain an edge.
Go to www.ScientificAmerican.com/aug2012/olympics

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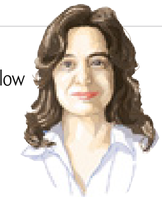
Mariette DiChristina is editor in chief of *Scientific American*. Follow her on Twitter @mdichristina



Destroyers That Create

IN A 1783 PAPER ENGLISH SCHOLAR JOHN MICHELL ENVISIONED a voracious cosmic monster: a star that was massive enough that its gravity would swallow light. He speculated that many such behemoths might exist, detectable only by their gravitational effects. Two centuries later, in 1967, American physicist John Wheeler gave the idea an evocative name: black hole. Just a few years afterward, in 1974, British astrophysicist Stephen Hawking taught us that black holes aren't so black after all: they emit radiation and will eventually evaporate.

Yet we've learned a lot since then about these destructive cosmic engines, as you'll find in "The Benevolence of Black Holes," this issue's cover story by Caleb Scharf of Columbia University—and an excerpt from the latest entry in our *Scientific American* book imprint series with Farrar, Straus and Giroux. Starting on page 34, the feature article explains how the feeding habits of black holes can have surprising effects on the galaxy they occupy.

Too little black hole activity, and a galaxy might produce a surfeit of youthful stars exploding as supernovae. Too much, and it would suffer from reduced star formation, robbing it of the star-fused heavy elements such as iron, silicon and oxygen that form our own planet. Fortunately, our Milky Way sports a supermassive black hole with four million solar masses that is "just right": active enough to churn things up productively for star formation but not so much that it eliminated the possibility of our own solar system's existence. In fact, Scharf argues, our galaxy's black hole had much to do with our ability to live in this place at this time. "The entire chain of events leading to you and me would be different" without such black holes, he writes. "We owe so much to them." SA

Announcing Our Tablet App

Scientific American has had an iPad tablet special edition, Origins and Endings, available since December 2010. Now we are delighted to add to our family of product offerings the monthly *Scientific American* Tablet Edition for iPad, commencing with this issue. The tablet editions will combine the in-depth science and technology coverage that you rely on from us—including the feature articles, columns and essays by scientist authors and expert journalists—with enriching videos, audio interviews, interactive graphics, slide shows, and more. In addition, the app will provide daily updates from the world of science and technology, written by our staff and bloggers.

You can also download a free July issue sample now from Apple's iTunes Store. We will work toward delivering other formats in the upcoming months. As always, please let us know what you think. Write to us at editors@sciam.com. *—M.D.*

Illustration by Nick Higgins

editors@sciam.com

April 2012

FOOD POISONING'S EFFECTS

Maryn McKenna does not mention controls for medical history in her article on evidence that foodborne pathogens cause lifelong consequences, "Food Poisoning's Hidden Legacy." An elevated incidence of renal impairment and circulatory problems within six years after individuals suffered severe immediate symptoms of *Escherichia coli* ingestion, as compared with those suffering mild or no symptoms, does not prove their *E. coli* exposure was the cause. That conclusion assumes that there was no preexposure renal or circulatory dysfunction. For instance, a compromised excretory system could cause a more severe response to *E. coli* ingestion and, if not identified a priori, could later be perceived as a consequence of the exposure. Alternatively, those with a propensity for development of these medical conditions may have a heightened sensitivity to *E. coli*. Correlation alone does not prove causality.

Peter Irwin
via e-mail

"Correlation alone does not prove causality."
—PETER IRWIN *VIA E-MAIL*

Affected joints after infection with *Salmonella* bacteria, reported by McKenna, are an old, but apparently forgotten, problem. Those of us who have worked in developing countries have seen, treated and followed up on patients with typhoid fever, a severe infection caused by *Salmonella typhi*. Pain and swelling of the joints may continue long after discharge and apparent recovery. The different types of joint problems following typhoid infection listed by surgeon William W. Keen in 1898 included joint infection during the illness, rheumatic typhoid arthritis and septic typhoid arthritis. And Charles W. Wilson reported patients developing swollen joints after typhoid infections in the *Journal of Bone and Joint Surgery* in May 1899. We now see that other salmonellae can produce the same long-term problems.

Alan Dugdale
Brisbane, Australia

BREATH-DEFYING

On reading "The Limits of Breath Holding," by Michael J. Parkes, I was reminded that in 1958 I decided to see how long I could hold my breath underwater. I found that if I floated face down and relaxed, I could flex my diaphragm muscles repeatedly to delay the urge to take a breath. Eventually I was able to do so for almost four minutes.

Jon Otterson
Madison, Wis.

There is a counterpart to holding one's breath: expelling air completely and seeing how long one can go before inhaling. There is a break point there, but the diaphragm is "held" in a state of complete relaxation instead of contraction. Does the same mechanism affect both sides of this coin?

Bryon Moyer
via e-mail

My foster mom claims that one late evening I was too quiet, and she found me unresponsive and turning blue. I was fortunate in not becoming another statistic of sudden infant death syndrome (SIDS). Could the role of a not so fully developed or underdeveloped diaphragm explain "involuntary breath holding" in infants and thus SIDS?

Bennett A. Wallace
Louisville, Ky.

PARKES REPLIES: The last two questions both highlight the need for more research on the diaphragm. Regarding Moyer's comments, we know that people can perform only very short breath holds with deflated lungs. Yet is the diaphragm "held" at its relaxed length with an isometric contraction or just completely relaxed? Further, these short breath holds neither confirm nor refute the hypothesized role of the diaphragm in the break point. Its chemoreceptors could still be stimulated by the rapid rise in carbon dioxide or the fall in oxygen. As for Wallace's question, many hypotheses attempt to explain SIDS. Experimentally testing the hypothesis of a "not so fully developed or underdeveloped diaphragm" in infants is not easy.

DEFECTIVE DINOS

"Time Traveler," Richard Milner's short essay on artist Charles R. Knight, makes no mention of the many errors of reconstruction we now know to be in Knight's paintings of prehistoric creatures. It seems ironic to praise Knight for his illustrations of living creatures and to suggest that what he learned from these observations informed his dinosaur paintings and to then provide the reader with Knight's view of a *T. rex* and *Triceratops* with dragging tails.

John Byrne
via e-mail

MILNER REPLIES: Knight was keenly aware that a paleoartist's images are simply the best-informed guesses possible at the time, and his were made in collaboration with the top paleontologists of his day. Over the years he frequently updated his restorations as more complete fossils were discovered. In retrospect, his paintings have became valuable snapshots of the changing state of scientific knowledge.

The current obsession with tail dragging seems a trivial point on which to attack Knight's genius. In the image from Knight's mural at the Field Museum that Byrne refers to, one individual stands upright with its tail braced against the ground, while the other's torso is cantilevered forward, with tail held off the ground—thus hedging Knight's bets on its habitual posture. His achievements in creating the first scientifically sound and artistically beautiful restorations of prehistoric creatures remain unassailable.

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POLIO PIONEER

An important piece of history on the development of oral polio vaccine is missing in "Birth of a Cold War Vaccine," by William Swanson: neither Albert B. Sabin nor Jonas E. Salk received the Nobel Prize in Physiology or Medicine for their vaccines. Instead, in 1954, the Nobel committee awarded it to John Franklin Enders, then at Harvard Medical School, and his colleagues.

Prior to the work of the Enders group, it was not possible to produce a polio vaccine, because people thought that this virus, which affects nerve cells, could be grown only in nerve tissue. (Vaccine based on nerve tissue–grown viruses can cause allergic encephalomyelitis, inflammation of the brain and spinal cord.) Enders and his associates found that this virus could be grown in monkey kidney cells, and that is what made it possible to develop a polio vaccine.

Pinghui V. Liu
Boca Raton, Fla.

STRESS MASTER

It is a sad coincidence that "This Is Your Brain in Meltdown"—Amy Arnsten, Carolyn M. Mazure and Rajita Sinha's article describing how neural circuits for self-control shut down under stress—hit the newsstands the same week as the killing of 16 civilians in Afghanistan by a U.S. soldier. One can only hope that the authors' work and that of others will help reduce and perhaps prevent such tragedies and meltdowns in general. The current results do raise anew the fear, however, that every misbehavior, from murder on down to cheating at Scrabble, will eventually, and conveniently, be ascribed to a brain malfunction.

André Rocque
Department of Philosophy
Collège Montmorency, Laval, Quebec

I have observed that a small minority of people can "rise to the occasion"—their memories and minds do not go blank under stress—and that such people are more capable than most others in stressful situations. I wonder if the signaling pathways in their brain might differ from the typical person? It seems that champion players of the game show *Jeopardy* would be a ready sample of such individuals.

Tim Budell
Westford, Vt.

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Can the U.S. Get an "A" in Science?

Teachers, scientists and policy makers have drafted ambitious new education standards. All 50 states should adopt them

CHRISTOPHER CHURCHILL *Gallery Stock*

Americans have grown accustomed to bad news about student performance in math and science. On a 2009 study administered by the Organization for Economic Co-operation and Development, 15-year-olds in the U.S. placed 23rd in science and 31st in math out of 65 countries. On last year's Nation's Report Card assessments, only one third of eighth graders qualified as proficient in math or science. Those general statistics tell only a piece of the story, however. There are pockets of excellence across the U.S. where student achievement is world-beating. Massachusetts eighth graders outscored their peers from every global region included, except Singapore and Taiwan, on an international science assessment in 2007. Eighth graders from Minnesota, the only other U.S. state tested, did almost as well.

What do Massachusetts and Minnesota have in common? They each have science standards that set a high bar for what students are expected to learn at each grade level. Such standards form the scaffolding on which educators write curricula and teachers plan lessons, and many experts believe them to be closely linked with student achievement.

Unfortunately, the quality of most state science standards is "mediocre to awful," in the words of one recent report from the Thomas B. Fordham Institute, an education think tank in Washington, D.C. Several states present evolution as unsettled science—"according to many scientists, biological evolution occurs through natural selection," say New York State's standards. Wishy-washiness is also creeping into the way schools teach climate change, as some parents pressure teachers to "balance" the conclusions of the majority of scientists against the claims of a tiny but vocal clan of skeptics. We can't have a scientifically literate populace if schools are going to tap-dance around such fundamentals.

Now a group of 26 states has collaborated with several organizations on ambitious new standards, known as the Next Generation Science Standards, that all 50 states, plus the District of Columbia, will be able to adopt starting early next year. The first draft, released in May, explicitly included evolution and climate change. A second draft will be available for comment this fall.

The standards are based on recommendations from the National Research Council and were funded in part by the Carnegie Corporation of New York. In addition to tackling shortcomings such as those mentioned above, they put new emphasis on engineering, which is crucial to our country's economic competitiveness, and stress the process of science as much as the content.

Any system of education standards has potential downsides. Mandate too much, and kids will grow bored or overwhelmed and teachers will lose autonomy. But these new standards have already won over important potential critics. Carolyn Wallace, a science education researcher at Indiana State University and a former high school science teacher who believes many standards systems are too "authoritarian," says the Next Generation standards leave room for teachers to be more creative in how they present material to kids. She does worry that the standards impose more than can reasonably be taught in one school year. Hers is a serious concern that the standards developers should address.

There is little doubt that these standards will require more classroom time to be devoted to science—and that is good. Harold Pratt, a former president of the National Science Teachers Association, says that in elementary school, science has often been squeezed out entirely by the reading and math requirements of the No Child Left Behind law. Many states currently require only two years of science, and California governor Jerry Brown recently proposed cutting that to just one. Accommodating the Next Generation standards would probably require three.

Although these science standards are too new for politicians to have weighed in on them, the general movement toward common standards has bipartisan support. In a contentious election year, the idea that our kids deserve a world-class science education should be one issue we can all agree on. SA

SCIENTIFIC AMERICAN ONLINE
Comment on this article at ScientificAmerican.com/aug2012

Arturo Casadevall is Leo and Julia Forchheimer Chair in Microbiology and Immunology at the Albert Einstein College of Medicine and editor in chief of *mBio.*

Ferric C. Fang is a professor of laboratory medicine and microbiology at the University of Washington and editor in chief of *Infection and Immunity.*

Winner Takes All

Intense competition among scientists has led to abuses. Is there a better way?

When Isaac Newton developed calculus and his theory of gravity, he reaped a reward far greater than stock options in a start-up or a big year-end bonus. He got credit for his work and recognition among his peers—and eventually the wider world. Since Newton, science has changed a great deal, but this basic fact has not. Credit for work done is still the currency of science.

How should credit for scientific work be assigned? The question has tremendous implications for how science is done and what society gets from its investment. Since the earliest days of science, bragging rights to a discovery have gone to the person who first reports it. This "priority rule" has led to some colorful disputes—Newton famously got into a tussle with Gottfried Wilhelm Leibniz, who wanted credit for inventing calculus—but by and large, the rule has worked well. In recent years, however, intense competition among scientists has led to difficulties, and we have begun to wonder if there isn't a better way.

At its best, the priority rule fosters healthy competition, which can be a strong motivator for scientists to innovate and rapidly solve problems. Economists view scientific knowledge as a public good, which means that competitors are free to make use of that knowledge once it is publicized. The priority rule provides a potent incentive for scientists to share their knowledge. Some think that the priority rule also helps to ensure that society gets the optimal return from its investment in science because rewards go to those scientists who benefit society the most.

The winner-take-all aspect of the priority rule has its drawbacks, however. It can encourage secrecy, sloppy practices, dishonesty and an excessive emphasis on surrogate measures of scientific quality, such as publication in high-impact journals. The editors of the journal *Nature* have recently exhorted scientists to take greater care in their work, citing poor reproducibility of published findings, errors in figures, improper controls, incomplete descriptions of methods and unsuitable statistical analyses as evidence of increasing sloppiness. (*Scientific American* is part of Nature Publishing Group.)

As competition over reduced funding has increased markedly, these disadvantages of the priority rule may have begun to outweigh its benefits. Success rates for scientists applying for National Institutes of Health funding have recently reached an all-time low. As a result, we have seen a steep rise in unhealthy competition among scientists, accompanied by a dramatic proliferation in the number of scientific publications retracted because of fraud or error. Recent scandals in science are reminiscent of the doping problems in sports, in which disproportionately rich rewards going to winners has fostered cheating.

The importance of teamwork in science has never been greater. Studies of publications over the past 50 years show that teams increasingly dominate science and are contributing the highest-impact research. Collaborators, consortia and networks are essential for tackling interdisciplinary problems and massive undertakings, such as the Human Genome Project. The priority rule may be undermining this process.

The appropriateness of the priority rule for science has never been seriously questioned. Is it best suited to the modern scientific age, in which scientists operate in large teams that put a premium on cooperation? An alternative system that celebrates team effort toward solving problems may work better. Industry, which favors collective goals over individual achievement, and the NIH Intramural Research Program, which encourages risk taking and collaborative partnerships with industry and academia, provide contrasting but instructional examples. Perhaps scientists would gladly trade the benefits of the priority rule (individual reward) for a system that offers greater stability of support and collegiality, freer sharing of information, more fairness, and improved scientific rigor and cooperation. This would be a discovery of enormous benefit to the scientific enterprise and the society it serves. SA

SCIENTIFIC AMERICAN ONLINE
For a list of books and articles relevant to this topic, go to ScientificAmerican.com/aug2012/priority-rule

Illustration by Carl Wiens

Cognitive Neuroscience, cont.

Windows on the Mind

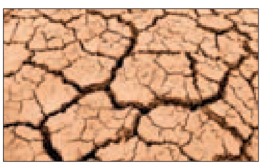
What's the connection behind eye movements and subliminal thought? Join Dr. Macknik and Dr. Martinez-Conde in a look at the latest neurobiology behind microsaccades, the involuntary eye movements that relate to perception and cognition. Learn how microsaccades suggest bias toward certain objects, their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

Champions of Illusion

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

Sleights of Mind

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



CLIMATOLOGY

Speaker: Yohay Carmel, Ph.D.

Prioritizing Land for Nature Conservation: Theory and Practice

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

Facing a New Mega-Fire Reality

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

HUMAN EVOLUTION

Speaker: Chris Stringer, Ph.D.

Human Evolution: the Big Picture

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

The First Humans

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

The Neanderthals: Another Kind of Human

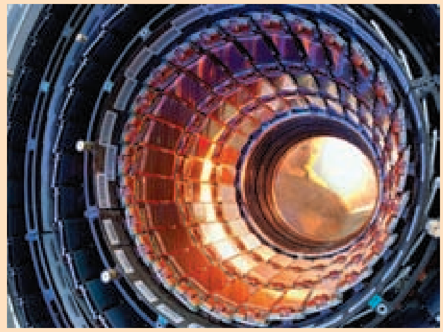
Our close relatives, the Neanderthals, evolved in parallel with *Homo sapiens*. Often depicted as bestial ape-men, in reality they walked upright as well as we do, and their brains were as large as ours. So how much like us were they? What was their fate? Track the evolution of the Neanderthals in light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

The Rise of *Homo Sapiens*

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

SCIENTIFIC AMERICAN Travel HIGHLIGHTS

INSIDER'S TOUR OF CERN



Pre-cruise: October 22, 2012—From the tiniest constituents of matter to the immensity of the cosmos, discover the wonders of science and technology at CERN. Join Bright Horizons for a private full-day tour of this iconic nuclear-research facility. Whether you lean toward concept or application, there's much to pique your curiosity. Discover the excitement of fundamental research and get an insider's look at the world's largest particle physics laboratory.

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

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

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

EPHESUS

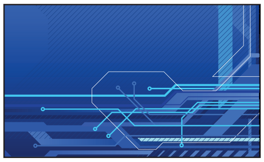
November 1, 2012—Many civilizations have left their mark at Ephesus. It's a complex and many-splendored history, often oversimplified. Bright Horizons pulls together three important aspects of understanding Ephesus that are rarely presented together. You'll meander the Marble Road, visit the legendary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

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

ATHENS

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

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



NANOSCIENCE

Chris Sorensen, Ph.D.

Fire, Fractals and the Divine Proportion

Physicist Chris Sorenson discusses the mysteries, beauties, and curiosities of soot. Take an unlikely journey of discovery of soot to find fractal structures with non-Euclidian dimensionality, networks that tenuously span space and commonalities among spirals, sunflowers and soot. Gain an appreciation for the unity of Nature, and the profound lessons in the commonplace as well as the sublime through soot!

Light Scattering

Take a *particle* physics perspective and ask: how do particles scatter light and why does light scatter in the first place? What are the effects of scattering on the polarization? How do rainbows, glories and sundogs work? How do light scattering and absorption effect the environment? Get the latest on scattering and see your universe in a new light.

Nanoparticles: The Technology.

Nanoscience has spawned a significant nanotechnology. Explore new nanomaterials such as self cleaning surfaces and fibers stronger yet lighter than steel. Then we'll do some informed daydreaming about far reaching possibilities like nanobots that could take a "fantastic voyage" inside your body or stealth materials for the invisible man. Enjoy reality science fiction at its best!

Nanoparticles: The Science.

What makes "nano" so special? Why does nano hold such great promise? Take a look at the clever chemistry that creates the nanoparticle building blocks of the new nanomaterials. Find out why physical properties of nanoparticles differ from larger particles. When this session is over, you'll understand why small can be better.

ASTROBIOLOGY

Speaker: Seth Shostak, Ph.D.

Hunting for Life Beyond Earth

Is Earth the only planet to sport life? Researchers are hot on the trail of biology beyond Earth, and there's good reason to think that we might find it within a decade or two. How will we find alien biology, and what would it mean to learn that life is not a miracle, but as common as cheap motels?

Finding E.T.

Life might be commonplace, but what about intelligent life? What's being done to find our cosmic confreres, and what are the chances we'll discover them soon? While most people expect that the cosmos is populated with anthropomorphic aliens aka "little gray guys with large eyes and no hair" you'll hear that the truth could be enormously different.

What Happens If We Find the Aliens?

One-third of the public believes that aliens are visiting Earth, pirouetting across the skies in their saucers. Few scientists agree, but researchers may soon discover intelligent beings sharing our part of the galaxy. Could we handle the news? What facts could be gleaned

immediately, and what would be the long-term effects such a discovery would have on us and our institutions, such as religion?

The Entire History of the Universe

Where and when did the cosmos begin, and what's our deep, deep future? The book of Genesis gives only a short description of the birth of the cosmos, but modern science can tell a more complex tale. How did the universe get started, and could there be other universes? And how does it all end, or does it end at all?

SKEPTICISM

Speaker: Michael Shermer, Ph.D.

The Believing Brain: From Ghosts and Gods to Politics and Conspiracies — How We Construct Beliefs and Reinforce Them as Truths

The brain as a "belief engine"? Learn how our brains' pattern-recognition and confirmation bias help form and reinforce beliefs. Dr. Shermer provides real-world examples of the process from politics, economics, and religion to conspiracy theories, the supernatural, and the paranormal. This discussion will leave you confident that science is the best tool to determine whether beliefs match reality.

Skepticism 101: How to Think Like a Scientist

Harvest decades of insights for skeptical thinking and brush up on critical analysis skills in a lively session that addresses the most mysterious, controversial, and contentious issues in science and skepticism. Learn how to think scientifically and skeptically. You'll see how to be open-minded enough to accept new ideas without being *too* open-minded.

The Science of Good and Evil: The Origins of Morality and How to be Good Without God

Tackle two challenging questions of our age with Michael Shermer: (1) The origins of morality and (2) the foundations of ethics. Dr. Shermer peels back the inner layers covering our core being to reveal complex human motives — good and evil. Gain an understanding of the evolutionary and cultural underpinnings of morality and ethics and how these motives came into being.

The Mind of the Market: Compassionate Apes, Competitive Humans, and Other Lessons from Evolutionary Economics

How did we evolve from ancient hunter-gatherers to modern consumer-traders? Why are people so irrational when it comes to money and business? Michael Shermer argues that evolution provides an answer to both of these questions through the new science of evolutionary economics. Learn how evolution and economics are both examples of complex adaptive systems. Get your evolutionary economics tools together.

SCIENTIFIC AMERICAN Travel HIGHLIGHTS

IGUAZU FALLS

March 5–7, 2013 — Surround yourself with 260 degrees of 240 foot-high walls of water at Iguazu Falls. Straddling the Argentinian-Brazilian border, Iguazu Falls is split into about 270 discrete falls and at peak flow has a surface area of 1.3 million square feet. (By comparison, Niagara Falls has a surface area of under 600,000 square feet.) Iguazu is famous for its panoramic views and breath-taking vistas of huge sprays of water, lush rainforest, and diverse wildlife.

You'll walk Iguazu National Park's extensive and well-engineered circuit paths over the Falls, go on a boat ride under the Falls, be bowled over by the massiveness and eco-beauty, and take a bazillion pictures.

MACHU PICCHU

February 15–20, 2013 — Scale the Andes and absorb Machu Picchu's aura. Visit this legendary site of the Inca World, draped over the Eastern slopes of the Peruvian, wrapped in mystery. Whether it was an estate for the Inca emperor Pachacuti or a site for astronomical calculations, it captures the imagination. Visit Machu Picchu, and see for yourself the massive polished dry-stone structures, the Intihuatana ("Hitching Post of the Sun"), the Temple of the Sun, and the Room of the Three Windows. Iconic ruins, rich flora and fauna, and incomparable views await your eye (and your lens).

EASTER ISLAND

Febrruary 16–20, 2013 — The moai of Easter Island linger in many a mind's eye, monumental statues gazing inland, away from the South Pacific. Join Bright Horizons on a four-day pre-cruise excursion to explore the mysteries of Rapa Nui. Visit archaeological sites, learn about the complex cultural and natural history of the island, and absorb the ambiance of one of the most remote communities on Earth. Come along on an adventure where archaeology and environment create memories and food for thought.

GALAPAGOS

February 12–20, 2013 — Enter an unearthly natural world in an eight-day pre-cruise excursion to the Galapagos Islands. "See the world in a grain of sand" and hone your knowledge of evolution with your observations in the Galapagos, a self-contained natural history laboratory. We'll tour Santiago, Chile, and straddle the Equator at the "Middle of the World" complex in Quito, Ecuador. Then off to the Galapagos for a four-day expedition on the mv Galapagos Legend. Accompanied by certified naturalists see the incredibly diverse flora and fauna up close. You'll have the opportunity to swim and snorkel, and photograph legendary wildlife and wild landscapes. Join Bright Horizons in the Galapagos for all the intangibles that communing with nature provides.

MEDICINE

Not Just "Small Adults"

Few medications have been proved safe for children, leaving doctors in a bind

It is a conundrum that has frustrated pediatricians for decades: children get sick and need drugs, yet few medications have been approved for their use. A recent study and a government report published in February concluded that, most of the time, doctors are forced to prescribe drugs to young patients without adequate data, putting kids at risk for overdoses, side effects and long-term health problems. In late June Congress was poised to strengthen existing laws that encourage pharmaceutical companies to test medicines in kids, but that won't solve the safety problems associated with pediatric drugs.

Drugmakers resist testing their products in children because doing so is risky, expensive and difficult—and it is rarely worthwhile from a business perspective because children make up a small percentage of the world's drug consumers. Yet children metabolize drugs differently from adults. "The adage that a child is not just a small adult is true: you can't simply scale down a dose of a drug from adults and expect it to behave identically in a small child," says Peter Adamson, a pediatrician and pharmacologist at Children's Hospital of Philadelphia. A 2000 study revealed, for instance, that the seizure drug gabapentin (Neurontin) requires higher than expected doses for children younger than five and that it can make them hostile and hyperactive. Pain relievers, antibiotics and asthma medications are among other drugs often prescribed off-label.

Adamson was a co-author of a February Institute of Medicine report highlighting other ongoing issues in pediatric drug safety: some studies have never been made public, others have been too small to yield clinically useful data, and few studies have investigated the long-term effects of drugs in youngsters. The June legislation would grant more power to the FDA to ensure that drugmakers follow through with trials, test drugs in newborns and make past studies public. But it won't address the vital need for data on how drugs taken in youth might affect long-term health.

—Melinda Wenner Moyer

STEVEN ERRICO *Getty Images*

FURTHER READINGS AND CITATIONS ScientificAmerican.com/aug2012/advances

CHEMISTRY

Why Some Tomatoes Taste Better

Overlooked fragrant compounds make huge contributions to tomato flavor, which suggests a new way to improve the taste of high-yield crops

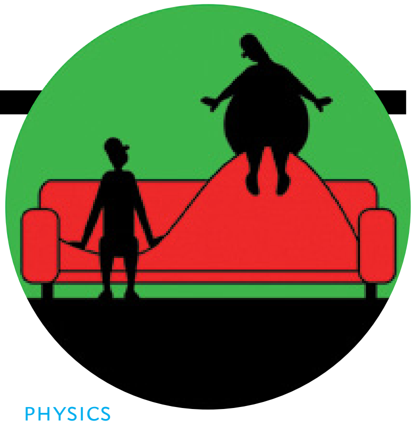
The typical supermarket tomato is ripe-red, firm to the touch and free of blemishes—as well as of flavor. Since at least the 1970s, U.S. consumers have lamented the beautiful but bland fruits that farmers breed not for taste but rather for high yield and durability during shipping. Recently organic farmers and foodies have championed the superior flavors of heirloom tomatoes—older varieties that come in an assortment of shapes, sizes and colors. In a study published in June in *Current Biology,* researchers took a close look at the chemical composition of both standard tomatoes and more than 100 different heirloom varieties, which they also fed to 170 volunteers in a taste test. Their new findings confirm what scientists have learned in recent years: a tomato's flavor depends not only on the balance of sugars and acids within the fruit but also on subtle fragrant compounds—many of which are lacking in the modern supermarket tomato.

Harry Klee of the University of Florida has been studying tomato flavor for the past 10 years. Some of the shortcomings of supermarket tomatoes, he explains, arise because farmers have bred the plants to produce as much fruit as possible. The more fruit an individual tomato plant produces, the less sugar it can invest in each tomato, Klee says. Knowing that tomato flavor depends on so much more than sugar, however, Klee and his colleagues began a research project three years ago to analyze the chemical potpourri that determines a tomato's taste. Klee thinks what he has found suggests a new way to enhance the flavor of tomatoes without sacrificing the economy of high-yielding plants.

Klee's team grew 152 varieties of heirloom tomatoes in fields and greenhouses at the University of Florida and bought standard tomatoes from a local supermarket. The scientists sliced up the fruit and offered the wedges to volunteers who carefully chewed, tasted and swallowed each piece of tomato, rating the texture and the intensity of sweetness, sourness and bitterness, as well as the overall flavor and how much they enjoyed eating that particular sample. As expected, the volunteers in Klee's new study preferred the flavor of tomatoes with a lot of sugar to less sweet fruit—but sugar content did not entirely explain their preferences. Chemicals known as volatile compounds, which drift into our nostrils once a fruit has been sliced or bitten, also contributed to flavor.

In Klee's analysis, the most abundant volatile compounds in a tomato—the C6 volatiles—barely influenced what people thought of the fruit's flavor. Instead a less prevalent volatile compound called geranial made a huge difference. Geranial, Klee concluded, somehow improves a tomato's overall flavor, perhaps by enhancing innate sweetness. Compared with heirloom varieties, standard tomatoes have less geranial and other volatile compounds. "They're kind of like light beer," he says. "Even if all the chemicals are there, they are at lower levels." By breeding or genetically modifying tomatoes to contain lots of the volatile compounds taste testers prefer, scientists could produce supersweet and flavorful varieties without increasing the sugar content. *—Ferris Jabr*

PAUL TAYLOR *Getty Images*



PHYSICS

Fabrics That Push Back

Paradoxical materials could grow when compressed

Call it the reverse psychology of stuff. Imagine a cushion that swells up instead of compressing when you sit on it. Or a rubber band that shrinks instead of elongating when you stretch it. If two physicists at Northwestern University are right, scientists may soon be able to make materials with such mind-boggling behavior.

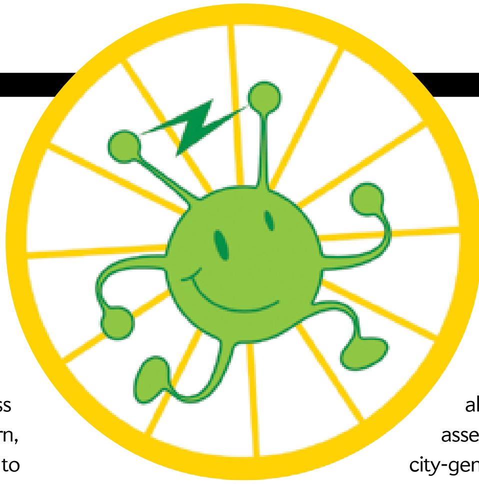
The two researchers, Adilson Motter and Zachary Nicolaou, describe their proposal in work that appeared online in May in *Nature Materials.* (*Scientific American* is part of Nature Publishing Group.) They show how the unusual response, called negative compressibility, could theoretically emerge from putting together the right building blocks into a "metamaterial"—a material whose behavior is dictated not by its chemical or molecular composition but by its patterning at larger scales.

The molecules of such a material would act like springs in a jack-in-the-box: when slightly compressed, they transition into an expanded state. And just as it takes effort to put jack-in-the-box springs back into the box, the materials would require energy to be restored to their original state. A negatively compressible material could be built by stacking up many such springlike molecules (or something equivalent to them) like Lego bricks. "Everything that's needed to build this material exists," Motter says, although no one has done the actual engineering to build it.

And what would the material be good for? The most promising applications might be in sensors and actuators, where the materials could amplify a force by expanding or contracting, or in safety gear such as seat belts, Motter notes. For now, though, he says, the idea is just a curiosity.

—Davide Castelvecchi

Illustrations by Thomas Fuchs



ENGINEERING

Going Viral

Bacteria-eating viruses may power cell phones

In their search for eco-friendly energy sources, scientists have learned how to harness power from ever smaller living things: first corn, then algae, now bacteria. By figuring out how to generate electricity using the M13 bacteriophage, a virus that infects bacteria, engineers at the University of California, Berkeley, have gone smaller still. Although the virus-powered device produces only a tiny bit of energy, it may one day pave the way for cell phones that can be charged while you walk.

The device relies on a property known as piezoelectricity, which can translate mechanical energy, say, a finger tap, into electrical energy. Most cell-phone microphones are piezoelectric and convert the energy from sound waves into electrical output that is transmitted and translated back into sound waves in the recipient's phone. The problem with these piezoelectric devices, Berkeley bioengineer Seung-Wuk Lee says, is that they are made out of heavy metals such as lead and cadmium. Many biomolecules such as proteins and nucleic acids are also piezoelectric—they generate electricity when compressed—but lack the toxicity of traditional devices.

Lee and his colleagues found that the pencil-shaped M13 phage fits all their requirements. Because the virus infects only bacteria, it is safe for humans. And it is cheap and easy to create: scientists can get trillions of viruses from a single flask of infected bacteria. The shape of the virus is also important because M13 can easily self-assemble into thin sheets. To improve the electricity-generating power of M13, Lee's team tweaked the amino acid content of the virus's outer protein coat by adding four negatively charged glutamate molecules. The researchers stacked sheets of viruses on top of one another to amplify the piezoelectric effect.

When the scientists attached the one-square-centimeter virus film to a pair of gold electrodes and pressed firmly on one of those electrodes, the film produced enough electricity to light up a liquid-crystal display of the numeral 1. Although it generated only a small amount of power—400 millivolts, or about one quarter of the energy of a AAA battery—the study shows that biomaterial piezoelectrics are feasible, Lee says.

"This will bring a lot of excitement to the field," says Zhong Lin Wang, an engineer at the Georgia Institute of Technology who was not involved in the study. "By utilizing the properties of these biomaterials, we can find unique applications in the future," such as a pacemaker powered by the beating of one's heart. —*Carrie Arnold*

PROMOTION

The Agenda Setters

Bringing Science to Life

USA Science and Engineering Festival

Walter E. Washington Convention Center | Washington, D.C. | April 28—29, 2012

SCIENTIFIC AMERICAN was proud to be a key media sponsor for the USA Science and Engineering Festival. Our booth featured hands-on encounters that connected students with science discovery in exciting ways. The challenges explored Outer Space and Inner Space (the universe and our brain), which represent ongoing themes from SCIENTIFIC AMERICAN and Scientific American MIND.

OCEANOGRAPHY

For Some Species, Plastic Is Fantastic

Garbage in the North Pacific may help some species proliferate at the expense of others

"LIKE WEEDS": A water strider

ANTHONY SMITH

Plastic's durability helped to make it a popular miracle material in the early 20th century. Its omnipresence, however, may now be disrupting ecosystems in some surprising ways. A new study by researchers at the Scripps Institution of Oceanography in La Jolla, Calif., shows that the concentration of plastic has increased by 100 times over the past 40 years in the North Pacific Subtropical Gyre—an enormous calm spot in the middle of a clockwise rotation of ocean currents that falls between East Asia and the West Coast of the U.S., with Hawaii as its approximate midpoint. The size of the area is estimated to be more than 18 million square kilometers.

The study, published online on May 9 in *Biology Letters,* also documented for the first time a rise in egg densities of *Halobates sericeus,* a water strider that lays its eggs on floating objects. The team collected and analyzed data on bits of plastic less than five millimeters across in the North Pacific Ocean, including records from two recent voyages, published data from other sources and data developed from archived samples in the Scripps collection taken in the early 1970s. Author Miriam Goldstein, who is a biological oceanography Ph.D. candidate at Scripps, notes that a 2011 study that examined the North Atlantic Subtropical Gyre found no increase in plastic since 1986.

Higher concentrations of floating plastic debris offer more opportunities for the pelagic strider to lay eggs. This marine insect—closely related to pond striders—spends its entire life out on the open ocean and takes its place in the food web by consuming zooplankton and larval fish and being eaten by crabs, fish and seabirds.

Floating objects are historically rare in the North Pacific. "Striders would have been lucky to find a feather or a bit of floating wood," Goldstein says. Now floating plastic pieces are more common and offer a surface on which striders can lay their bright yellow, rice grain–size eggs.

Although researchers found an increase in eggs, they did not find an increase in the insects themselves. That could be because there were not enough samples from the early 1970s with which to adequately compare them, but equally likely crabs or small surface-feeding fish may be eating the eggs, Goldstein notes.

Researchers are concerned that this proliferation of plastic may be giving striders, microbes, animals and plants that grow directly on the plastic an advantage over oceanic animals that are not associated with hard surfaces, such as fish, squid, tiny crustaceans and jellyfish. "While these organisms [that grow directly on the plastic] are native, they're kind of like weeds," Goldstein explains, in that they grow, reproduce and die quickly. In contrast, the organisms in the water column tend to be more biodiverse. More than half of the ocean is part of the subtropical gyres, and changing the way that these gyres function by adding lots of plastic trash could have unpredictable consequences. "While our study only looks at one little insect in one area of the ocean, it shows that tiny pieces of plastic do have the potential to alter the ecology of the open sea," she says.

—Carrie Madren

AGRICULTURE

Water for Crops

The 14-year-old winners of the Google Science Fair's Science in Action Award, sponsored by *Scientific American*, discuss their project: a way for subsistence farmers to grow crops in larger quantities using hydroponics instead of soil

WINNERS: Shongwe (*left*) and Mahlalela

Why did you decide to enter the Google Science Fair?

Shongwe: Being born and raised in Swaziland, I have experienced the challenges that our country is facing. My work in many community development projects, through the mentorship of our teacher and environmental club patron, stimulated me to ask questions.

Mahlalela: At first it was just about helping my friend who has taken our teacher's advice to think big and take part in such activities as the Google Science Fair. I felt the need to help myself, my family and the community at large. We then asked our teacher if this is a good idea. I remember our teacher saying, "Go for it, boys—this is brilliant."

How does your project impact the community you grew up in?

Shongwe: To solve low food productivity, I believe that Swaziland neither needs the tons of food aid coming from Western and Eastern countries nor complex strategies the country cannot afford. Educating subsistence farmers is the key, and our experimental project has proved to be one of the best approaches. If we can empower Swazi subsistence farmers with knowledge of simplified hydroponics and production of organic crops, one challenge—food shortage in the country—could be significantly reduced. Apart from each family having enough food, surplus crops could be sold to local markets, reducing the high food prices that are mainly a result of the cost of transporting vegetables from South Africa. In addition, the project eliminates tilling, which results in soil erosion.

What does this new recognition mean to you?

Shongwe: It means a lot because I once considered being a scientist, and this could be the start of it all. I cannot express my feelings enough, not to mention how Swaziland could change for the better. Even if it could not change the whole country, targeting Bonkhe's [rural] community could make a difference, creating a self-sustainable community by developing the people.

Mahlalela: It lets me know that my age does not limit my abilities and that I can be as useful to the community as much as any other person. Being part of a solution in a local community is as important as winning the prize.

Who are your scientific inspirations and why?

Shongwe: My scientific inspirations are all the people and businesses that the community has at heart, including my patron teachers, friends who helped me in my project and business people who invest in community development.

Mahlalela: Albert Einstein and Stephen Hawking are my scientific inspirations. I find it hard to believe how all their discoveries and contributions to our understanding about the universe are possible. I'm very passionate about physics and physical science. Space science and all the scientific theories and discoveries evolving each day inspire me most.

What do you think was the most revolutionary invention of the past century?

Shongwe: I think it is the ARVs [antiretroviral drugs] because they save lives. One major challenge of Swaziland today is HIV/AIDS. Swaziland has more than 100,000 orphans because of HIV/AIDS deaths in just 10 years.

But I see every invention revolving around the introduction of computers, the Internet and software as substantial. Without these, all other inventions would take much more time and effort to invent.

Mahlalela: For the past 100 years I think the communications devices and transportation equipment, such as the airplane, are the most revolutionary because they opened a gateway toward globalization.

For the past 10 years I believe it is the ARVs—they saved a lot of people's lives.

—The Editors

PROFILE

NAMES
Sakhiwe Shongwe and Bonkhe Mahlalela

TITLE
Students, Lusoti High School

LOCATION
Simunye, Swaziland

COURTESY OF TITUS MANDLA SITHOLE

PROMOTION

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WHAT IS IT?

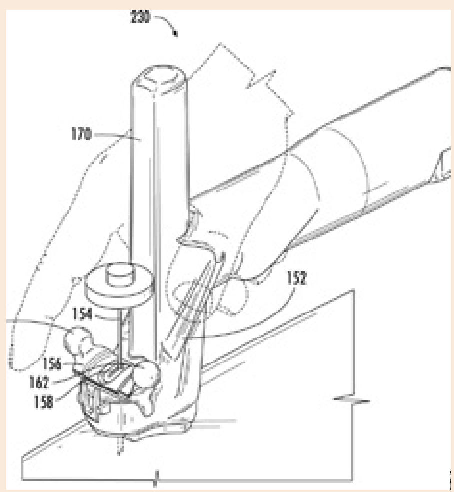
Gut feeling: A microscopic view of an over-the-counter drug is one of this year's Wellcome Images Awards winners. Loperamide, a spiky sample seen here at 150 microns, is used to treat diarrhea. The drug works by slowing the movement of stool through the gastrointestinal tract, which allows more time for water to be absorbed out of it. Annie Cavanagh, former multimedia manager at University College London's School of Pharmacy, worked with her colleague David McCarthy to create this false-colored micrograph of the crystal group. They have imaged other common drugs, which Cavanagh hopes will spur interest in pharmaceutical studies. *—Ann Chin*

PATENT WATCH

Ultrasound-guided probe device: When doctors inject a patient with a needle, they cannot see what they are getting themselves into. Underneath the skin, where they hope there is a vein waiting to be tapped, is a dark, mysterious world. This struck Stephen Ridley, now president and chief medical officer of Soma Access Systems in Greenville, S.C., as a problem. "You literally do this blind," he says.

Ultrasound can help image tissues that are inside, but it is bad at imaging the needle itself. The needle's round, metallic surface simply scatters the ultrasonic waves and basically appears invisible. So Ridley, whose background is in engineering and medicine, designed a potential solution: combining ultrasound and magnets. The ultrasound shows the tissue, and a small magnet at the tip of the needle is picked up by an array of magnets in the ultrasound probe. The magnetic field generated does not interfere with the ultrasound and allows doctors to see both the tissue they are piercing and the needle they are piercing it with. The system helps them line up their needle beforehand, removing much of the guesswork they have dealt with before.

Ridley started this idea with a particular procedure in mind: central venous access, in which doctors place a large catheter into a deep vein, often to administer blood or lifesaving fluids after trauma. Yet since showing the device, patent No. 8,152,724, to specialists, he has realized that the applications could go beyond that one procedure. Physicians can use the needle-imaging technology for everything from amniocentesis to making sure medication is injected properly into joints. *—Rose Eveleth*



COURTESY OF ANNIE CAVANAGH *Wellcome Images (drug)*; COURTESY OF U.S. PATENT AND TRADEMARK OFFICE *(probe)*

COMMENT AT ScientificAmerican.com/aug2012

ENGINEERING

More Charge for the Buck

A new car battery offers greater flexibility, more power and, potentially, lower overall costs

BRAD BERMAN *Redux Pictures*

New lithium-ion technology may finally make batteries cheap and durable enough to turn electric cars from a niche product into a mass-market mode of transport. Waltham, Mass.–manufacturer A123 Systems has produced a cell that delivers 20 percent more power, works at temperatures as low as –30 degrees Celsius and as high as 60 degrees C, and should be just as easy as current batteries to manufacture.

Independent scientists who have been scrutinizing the company's claims say they are impressed. From the few details that A123 will reveal, the new battery, known as Nanophosphate EXT, seems to be based on the same lithium iron phosphate chemistry found in other A123 batteries that appear everywhere from electronics to hybrid electric buses but with improved properties.

The increased power and expanded temperature range suggest that A123 scientists have improved the way that electrons and ions shuffle through the battery system. That fact, in turn, suggests a refinement in one or all of three places: the electrolyte (the ion-carrying guts of the battery); the interface between the electrolyte and the electrodes (the charge-collecting plates); and the electrodes themselves. Manufacturing innovations may also contribute. Although A123 is not divulging specifics about what new advances went into this battery, the firm holds patents relating to work on novel electrode and electrolyte materials as well as battery structures. "If this is real, it's a major breakthrough," says Jeffrey Chamberlain, who leads the Energy Storage initiative at Argonne National Laboratory and was not involved in this research.

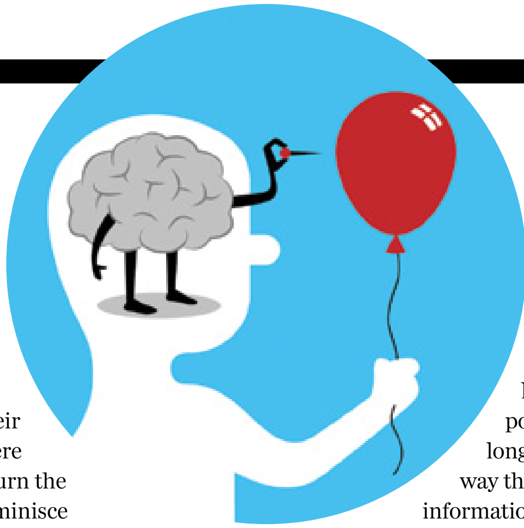
The new batteries may first find use not in all-electric cars but in microhybrids because they might last much longer than current lead-acid batteries. A123's batteries are slightly more expensive (roughly $250 more per battery) but also half as heavy and 30 percent as small.

First the firm will have to survive, however. It has been reporting large losses in the wake of a major battery recall last year. It is hoping this new battery will help the company make a fresh start. "The proof is in the pudding," Chamberlain says. —*David Biello*

PSYCHOLOGY

Mind Pops

Researchers delve into an unusual form of Proustian memory



In everyday life, people often search their memory for specific information: "Where did I leave the car keys?" "Did I really turn the oven off?" Other times they actively reminisce about the past: "Remember that crazy night out last week?" Not all recall is a choice, however; some forms of memory are involuntary. Perhaps the most famous example is a scene from French novelist Marcel Proust's *In Search of Lost Time* (also called *Remembrance of Things Past*). As the narrator drinks some tea and eats a small, plump sponge cake known as a madeleine, the taste brings up a memory of eating the same treat at his aunt's house when he was young.

Researchers are beginning to study a related form of memory called mind pops, fragments of knowledge, such as words, images or melodies, that drop suddenly and unexpectedly into consciousness. Unlike the Proustian example, mind pops, a term coined by University of California, San Diego, emeritus professor George Mandler, seem completely irrelevant to the moments in time and thought into which they intrude. They are more often words or phrases than images or sounds, and they usually happen when someone is in the middle of a habitual activity that does not demand much concentration. (For example: you are doing the dishes when the word "orangutan" springs into your mind for no obvious reason.) Most notably, identifying a trigger for a mind pop in the surrounding environment or even in previous thoughts is extremely difficult—they seem to come out of nowhere.

Psychologists are discovering that mind pops are not truly random—they are linked to our experiences and knowledge of the world, albeit with hidden threads. Research on mind pops is preliminary, but so far studies suggest that the phenomenon is genuine and common. Some people notice their mind pops much more often than others, and frequent mind popping could quicken problem solving and boost creativity. Yet in some people's minds—such as those with schizophrenia—mind pops might evolve from benign phenomena into unsettling hallucinations.

Lia Kvavilashvili, a psychologist at the University of Hertfordshire in England, and Mandler propose that mind pops are often explained by a kind of long-term priming. Priming describes one way that memory behaves: every new piece of information changes how the mind later responds to related information. "Most of the information we encounter on a daily basis activates certain representations in the mind," Kvavilashvili explains. "If you go past a fish-and-chips shop, not only the concept of fish may get activated but lots of things related to fish, and they may stay activated for a certain amount of time—for hours or even days. Later on, other things in the environment may trigger these already active concepts, which have the feeling of coming out of nowhere." This phenomenon can boost creativity because, she says, "if many different concepts remain activated in your mind, you can make connections more efficiently than if activation disappears right away."

Recently Kvavilashvili and her colleagues published a study looking at a possible dark side of mind pops. The researchers wondered just how similar everyday involuntary recall is to intrusive thoughts and hallucinations observed in mental disorders such as depression, post-traumatic stress disorder and obsessive-compulsive disorder. The results, which appear in an April issue of *Psychiatry Research,* suggest that mind pops are more common among the mentally ill than among the healthy, but it is far too soon to definitely link the sudden memories to hallucinations.

Kvavilashvili has been working on more studies about the phenomenon, in particular one on musical mind pops and their relation to songs that continually replay in people's heads. "The study of mind popping is still in its infancy," she notes. "I got curious about them because they seemed so random, but these mind pops are genuine fragments of knowledge about the world. What it shows us is that our subconscious often knows the meaning of an experience, even if consciously we don't." *—Ferris Jabr*

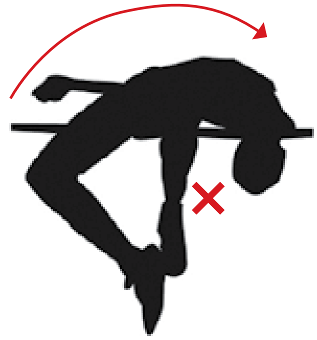
FACT FINDER

Information bits from the news

HIGH-JUMP PHYSICS

As you watch high jumpers sail over the bar this summer at the London Olympic Games, keep this equation in mind: $U^2 = 2gH$. It explains why most of jumpers do the backward flip known as the Fosbury Flop. As University of Cambridge mathematician John Barrow writes in his book *Mathletics: A Scientist Explains 100 Amazing Things about the World of Sports* (W. W. Norton, 2012), the Fosbury Flop keeps one's center of gravity low to the ground, and the lower one's center of gravity, the less energy is required to successfully jump over the bar. In the above equation, U is the speed of the jumper (and thus the energy required), g is the acceleration caused by gravity, and H is the height of the center of gravity. Surprisingly, it is possible for the high jumper's body to fly over the bar while his or her center of gravity passes below it.

Now, you might ask, why do many of the jumpers leap backward? That part is easy: when your back is to the pole, there is less chance that your arms or legs will hit the bar and knock it down. *—Rose Eveleth*



THINKSTOCK

COMMENT AT ScientificAmerican.com/aug2012

Best of the Blogs

TECHNOLOGY

A Hacker-Ready Chip

Researchers discover a dangerous weakness in computer hardware

A pair of security researchers in England recently released a draft of a paper that documents what they describe as the "first real-world detection of a backdoor" in a microchip—an opening that could allow a malicious actor to monitor or change the information on the chip. The researchers, Sergei Skorobogatov of the University of Cambridge and Christopher Woods of Quo Vadis Labs in London, conclude that the vulnerability made it possible to reprogram the contents of supposedly secure memory and obtain information about the internal logic of the chip. The chip's manufacturer, California-based Microsemi, issued a statement saying it had "not been able to confirm or deny the researchers' claims."

The reported security breach is a particular concern because of the type of chip involved. The affected chip, ProASIC3 A3P250, is a field-programmable gate array (FPGA). FPGAs are used in an enormous variety of applications, including communications and networking systems, the financial markets, industrial-control systems and a long list of military systems. Each customer configures an FPGA to implement a unique—and often highly proprietary—set of logical operations. Any mechanism that could allow unauthorized access to the internal configuration of an FPGA creates the risk of intellectual-property theft. In addition, the computations and data in the chip could be maliciously altered.

Assuming that the researchers' claims stand up to scrutiny, an important question immediately comes to mind: How did this vulnerability end up in the hardware in the first place? It is possible that the backdoor was inserted at the behest of a nation-state with malicious intent. It is also possible that the backdoor exists because of carelessness. Someone in the design process could have inserted it to enable testing without realizing that it would later be discovered and potentially exploited.

Regardless of the source of the vulnerability, its presence should serve as a wake-up call about the importance of hardware security. The overwhelming majority of cybersecurity vulnerabilities identified to date have involved software, which can be replaced, updated, altered and downloaded from the Internet. In contrast, a hardware vulnerability is built into the actual circuitry of a chip and can be very difficult to address without replacing the chip itself.

This certainly won't be the last time that a hardware security vulnerability will be identified, and we should put in place preemptive measures to minimize the risks they might pose. *—John Villasenor*

Villasenor is a nonresident senior fellow at the Brookings Institution.

Adapted from the Guest Blog at blogs.ScientificAmerican.com/guest-blog

QUICK CHANGER: A common octopus

MICHAEL PATRICK O'NEILL *Photo Researchers, Inc.*

BIOLOGY

Vanishing in Plain Sight

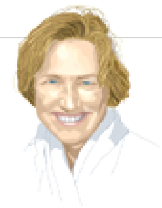
Octopuses can make themselves invisible

Amazing masters of disguise, octopuses can essentially vanish, right before your eyes, into a complex scene of colorful coral or a clump of kelp waving in the currents. How do these invertebrates manage this quick-change feat? Small pigment-filled cells, called chromatophores, and reflective ones, called iridophores and leucophores, in the skin of most octopuses allow them to create nuanced patterns of color and luminosity and even to harness polarized light to fool other ocean life. Scientists, however, have debated just what information they use to craft this overall effect. A paper published online in *PLoS ONE* suggests octopuses focus on a limited selection of nearby objects to determine their disguise, as opposed to incorporating the general hues and patterns of a whole area into their skin display.

The researchers, from Ben-Gurion University of the Negev in Israel and the Anton Dohrn Zoological Station Naples in Italy, studied digital underwater photographs of the common octopus (*Octopus vulgaris*) and the day octopus (*O. cyanea*) camouflaging in their natural habitats. They then ran those images through a computer program that picks out clusters of similar colors, lights and patterns. The almost invisible octopuses in the images most closely matched distinct landmarks such as corals or noticeable rocks.

The new paper does not, however, solve the debate about how these color-blind animals can create such a stunning, full-color display. The discovery of light-sensing proteins (opsins) in their skin suggests that they might be able to detect and react to color and light conditions locally. Yet so far only one hue of these cells has been discovered, so scientists are still searching for more clues about how these crazy cephalopods choose their wild disguises. *—Katherine Harmon*

Adapted from the Octopus Chronicles blog at blogs.ScientificAmerican.com/octopus-chronicles

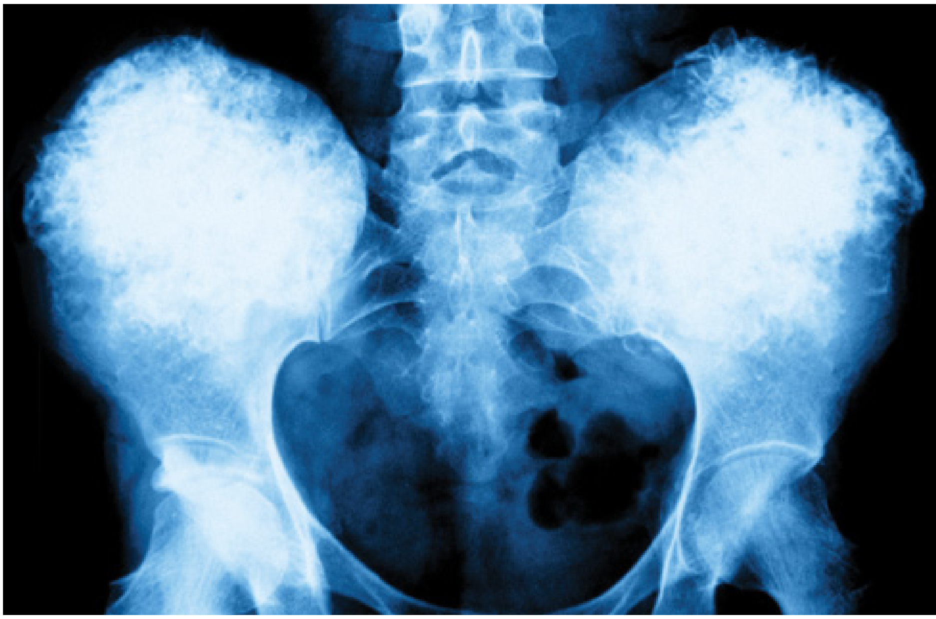


Deborah Franklin is based in San Francisco and has reported on science and medicine for NPR, the *New York Times, Fortune* and *Health Magazine*.

Cracks in the Bone Test

Current screens for osteoporosis are flawed, but doctors are repairing their methods

Hip fractures kill and cripple far too many elderly women and men. Every year roughly 350,000 people in the U.S. shatter their hips and end up in the hospital, where more than 14,000 of them die. Another 24 percent die within a year of the injury; half lose their ability to walk. Most of these fractures, which cost about $17 billion in medical care annually, result from a withering of the skeleton known as osteoporosis.



X-RAY alone is not enough to accurately assess risk for osteoporosis.

Physicians have long used x-rays to estimate the density of bone minerals—a rough indicator of bone strength. In 2011 the influential U.S. Preventive Services Task Force, which sets testing standards that Medicare and other health insurers tend to follow, began urging all women to get an enhanced x-ray—known as a DXA (*d*ual-energy *x*-ray *a*bsorptiometry) scan—of the hip or lower spine to check for small fractures or worn spots at age 65. The National Osteoporosis Foundation suggests that all men have the same screening scan by age 70.

Although everyone benefits from such baseline bone scans, most healthy people do not need screens every two years. "Repeat bone density testing has been oversold as a screening tool," says Steven R. Cummings, a bone researcher at the University of California, San Francisco. Evidence shows many doctors focus too narrowly on reduced bone density, particularly in younger women, confusing one sign of osteoporosis risk with the disease itself. A better measure of skeletal health, Cummings suggests, puts bone density in a broader context, taking into account smoking status, drug interactions and history of prior fractures. Together these factors more accurately predict the risk of serious bone breaks, offering a better a guide to who should start taking fracture-preventing drugs and who should not.

THE ROOTS OF OSTEOPOROSIS

FOR CENTURIES doctors assumed frail bones and stooped postures were just irreversible aspects of aging. In the 18th century, however, investigators began to uncover hints in experiments with animals that bones undergo continual remodeling throughout life.

Eventually scientists identified the key members of the bone construction crew: three types of specialized cells. Osteoclasts excavate small pits in old or cracked bone, whereas osteoblasts extrude into those pits a blend of soft collagen and other proteins, which they subsequently harden with calcium phosphate and other minerals. A third group of cells, the osteocytes, helps to coordinate skeletal repair via chemical signals to the demolition and construction crews. By overhauling about a million scattered, tiny patches of bone at a time, the adult human body renews its entire skeleton approximately every 10 years.

A remodeled chassis might seem like an automatic upgrade, but cross-sectional views of hips and vertebrae reveal that new bone is not as well crafted as the original. The honeycombed interior of freshly laid trabecular (from the Latin for "small beam") bone surrounding the marrow has fewer cross-struts to lend it strength and elasticity. Even though the hard outer shell, or cortical bone, grows thicker in some spots over time, autopsies show that these thickened sections are often riddled with holes.

The consequences of this lopsided bone repair—more destruction than construction of the adult skeleton over time—hit women harder and earlier in life than men. In the late 1930s endocrinologist Fuller Albright finally began to puzzle out why. Based partly on the bone-building benefits of estrogen in animal experiments, Albright surmised that the back and hip pain and collapsed vertebrae of his osteoporotic female patients might be related to the sudden drop of estrogen in menopause. He gave

PHOTO RESEARCHERS, INC.; COLORIZATION BY MONICA SCHROEDER

some of his patients estrogen, and, sure enough, many reported pain relief. Blood and urine tests for calcium and other bone metabolites confirmed that as long as they were taking the estrogen, they lost less bone.

Albright's findings began to reframe osteoporosis as a treatable progressive disorder. His work launched a new wave of research into bone biology that continues today and has stimulated a lucrative market for drugs that either spur the creation of new bone or—in most cases—slow the loss of old bone. Hip fractures were the main concern because they are so deadly, but many other types of fractures significantly reduce quality of life. As scientists began testing the new drugs, they needed a machine that could detect subtler changes in bone than conventional x-rays. Eventually the DXA scan emerged as the clinical standard for measuring bone density: it compares how hard bone and soft tissue differentially absorb low-energy beams directed at the same spot in the skeleton. As DXA scanners became less expensive in the 1990s, the market for bone drugs soared.

Better Than a Bone Scan

A new online calculator called FRAX computes a 10-year probability of fractures based on many risk factors, including:

- **Age, gender, weight and height, all of which have complex relations to risk**
- **History of previous fractures in patient or parents**
- **Whether the patient smokes, which may weaken bone**
- **Alcohol consumption (more than three drinks a day may increase risk)**
- **Whether the patient takes glucocorticoid drugs, particularly oral medication, which may increase risk**
- **Whether the patient has lost bone to disease or trauma**
- **Bone mineral density, an indicator of bone strength**

RISK IS NOT DISEASE

BONE DENSITY TESTS quickly became a rite of passage for many postmenopausal women in their 50s. When doctors started scanning these women, however, a problem emerged, says Cummings, who has co-authored some of the largest studies of osteoporosis in the past three decades. Instead of regarding "low bone density" as one sign of risk, doctors equated it with full-blown osteoporosis. Even worse, under the banner of early detection and prevention, bone density that was slightly lower than average got its own medical label—osteopenia—and some doctors started treating that condition with drugs, too.

The conflation of disease with disease risk might not be so bad, Cummings says, if bone density tracked tightly with the incidence of serious fractures at every age, under every condition. But it does not. Among 16,000 postmenopausal women in Manitoba who received baseline bone scans at age 50 or older, for example, most of those who eventually suffered fractures had normal bone density, according to a 2007 study in the *Canadian Medical Association Journal*. As the studies piled up, Cummings notes, "it quickly became evident that in a group of people with the same bone mineral density, some got fractures and others didn't. Clearly, some other feature of bone plays an important role here."

That should not come as a surprise, says Markus Seibel, who studies bone metabolism at the University of Sydney. Much of modern medicine is about treating risk instead of symptoms, he notes. Doctors attempt to lower bad cholesterol in hopes of preventing a heart attack, for example. But relying strictly on numbers to predict health outcomes is tricky. "The more we move away from actual disease, the harder it is to predict what will happen in a particular patient," Seibel says.

So far, Seibel observes, scientists have not identified the underlying physiological features that make a bone resistant or prone to cracks. Large epidemiological studies, however, have revealed more characteristics of people that, when taken together with measurements of bone density, can help improve predictions about who will suffer a major fracture. In 2008 the World Health Organization integrated 12 of the most influential of these risk factors into an algorithm that is the basis for an easy-to-use online risk calculator known as FRAX.

BEYOND BONE DENSITY

FRAX RELIES ON a long list of variables that influence risk: age; sex; weight; height; previous fractures in patients and their parents; current smoking status; prior chronic treatment with glucocorticoids; a diagnosis of rheumatoid arthritis (not osteoarthritis); a diagnosis of secondary osteoporosis (bone loss from a trauma or illness); level of alcohol consumption (more than three daily glasses of wine, or the equivalent, increases the likelihood of a break); and low bone mineral density at the femoral neck (a frequent site of hip fracture, just below the bony knob of the upper thigh bone).

After patients fill out a simple online survey, the FRAX calculator weights the risk factors according to the most recent data and spits out two numbers—a 10-year probability of hip fracture and a 10-year probability of any major fracture of the hip, spine, forearm or shoulder. Those numbers are a rough guide, the WHO emphasizes, and should not substitute for a doctor's clinical judgment about a particular patient. Someone who smokes and binge drinks frequently and has already had a painful fractured hip, for example, is probably more likely to suffer another broken hip than a light smoker and drinker of the same age who has had a painless vertebral fracture that could barely be detected by x-ray. Even so, the FRAX calculator would give those two people the same score.

Despite FRAX's flaws, Cummings says the tool is an improvement in risk prediction because it puts bone density in proper context as "one factor—an important factor but just one factor—in your likelihood of fracture." Bone health experts currently recommend a baseline bone scan and FRAX calculation around age 65. And anyone—male or female—older than their mid-50s who fractures any bone in the absence of a car accident or similar trauma should be evaluated for osteoporosis and considered for bone-building drugs. Too many emergency room doctors today, Seibel says, are still just setting the broken arm or wrist and sending the patient home. After late middle age, experience and statistics confirm, there is no such thing as a simple fracture. SA

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THE MATERIAL (SPORTS) WORLD

This summer, athletes will be relying on cutting-edge materials to help them glide through water, cut through air and jump as high as possible. Here are three of the revolutionary materials you'll see on Team USA this summer and why they may help us bring home the gold.

Run like the wind. Made from recycled plastic bottles, Nike's new lightweight TurboSpeed track suits are built to be fast. On average, runners finished two hundredths of a second faster per 100 meters than they did wearing the company's previous materials. This is because of Nike's proprietary AeroSwift technology. Tiny patterns and surface architectures are woven into the interior of the polyester fabric to maximize speed, much like dimples in a golf ball make it fly farther and faster.

Fly like a bird. Basketball uniforms have to be light and breathable so players can jump high, run quickly and stay cool throughout the game. Nike's new Hyper Elite 2012 shirts are designed from a material that pulls sweat away from the skin and eliminates cling, while the shorts, which feature cooling side perforations, weigh almost a pound less than other professional basketball shorts and are made of 100% recycled polyester.

Swim like a fish. Modeled after shark skin, the Speedo FastSkin3 Super Elite technology is the first three-part swim uniform—cap, goggles and suit—built to be used together. To make it, Speedo scanned the bodies of professional swimmers and created digital avatars, which they then used to test dozens of new materials and technologies. The result is a suit that resists water absorption and compresses the body into its most efficient and fastest swimming form. Wearing the FastSkin3, Michael Phelps has said he "feels completely at one with the water."

MATERIAL EVOLUTION IN POLE-VAULTING

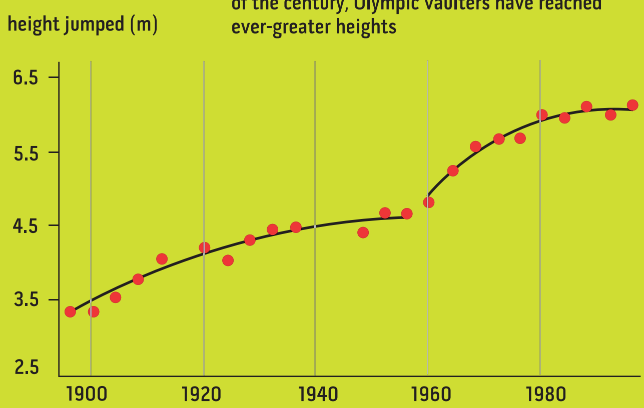
Pole-vaulting is as much about the pole as it is about the vaulter, because it is the pole's job to absorb, store and transfer energy from and to the athlete to help him jump as high as possible. Here's a look at how poles have changed over the years and why.

1 The first poles dating back to 829 B.C. were made of ash or hickory, which are very stiff materials. When athletes ran and subsequently planted their poles into the ground, most of the kinetic energy of their motion was lost rather than transferred to the poles as elastic potential energy. As a result, athletes typically had to climb the poles rather than be vaulted by them and they didn't get very high.

2 Vaulters switched to bamboo poles in the 1920s, which were much more bendable than previous ones. The poles therefore stored some of the athletes' motion as elastic potential energy, pushing them upwards. The days of pole-climbing were over. Pole-vaulting had begun.

3 Today's poles are made of fiberglass or carbon fiber, which are exceptionally light and bendable. As a result, vaulters can run faster and transfer almost all of their kinetic energy into elastic energy, propelling them ever higher. Once all the elastic energy has been transferred into gravitational potential energy—at the peak of the jump—vaulters clear the bar and fall back to the ground.

As pole material has evolved over the course of the century, Olympic vaulters have reached ever-greater heights



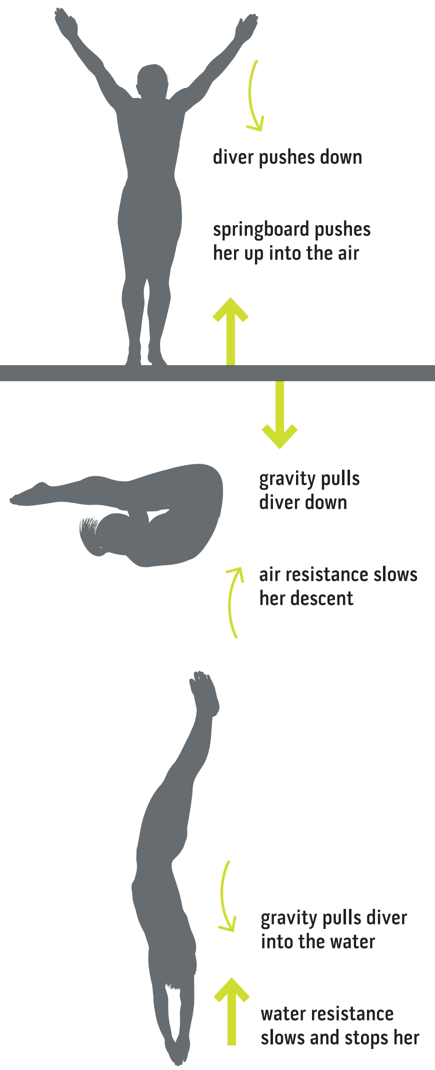
The Science of Sports

WHERE SCIENCE PLAYS INTO ATHLETICS AND COMPETITION

FEELING GRAVITY'S PULL

It's a force to be reckoned with.

Without gravity, Earth wouldn't revolve around the sun and life as we know it simply wouldn't exist.



TOUR DE FORCE: DIVING To achieve a perfect 10, divers have to manipulate a number of forces. A diagrammatic look at what is affecting a diver's body as she 1) jumps off the board, 2) twists mid-air and 3) enters the water with a perfect splash.

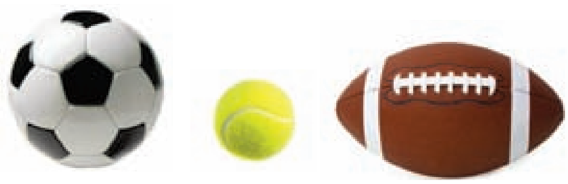
Yet athletes always seem to find ways to cheat this fundamental force. They jump higher than seems physically possible and sprint and pedal uphill almost effortlessly. Gravity-defying moves require huge amounts of energy, typically generated from muscle cells in athletes' legs. This is why training is crucial. Athletes have to build muscles that can wield extraordinary power on a regular basis.

Other athletes use gravity to their advantage, for instance to build record-breaking speed. In such sports, one major goal is to minimize opposing slowing forces like air resistance. This is why ski racers wear aerodynamic, tight-fitting uniforms and why lugers lie back as they sled. Gravity is also a friend to football and rugby players, who use their weight, a combination of gravity and their mass, as well as their momentum, a combination of their mass and their speed, to tackle opposing team members to the ground.

But when gravity is used to build momentum and an accident occurs, the law of conservation of momentum dictates that all the momentum that has been built up must be transferred elsewhere—for instance, as a force hitting the athlete's body. This is why protection in sports is essential. Some athletes might consider gravity a nuisance and others may see it as an ally, but for everyone, it is a force to be reckoned with.

AERODYNAMIC

The importance of shape, speed and spin.



Bend it like Beckham. This phrase describes English soccer player David Beckham's uncanny ability to deliver "bending" free kicks that curve and dip at the end, evading goalkeepers and almost always scoring points. Researchers have analyzed Beckham's masterful shots and determined that he kicks the ball off-center while bending his ankle in an L-shape, the combination of which curves the ball mid-flight. The airflow around the ball also shifts as it descends, slowing it down and allowing it to drop at the last moment into the goal.

Impeccable service. Tennis serves can clock at up to 160 miles per hour. But where does this power come from? According to experts, the best players get their racket heads moving quickly by keeping their serving arms loose. That way, their swings can be properly accelerated by their legs, shoulders and torsos. Players then snap their wrists before hitting the ball to add more speed. They also need to toss the ball high and in front—not behind—so that the racket head meets the ball at the peak of its toss.

The flight of a football. Footballs are notoriously difficult to throw, and much of the challenge is rooted in the ball's oblong shape. Quarterbacks have to spin the ball so it rotates lengthwise along its axis. If the spin is off even by a bit, the ball will wobble as it flies, slowing it down and shortening its trajectory. Speed is another important factor—the faster the ball is thrown, the less drag it experiences and the farther it will go.

BEATING THE ODDS

How do we know when athletic greatness is truly profound?

At the 2009 world swimming championships in Rome, swimmers broke at least four world records every single day. But few of these accomplishments reflected true performance gains—instead, most have been attributed to improvements in swimsuit technology. This dilemma has led many sports enthusiasts to wonder: how many record-breaking athletes are truly faster than their historical competitors, and how many instead have their gear, diets or even plain old good luck to thank? How do we know which sports heroes truly deserve to be recognized as the best of the best, and who's at the top right now?

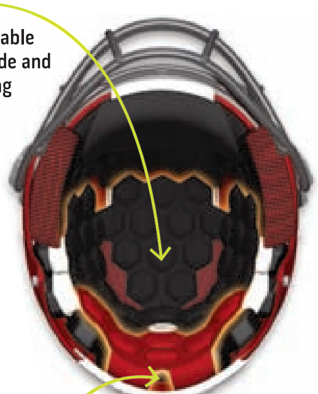
One clear phenom today is Jamaican sprinter Usain Bolt—and a close look at the numbers tells you why. Most athletes beat records by just a hair, shaving off less than a tenth of one percent of the time. When Carl Lewis broke the world record for the 100 meter sprint in 1991, for instance, he did so by reducing the record time by 0.4 percent. In 2005, Jamaican 100 meter sprinter Asafa Powell beat Tim Montgomery's record by just 0.1 percent. But three time Olympic gold medalist Usain Bolt's most recent 100 meter record beats Powell's best time by a whopping 1.64 percent. That kind of improvement —akin to beating the current marathon record by more than two full minutes—is far too big to be an artifact of chance or a particularly good pair of running shoes.

EYES ON THE PRIZE: Many athletes rely on colored contact lenses to reduce glare or increase peripheral vision.

FACE FRAME: Enhanced frontal and mandible protection

HINGE CLIPS: Disperses energy from frontal impacts

LINER: Inflatable back/neck/side and crown padding



OCCIPITAL LOCK Cradles the back of the head for stability

HEADS UP A growing number of former NFL players are suffering from a debilitating dementia-like disorder called chronic traumatic encephalopathy, which experts believe is linked to repeat concussions. This concerning trend is inspiring helmet manufacturers to re-think their approach to head protection. Here's a close look at the Riddell 360, a revolutionary new helmet that was rated in 2012 as the safest adult football helmet around.

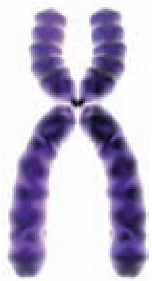
SPORTS DESIGN an anatomical history

1 Brown tobacco spittle-covered "spitballs" were used in baseball until they were banned in the 1920s.

2 Tennis rackets were made from cow intestines until the 1990s.

3 16th century soccer balls were made from inflated pig bladders covered in leather.

GENETIC ENGINEERING: Recent research suggests athletic prowess is partially rooted in a single gene.



PLAYING IT SAFE

Some companies are thinking outside the helmet.

When people think about protection, they think about gear that absorbs or deflects impact—things like knee pads, mouth guards and helmets. This kind of damage control is crucial, of course, but it's not the only solution. Some innovative scientists are also developing preventive protection: training clothes that make muscles and joints more harm-resistant as well as devices that predict the likelihood of future injury.

Take Evidence-Based Apparel, a California-based company that makes athletic clothing with built-in supportive braces. Made with small elastics known as "neurobands," these braces—built into shirts and pants—stimulate and support surrounding muscles, ultimately strengthening them and reducing their energy demands so that they are less susceptible to injury. The Los Angeles Dodgers and the Kansas City Royals have worn these shirts to prevent shoulder injuries, and the company is working with long-distance swimmer Diana Nyad to customize a suit for her second attempt to swim from Cuba to Miami in 2012.

And wouldn't it be nice for athletes to have clothes that tell them when they need to rest? A team at Northeastern University in Boston is designing shirts embedded with motion sensors and conductive fibers that record the motions of baseball pitchers' arms and track their changes on a computer. The sensors detect when the pitcher's technique starts breaking down, as might occur when he or she gets tired. Since most injuries are fatigue-related, the shirt—which is expected to cost about $200— can alert athletes and coaches before muscle tears and elbow problems develop. Similarly, New York-based company CA Technologies has been working with the Italian soccer team A.C. Milan, collecting data from sensors that the players wear as they train, to find more general patterns indicative of sports injury risk.

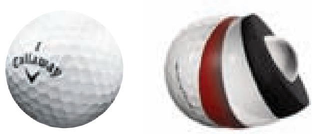
FIGHTING COLORS: Wearing red increases the chances that a sports team will win.

DAZZLING DESIGN

The most innovative designs for the highest performance.

Sports is as much about gear as it is about winning, and every year brings new technological breakthroughs to our tracks, stadiums, courses and slopes. Here's a quick look at three new designs that are creating a buzz in the sports community.

Adidas ClimaCool running shoes. For long-distance runners, staying cool is a must, because three-quarters of the body's energy is typically used to prevent overheating. That's why Adidas's ClimaCool running shoe, launched in March 2012, provides a major advantage. The shoe features 360-degree air channels, similar to wind tunnels, that evaporate sweat and boost circulation on all sides of the foot, keeping it cool and dry. Not only will runners feel more comfortable in the ClimaCool shoe, but they will also conserve extra energy.



Callaway HEX Black Tour balls. Phil Mickelson credited this ball in his 2012 victory at Pebble Beach, and for good reason. Whereas golfers usually have to choose between balls that travel far or provide good green control, the HEX ball offers both, thanks to a dual core that tailors the ball's spin depending on playing conditions. When hit from the tee, the ball spins low, lengthening the drive; hits that are closer to the green induce higher spin for more control. The ball is also covered with more aerodynamic dimples than most other golf balls are, reducing drag so that the ball is more stable in the air and travels farther.

Blizzard Cochise skis. These snow skis have a naturally curved shape that gives them a lightweight feel in powdered snow and also makes them exceptionally stable in hard snow. Their rockered construction comes from the ski's flipped wood core. The ski is literally made upside down in its mold, and the downward-facing convex side forms a natural rocker shape, which is smoother and more performance-enhancing than artificially produced curves. *SKI* magazine named these skis as their #1 choice for deep snow in 2012.

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David Pogue is the personal-technology columnist for the *New York Times* and host of *NOVA scienceNOW*, whose new season premieres in October on PBS.

Siri, Why Aren't You Smarter?

Speech-recognition software is great—unless you're trying to use it on a phone

When Apple unveiled the iPhone 4S last year, the new phone *looked* just like the previous one. It had a better camera and a faster chip, but it could *do* only one new thing: Siri.

Siri, as everyone knows by now, is a software assistant that takes spoken orders. No training necessary: just hold down the "Home" button and speak casually.

Siri lit the cultural world on fire. There were YouTube parodies, how-to guides and copycat apps for Android phones. Pundits have proposed new rules of etiquette for using phones in public now that people are speaking to them even when they're *not* on a call. Speech recognition became all the rage; suddenly, it popped up in television sets and, of course, rival phones. At the crest of the hype, it looked like the way we interact with our gadgets had changed forever.

And then—the backlash.

"Siri Is Apple's Broken Promise" was the headline at gadget site Gizmodo. People griped that sometimes you'd dictate a whole paragraph, the phone would think and then type—nothing at all. Now there has been a class-action lawsuit asserting that Apple made false claims. (According to Apple, Siri is still in beta testing.)

What happened? How could Siri, the savior of electronics, turn out to be such a bust?

What everybody's missing is the difference between Siri, the virtual assistant, and Siri, the speech-recognition engine. As it turns out, these two different functions have wildly different track records for success.

The assistant half of Siri comes from a *company* called Siri, which Apple bought. (It was a spin-off from a military artificial intelligence project that wound up at the research firm SRI. Get it?)

But the *dictation* feature—the text-to-speech part—is provided by Nuance, the company that brought us software such as Dragon NaturallySpeaking.

When you dictate, you generate an audio file that is transmitted to Nuance's servers; they analyze your speech and send the text back to your phone. That is why, when your Internet signal isn't great or when the cell network is congested, Siri may come up short. (When you're on Wi-Fi, dictation works far better.)

That requirement to shuttle data to and from remote servers is at the heart of Siri's frustratingly inaccurate dictation talents.

There are other challenges to the dictation feature, too. Irregular background noise, wind and variable distance from mouth to microphone all make transcription perfection on a cell phone a towering task—and the results are much less accurate than what you would get using PC dictation software, which faces none of those difficulties. Using Siri (and the even less polished dictation feature on Android phones), you might have to correct two or three errors per paragraph.

Desktop dictation software fares much better—close to 100 percent accuracy—because it doesn't have any of those particular challenges. And on your PC, you train the software to recognize only one voice: yours. There's no training on the phone. The computational task is ridiculously hard.

The backlashers have a point. We're used to consumer technology that works every time: e-mail, GPS, digital cameras. Dictation technology that relies on cellular Internet, though, only sort of works. And that can be jarring to encounter in this day and age.

But let's not throw the Siri out with the bathwater. The "virtual assistant" portion of Siri—all those commands to set an alarm, call someone, text someone, record an appointment—works solidly. Even if all you use are basic commands such as "Wake me at," "Call," "Text" and "Remind me," you save time and fumbling.

Free-form cellular dictation is a not-there-yet technology. But as an interface for controlling our electronics, it makes the future of speech every bit as bright as Siri promised a year ago.

Just wait till she comes out of beta. SA

SCIENTIFIC AMERICAN ONLINE
Eight ways to boost Siri's voice recognition: ScientificAmerican.com/aug2012/pogue

Illustration by Tom Whelan

The matter-eating beast at the center of the Milky Way may actually account for Earth's existence and habitability

By Caleb Scharf

ASTROPHYSICS

THE BENEVOLENCE OF BLACK HOLES

OUR EXISTENCE IN THIS PLACE, THIS MICROSCOPIC CORNER OF THE COSMOS, IS FLEETING. WITH utter disregard for our wants and needs, nature plays out its grand acts on scales of space and time that are truly hard to grasp. Perhaps all that we can look to for real solace is our endless capacity to ask questions and seek answers about the place we find ourselves in. One of the questions we are now asking is how deeply our specific circumstances are connected to this majestic universal scheme of stars, galaxies and black holes.

Adapted from Gravity's Engines: How Bubble-Blowing Black Holes Rule Galaxies, Stars, and Life in the Cosmos, *by Caleb Scharf, by arrangement with Scientific American/ Farrar, Straus and Giroux, LLC (US), Penguin Press (UK), Hayakawa Shobo (Japan) and Prószyński (Poland). Copyright © 2012 by Caleb Scharf.*

Lots of cosmic phenomena can potentially influence the existence of life, but some are a little more important than others. Black holes are on that list because of their unique nature. No other object in the universe is as efficient at converting matter into energy. No other object can act as a gigantic spinning electrical battery capable of expelling matter at nearly light speed across tens of thousands of light-years. Black holes also ensnare nearby matter like nothing else can—they are the universe's ultimate competitive eaters. And like a competitive eater, they often ingest matter in great gulps rather than steadily snacking.

Matter falling into a black hole does not go down quietly. It moves at a tremendous

LAST GASP: The swirling disk of matter falling into a black hole radiates intensely and shoots high-speed bursts of plasma back into the galaxy.

Illustration by Vault 49

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speed as it approaches the event horizon, spiraling around in hypervelocity loops if the black hole is spinning. Should that material intersect and collide with anything else on the way, the potential exists for an enormous release of kinetic energy, converted into the motion of atomic and subatomic particles and electromagnetic radiation. Produced well before reaching the event horizon, these particles and photons can escape, surging back out into the universe. A crude analogy is to liken this to water draining noisily from a bathtub. As the liquid falls into the drainpipe, some of its swirling kinetic energy is converted into sound waves, water bashing against molecules of air. The sound waves move faster than the water, and they escape. In the case of a giant black hole, the energy expelled during such digestive episodes can have wide-ranging effects on the surrounding galaxy.

When astronomers talk about matter being fed into supermassive black holes, they talk about "duty cycles," just like the episodic sloshing of clothes inside a washing machine. The speed of a black hole duty cycle describes how rapidly it changes back and forth from feeding on matter to sitting quietly. The supermassive black hole at the center of our own Milky Way galaxy is quiet now, but it, too, switches on from time to time. The duty cycle astronomers have inferred for our central black hole turns out to share a connection with the overall flavor of the galaxy. It also offers intriguing hints about how the solar system manages to support life.

ON DUTY

THE RESULTS of astronomical surveys indicate that the duty cycle of a giant black hole relates, surprisingly, to the host galaxy's stellar medley. The same dynamical processes that send matter hurtling into a black hole—and therefore set its duty cycle—likely influence the kinds of stars that populate a galaxy, and the energy pouring out of a flaring black hole at the peak of the duty cycle can spice up the galaxy's stellar contents. These contents are a critically important clue to the nature of a galactic system. The stars in a galaxy can be reddish, yellowish or bluish; blue stars are typically the most massive. They are therefore also the shortest-lived, burning through their nuclear fuel in as little as a few million years. This means that if you detect blue stars in the night sky, you are catching sight of youthful stellar systems and the indications of ongoing stellar birth and death.

Astronomers find that if you add together all the light coming from a galaxy, the overall color will tend to fall into either a reddish or a bluish category. Red galaxies tend to be ellipticals, and blue galaxies tend to be spirals. In between these two color groups is a place considered to be transitional, where systems are perhaps en route to becoming redder as their young blue stars die off and are no longer replaced. With nary a sense of irony or, indeed, color-mixing logic, astronomers call this intermediate zone the "green valley."

Over the past billion years it has been the largest so-called green valley spiral galaxies that have had the highest black hole duty cycles. They are home to the most regularly growing and squawking giant black holes in the modern universe. These galaxies contain 100 billion times the mass of the sun in stars, and if you glance at any one of them, you are far more likely to see the signs of an eating black hole than in any other variety of spiral. One in every 10 of these galaxies contains a black hole actively consuming matter—in cosmic terms, they are switching on and off constantly.

The physical connection between a galaxy being in the green valley and the actions of the central black hole is a puzzle. This is a zone of transition, and most galaxies are either redder or bluer than this. A system in the valley is in the process of changing; it may even be shutting down its star formation. We know that supermassive black holes can have this effect in other environments, such as galaxy clusters and youthful large galaxies. It might be that their actions are "greening" the galaxies. It might also be that the same circumstances causing the transformation of a galaxy are feeding matter to the black hole.

As we study other nearby spiral galaxies, we do find evidence that the black holes pumping out the most energy have influenced their host systems across thousands of light-years. In some cases, the fierce ultraviolet and x-ray radiation from matter feeding into the holes can propel windlike regions of heated gas outward. These wash across a galaxy's star-forming regions like hot-weather fronts spreading across a country. Exactly how this impacts the production of stars and elements is unclear, but it is a potent force. Equally, the trigger for such violent output can influence the broader sweep of these systems. For example, the inward fall of a dwarf galaxy captured by the gravity well of a larger galaxy stirs up material to funnel it toward the black hole. It is like fanning the embers of a spent fire to relight it. The gravitational and pressure effects of that incoming dwarf galaxy can also dampen or encourage the formation of stars elsewhere in the larger system. Some or all of these phenomena could help explain why a supermassive black hole's activity roughly correlates to the age (and hence color) of the stars around it.

IN BRIEF

Black holes, such as the four-million-solar-mass lurker at the center of our galaxy, are not simply consumers. They also radiate copious amounts of energy as they devour nearby matter.

A black hole's feeding habits can have a surprising influence on the galaxy. Too much black hole activity, or too little, and stars with the right conditions for life as we know it could be scarce.

The Milky Way occupies a galactic sweet spot, with a black hole that appears to act out just often enough to stir things up and keep the galaxy's stellar population at a perfect simmer.

The connection between black holes and life is complex, but our galaxy's central black hole seems to have made numerous contributions to our ability to exist at this place and time.

Remarkably, astronomers have recently realized that our Milky Way itself is one of these very large green valley galaxies. What this means is that our supermassive black hole should be on a fast duty cycle, which is quite a surprise. The black hole lurking at the center of our galaxy does not seem so active—in fact, it betrays itself most convincingly by its insidious effect on the orbits of galactic core stars. By this measure, it is only four million times the mass of the sun, a relative whippersnapper. Yet according to our canvassing of the universe, it should be one of the very busiest.

To paraphrase Humphrey Bogart, of all the places in all the galaxies in all the universe, we had to go and find ourselves in this one. It is of course tempting to be skeptical: we have not thought of our galaxy as playing host to a particularly hungry supermassive black hole. But perhaps this is just a question of timing, of our short lives compared to the lifetime of the cosmos.

Indeed, it appears things were quite different not so long ago. We see x-rays echoing off interstellar clouds of gas that are 300 light-years from the galactic center. From our perspective, then, something big and powerful in the very core of the galaxy was throwing out a million times more x-ray light 300 years ago than it is today. And in 2010 a small team from Harvard University announced a remarkable discovery: a faint but enormous structure in the gamma-ray light coming from the inner galaxy. It was spread across the sky and looked exactly like a pair of bubbles, each reaching 25,000 light-years up and away into intergalactic space. Glowing with gamma-ray photons, these bubbles are anchored at their bases to the very core of the Milky Way; they may be the signposts of an episode of black hole growth and activity that occurred within the past 100,000 years.

The pieces of evidence are adding up to a compelling picture of our home environment. If the Milky Way obeys the rules that we see in tens of thousands of other galaxies, then it must contain a black hole that is getting fed very regularly. The hole may not be the largest or the most prolific at producing energy when it eats, but it is a busy object, a stormy chasm in our midst. We should expect the reignition of this gravitational engine at any time.

FAST, NOT FURIOUS

CLEARLY, our Milky Way and its central black hole belong to a special club. They hold a distinctive status within today's universe, one that points to a possible connection between the cosmic environment and the phenomenon of life here on Earth. Scientists and philosophers sometimes discuss what are called "anthropic principles." The word "anthropic" is derived from ancient Greek and means that something pertains to humans or to the period of human existence. Anthropic principles usually tackle the awkward question of whether or not our universe is somehow just right for life to occur. The argument goes that if only a few fundamental physical laws, or physical constants, in the universe were just a bit different, it would have failed to produce life. But we do not currently have good explanations for why the physical parameters of the universe are what they are. So the question stands out: Why did our universe turn out to be so suitable for life at all? Isn't that incredibly unlikely?

Like many scientists, I grow uncomfortable when faced with these questions. We are determined to try to overcome any prejudice that we are "special" in any way. Just as Copernicus proposed that Earth is not at the center of the solar system, we are not central to the universe. Moreover, the universe described by modern cosmology *has* no meaningful center. Yet some of the anthropic arguments are trickier to respond to. One possible solution to the discomfort of assigning ourselves a special status hinges on a conceptual and physical picture of nature that allows for multiple realities or multiple universes. For example, if our universe is merely one of many that exist within a higher-dimensional version of spacetime, then it is no surprise that we exist here. We simply exist in a universe that has the conditions that allow for the phenomenon of life—there is nothing special about it. It is just an island that has the right climate.

We should expect our galaxy's supermassive black hole to reignite at any time.

That is all quite entertaining stuff, but it also makes us think a little more about exactly what the laundry list of conditions is for life in a universe. It really is striking that the Milky Way, containing us, lands smack dab in the sweet spot of supermassive black hole activity. It is possible that this is not mere coincidence, and the first question that springs to mind is whether our solar system experiences direct physical ramifications of the activity of a black hole some 25,000 light-years away.

Could it affect the suitability of our suburban galactic neighborhood for life-bearing planets? When our central black hole switches on, eating and pumping out energy, the evidence does not suggest that it is enormously bright from our viewpoint. The huge gamma-ray glowing bubbles extending out from the galactic disk definitely indicate some pretty hefty energy production, but not directed toward us. If larger events ever occurred, they must have been in the distant past, perhaps even before the formation of our solar system 4.5 billion years ago. Since then, our central monster most likely has had only a modest physical impact on distant galactic suburbs like those of our solar system.

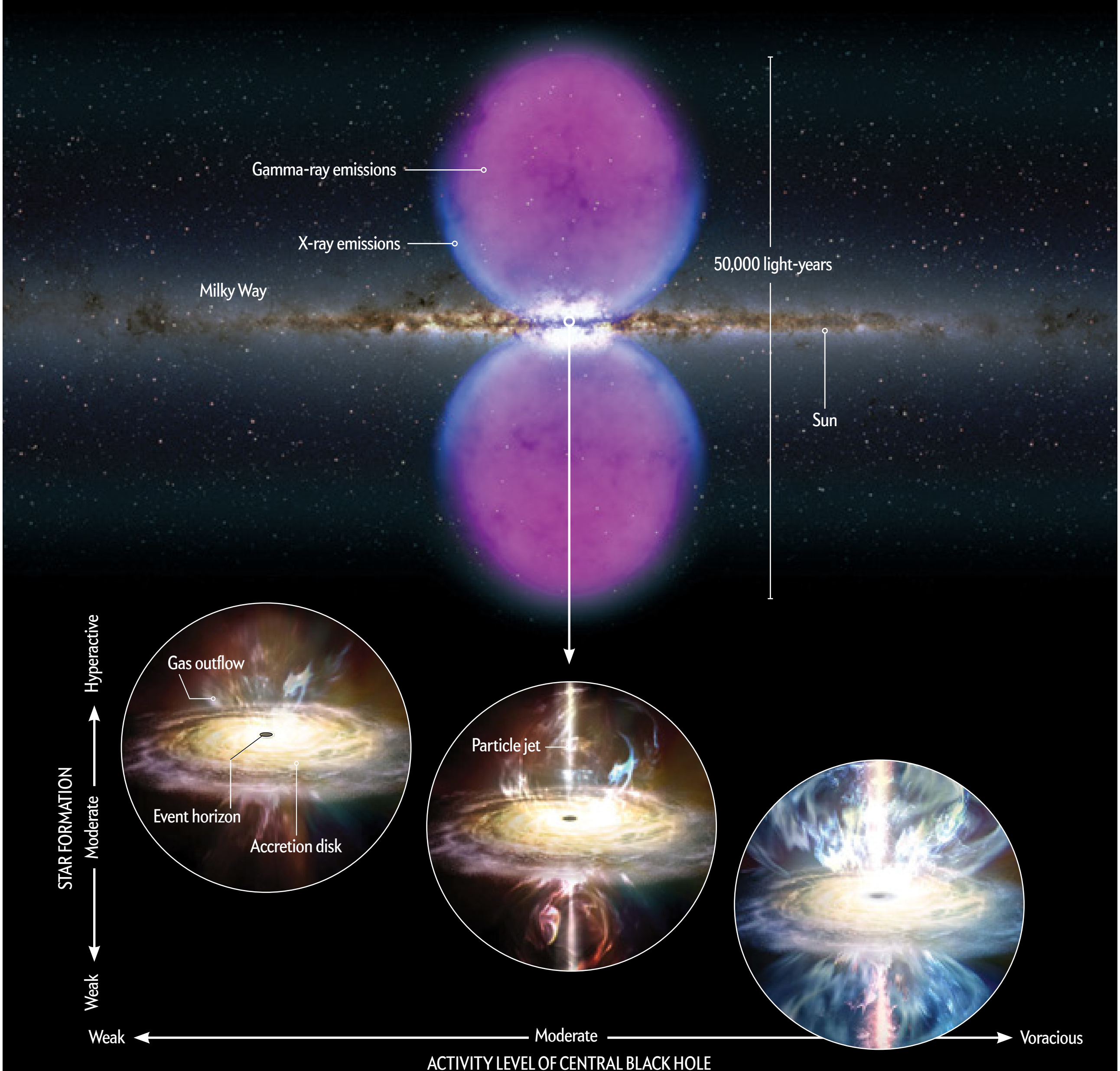
From the point of view of life, this may be a good thing. A planet like Earth could be sideswiped by a large increase in ambient interstellar radiation in the form of high-energy photons and fast-moving particles. Radiation can have a deleterious effect on the molecules inside organisms, affecting even the structure and chemistry of our atmosphere and oceans. We may be relatively well shielded at 25,000 light-years from the galactic center, but if we lived closer, it might be a different story. The fact that we *do not* live on a planet closer to the core may not be coincidental. Similarly, perhaps we should not be surprised to find ourselves here at this time, rather than billions of years in the past or in the future.

Our galaxy has, like so many others, coevolved with its central supermassive black hole. Indeed, the clues we seek may speak both to the question of how our central black hole can directly influence life on Earth and to its role as an indicator of the present state of our galaxy in general. The connection between supermassive black holes and their galaxies provides us with a real tool

Black Hole Effects, Felt Far and Wide

The Milky Way's supermassive black hole is but a speck on the scale of the galaxy as a whole. But at four million solar masses, it is a hefty speck, and it does throw its weight around from time to time. In 2010 researchers identified a pair of "bubbles" glowing with gamma rays, each reaching some 25,000 light-years from the galactic center, where the black hole lurks.

The bubbles may be the traces of a black hole outburst in the relatively recent past—a feeding episode in which many scraps, instead of sinking into the hole, were sent flying in the form of charged particles and high-energy radiation. Fortunately, perhaps, the burst of energy that fueled the bubbles was not directed at the solar system, out in the suburbs of the galaxy.



Not Too Hot, Not Too Cold

The vast amounts of energy unleashed as a black hole feasts may have a powerful damping effect on star formation. Without that regulatory outflow (*left*), a galaxy could find itself overstuffed with youthful stars exploding as supernovae. An overactive black hole (*right*), conversely, could quash star formation and leave its galaxy short of the star-fused heavy elements—such as iron, silicon and oxygen—that make up our planet. Our moderately active black hole (*center*) strikes a balance.

NASA GODDARD SPACE FLIGHT CENTER (*Milky Way's gamma-ray bubbles*)

Illustrations by Ron Miller (black hole insets) for gauging galactic history. The ferocious, black hole–powered quasars of the younger universe generally occur in the biggest elliptical galaxies, mostly sitting in the cores of galaxy clusters. These galaxies formed hard and fast and early; by now their stars are almost all old, and their raw gas is mostly too hot to form new stars or planets. Other ellipticals, those huge dandelion heads of stars, seem to have formed later as galaxies merged. Something along the way has "quenched" their formation of stars. We think that less violent but still incredibly powerful output from supermassive black holes is an excellent candidate for this regulatory role. The spirals with bulges of central stars jutting high above and below the galactic disks also show the signs of an intimate history with their central black holes. They follow some of the same patterns as the ellipticals. In both, the central black hole mass is 1/1,000th the mass of the surrounding stars. Our neighbor Andromeda is one of these systems, its generous stellar bulge covering a black hole more than 20 times the size of ours.

Lower down the pecking order are bulgeless galaxies, like many spirals. Although the Milky Way is a vast galaxy, one of the biggest in the known universe, it harbors a relative pipsqueak of a black hole. The lack of a stellar bulge is a mystery: either the galaxy had less raw material to form from in the first place, or the regulating black hole never really kicked in, or fewer small galaxies and clumps of matter have fallen into the system across time. The incredibly numerous dwarf galaxies also come up short in the black hole department. The true dwarfs of the galactic zoo are quite pitiful things, often with just a few tens of millions of stars or so, evincing little sign of the gas or dust that will make new ones. Those that are rich in interstellar soup are often so dark, so devoid of stars, that it is as if someone forgot to light the fuse.

Our galaxy still makes stars, at a rate of approximately three solar masses a year. This is not much on an individual human timescale, but it means that there have been at least 10 million new stars born in the Milky Way since our ancestors started walking upright somewhere in Olduvai Gorge in Tanzania. This is not bad for a place within a universe that is almost 14 billion years old. The giant galaxies of the young universe, blazing with the quasar light from their cores, are in some senses long burned out. The annoyed belches of their central black holes quench the formation of any new stars; the rippling pressure waves from their flatulent bubbles of nearly light-speed matter prevent material from cooling down and condensing into stellar systems. Meanwhile the Milky Way keeps trudging along.

PERFECT FOR LIFE

THAT WE LIVE in a large spiral galaxy with very little central stellar bulge and a modest central black hole may be a clue to the type of galaxies best suited to life: ones that did not spend their pasts building colossal black holes and fighting the demons unleashed in the process. New stars continue to form in a galaxy like ours but with different vigor from other systems. Most new stars are forming on the edges of the spiral arms as great circulating pressure waves disturb the disk of gas and dust. The stars are also forming farther from the galactic center than they used to. Astronomers say that we live in a region of "modest" star formation. Very active star formation produces an awfully messy environment. It builds the massive stars that burn through their nuclear fuel the fastest, ending up as colossal supernova explosions. Planetary atmospheres can be blasted away or chemically altered by radiation. Fast-moving energetic particles and gamma rays can pummel the surface of a world. Even the flux of ghostly neutrinos released in stellar implosion is intense enough to damage delicate biology. And those are just the moderate effects. Too close to a supernova, and there is a good chance your entire system will be vaporized.

Yet these are also the very mechanisms by which the rich elemental stew inside stars spreads out into the cosmos. This raw material creates stars as well as planets. They are planets with complex chemical mixtures of hydrocarbons and water, layered and dynamic, stirred by the heat of heavy radioisotopes, with billions of years of geophysics ahead of them. So somewhere in between the zones of forming and exploding young stars and the nursing homes and graveyards of ancient ones is a place that is "just so," and our solar system resides in such an environment. It is far enough from the galactic center but not too close to the busy and explosive realms of stars that are forming right now.

The connection between the phenomenon of life and the size and activity of supermassive black holes is quite simple. A fertile and temperate galactic zone is far more likely to occur in the type of galaxy that contains a modestly large, regularly nibbling black hole rather than a voracious but long since spent monster. The fact that there are *any* galaxies like the Milky Way in the universe at this cosmic time is intimately linked with the opposing processes of gravitational agglomeration of matter and the disruptive energy blasting from matter-swallowing black holes. Too much black hole activity, and there would be little new star formation, and the production of heavy elements would cease to occur. Too little black hole activity, and environments might be overly full of young and exploding stars—or too little stirred up to produce anything. Indeed, change the balance at all, and you change the whole pathway of star and galaxy formation.

The entire chain of events leading to you and me would be different or even nonexistent without the coevolution of galaxies with supermassive black holes and the extraordinary regulation they perform. The total number of stars in the universe would be different. The numbers of low- and high-mass stars would be different. The forms of the galaxies would likely be different, and their organization of gas, dust and elements would almost certainly be different. There would be places that had never been scorched by the intense synchrotron radiation of a supermassive black hole. There would be other places that had never received that jolt, that kick in the pants, that got star or planet formation up and running.

This fertile corner of the cosmos has been governed by all that has gone on around it, including the behavior of the black hole at our galactic center. The very places that have sealed themselves away from the rest of the universe have served as one of the most influential forces shaping it. We owe so much to them. SA

SCIENTIFIC AMERICAN ONLINE
To watch an interview with Scharf about black holes, visit ScientificAmerican.com/aug2012/black-holes

NEUROSCIENCE

The Joyful Mind

A new understanding of how the brain generates pleasure could lead to better treatment of addiction and depression—and even to a new science of happiness

By Morten L. Kringelbach and Kent C. Berridge

IN THE 1950S PSYCHIATRIST ROBERT HEATH OF TULANE UNIVERSITY launched a controversial program to surgically implant electrodes into the brains of patients institutionalized with epilepsy, schizophrenia, depression and other severe neurological conditions. His initial objective: to locate the biological seat of these disorders and, by artificially stimulating those regions, perhaps cure individuals of their disease.

SCIENTIFIC AMERICAN (*photoillustration*); GETTY IMAGES (*head outline*); THINKSTOCK (*images inside head*); COURTESY OF NASA (*moon*)

According to Heath, the results were dramatic. Patients who were nearly catatonic with despair could be made to smile, converse, even giggle. But the relief was short-lived. When the stimulation ceased, the symptoms returned.

To extend the potential therapeutic benefit, Heath fitted a handful of patients with buttons they could press themselves whenever they felt the urge. Some felt the urge quite frequently. One patient—a 24-year-old homosexual whom Heath was attempting to cure of depression (and of his desire for other men)—was compelled to stimulate his electrodes some 1,500 times over the course of a single, three-hour session. According to Heath, this obsessive self-stimulation gave the subject, patient B-19, "feelings of pleasure, alertness, and warmth (goodwill)." The end of his session was met with vigorous protest.

The experiments helped to define a set of structures that would come to be known as the "pleasure center" of the brain. They also spawned a movement—both in science and in popular culture—to better understand the biological basis of pleasure. Over the next 30 years neurobiologists identified the chemicals that the brain regions delineated by Heath and others send and receive to spread their tidings of joy. And people began to imagine brave new worlds in which activation of these centers could produce instant bliss.

Yet the discovery of the brain's alleged pleasure center has not led to any breakthroughs in the treatment of mental illness. It may have even misled scientists into thinking they understood how pleasure is encoded and generated within the brain. Studies in rodents and humans now suggest that activating these structures with electrodes or chemicals does not actually produce pleasure at all. It may merely precipitate craving and hence the manic drive to self-stimulate.

With the help of modern molecular biological techniques, combined with improved methods for deep-brain stimulation, our laboratories and others are redefining the brain's pleasure circuitry. We are finding that the pleasure-generating systems in the brain are much more restricted—and much more complex—than previously thought. By pinpointing the true neurological underpinnings of pleasure, we hope to pave the way to more targeted and effective treatments for depression, addiction and other disorders—and perhaps to offer new insights into the roots of human happiness.

MISLEADING ELECTRODES

WHETHER EXPERIENCED as shivers of delight or the warm thrum of contentment, pleasure is more than an ephemeral extra—that is, something to be sought only after one's more basic needs have been met. The sensation is actually central to life. Pleasure nourishes and sustains animals' interest in the things they need to survive. Food, sex and, in some cases, social communion generate positive feelings and serve as natural rewards for all animals, including ourselves.

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Kent C. Berridge is James Olds Collegiate Professor of Psychology and Neuroscience at the University of Michigan.

The first apparent insights into the biological basis of these feelings came nearly 60 years ago from the original discoverers of the so-called pleasure electrodes. James Olds and Peter Milner of McGill University were searching for brain regions that could influence animal behavior. Earlier studies from Yale University—in which electrodes had been inserted into rats' brains—had identified an area that, when stimulated, would cause an animal to avoid whatever action had coincided with the stimulation. While trying to replicate these findings, Olds and Milner came across a brain region that the rodents would take active steps to stimulate—in the same way that animals will repeat any task or behavior that yields a suitable reward.

Placing the electrodes in different regions—and sometimes not where they intended—the pair were surprised to find a part of the brain that animals seemed to enjoy having zapped with a mild electric current. Rats placed in a large box returned repeatedly to the corner in which the researchers would give them a small electric jolt. Using this approach, Olds and Milner found they could steer the rodents to almost any location. In some instances, the animals even chose stimulation over food. If the researchers pressed the button when the rats were halfway through a maze that promised a tasty mash at the end, the creatures simply stayed put, never bothering to proceed to the treat.

Even more surprising, when the electrodes were wired so that the rats could stimulate their own brain by pressing a lever, Olds and Milner discovered that they did so almost obsessively—some more than 1,000 times an hour [see "Pleasure Centers in the Brain," by James Olds; SCIENTIFIC AMERICAN, October 1956]. When the current was turned off, the animals would press the bar a few more times—and then go to sleep.

The results prompted Olds and Milner to declare, "We have perhaps located a system within the brain whose peculiar function is to produce a rewarding effect on behavior." The regions the researchers identified—including the nucleus accumbens, which reclines at the base of the forebrain, and the cingulate cortex, which forms a collar around the fibrous bundle that bridges the brain's left and right halves—thus became enshrined as the operational base of the brain's reward circuit.

Almost immediately other scientists reproduced these ef-

IN BRIEF

New research has uncovered hotspots in the brain that, when stimulated, enhance sensations of pleasure.

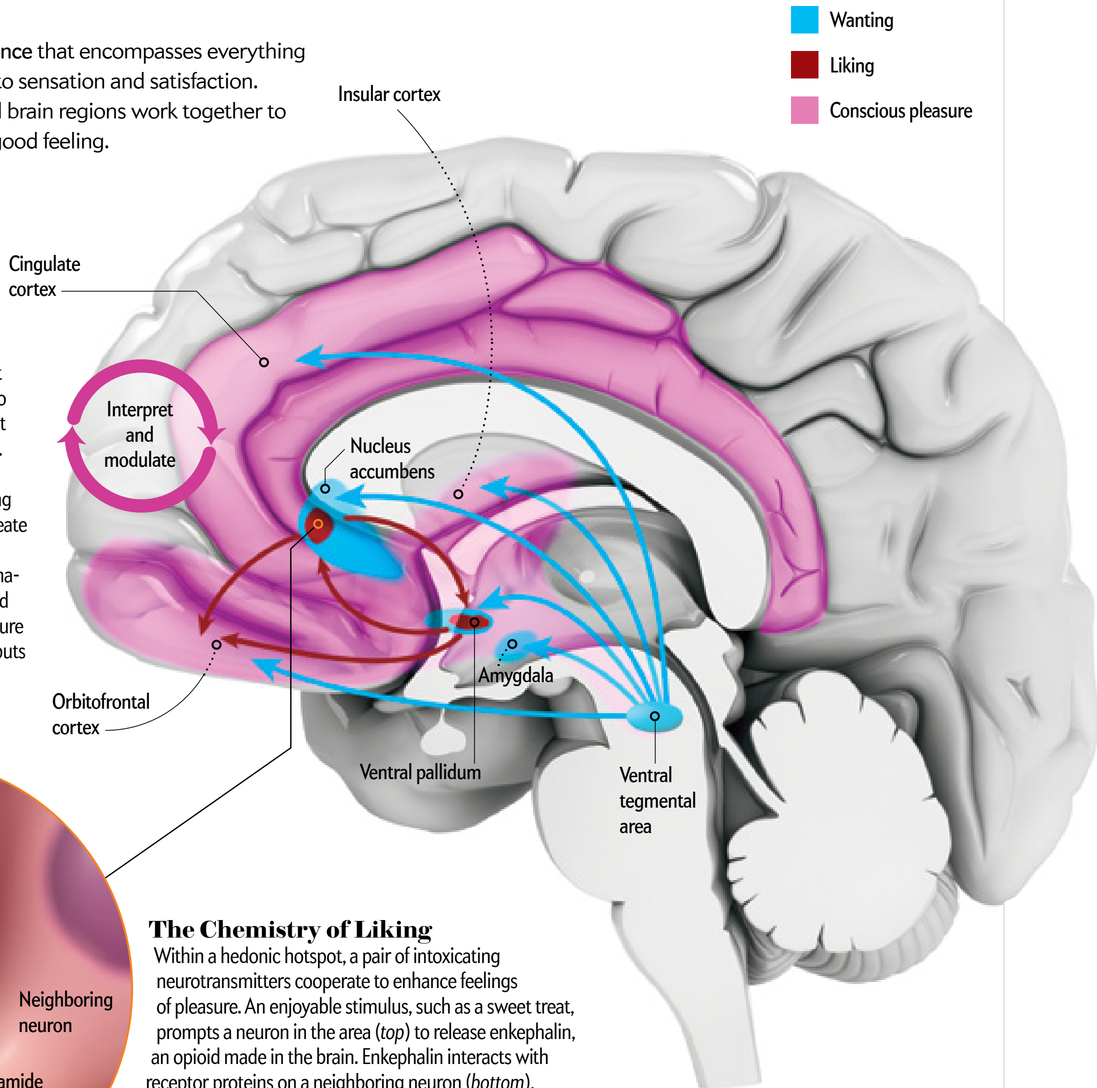
These hedonic hotspots differ from the "reward circuit" previously thought to be the basis of good feelings—a pathway now believed to mediate desire more than enjoyment.

Higher brain regions receive information from these pleasure and reward circuits to consciously represent the warm glow we associate with joy.

A decoupling of the brain systems that generate "wanting" and "liking" may underlie addictive behavior—a clue that may lead to new treatments.

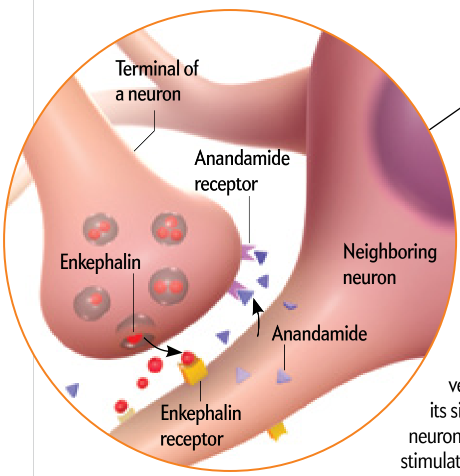
Paths to Pleasure

Pleasure is a complex experience that encompasses everything from anticipation and desire to sensation and satisfaction. So it's no surprise that several brain regions work together to generate this warm glow of good feeling.



Wanting and Liking

A neural circuit (*blue*) that begins near the brain stem and reaches out to the forebrain was once thought to be the sole mediator of pleasure. But it is actually more focused on desire. In addition to this pathway, several so-called hedonic hotspots, including two shown here (*red*), interact to create a sense of liking. A quilt of cortical regions (*pink*) then translates information received from the "wanting" and "liking" circuits into conscious pleasure and adjusts this feeling based on inputs from other brain regions.



The Chemistry of Liking

Within a hedonic hotspot, a pair of intoxicating neurotransmitters cooperate to enhance feelings of pleasure. An enjoyable stimulus, such as a sweet treat, prompts a neuron in the area (*top*) to release enkephalin, an opioid made in the brain. Enkephalin interacts with receptor proteins on a neighboring neuron (*bottom*), potentially triggering production of anandamide, the brain's version of marijuana. As anandamide diffuses away from its site of synthesis, it can interact with receptors on the first neuron, intensifying the sensation of pleasure and perhaps even stimulating the production of more enkephalin. Together these chemicals form a pleasure-boosting loop of liking.

fects, making similar findings in higher primates and humans. Heath, in particular, pushed the interpretation of his results to the limit, insisting that stimulating these regions not only reinforces a behavior but produces sensations of euphoria. In the minds of many scientists and the general public, these structures became known as the brain's chief pleasure center.

About 10 years ago, though, the two of us began wondering whether the act of electrical self-stimulation was really the best measure of pleasure. How do we know that subjects stimulate those regions because they like the way it feels and not for some other reason? To probe the pleasure circuitry more precisely, we felt we needed to devise a different way of assessing what subjects—including animals—actually enjoy.

A MEASURE OF PLEASURE

FOR EXPERIMENTS IN PEOPLE, assessing pleasure is fairly straightforward: just ask. Of course, the resulting ratings might not fully capture or accurately reflect the underlying sensations. Further, such inquisition is not possible in laboratory animals—the subjects in which biology is most easily explored.

An alternative approach takes its lead from Charles Darwin. In his 1872 book *The Expression of the Emotions in Man and An-*

Illustration by AXS Biomedical Animation Studio *imals,* Darwin noted that animals change their affect in response to environmental situations—in other words, they make faces. We now know that the neural mechanisms underlying such expressions work similarly in most mammalian brains. Hence, certain facial gestures have been conserved in animals as distantly related as rodents and humans—including the "yummy faces" we make in response to tasty food.

Food is one of the most universal routes to pleasure—as well as an essential requirement for survival. It is also one of the most accessible experimental tools used by psychologists and neuroscientists studying animal behavior. In our studies, we have found that the response to food provides a window through which we can observe unspoken pleasures.

Anyone who has spent time around babies knows that even the youngest humans have ways of advising their caregivers about the palatability of a meal. Sweet tastes elicit a contented licking of the lips, whereas bitter tastes tend to be met with gaping mouths, shaking heads and a vigorous wiping of the mouth. The same responses seen in human infants also occur in rats, mice and nonhuman primates. The more subjects like the taste, the more often they will lick their lips. By making video recordings of subjects' responses to food and then counting the number of times their tongues dart out—as if to capture every last molecule of flavor—we can measure how much a given gustatory stimulus is liked. And we have used that information to assess where pleasure really resides in the brain.

Pleasure does not arise in the brain quite where—or how—past thinking said it should.

WANTING IS NOT LIKING

ONE OF THE FIRST THINGS we discovered is that pleasure does not arise in the brain quite where—or how—past thinking said it should. The regions first identified by Olds and Milner and others, positioned at the front of the brain, are activated by the neurotransmitter dopamine, released by neurons that originate near the brain stem. If these frontal areas truly regulate pleasure, we reasoned, flooding them with dopamine—or removing dopamine entirely—should alter how an animal responds to an enjoyable stimulus. That is not what we found.

For these experiments, our colleague Xiaoxi Zhuang of the University of Chicago engineered mice lacking a protein that retrieves dopamine once it has been released by an excited neuron, returning the neurotransmitter to the cell's interior. Animals with such a knockout mutation maintain unusually high concentrations of dopamine throughout their brain. Yet we found that the mice do not appear to derive more pleasure from sweets than their unaltered cage mates do. Relative to normal rodents, the dopamine-doped mice do speed more quickly toward sweet rewards; however, they do not lick their lips any more often. On the contrary, they do so even less than mice with average amounts of dopamine.

We see the same thing in rats that have dopamine elevated by other means. For example, injecting amphetamine into the nucleus accumbens causes dopamine in that area to rise. Again, however, sugary treats seem no more pleasant to these rats after their chemically assisted dopamine boost—although the animals are more motivated to obtain them.

Conversely, rats that have been depleted of their dopamine show no desire for sugary treats at all. These animals will actually starve to death unless they are actively nursed. Yet dopamine-free rats that have no interest in food nonetheless find whatever sweets might be placed into their mouth whisker-licking good.

So it seems that dopamine's effects may be subtler than previously understood. The chemical appears to contribute more to motivation than to the actual sensation of pleasure itself. In humans, too, dopamine levels appear to track more closely with how much individuals claim to "want" a delicious tidbit than with how much they say they "like" it.

The same may be true in addiction. Drugs of abuse flood the brain with dopamine—particularly those regions associated with "wanting." This dopamine barrage not only triggers intense craving, it renders cells in these regions more sensitive to future drug exposure. Moreover, work from our colleague Terry Robinson of the University of Michigan suggests that this sensitization can persist for months or years. Thus, even after the drug no longer brings pleasure, Robinson reasons, an addict can still feel a strong urge to use—an unfortunate consequence of dopamine's actions.

Given this new understanding, we believe that the "pleasure" electrodes that stimulate accumulation of this chemical in the brains of rats—and humans—might not have been as enjoyable as was originally assumed. In support of this view, we find that activation of electrodes that elevate dopamine in the nucleus accumbens will motivate a rat to eat and drink, yet the same stimulation does not make that food more pleasing—just the opposite. Rats that are moved to eat sweets by electrical stimulation wipe their mouth and shake their head—signs of active dislike, as if the current had rendered the sweetness bitter or disgusting to them. The fact that the electrodes compel rats to consume large quantities of a food that is not bringing them pleasure is evidence that wanting and liking are controlled by different mechanisms in the brain.

We think the differential control also occurs in humans. The application of current through the classic pleasure electrodes led at least one patient to a strong desire to drink. In others, including B-19, electrical stimulation triggered an urge for sex. At the time, such sexual cravings were considered evidence of pleasure. Yet in our extensive reviews of the literature, we have never come across evidence that a patient implanted with these electrodes found them expressly pleasurable. B-19 never once exclaimed, "Oh, that feels nice!" Instead stimulation of the pleasure electrodes simply made him and the others want more stimulation—probably not because they liked it but because they were made to desire it.

HEDONIC HOTSPOTS

WANTING AND LIKING are both involved in making an experience feel rewarding. So it makes sense that the real pleasure centers in the brain—those directly responsible for generating pleasurable sensations—turn out to lie within some of the structures previously identified as part of the reward circuit. One of these so-called hedonic hotspots lies in a subregion of the nucleus accumbens called the medial shell. A second is found within the ventral pallidum, a deep-seated structure near the base of the forebrain that receives most of its signals from the nucleus accumbens.

To locate these hotspots, we searched for brain regions that, when stimulated, amplify the sensation of pleasure—for example, making sweet things even more enjoyable. Chemically stimulating these hotspots with enkephalin—a morphinelike substance made in the brain—enhances a rat's liking of sweets. Anandamide, the brain's version of the active ingredient in marijuana, does the same. Another hormone called orexin, which is released by the brain during hunger, may also stimulate hedonic hotspots, helping to enhance the flavor of food.

Each of these spots is just a fraction of the size of the larger structure in which it lies—only about one cubic millimeter in a rat brain and probably no more than a cubic centimeter in a human. Yet like the islands of an archipelago, they link to one another—and to other brain regions that process pleasure signals—to form a powerful, integrated pleasure circuit.

That circuit is fairly resilient. In our experience, disabling individual components within the pleasure circuit does not diminish the typical response to a standard sweet—with one exception. Damaging the ventral pallidum appears to eliminate an animal's ability to enjoy food, turning a nice taste nasty.

On the other hand, intense euphoria is harder to come by than everyday pleasures. The reason may be that strong enhancement of pleasure—like the chemically induced pleasure bump we produced in lab animals—seems to require activation of the entire network at once. Defection of any single component dampens the high.

Whether the pleasure circuit—and in particular, the ventral pallidum—works the same way in humans is unclear. Not many people come to the clinic with discrete damage to these structures without injuries in surrounding areas. Thus, it is difficult to assess whether the ventral pallidum and other components in the circuit are essential to the sensation of pleasure in humans. We know of one patient whose ventral pallidum became damaged during a massive drug overdose. Afterward, he reported that his feelings were dominated by depression, hopelessness, guilt and an inability to feel pleasure—potentially supporting a central role for this heretofore underappreciated structure.

ENOUGH IS ENOUGH

THE CIRCUIT does not act alone in regulating feelings of joy. To add that warm gloss of pleasure to a sensation or experience, additional brain regions come into play. These higher structures help to determine how delightful an experience is, based on current conditions, such as whether one is hungry or full or has simply had enough of one particular pleasure. After eating an entire pan of brownies, for example, even an admitted chocoholic tends to find a candy bar much less appealing.

In the case of food, such selective satiety may have evolved in part because it encourages animals to obtain a wide variety of nutrients rather than fixating on one favorite meal. It seems to be encoded in a part of the brain called the orbitofrontal cortex. This area, located in the underbelly of the prefrontal cortex, which in humans hangs just above the eyes, receives information from the nucleus accumbens and ventral pallidum. It seems to modulate how pleasure is consciously represented—suffusing a sensation with that delicious glow we associate with gratification and toning down the feelings when enough is enough.

With the help of powerful neuroimaging techniques, we have found that the activity of a small region within the orbitofrontal cortex, called the midanterior site, correlates tightly with the subjective pleasantness of a nice sensation, such as the taste of chocolate milk. At the first sip, for example, the site is alight with activity. Yet once subjects have consumed enough of the sweet stuff, the midanterior site shuts down, rendering the experience no longer pleasurable.

Further evidence that the midanterior site is important for human pleasure comes from studies of therapeutic deep-brain stimulation [see "Sparking Recovery with Brain 'Pacemakers,'" by Morten L. Kringelbach and Tipu Z. Aziz; SCIENTIFIC AMERICAN MIND, December 2008/January 2009]. The procedure is being used to treat a few conditions, including to relieve suffering in patients with otherwise untreatable chronic pain. In one patient of ours, an amputee who was feeling pain in his missing limb, stimulation of an area within the brain stem not only relieved the pain but induced deep feelings of pleasure. Simultaneous neuroimaging revealed a burst of activity in the midanterior site as well. Whether such stimulation of specific hotspots in the pleasure system can be used to treat depression or other forms of anhedonia—an inability to experience pleasure—remains an active area of investigation.

Similarly, additional research may reveal how the circuits that govern pleasure and reward are linked. Under normal circumstances, the hedonic hotspots are coupled with the dopamine-driven reward system, such that we desire things that make us feel good and avoid or are indifferent to things that do not. In the case of addiction, these systems somehow become disconnected, causing the individual to continue to crave things that no longer bring pleasure. Such dissociation might also possibly contribute to other types of compulsive behaviors, such as binge eating and gambling. Understanding how and why such uncoupling can occur could reveal better ways to reverse the brain changes that drive addiction, thus restoring the natural alignment between wanting and liking.

Aristotle once observed that happiness consists of two key ingredients: *hedonia,* or pleasure, plus *eudaimonia*—a sense of meaning. Although scientists have made some progress in uncovering the biological basis of *hedonia,* we know very little about how the brain gives rise to a broader sense of a life well lived. We hope, however, that with time this puzzle, too, can be solved and that the discoveries will help people unite pleasure and purpose, elevating everyday experiences to something truly satisfying, perhaps even sublime. SA

MORE TO EXPLORE

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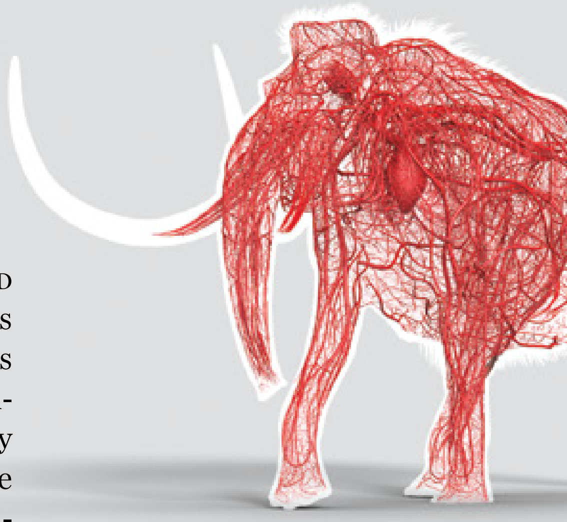
SCIENTIFIC AMERICAN ONLINE
Watch a video of infants, nonhuman primates and rats showing pleasure and displeasure at **ScientificAmerican.com/aug2012/pleasure**

EVOLUTIONARY BIOLOGY

New Life for Ancient DNA



Biotechnology reveals how the woolly mammoth survived the cold and other mysteries of extinct creatures

By Kevin L. Campbell and Michael Hofreiter

FOR MORE THAN 150 YEARS SCIENTISTS HAVE PRIMARILY RELIED on fossilized bones and teeth to reconstruct creatures from deep time. Skeletons divulge the sizes and shapes of long-ago animals; muscle markings on bones indicate how brawny the creatures were and how they may have moved; tooth shape and wear attest to the kinds of food eaten. All in all, researchers have managed to extract extraordinary quantities of information from these hard parts. On rare occasions, they have chanced on exquisitely preserved mummies and frozen carcasses that have

IN BRIEF

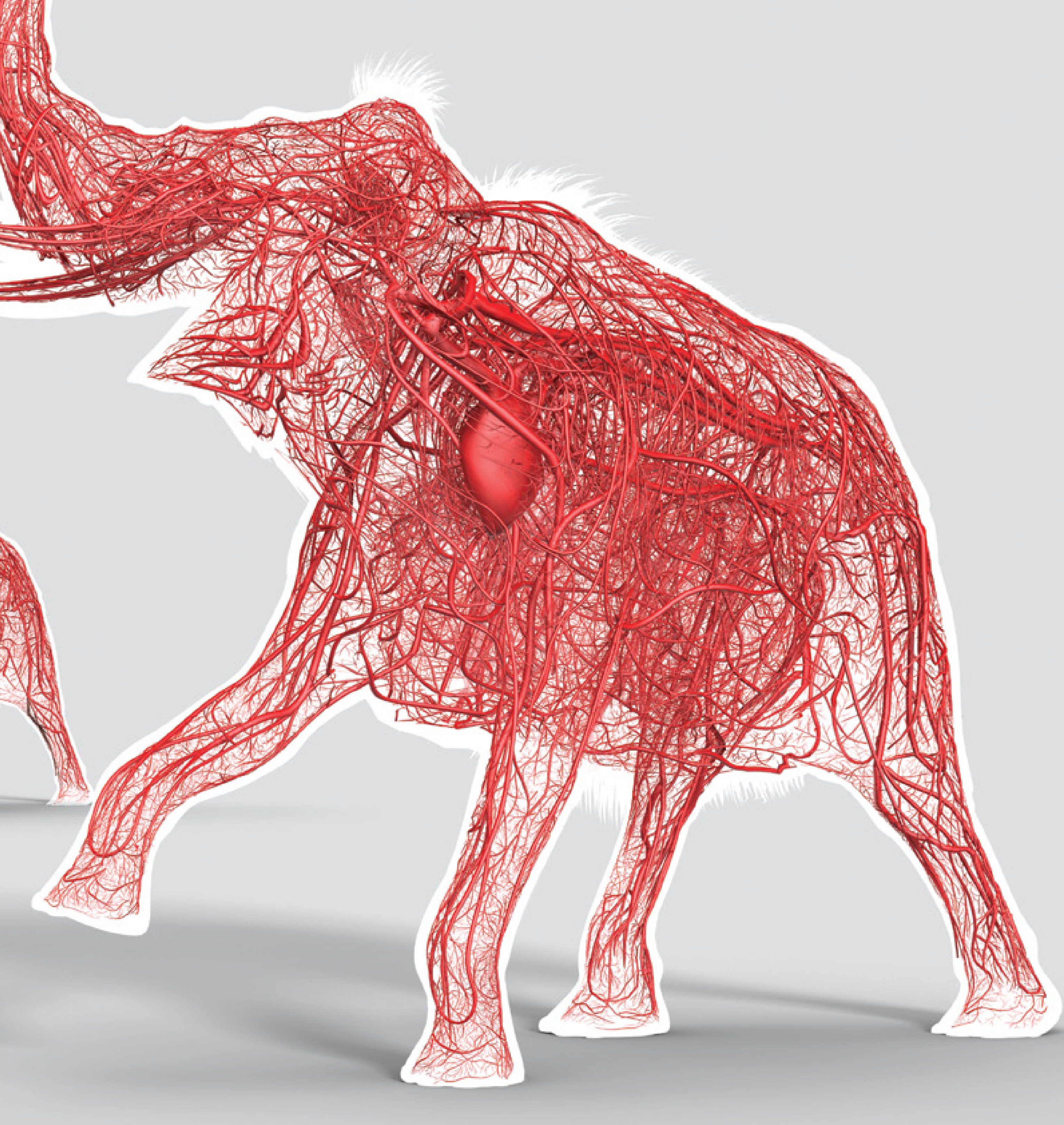
Scientists' understanding of extinct creatures has long relied almost entirely on fossils of their bones and teeth.

But recent advances in ancient DNA research are revolutionizing studies of ancient beasts.

Researchers can now re-create the genes of these animals and study the proteins they encoded.

That scientists might one day be able to study such paleophysiology was unthinkable just a decade ago.

Illustration by Bryan Christie



Kevin L. Campbell is a professor of environmental and evolutionary physiology at the University of Manitoba in Canada. His research focuses on hemoglobin in living mammals and on the properties and evolution of resurrected proteins from extinct mammals.

Michael Hofreiter is a professor of biology at the University of York in England. He uses ancient DNA sequences to study how animals responded to environmental change.

allowed them to add more detail to their reconstructions, such as the length of the fur, the shape of the ears, the specific contents of an animal's last supper. Yet for all that scientists have been able to deduce about the physical characteristics of life-forms from past eras, we know very little about the physiological processes that sustained them.

That gap is closing, however. Recent advances in biotechnology now allow us to reassemble ancient genes from extinct animals and resurrect the proteins those genes encode—proteins that both form and drive the cellular machinery that underlies life-giving processes. The work heralds the dawn of a thrilling new scientific discipline: paleophysiology, the study of how the bodies of bygone organisms functioned in life. We are still in the earliest days of this research, but already we have gained stunning insights into how one iconic beast of prehistory—the woolly mammoth—adapted to the brutal conditions of its Ice Age world. Although the *Jurassic Park* dream of cloning prehistoric animals remains out of reach, our work has demonstrated the feasibility of observing key physiological processes that took place in creatures that have long since vanished from the face of the earth.

COLD CASE

FOR ONE OF US (Campbell), the inspiration for this venture began one evening in 2001 while watching a television show documenting the exhumation of woolly mammoth remains from Siberian permafrost. Given the highly publicized cloning of Dolly the sheep, announced in 1997, pundits on the show speculated—wrongly, it turns out—that DNA from this mammoth might soon permit scientists to bring these creatures back to life. Campbell's own vision was far more targeted than that colossally complicated enterprise and, ultimately, more feasible. He wanted to find out how these extinct cousins of today's Asian elephants managed to adapt to the cold climate in the high latitudes where they lived.

The fossil record shows that the ancestors of woolly mammoths originated in the subtropical plains of Africa and only moved into Siberia less than two million years ago, just as the earth was entering one of the most profound cooling events in its history: the Pleistocene ice ages. As is true of African elephants, the main physiological challenge the mammoth ancestors would have faced in their homeland was avoidance of overheating. Once the lineage migrated north and the world cooled, however, conservation of body heat became paramount.

Because almost everything we know about the biology of extinct species has been inferred from detailed studies of their fossilized, frozen or mummified remains, discussions of mammoth cold adaptation have primarily been limited to physical attributes that are directly observable from recovered carcasses, such as the thick, woolly undercoat for which these mammoths are named. Physical features are only one part of the story, however—and probably a minor one at that. Indeed, a network of physiological processes was undoubtedly essential for their survival in the cold. Unfortunately, these processes leave no traces in the fossil record, so our only hope of studying them is to recover tattered bits of DNA from ancient remains, piece the genes together in their entirety, insert them into living cells and coax the cells to re-create the proteins that once controlled these processes. We can then observe precisely how the proteins of extinct animals functioned compared with those of their living relatives.

Thus, Campbell's idea of studying cold adaptation in mammoths using preserved DNA, though orders of magnitude simpler than actually raising the beasts from the dead, was still going to require a massive amount of fancy biotechnological footwork. As luck would have it, major advances in ancient DNA research were around the corner that would help pave the way to realizing his goal.

Even under the best circumstances, DNA in long-dead specimens, if it has been preserved at all, persists in exceedingly small amounts. It is also highly fragmented and riddled with chemical damage. The cells of living organisms contain two kinds of DNA: simple loops of DNA in the cell's energy-producing organelles, or mitochondria, and the much more complex DNA in the cell nucleus. Early studies of ancient DNA focused on the mitochondrial va-

HOW IT WORKS

Breathing Life into Mammoths

By reconstructing ancient genes, scientists can re-create the proteins they encoded and observe how they behave, thereby gaining insights into the physiology of extinct animals. For instance, resurrection of the red blood cell protein hemoglobin from a woolly mammoth (*below*) has shown that the temperature-sensitive protein evolved adaptations that enabled it to do its job of delivering oxygen to body tissues in the cold conditions these beasts faced.

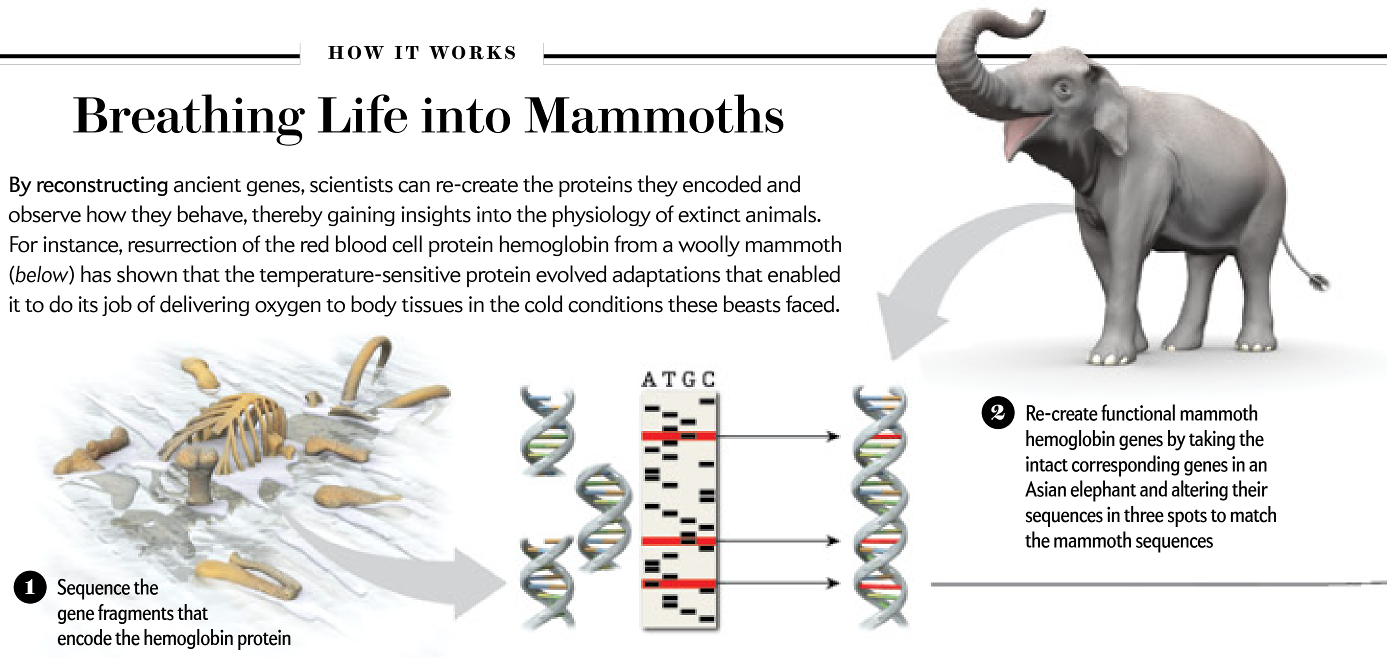


Illustration by Emily Cooper

riety because it is much more abundant than nuclear DNA: each cell has hundreds of mitochondria but only one nucleus. Yet mitochondrial DNA accounts for a minute fraction of all the genetic material in a cell; it encodes only a handful of proteins, all used only in mitochondria. The real action is in nuclear DNA. Scientists initially believed it was impossible to recover enough ancient nuclear DNA to study it. Yet in 1999 Alex Greenwood, now at the Leibniz Institute for Zoo and Wildlife Research in Berlin, and his colleagues reported that they had found evidence in permafrost remains showing that small fragments of nuclear DNA could survive for tens of thousands of years in amounts sufficient for analysis.

Although Greenwood's work demonstrated that it was possible to obtain short snippets of nuclear sequences (that is, pieces containing up to 70 nucleotides—the "letters" of the genetic code) from creatures as old as woolly mammoths, it remained largely impractical to sequence the hundreds to thousands of nucleotides that make up each complete gene. Furthermore, Greenwood's approach entailed the destruction of large amounts of hard-won ancient DNA. By borrowing a technique called multiplex PCR that molecular biologists use to generate multiple copies of DNA from extant organisms, though, one of us (Hofreiter) came up with a solution to these problems, thus clearing a key hurdle to studying the physiology of extinct organisms. In a first proof of principle, his research team assembled the first complete mitochondrial genome (a 16,500-nucleotide sequence) from an Ice Age species—the mammoth—publishing the findings in 2005.

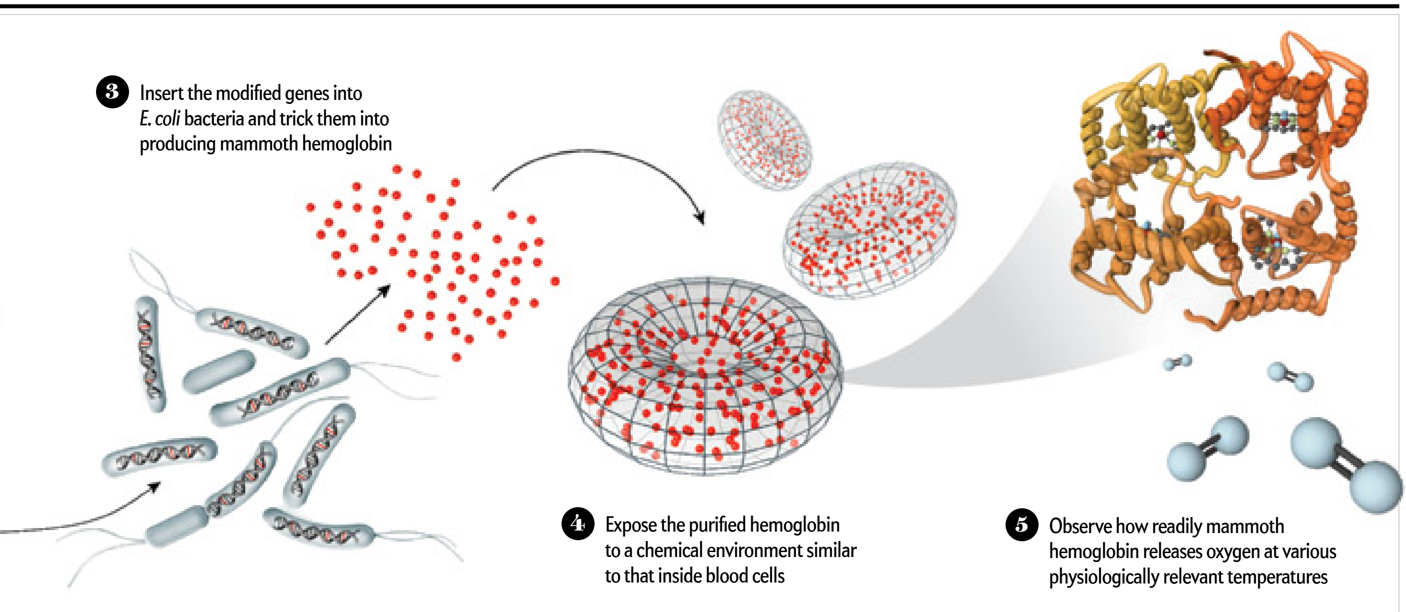
BLONDES AND REDHEADS

HAVING HONED its ancient DNA-sequencing technique, Hofreiter's team in Leipzig, Germany, then used it to reconstruct the first complete nuclear gene from an extinct species. Once again, the source of the DNA was a mammoth, specifically an exceptionally well-preserved 43,000-year-old thigh bone that Eske Willerslev of the University of Copenhagen found in northern Siberia. The team chose a gene called *melanocortin 1 receptor* (*MC1R*) that is known to help determine coloration in bird feathers and mammalian hair. *MC1R* was appealing because it is short and easy to insert into cells where its molecular activity could be measured, enabling investigators to link DNA sequences to observable traits.

Given that the hair recovered from permafrost-preserved mammoths tends to be either light or dark in color, Hofreiter and his collaborators postulated that differences in gene function—as opposed to chemical factors in the sediments to which the hairs had been exposed for tens of thousands of years—might have underlaid these two distinct hair colors. Sequencing all 1,236 nucleotides making up the complete *MC1R* gene revealed two separate gene variants, or alleles. The first allele differed from the corresponding African elephant gene at a single nucleotide, whereas the second allele contained three additional mutations, all of which produced substitutions of amino acids (the building blocks of proteins) in the resulting protein.

Although Hofreiter and his collaborators were intrigued to find that two of these substitutions occurred at positions in the protein that have rarely changed over the course of evolution, the absence of comparable mutations in other mammals made it impossible to gauge whether these unusual replacements influenced mammoth coat coloration. Analysis of the gene's activity in cells, however, showed that one of the three mutations in the second allele produced a substitution that made a less active version of the pigmentation gene. To judge from the molecular activity of pigmentation genes of other mammals, this weaker variant probably helped to make the fur of some mammoths blond.

By remarkable coincidence, Hopi Hoekstra, then at the University of California, San Diego, and her colleagues simultaneously discovered that some populations of modern-day beach mice carry an *MC1R* gene variant that produces the same key amino acid exchange found in the second mammoth allele. More important, the mice carrying this variant had light-colored fur, which provides natural camouflage in the sandy environments they inhabit. For mammoths the benefit of being blond is much less clear because blond individuals would still have been highly conspicuous on the treeless landscape of primeval Siberia. It is con-



RARE CARCASSES such as this 42,000-year-old baby mammoth found in Russia contain a wealth of information, but only DNA can reveal the exact biological processes that sustained these animals during life.

ceivable, however, that a pale pelage helped these animals stay warm in this cold, windy environment, as has been shown for extant birds and mammals with light coloration. That may sound counterintuitive in that light-colored hair reflects a lot of solar radiation, but such hair also scatters some of the incoming radiation toward the skin, where it is absorbed as heat. In contrast, dark fur absorbs solar radiation at its outer surface, where wind rapidly dissipates the heat it provides.

Fresh off its success in reconstructing ancient nuclear genes from mammoths, the Hofreiter group turned its attention to Neandertals, relatives of *Homo sapiens* that lived in Eurasia and went extinct around 28,000 years ago. The team obtained a 128-nucleotide fragment of the *MC1R* gene that coded for an amino acid substitution not seen in humans today. As with the mammoth allele, functional analysis indicated that this single change makes the protein less active than the standard human version. Given that *MC1R* gene variants with similar reductions in function occur in modern-day humans of European descent who have red hair and fair skin, we speculated that some Neandertals might also have had red hair and fair skin (albeit because of a different mutation with similar effects on the protein's activity). At the high latitudes where Neandertals lived, the ultraviolet light needed to synthesize vitamin D is in short supply. Fair coloration may have helped Neandertals absorb enough ultraviolet light, which penetrates dark skin less readily.

These pioneering studies unambiguously demonstrated that the genetic reconstruction of observable traits had now become a practical reality. We were now ready to use this powerful new tool to follow the living processes of extinct species—true paleophysiology.

WHEN BLOOD RUNS COLD

ALL LARGE cold-adapted mammals around today—from reindeer to musk ox—possess a system of closely packed arteries and veins that run antiparallel to one another along the limbs and extremities. This arrangement, known as a rete mirabile, or "wonderful net," forms a highly efficient countercurrent heat exchanger in which warm, oxygenated arterial blood exiting the body core transfers most of its heat to cold venous blood returning toward the heart. The resulting thermal gradient permits the temperature of extremities in contact with cold surfaces, such as the footpad, to be maintained just above freezing, drastically reducing overall heat loss. These heat savings mean fewer calories are required to keep warm, thereby providing a crucial advantage for Arctic species during winter, when calories are often hard to come by. Paradoxically, this anatomical adaptation deprives the extremities of the heat energy needed to ensure that hemoglobin functions properly. In vertebrate animals, the red blood cell protein hemoglobin collects oxygen from the lungs and then delivers it to tissues. Breaking the weak chemical bond between hemoglobin and oxygen requires energy, however, so hemoglobin's ability to deliver oxygen to tissues plummets with declining temperature.

To compensate for this shortcoming, the hemoglobins of cold-tolerant mammals require a supplementary heat source. Although the precise molecular mechanisms underlying this trait are not well understood, they generally appear to involve the binding of other molecules inside the blood cells to the hemoglobin. The formation of chemical bonds between these molecules and hemoglobin releases heat energy that can be donated to help discharge hemoglobin's oxygen to the tissues.

Campbell's team—which until then was working indepen-

GETTY IMAGES

dently from the Hofreiter group—hypothesized that mammoth hemoglobin, too, evolved changes that facilitated oxygen release in the cold. Sequencing of mammoth hemoglobin genes and comparison of those sequences with those of Asian elephant hemoglobin genes could presumably reveal if such changes occurred and what they were.

Early attempts in collaboration with Alan Cooper of the University of Adelaide in Australia to sequence the two mammoth genes that produce the different so-called globin chain proteins that form the backbone of hemoglobin met with major setbacks: most available mammoth samples were simply not of high enough quality to obtain workable segments of DNA. At this point, Campbell and Cooper's group joined forces with Hofreiter's group, and using the same DNA extract involved in the *MC1R* study, we soon obtained the complete coding sequence of the two mammoth hemoglobin genes and thus learned the amino acid sequences of the globin chains.

The initial DNA-sequencing results revealed that one of the mammoth globin chains differed from Asian elephants at three of 146 amino acid positions—a finding that quickly became a source of great excitement because we were convinced this trio of amino acid substitutions contained the clear genetic signature of physiological cold adaptation. Preliminary support for this hypothesis came in the form of a rare human hemoglobin variant, termed hemoglobin Rush, which carries one of the mutations found in the mammoth sequence. Although the Rush protein differs from the normal human blood protein at only a single amino acid position, the difference radically alters the biochemical properties of hemoglobin in a way that markedly reduces its temperature sensitivity and thus allows it to release its oxygen more readily in the cold, just as the hemoglobins of cold-adapted mammals do.

The next step toward establishing that the changes evident in the mammoth hemoglobin were adaptations to a cold climate was to resurrect the ancient hemoglobin and watch it in action. To make copies of the genes for mammoth hemoglobin components, we obtained intact hemoglobin genes from Asian elephant blood and altered them at the three mutation sites to match the mammoth sequences. We then inserted the resulting mammothlike genes into *Escherichia coli* bacteria, tricking them into assembling mammoth hemoglobin indistinguishable in form and function from that once circulating in the blood of the 43,000-year-old specimen that yielded up its DNA.

For the first time in history we were now in the enviable position of analyzing an important physiological process of an extinct species in precisely the same manner that we would use to study that process in a modern animal. We carefully measured the ability of both mammoth and elephant hemoglobins to bind and offload oxygen at various physiologically relevant temperatures in solutions that mimicked the chemical environment found inside red blood cells. As predicted from the hemoglobin Rush studies, the mammoth protein did indeed relinquish oxygen much more readily than Asian elephant hemoglobin did at cold temperatures (both hemoglobins functioned the same at normal core body temperature of around 37 degrees Celsius). Intriguingly, the ability of the mammoth hemoglobin to bind to additional molecules and thus create the supplemental heat source needed to deliver its oxygen payload arose by completely different genetic changes than those found in the hemoglobins of modern Arctic mammals, as comparisons of the mammoth hemoglobin gene sequences with sequences from their modern counterparts show. It bears mention that whereas the mammoth mutation is adaptive for cold tolerance, the human Rush variant is not, because it destabilizes the protein such that carriers are chronically anemic. The question of why this undesirable property arises in human, but not mammoth, hemoglobin still needs to be answered.

RAISING THE MAMMOTH?

OF COURSE, the hemoglobin adaptation is only one piece of the puzzle of how woolly mammoths adapted to life in the cold; many other biochemical adaptations of these animals, not to mention those of dozens of other extinct species, remain to be elucidated. Unfortunately, the spate of ancient genomes that scientists have sequenced in recent years are unlikely to be of much help in this regard because the so-called shotgun-sequencing technique used to obtain them yields a random assortment of sequences that, though good for big-picture assessments, are generally not accurate or complete enough to offer physiological insights unless the sequencing is repeated so many times as to be relatively cost-prohibitive.

A new approach called hybridization capture generates deeper coverage of target genes at a much lower cost and so may resolve that issue, allowing for large-scale studies comparing the important gene networks of, say, Siberian mammoths from relatively warm interglacial periods with those from the frigid glacial maximums, when the glaciers were at their thickest. Hybridization capture could also enable investigators to compare geographically disparate populations of the same species—Siberian and Spanish mammoths, for instance. Such studies would not only allow an assessment of genetic variability within the species but could provide insight into novel physiological adaptations in response to local geographic and climatic conditions. Exciting as these future prospects are (imagine watching 50,000 years of evolution unfold before your eyes), our ability to analyze paleophysiology is somewhat limited. Ideally, we would study extinct proteins in vivo because many properties of proteins become visible only in a living organism. Such studies are unlikely to occur anytime soon, however, because they would require re-creating an extinct species.

For now we will have to content ourselves with observing ancient proteins in test tubes and cell cultures. Already we are using the techniques to probe the physiology of other vanished creatures—among them, the mastodon and a more recently extinct Arctic marine mammal known as Steller's sea cow. The infinitely more complex possibility of cloning these animals will remain in the realm of fantasy for the foreseeable future. Meanwhile we will continue breathing life into these long-dead beasts one ancient protein at a time. SA

MORE TO EXPLORE

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To view an interactive explanation of mammoth hemoglobin resurrection, visit **ScientificAmerican.com/aug2012/mammoth**

CLIMATE

LAKES ON ICE

Scientists are tracking how water atop Greenland's ice sheet pools and drains. The findings could help predict future rises in sea level *By Sid Perkins*

Every summer near-perpetual sunlight pours down on much of the ice-swaddled island of Greenland. On many parts of the ice sheet, especially at lower elevations, meltwater flows across the surface and collects in deep-blue ponds and lakes, such as the one shown here. Unlike the lakes we swim in, these water bodies can disappear in a wink: a lake that would fill the Superdome in New Orleans more than a dozen times can drain through a crack in the ice in just 90 minutes.

Researchers have fanned out across Greenland to investigate details of how the lakes might affect the ice sheet and sea level in the future. From recent field studies, they know that when the lakes drain suddenly, they can send meltwater down to the bedrock, where it temporarily lubricates the ice sheet's seaward migration, says Sarah Das, a geophysicist at the Woods Hole Oceanographic Institution. Scientists fear that if the region continues to warm, sudden draining may occur more frequently and over a much broader area of the ice sheet. That could speed the calving of glaciers and contribute to sea-level rise.

Lakes atop the ice sheet also contribute to melting: the ice underneath them thins twice as fast as exposed ice nearby, says Marco Tedesco, a glaciologist at the City College of New York. This summer Tedesco is using a remote-controlled boat to take measurements that will reveal whether the darkness of the lakes correlates with their depth—data that may help analysts better estimate the depths of surface lakes that show up on satellite images and therefore better predict the ice sheet's rate of melting. Laurence C. Smith, a geographer at the University of California, Los Angeles, is comparing rates of surface melting with flow rates in rivers fed by the meltwater. If the two rates diverge substantially, the difference could indicate that some of the meltwater is accumulating below the ice sheet, where it can help to speed the flow of ice to the sea. SA

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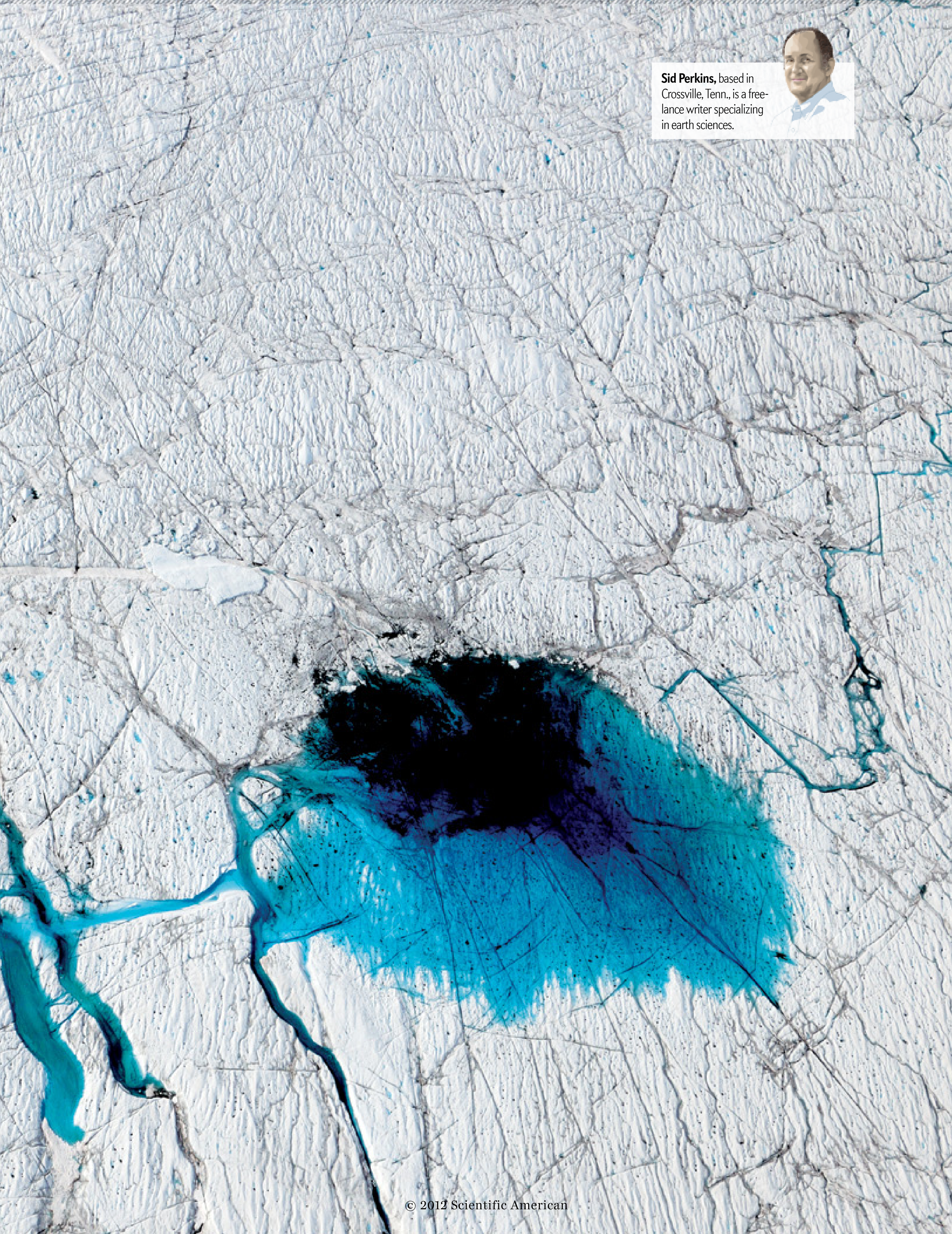
For more images by photographer James Balog, see ScientificAmerican.com/aug2012/glacial-lakes

Photograph by James Balog



Sid Perkins, based in Crossville, Tenn., is a freelance writer specializing in earth sciences.

ATMOSPHERIC SCIENCE

DEADLY RAYS FROM CLOUDS

Thunderstorms give out powerful blasts of gamma rays and x-rays, shooting beams of particles—and even antimatter—into space. The atmosphere is a stranger place than we ever imagined

By Joseph R. Dwyer and David M. Smith

SOON AFTER THE SPACE SHUTTLE *ATLANTIS* LAUNCHED A NEW OBSERVATORY INTO ORBIT IN 1991, Gerald Fishman of the NASA Marshall Space Flight Center realized that something very strange was going on. The Compton Gamma Ray Observatory (CGRO), designed to detect gamma rays from distant astrophysical objects such as neutron stars and supernova remnants, had also begun recording bright, millisecond-long bursts of gamma rays coming not from outer space but from Earth below.

Astrophysicists already knew that exotic phenomena such as solar flares, black holes and exploding stars accelerate electrons and other particles to ultrahigh energies and that these supercharged particles can emit gamma rays—the most energetic photons in nature. In astrophysical events, however, particles accelerate while moving almost freely in what is essentially a vacuum. How, then, could particles in Earth's atmosphere—which is certainly nowhere close to being a vacuum—be doing the same thing?

Early data initially led us and other experts to believe that these so-called terrestrial gamma-ray flashes originated 40 miles above the clouds, but we have now determined that they

STEPHEN ALVAREZ *Getty Images*

are produced much farther down by electric discharges inside garden-variety thunderclouds. Meanwhile increasingly sophisticated theories devised to account for the freakish gamma rays have struggled to keep up with observations: time and again, experiments have detected energies that were previously thought impossible in the atmosphere. Even antimatter has made a surprise appearance.

Twenty-one years later researchers have a good idea of what might create these terrestrial gamma-ray flashes, although uncertainties remain. Adding to the urgency of this fascinating puzzle are its possible implications for human health: if an aircraft travels too close to the sources, the gamma rays could pose a radiation hazard for people riding inside.

Joseph R. Dwyer is an astrophysicist who became interested in lightning after moving to central Florida—the lightning capital of the U.S. He is a professor at the Florida Institute of Technology.

David M. Smith is an associate professor of physics at the University of California, Santa Cruz, and studies lightning, Earth's radiation belts and solar flares. He also conducts observational studies of x-rays and gamma rays from black holes.

TWO BIRDS WITH ONE STONE?

AT FIRST, scientists wondered if the gamma rays could be related to another type of atmospheric marvel discovered only a few years earlier. Cameras trained above thunderclouds had photographed bright, brief flashes of red light, 50 miles above the ground and miles wide, that looked like giant jellyfish. These impressive electric discharges were whimsically named "sprites." Because sprites almost reach the edge of space, it seemed plausible that they might shoot out gamma rays that an orbiting probe could see.

Soon theoretical physicists made the first attempts to explain how sprites could produce space-bound gamma rays. Sprites are thought to be side effects of ordinary lightning occurring in clouds far below. Lightning is an electrically conducting channel that temporarily opens through the air, which is otherwise an electric insulator. The bolt carries electrons between regions of the atmosphere or between the atmosphere and the ground. It is caused by an imbalance of electrostatic charge and is triggered by the resulting electric fields, whose potential differences may exceed 100 million volts.

The violent rush of electrons partially restores the electrostatic balance. Yet just as tamping down a bump in a rug often causes another bump to spring up elsewhere, a discharge inside a cloud often causes the field to spring up elsewhere, including on the ground—where it may later lead to upward lightning—or near the bottom of the ionosphere—where a sprite may result.

In 1992 Alexander V. Gurevich of the Lebedev Physical Institute in Moscow and his collaborators calculated that such secondary electric fields near the ionosphere might produce avalanches of energetic electrons, which, bumping into atoms, would unleash high-energy photons—x-rays and the even more energetic gamma rays—in addition to the sprites' characteristic red glow. The mechanism they proposed derived from a suggestion made by Nobel Prize–winning Scottish scientist C.T.R. Wilson back in the 1920s. At low energies, electrons being pushed by an electric field act like drunken sailors, bouncing from molecule to molecule and losing their energy with each collision. At high energies, however, the electrons travel in a straighter line, picking up even more energy from the electric field, which makes any collisions even less effective at disturbing their path, and so on—a self-reinforcing process. This sequence differs from our everyday experience, in which the faster we go, the more drag force we suffer, as any bicyclist can attest.

These "runaway" electrons could conceivably accelerate up to nearly the speed of light and travel for miles before they stop instead of the few feet an electron might usually move in air. Gurevich's team reasoned that when a runaway electron finally did bump into a gas molecule in the air, it could kick another electron free, and that electron could then itself run away. The result would be akin to a chain reaction: an avalanche of high-energy electrons that grew exponentially with distance and could go as far as the electric field extended. The avalanche effect, Gurevich and his collaborators calculated, could increase the production of x-rays and gamma rays by many orders of magnitude. For a while, this picture seemed very compelling because it unified two separate atmospheric phenomena: gamma-ray flashes and sprites. As we will see, reality turned out to be more complicated.

THE INNOCENCE OF SPRITES

OVER THE NEXT SEVERAL YEARS, from 1996 onward, increasingly refined versions of the theory were developed that modeled sprites as a manifestation of runaway-electron avalanches that produced gamma rays. One piece of evidence that supported this sprite model was the energy spectrum of gamma rays. Higher-energy gamma rays go farther through air than lower-energy ones do, so they are more likely to make it to space. By counting how many gamma-ray photons arrive at a spacecraft at each energy level, scientists can infer the altitude of the source that produced them. The first examinations of the gamma-ray energies seen by CGRO pointed to a very high source altitude, consistent with sprites.

Then, in 2003, things took an unexpected turn. While working at a lightning-research facility in Florida and measuring the x-ray emissions reaching the ground from rocket-triggered lightning, one of us (Dwyer) and his collaborators detected a very bright burst of gamma rays that emanated from the thundercloud overhead and washed over the terrain around us [see "A Bolt out of the Blue," by Joseph R. Dwyer; Scientific American, May 2005]. On our instruments, this burst looked exactly like one of the ter-

IN BRIEF

Thunderclouds emit gamma rays in powerful, millisecond-long bursts called terrestrial gamma-ray flashes, first discovered by space observatories.

These bursts can also produce beams of electrons and even of antimatter that can travel halfway around the globe.

All proposed explanations for the phenomena involve strong electric fields unleashing avalanches of electrons inside clouds, but none fully accounts for the sheer energies of the gamma rays.

New dedicated space missions and research aircraft may solve the mystery, as well as find out if the flashes pose radiation exposure risks for airline flights.

restrial gamma-ray flashes that everyone thought originated much higher: the rays had the same energies and the same duration of about 0.3 millisecond. At the time, everyone assumed that the flashes came from much too high up to be seen on the ground. The similarity implied that perhaps lightning bolts inside thunderclouds might be direct sources of the gamma rays reaching CGRO, but at the same time, the idea seemed kind of crazy: the flash would have had to be unbelievably bright to get enough gamma rays out into space through all that atmosphere.

Soon, however, other developments would undo the purported link between sprites and gamma rays. In 2002 NASA had launched the Reuven Ramaty High Energy Solar Spectroscopic Imager, or RHESSI, to study x-rays and gamma rays from the sun. But RHESSI's large germanium detectors were perfect for measuring gamma rays coming from the atmosphere as well, although they would have to do so through the back of the spacecraft, while the observatory faced our star. One of us (Smith), an astrophysicist and solar physicist, was on the RHESSI instrument team and recruited Liliana Lopez, then an undergraduate student at the University of California, Berkeley, to comb through RHESSI's continuous, years-long stream of data to look for evidence of gamma rays from below. At the time, terrestrial gamma-ray flashes were thought to be very rare. Instead Lopez found a treasure trove: RHESSI was detecting a flash once every few days, about 10 times the rate of CGRO.

RHESSI measured the energies of the gamma-ray photons in each burst much better than CGRO ever did. Their spectrum looked just like what would be expected from runaway electrons. Yet by comparing it with simulations, we deduced that the gamma rays had gone through a lot of air, so they had to originate at altitudes between roughly nine and 13 miles—typical of the tops of thunderstorms but far below the nearly 50-mile height where sprites live.

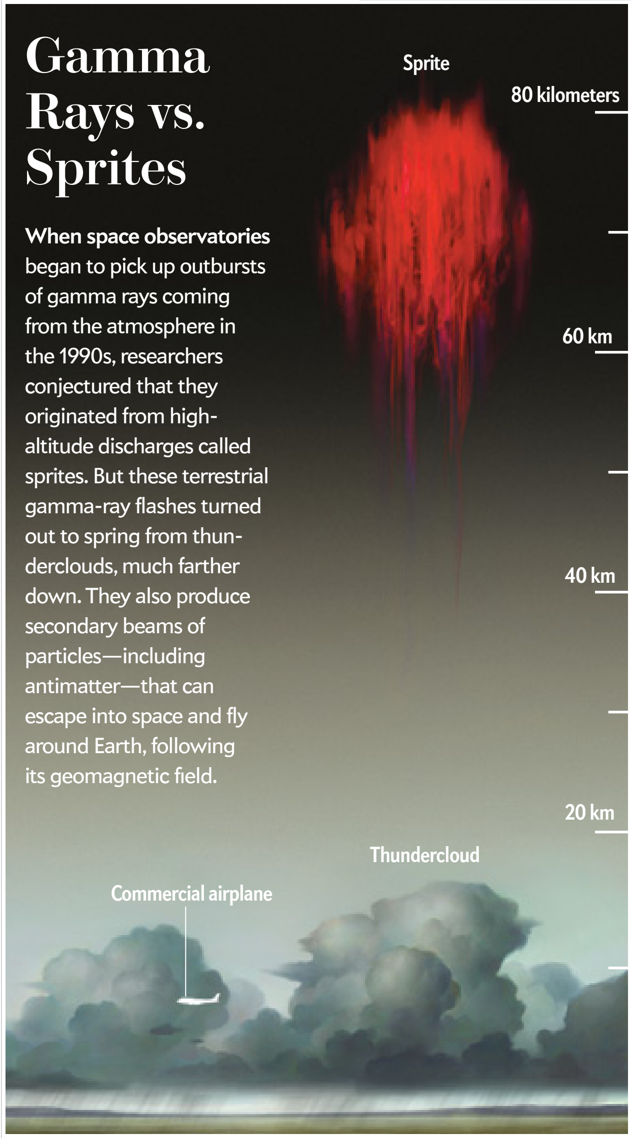
Further independent evidence quickly accumulated favoring a lower-altitude origin of gamma rays rather than a connection with sprites. Radio measurements made by Steven Cummer of Duke University of some of the lightning associated with the RHESSI events found that these lightning flashes were much too weak to make sprites. Moreover, the RHESSI map of gamma-ray flashes around the world looked very much like the map of normal lightning, which is concentrated in the tropics, and very little like the map of sprites, which sometimes cluster at higher latitudes in such spots as the Great Plains of the U.S.

One remaining argument in favor of sprites as the origin, though, was that the energy spectrum from the CGRO events seemed to point toward a high-source altitude, more consistent with sprites than thunderstorms. Many of us started to believe that there might be two kinds of gamma-ray flashes, low- and high-altitude ones. But the final blow to the sprite idea came when we realized that terrestrial gamma-ray flashes were much brighter than previously thought. In fact, working with then graduate student Brian Grefenstette in 2008, we determined that they were so bright that CGRO was being partially blinded by them and could not measure their full intensity. (This saturation also affected RHESSI, though to a lesser extent.) When researchers at the University of Bergen in Norway reanalyzed the data in 2010, they found that taking instrument saturation into account made the results consistent with lower-altitude sources.

In less than two years, then, the putative altitude where gamma-ray flashes form plummeted more than 30 miles. It is rare in science to witness a paradigm shift happen so rapidly. This change is ironic, given that when we became involved in this field of research a decade ago, sprites were the one shining example of how energetic radiation can be produced in our atmosphere. Now, 10 years later, just about everything—thunderclouds, various kinds of lightning, laboratory sparks—seems to make detectable high-energy radiation but apparently not sprites. The consensus now is that the low energy of sprites' radiation implies that they are not responsible for gamma-ray flashes after all.

DISCHARGES COMPARED

Gamma Rays vs. Sprites



When space observatories began to pick up outbursts of gamma rays coming from the atmosphere in the 1990s, researchers conjectured that they originated from high-altitude discharges called sprites. But these terrestrial gamma-ray flashes turned out to spring from thunderclouds, much farther down. They also produce secondary beams of particles—including antimatter—that can escape into space and fly around Earth, following its geomagnetic field.

BRING ON THE ANTIMATTER

SO IF IT IS NOT SPRITES that produce gamma-ray flashes, what does? And does the process still involve runaway-electron avalanches? As it turns out, the avalanche mechanism as modeled by Gurevich and company, though too energetic to have anything to do with sprites, is not powerful enough to generate the large luminosities seen by RHESSI or the newly analyzed CGRO data. Cal-

Illustrations by Brian Despain

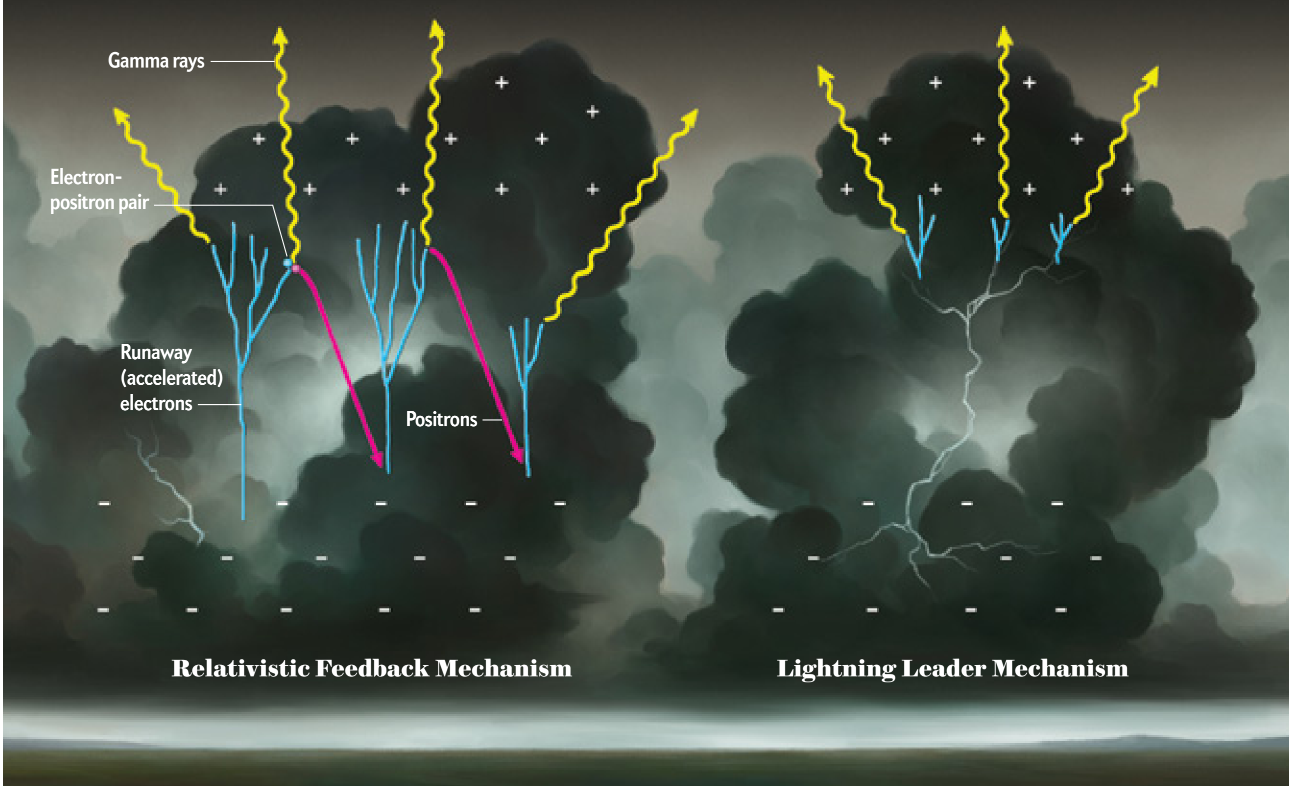
POSSIBLE EXPLANATIONS

What Causes the Gamma-Ray Flashes?

Scientists agree that terrestrial gamma rays probably involve cascades of electrons that, once set loose from their atoms, accelerate to nearly light speed in the intense electric fields inside thunderclouds. Then, when these electrons hit atomic nuclei in air molecules, they release gamma-ray photons. But to explain the photons' energies—which are comparable to those produced in stellar explosions—some additional mechanism must be at play.

In the relativistic feedback hypothesis (*left*), some of the gamma rays generate new matter—pairs of particles consisting of one electron and one positron, the antimatter analogue of the electron. Because positrons have electric charge opposite to the electrons, they would travel downward and trigger new electron cascades.

In the lightning leader hypothesis (*right*), a powerful lightning bolt would keep releasing new electron cascades as it grows from the bottom of the cloud to its top.



culations by Dwyer, however, had shown that a supercharged version of the electron avalanche mechanism could release trillions of times more energy than previously envisioned and could do so inside a thundercloud. Astoundingly, such a mechanism would also involve the production of copious antimatter.

If the electric field inside a thundercloud were strong enough, runaway electrons—assuming they form somehow—should accelerate to nearly the speed of light and, when they bumped into atomic nuclei in air molecules, could emit gamma rays. In turn, the gamma-ray photons could interact with atomic nuclei to produce pairs of particles: electrons and their antimatter twins, positrons. The positrons would run away as well, gaining energy from the electric field. But while electrons move upward in the field, the positrons, which have opposite electric charge, would move downward. When the positrons reached the bottom of the electric field region, they would bump into air atoms and knock out new electrons that would again run away toward the top.

In this way, the upward-going electrons would create downward-going positrons, which in turn would create more upward-going electrons, and so on. As one avalanche led to others, the discharges would quickly spread over a broad area of the thundercloud, up to several miles wide. The numbers predicted by this model—known as the relativistic feedback discharge model—perfectly matched the intensity, duration and energy spectrum of the gamma rays seen by CGRO and RHESSI.

The positive feedback from positrons is analogous to the annoying screech we get by holding a microphone up to a speaker. Of course, if we want a loud noise, we could just as well shout into the microphone. That logic is behind another possible explanation, albeit one that has not yet been fully worked out mathematically: that gamma-ray flashes are more energetic versions of the bursts of x-rays emitted by lightning as it approaches the ground. For several years researchers at the Florida Institute of Technology, the University of Florida, and the New Mexico Institute of Mining and Technology have been measuring these x-rays, both from lightning that is artificially triggered with rockets and from natural lightning that strikes the ground. X-ray "movies" from a fast x-ray camera in Florida show that the bursts emanate from the tip of the lightning channel as it travels from the cloud to the ground. Most scientists think that the x-rays are generated by runaway electrons, accelerated by strong electric fields in front of the lightning. Perhaps, for reasons we have yet to figure out, lightning that moves through the electric field inside a thundercloud does a better job of making these runaway electrons. If this idea is correct, then the flashes seen by spacecraft from hundreds of miles away could be just a version—amplified through some still unknown mechanism—of the lightning-generated x-rays seen on the ground by detectors a few hundred feet from the bolt.

OUT OF THE BLUE

BY THE END OF 2005 we were confident that most terrestrial gamma-ray flashes stemmed from inside or near the tops of thunderclouds, regardless of whether antimatter or souped-up lightning bolts were involved. Before we could get too cozy with that new paradigm, however, something seemed to put our understanding into question again: one of the events picked up by RHESSI was smack in the middle of the Sahara Desert—on a sunny day with no thunderclouds in sight.

We and our students spent months struggling over this one. It turns out that thunderclouds did form that day—just not where the spacecraft was looking. The storms were several thousand miles to the south, over the horizon from RHESSI. Their gamma rays, which, like all forms of light, travel in a straight line, could not have reached the craft.

Charged particles such as electrons, on the other hand, naturally travel in trajectories that tightly spiral around the curved lines of Earth's magnetic field. The storms were precisely at the other end of the magnetic field line going through the spacecraft. Electrons that reached very high altitudes could have circumnavigated the planet and smashed into RHESSI's detectors, forming gamma rays in the process. It seemed impossible, though, that electrons unleashed inside a thundercloud could make it through many, many miles of atmosphere to an altitude in space where they could hitch a ride around the field lines. The new observation seemed once again to require a high-altitude source.

Last year, moreover, the Fermi Gamma-ray Space Telescope observed more of these circumnavigating beams and made a startling discovery: that a sizable fraction of the beams consist of positrons. Thus, it appears that atmospheric phenomena can blast not only electrons and gamma rays into space but also antimatter particles. In hindsight, we should have expected to see these positrons, given how energetic the gamma rays are. Yet considering how unusual it is to observe antimatter in nature, Fermi's finding was astonishing.

The explanation for the Sahara finding, our team soon realized, was not that the gamma rays were coming from a high altitude but rather that they were produced inside thunderclouds in more copious numbers than had been thought possible. Some of those headed for space, ran into the occasional air molecule above 25 miles of altitude or so and created secondary electron-positron pairs, which then hitched a ride on the magnetic field lines around the globe. Next time you see a tall thundercloud, stop to remember that it is capable of shooting high-energy particles into space that can be detected on the other side of the planet.

NEW OUTLIERS

THE APPEARANCE OF POSITRONS was not to be our last shock. Later in 2011 the Italian Space Agency's AGILE observatory found that the energy spectrum of terrestrial gamma-ray flashes extends up to 100 mega-electron-volts, a value that would be amazing even if it came from a solar flare. If correct, these observations cast doubt on our models because it seems highly unlikely that the runaway mechanism could generate such energies by itself. In fact, it is not clear what could possibly accelerate electrons to such energies inside thunderstorms. At this point, we need more observations to help guide the theory. Fortunately, teams from the U.S., Europe and Russia are now beginning to launch the first space missions dedicated to detecting terrestrial gamma rays.

Meanwhile, to get closer to the action, we and our collaborators have built an aircraft instrument designed to measure gamma rays from thunderstorms. Worry about the dangers of gamma-ray exposure prevents us from flying straight into a storm. But on an early test flight in which Dwyer took part, the plane inadvertently took the wrong turn. The feeling of terror was quickly supplanted by elation as our detectors suddenly lit up. Subsequent analysis showed that the region was accelerating runaway electrons of the same kind that we expect to make gamma-ray flashes. Fortunately, the emission stayed at a low level and did not undergo the explosive growth of the events seen from space. From these flights, we have found that thunderstorms most often emit a relatively harmless, continuous glow of gamma rays.

Preliminary calculations, however, show that if an airline flight happened to be struck directly by the energetic electrons and gamma rays inside a storm, passengers and crew members could—without feeling anything—receive up to a lifetime's natural radiation dose in a fraction of a second. A bit of good news is that we do not need to warn pilots to stay away from thunderstorms, because they already do so; thunderstorms are very dangerous places to be, with or without gamma rays.

In a way, the study of terrestrial gamma-ray flashes is completing the work of Benjamin Franklin, who purportedly sent a kite into a thunderstorm to see if it would conduct electricity and thereby showed that lightning was an electric discharge. Surprisingly, two and a half centuries after his kite experiment, scientists still have an incomplete understanding not only of how thunderclouds make gamma-ray flashes but even of how they make simple lightning. Both of us have spent much of our careers studying exotic objects far from the solar system, but we have been pulled back to Earth by the lure of this research. Perhaps even Franklin did not realize that thunderstorms could be so interesting. SA

MORE TO EXPLORE

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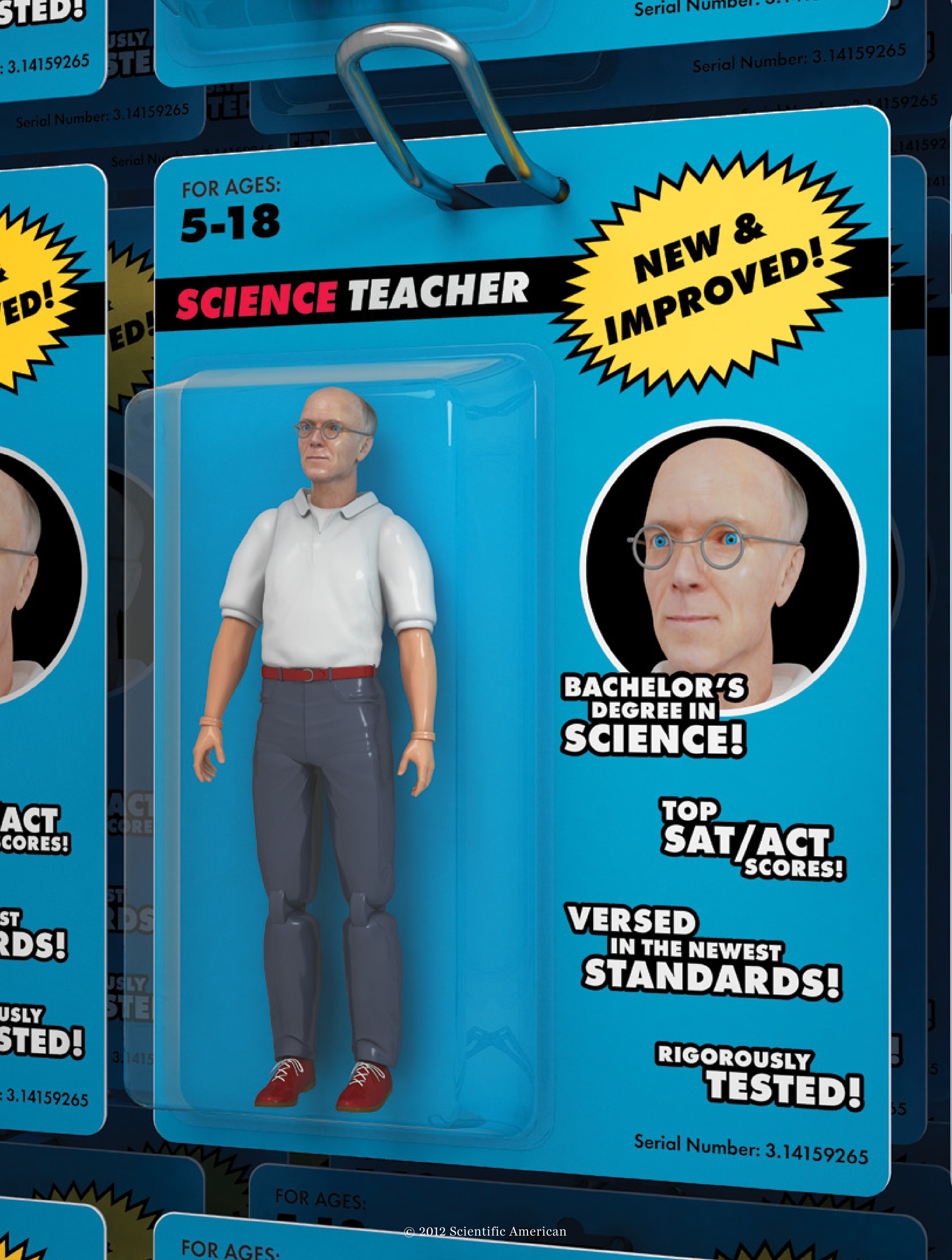
Watch a video of how thunderstorms generate gamma-ray bursts at **ScientificAmerican.com/aug2012/bursts**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EDUCATION

BUILDING A BETTER SCIENCE TEACHER

Experience and degrees don't matter in the classroom nearly so much as mastery of science and math and some plain old smarts

By Pat Wingert

Illustration by Benjamin Simon

Pat Wingert, a longtime education reporter at *Newsweek,* recently completed a year as a Spencer Fellow for Education Journalism at Columbia University, studying math and science education reforms. She is based in Washington, D.C.

IN A RENOVATED WAREHOUSE IN A WEARY-LOOKING SECTION OF TROY, N.Y., 25-YEAR-OLD KATIE BELLUCCI has the rapt attention of 27 fifth graders. They are singing, stamping, clapping and waving their hands in the air—far more excitement than you would expect for ratios and fractions. The class is working together on a word problem involving a fictional basketball team with a win-to-loss ratio of 9:3. What is the ratio of losses to total games played? Bellucci gets everyone involved in breaking down the process ("What do we need to do first?"). Once the class arrives at a fraction—wins plus losses, divided by losses, or (9 + 3)/3—she encourages them to reduce it. "Okay, who's got the GCF?" she says, referring to the greatest common factor. She zips up and down the aisles, cajoling one student and then another for one more piece of the solution. The students track her every move, knowing she may call on them even if their hands are down. "I'm seeing so many lightbulbs and so much diligence," she says. If an answer comes easily, she will push ahead with that student and ask for the how and why behind it. The bell rings, and as the kids file out for lunch, each one hands Bellucci an "Exit Ticket"—the solution to two problems that exemplify the core lesson of the day, which Bellucci will scrutinize to determine if the class mastered the day's objective.

Troy Prep, where Bellucci teaches, is one of the higher-performing public schools in New York State even though the vast majority of its students come from low-income families. In 2011, the second year the school was open, 74 percent of its fifth graders scored at the "proficient" level on the New York State math exam, as compared with only 66 percent of fifth graders across the state. Even more impressive, after two years in the school, 100 percent of Troy Prep's sixth graders scored in the proficient range. What accounts for the school's success? Doug Lemov, a leader of the Uncommon Schools Charter Network, of which Troy Prep is a part, does not hesitate: outstanding, well-trained teachers like Bellucci.

In recent years a mounting stack of research has shown that a good teacher is the single most important variable in boosting student achievement in every subject. A good teacher trumps such factors as socioeconomic status, class size, curriculum design and parents' educational levels. Stanford University's Eric Hanushek showed that students of highly effective teachers make about three times the academic gains of those with less talented teachers, regardless of the students' demographics. That is exactly the trouble with math and science education: there are too few teachers like Bellucci. The teacher dropout rate is high, and the education system rewards the teachers it has for the wrong reasons.

The crisis has not gone unnoticed. Not since the Russians launched Sputnik in 1957 have American policy makers, educators and businesses been so focused on improving math and science education. They have been spurred into action by the U.S.'s economic downturn and by growing competitiveness in China, which includes its students' top scores on international tests. Major players from President Barack Obama on down are describing the U.S.'s lagging performance in science and math education as a dire threat to the country's future competitiveness. According to results from two Nation's Report Card tests released earlier this year, only 32 percent of U.S. eighth graders are proficient in science and 35 percent are proficient in math. Meanwhile students from Shanghai earned top scores on the 2010 Program for International Student Assessment test in math and science, whereas Americans placed squarely in the middle of the pack. To

IN BRIEF

America's economic crisis and China's growing competitiveness have put new focus on math and science education, including how to improve the way programs train math and science teachers.

Research shows students of teachers who hold degrees in math and science score higher on math and science tests, yet only a minority of science and math teachers hold degrees in their subjects.

Teachers with math and science degrees are in high demand, but pilot programs and charter schools are learning better ways of recruiting and retaining highly skilled instructors.

Educators are also beginning to understand which techniques work best in the classroom, such as hands-on lessons, calling on students unexpectedly, and lessening the fear of errors.

help close the gap, President Obama has proposed infusing our school system with a fresh supply of talent. His prescription: making it a priority to prepare 100,000 highly effective math and science teachers by 2020 and raising learning standards in all 50 states [see "Can the U.S. Get an "A" in Science?" Science Agenda, on page 12]. "Maintaining our leadership in research and technology is crucial to America's success," the president said during last year's State of the Union address. "But if we want to win the future—if we want innovation to produce jobs in America and not overseas—then we also have to win the race to educate our kids."

Indeed, at the instigation of the White House, the U.S. seems to be embarking on a national experiment on how to encourage more effective math and science teaching. Increasingly, research is showing that much of what we thought we knew about how to prepare and reward teachers is wrong. According to the conventional wisdom, for instance, Bellucci should not be half as effective as she is. Before coming to Troy Prep, she had no classroom experience, and she never earned a master's degree in education. What she does have, and what research has shown is even more important, is strong mastery of her subject area: she holds a bachelor's degree in applied math and crunched numbers at an engineering firm before switching careers.

Yet in most school districts, teachers' raises and retirement benefits are pegged to experience and postgraduate degrees in education. In fact, classroom time does not predict student achievement as well as many experts have assumed. A new teacher's proficiency typically grows for a few years but then flattens out. The difference between the achievement scores of students who have a very experienced teacher and one who has been in the classroom for three years, like Bellucci, is small. Graduate degrees do not correlate with higher performance in the classroom, either. Analysts suspect that is because 90 percent of those degrees are master's degrees in general education rather than in a specific subject area. Conversely, several studies indicate higher math achievement among students whose teachers hold an advanced degree in math.

"AN UTTERLY CHAOTIC SYSTEM"

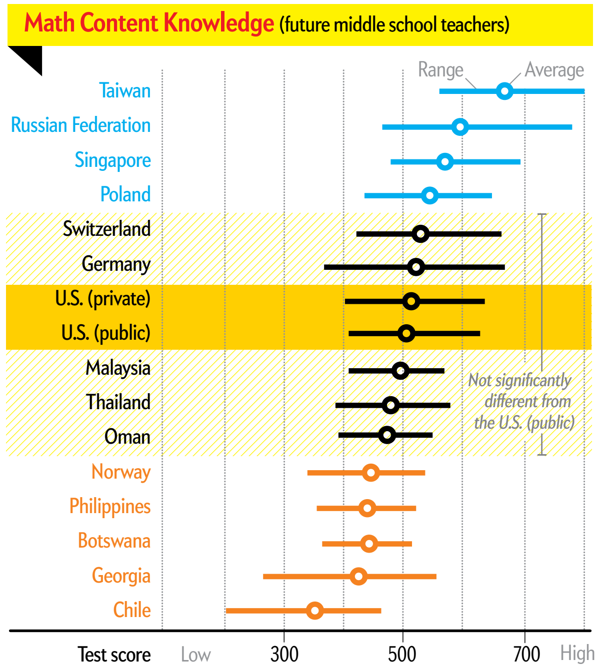
LEGISLATING CHANGE has not been easy. Since 2001 and the passage of former president George W. Bush's No Child Left Behind, states have been encouraged to hire teachers with degrees in the subjects they teach. As recently as 2008, however, only about 25 percent of science and math teachers at all grade levels held an undergraduate or graduate degree conferred by a math or science department or school. That is partly because of poor teacher retention. Every year 25,000 mathematics and science teachers, out of a corps of 477,000, leave the profession, with nearly two thirds citing job dissatisfaction. To fill vacancies, each state has devised its own rules and regulations for "alternative" and "emergency" hires, some of whom get great training and some of whom do not. Kate Walsh, president of the National Council on Teacher Quality, says, "It is an utterly chaotic system. The best way to summarize American teacher education programs is anything goes."

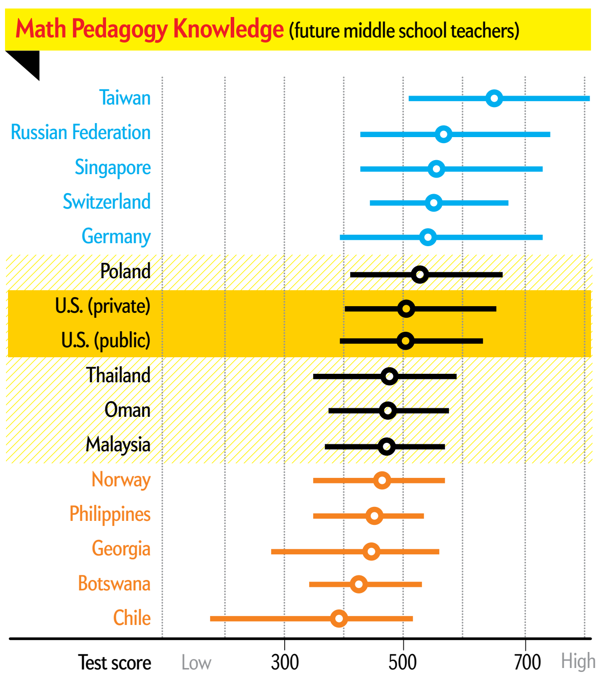
In general, teacher certification standards still vary widely from state to state. Some aspiring elementary school teachers, like those in Massachusetts, are required to take rigorous math classes designed for teachers and to score well on tough exams that probe for deep content knowledge. In other states, including Arkansas and Nevada, prospective teachers need only repeat a course they took in high school or one designed primarily to ease

FUTURE TEACHERS

Not So Prepared to Inspire

Americans completing their training to teach middle school math know significantly less geometry, algebra and numbers (a domain that includes fractions and decimals) than do their counterparts in Taiwan and Singapore. They also know less pedagogy—how students learn math and the best ways to teach it.





SOURCE: "BREAKING THE CYCLE: AN INTERNATIONAL COMPARISON OF U.S. MATHEMATICS TEACHER PREPARATION," BY MICHIGAN STATE UNIVERSITY CENTER FOR RESEARCH IN MATHEMATICS AND SCIENCE EDUCATION, 2010

The Value of Bringing Science Home

Yes, great teaching is important. But parents who encourage their kids in science and math are about five times more likely to raise the next Mark Zuckerberg or Mae Jemison *By Jon D. Miller*

Jon D. Miller is director of the International Center for the Advancement of Scientific Literacy at the University of Michigan.

Parents are the essential root of scientific literacy. Those who value science reflect that value in their choice of toys and books, in their use of zoos and museums, and in their own curiosity about the world in which they live. And their knowledge and interests have a profound influence on their children. Recent data from the Longitudinal Study of American Youth, through which my colleagues and I have been following 4,000 Generation Xers since 1987, show that 40 percent of children whose parents actively encouraged them in math and science planned to major in a STEMM (*s*cience, *t*echnology, *e*ngineering, *m*athematics or *m*edicine) subject in college, as compared with only 8 percent of children who did not receive the same level of encouragement.

Looked at another way, the children of parents who lack an interest in science are at a profound disadvantage. Educational and political leaders should find ways to help all parents—regardless of whether they majored in math or music or went to college—to engage their kids in STEMM (*opposite page*).

They can start by supporting and giving greater prominence to community programs that already do this. The Family Math program that originated at the Lawrence Hall of Science in Berkeley, Calif., has been adopted by museums and community groups throughout the nation and provides an effective way of introducing parents and kids to the math learning process during the elementary and middle school years. Increasingly, these programs, which bring families together to solve hands-on problems, are being offered through schools and have the added advantage of involving parents and teachers in the same process.

Ideally, parents, students and teachers should be involved in cooperative after-school, evening, weekend and summer programs to encourage math and science, and these programs need to continue over the precollege years rather than just a few days or a few weeks. Given the current fiscal crunch gripping public school systems throughout the nation, it is necessary for community and civic groups, churches and unions to foster the initiation and funding of these kinds of programs.

In the 20th century the U.S. did a number of things that produced a strong level of civic scientific literacy among adults. In cross-national studies, I have found that American adults are very competitive in the world in terms of civic scientific literacy: the U.S. ranks second only to Sweden in a comparison of 34 leading industrial nations. America's secret weapon in the 20th century was its commitment to broadening access to college education and its insistence on a set of general education requirements—including a full year of science for most baccalaureate students.

Americans should be proud of these policies and achievements, but one of the unfortunate consequences of our success is that it has masked the dismal performance of our middle schools and high schools in the teaching of science and mathematics. This is a deficit that parents can only partly redress. Schools, families, corporate leaders and policy makers need to work together to improve education. There is no reason that every high school graduate in the U.S. should not be scientifically literate.

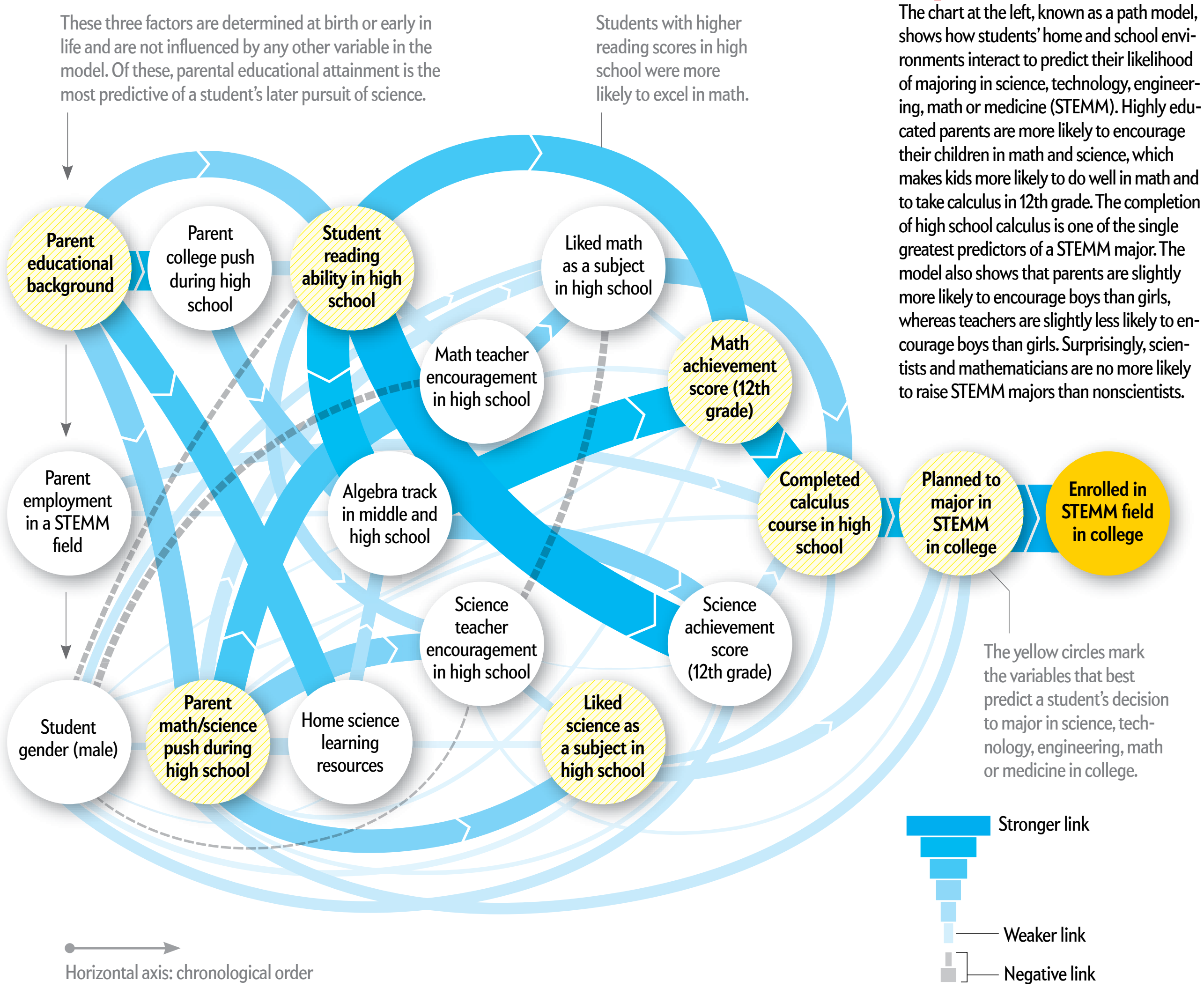
their math anxiety rather than increase their mastery of the content, according to the National Council on Teacher Quality.

This type of training pales by comparison with what higher-achieving countries offer. A 2007 study of prospective elementary and middle school mathematics teachers' content knowledge in 16 countries found that future American teachers knew less math than many of their counterparts. Whereas nearly all future middle school teachers in Singapore, Germany, Taiwan and Korea took courses in linear algebra and basic calculus, only about half of U.S. future teachers took those fundamental courses. When it came to algebra knowledge, American teachers scored dead last. One of the reasons for that is there is no agreement about what constitutes a quality teacher preparation program for math or any other subject. "Some [American teacher colleges] are competitive with the best in the world," says William Schmidt of Michigan State University, who directed the U.S. part of the survey. "But some are more like the ones in Botswana. We have that kind of range."

Equally disturbing was the survey's finding that the U.S. teacher preparation programs that ranked lowest in terms of future teachers' math knowledge tended to be at large public universities that produce the largest numbers of teachers. "The bottom quartile of the distribution—the colleges whose students don't know much math—produces more than half of the future middle school teachers of mathematics," Schmidt says. "States need to close those institutions that are doing a really poor job."

ROAD TO REFORM

THERE ARE REASONS for optimism. Some states are embarking on ambitious reform agendas, helped along by well-respected teacher training programs that are expanding, thanks to an influx of funds from companies and nonprofits. For the past few years the best math teachers in Louisiana, a state in the middle of a major overhaul of its teacher training program, have consistently come from Teach for America, the highly competitive national program that recruits top graduates from the nation's top colleges to make a two-year commitment to teach in hard-to-staff schools. Teach for America's recruits have higher college admission exam scores in math than most teachers, and some data have shown that higher scores correlate with higher effectiveness, says Jeanne Burns, associate commissioner of teacher



Steps to Science

The chart at the left, known as a path model, shows how students' home and school environments interact to predict their likelihood of majoring in science, technology, engineering, math or medicine (STEMM). Highly educated parents are more likely to encourage their children in math and science, which makes kids more likely to do well in math and to take calculus in 12th grade. The completion of high school calculus is one of the single greatest predictors of a STEMM major. The model also shows that parents are slightly more likely to encourage boys than girls, whereas teachers are slightly less likely to encourage boys than girls. Surprisingly, scientists and mathematicians are no more likely to raise STEMM majors than nonscientists.

SOURCE: "PATHWAYS TO A STEMM CAREER," BY JON D. MILLER AND LINDA G. KIMMEL, IN *PEABODY JOURNAL OF EDUCATION*, VOL. 87, NO. 1; 2012. BASED ON DATA FROM THE LONGITUDINAL STUDY OF AMERICAN YOUTH

education initiatives for the Louisiana Board of Regents. Studies of Teach for America in Tennessee and North Carolina schools have shown similarly positive results for science student achievement. Until now, only around a third of Teach for America's members have specialized in science or math, but that is about to change. This past February the organization committed to recruiting 11,000 new math and science teachers by 2015 for the 31 states it serves. The downside is that many of Teach for America's recruits drop out of teaching after just a few years.

A model program for retaining good teachers is UTeach, an innovative teacher training program that originated at the University of Texas at Austin in the late 1990s. Its goal is to prepare many more science and math teachers with a deep knowledge of their subject. It does so by offering freshmen with math or science majors two free semester-long teaching workshops staffed with mentors. Five years out, 82 percent of its teachers are still in the classroom. UTeach credits those high numbers to the fact that it gives students lots of time in real classrooms right from the start, "so they can decide if they like teaching or not," says Mary Ann Rankin, former dean of the University of Texas at Austin's natural sciences department who helped to launch the program. "Some are seduced once they have a really fun experience and see how rewarding it can be." At the end of four years, recruits graduate with a bachelor's degree in a field of science or math, plus all the courses needed for teacher certification.

UTeach has won recognition from the National Research Council, among many other groups, and has attracted enough funding from nonprofits and companies to help it expand. In the past three years the number of campuses offering the program has tripled to 30 in 14 states. (Most create their own versions of its witty name: the University of Kansas's is UKanTeach.) Meanwhile Rankin, who last year became the president and CEO of the National Math and Science Initiative, has made a commitment to keep the expansion growing. Her goal: 4,000 STEM (*s*cience, *t*echnology, *e*ngineering or *m*athematics) teachers prepared by UTeach by 2015.

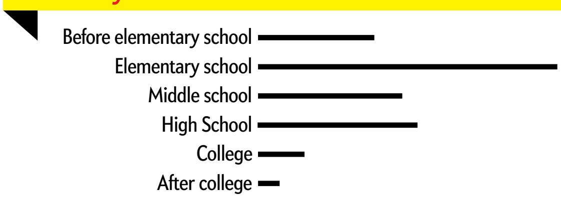
Other teacher training programs have had success by recruiting professionals with strong math and science backgrounds at later stages of their careers. The New Teacher Project (TNTP) focuses on those in their 20s and 30s "who made

SURVEY

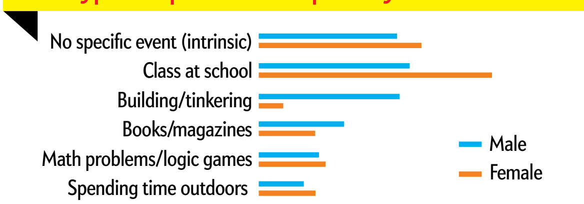
What Scientists Say

Scientific American collaborated with Adam Maltese, a science education researcher at Indiana University, on a study aimed at better understanding the experiences of science, math and engineering students and professionals. Based on data from a randomized sample of universities and online volunteers who completed a survey, men and women who pursue STEM degrees tend to become interested in science in elementary school. When asked which people and experiences helped to spark their interest, women were more likely than men to select a teacher, a class at school, solving math problems and spending time outdoors, whereas men were more influenced by tinkering, building and reading. As men and women enter college, passion for the field far outweighs all other influences as the main reason for their persistence.

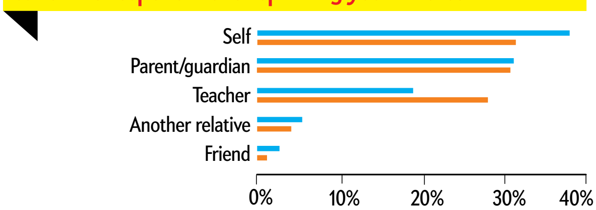
When did you first become interested in STEM?



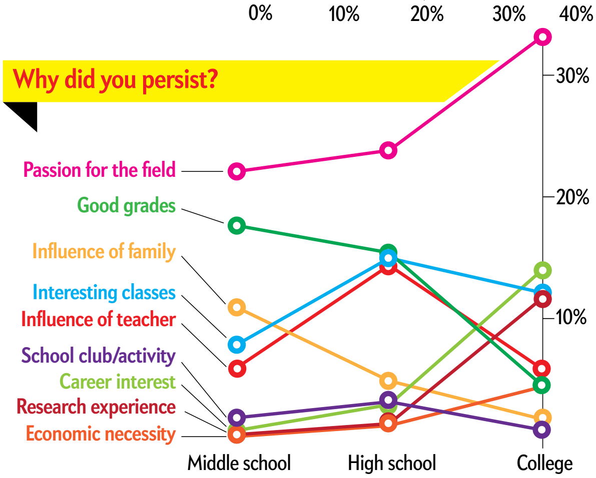
What type of experience first sparked your interest?



Who was responsible for sparking your interest?



Why did you persist?



the wrong (career) choice early on" and still have low opportunity costs associated with making the switch to teaching, says Tim Daly, president of TNTP. The program, an alternative training organization started by former Washington, D.C., schools chief Michelle Rhee, offers free teacher training to its fellows, who then go on to earn a subsidized master's degree in education while teaching. All their math and science teachers have strong backgrounds in their subjects, like Bellucci.

"We used to think there were all these people who would quit their jobs and go back to school, where they would take out a loan to pay for their master's program so they could become a teacher and make a pittance on the other end. That doesn't happen much," Daly says. "We find that the sweet spot for recruiting people is between the ages of 25 and 35. They are just a few years into their career and have a math or science skill set and a desire to do teaching as a vocation instead of a short-term experience. These are people who are good at these subjects and highly motivated, mission-oriented and willing to teach in a school where they are badly needed."

Whereas TNTP—like Teach for America—gets criticized by advocates of teacher colleges for their condensed training schedule, alternative programs that recruit people with deep content knowledge are an essential piece of the STEM solution, Daly says. "If you don't offer alternative certification, will anyone volunteer to do this?" he asks. "I would argue that the answer is no—no one will take on midcareer financial hardship when they have a mortgage and a family to go back to school to become a teacher. The number interested in doing that is zero."

LEARNING FROM "SUPERSTAR" TEACHERS

AS EDUCATORS and researchers learn more about the best ways to attract and train teachers, they are also formulating a better recipe for retaining them. Matthew G. Springer, assistant professor of public policy and education at Vanderbilt University, says pay may not be as clear a motivator as one would think. "There are only a handful of rigorous studies on merit-pay programs," Springer says, "and the number of different ways you can design them is tremendous. We've tested only a few models." But, he adds, the U.S. Department of Education's Schools and Staffing Survey has shown that it is about twice as hard to find a good math or science teacher as an elementary school teacher, and "one may conclude that could stem from the fact that there isn't more market-driven compensation." What is becoming more clear is the idea that excellent training and job satisfaction go hand in hand. Julia Toews, head of Basis Tucson, a 700-student charter school that is ranked among the nation's highest-performing schools in science and math, uses a combination of competitive pay, ongoing development and regular feedback to keep her staff motivated. Her teachers tend to come from the ranks of academe, graduate and postdoctoral students who decided they enjoyed teaching more than conducting research.

Toews is quick to add that holding an advanced degree in science or mathematics does not guarantee anyone a job. "Every teacher [applicant] has to do a teaching demonstration, and for every five I watch, I hire one," she says. Once applicants are hired, the school provides ongoing teacher development and regular feedback on teachers' performance and pays higher salaries than the local districts and private schools. With good results, "teachers get a lot of authority and freedom and creativity," Toews observes. "We make people want to stay."

Uncommon Schools' Lemov agrees that inadequate training may be behind many teachers' early departures from the profession. "Who doesn't know a lot of people who were teachers who are now realtors?" he asks. "Without the right training, they are not successful. When someone decides to go into teaching, they know they may not be paid well, but they think they're going to make a difference. If they end up leaving, it's because they're not making a difference. This is actually one of the hardest jobs in the world. We have to give the people who do this work better tools."

What might those tools look like? In other words, what are the specific techniques that, in the words of the White House, "prepare and inspire" students? There is little conclusive research, particularly when it comes to science instruction, write the authors of a 2010 National Research Council report, "Preparing Teachers." Experts agree that students need a mix of factual knowledge, opportunities to practice scientific inquiry and an understanding of "the nature of science," which refers to how scientists gather and make sense of new information. There are better data when it comes to math. Students need to both memorize facts like multiplication tables and think through deep conceptual knowledge before they take on higher-level mathematics. There is also "some evidence" to support the use of cooperative learning and individual assessments to tailor student instruction. But there is more agreement on what should be taught than on the best ways to teach that material.

Efforts to change that are under way. Deborah L. Ball, dean of the school of education at the University of Michigan, has devoted herself for more than a decade to identifying the specific skills that new teachers need before they are ready to take over a classroom. The program she helped to establish, Mathematical Knowledge for Teaching, aims to teach new instructors to diagnose accurately why a student is confused, to maintain a class's attention, and to put together a tool box that includes, for example, a variety of strategies to explain fractions. Her own experience in the classroom, as well as her years as a researcher, Ball says, has convinced her it is "very misguided" to assume good teaching is "intuitive."

Teachers who score high on the Mathematical Knowledge for Teaching skills are more likely to generate student success than those who do well on straight math tests, says Paul Cobb of Vanderbilt, who teaches the strategies to his own students and to experienced teachers looking to improve. Along with his colleague Kara Jackson of McGill University, Cobb has seen dramatically increased levels of student learning by training experienced teachers to use these same techniques. But he acknowledges that the groups were small—12 to 15 at a time—and the effort took more than a year. The challenge now is to figure out how to bring this kind of training to scale. "We know there are exceptional schools," Cobb says. "We're interested in creating exceptional districts."

Lemov, too, has identified 49 techniques that, in his words, "separate great teachers from the merely good." He has spent years observing superstar teachers and zeroing in on the concrete, reproducible traits that make them highly effective. First, Lemov's team focused on how to make reading instruction more effective, and now it is doing the same with math and science, producing teachers like Bellucci. Among the factors the team has noted so far: not letting students off the hook (coming back to a student who at first answered incorrectly to make sure they understand the correct answer) and normalizing error (showing students that getting something wrong before getting it right is normal).

STRIVING FOR THE TOP

WHILE THE DEBATE CONTINUES over the best ways to overhaul the training of math and science teachers, the Obama administration has pledged to continue to boost STEM education from the bully pulpit as well as the treasury. Its Race to the Top program (a national series of competitions that reward the states with the most ambitious education reforms with billions in extra federal aid money) has motivated states to overhaul their teacher evaluation programs and made it easier for charters such as Basis and Uncommon Schools to open and for alternatively trained teachers (like those from Teach for America and TNTP) to be hired. The competitions have encouraged states to do more to recruit STEM teachers with stronger core mastery and to link student performance to educational school reforms. Stimulus money has also been made available for schools to modernize their science laboratories, and federal money is funding programs such as the Robert Noyce Teacher Scholarship Program, which pays for teacher training for top science and math graduates in university settings. Even so, the administration knows it needs to do much more.

That is one of the reasons government officials are working closely with the nonprofit Carnegie Corporation of New York on what they call the "100Kin10" effort. In the past year they have succeeded in getting more than 100 government, business and nonprofit organizations to join the cause and raised $24 million in their first round of fund-raising from groups that include the Bill & Melinda Gates Foundation, Google and the Michael & Susan Dell Foundation. They are promising donors that investment of this money will be restricted to teacher training programs that have already proved their effectiveness by undergoing vetting by University of Chicago researchers. (So far UTeach and Teach for America are among dozens that have been green-lighted for investment, as have California State University, Arizona State University, Michigan State University, Boston College and the Woodrow Wilson National Fellowship Foundation.)

There is no doubt that the cause is creating heat and light, and its advocates insist that this time around, we will see real progress. "We know this is necessary, and we know this is possible, and it's not happening enough for enough kids," says Talia Milgrom-Elcott, who is managing STEM teacher initiatives for Carnegie. "We can do this by activating enough people around the country to make a decision to join us with their own resources, expertise and local knowledge. We can work together to reach this goal."

Although there is still a long way to go, there is no debate over how important this effort is. SA

MORE TO EXPLORE

Breaking the Cycle: An International Comparison of U.S. Mathematics Teacher Preparation. Michigan State University Center for Research in Mathematics and Science Education, 2010. **http://hub.mspnet.org/index.cfm/20671**

Preparing Teachers: Building Evidence for Sound Policy. National Research Council. National Academies Press, 2010.

Teach Like a Champion: 49 Techniques That Put Students on the Path to College. Doug Lemov. Jossey-Bass, 2010.

SCIENTIFIC AMERICAN ONLINE
Read more results from *Scientific American* and Indiana University's survey at **ScientificAmerican.com/aug2012/sa-survey**

HEALTH

QUIET LITTLE TRAITORS

Cells that permanently stop dividing have long been recognized as one of the body's defenses against cancer. Now they are also seen as a sometime culprit in cancer and a cause of aging

By David Stipp

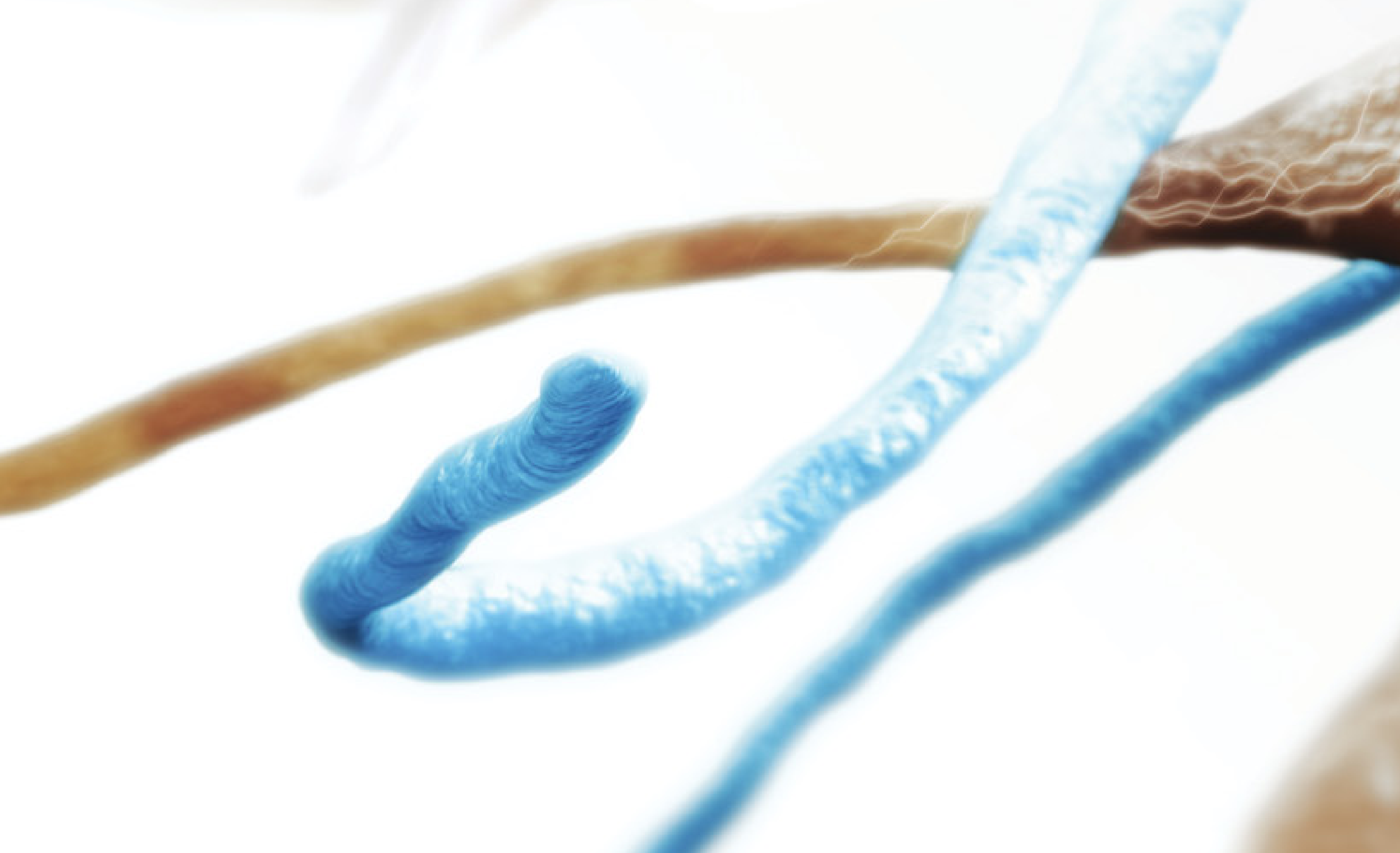
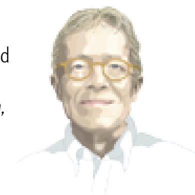


Illustration by Anatomy Blue

CELL SIGHTING: Investigators identify senescent cells—those that have lost the ability to divide—by their color. They turn blue when exposed to a particular chemical.

David Stipp is a Boston-based science writer who has focused on gerontology since the late 1990s. His book on the subject, *The Youth Pill: Scientists at the Brink of an Anti-Aging Revolution*, was published by Current/Penguin Group in 2010. Stipp blogs about aging science at www.davidstipp.com.



IN 1999 JAN M. VAN DEURSEN AND HIS COLLEAGUES AT THE Mayo Clinic in Rochester, Minn., wanted to see whether mangled chromosomes cause cancer. So they engineered mice deficient in a protein that helps to maintain chromosomal integrity. The rodents' coils of DNA were duly deranged. Surprisingly, though, the animals were not particularly tumor-prone. Instead they developed a strange grab bag of ills, including cataracts, dwindling muscles, rapid thinning of fat under the skin and progressive spinal curvature, that made them look like one-humped camels. They also tended to die young.

Van Deursen had no idea why those particular abnormalities showed up. Then, in 2002, he spotted a report on mice afflicted by accelerated aging and was struck by photographs showing that their backs became humped as they aged. Suddenly, it hit him: his camel-backed mice, too, were aging unusually fast. Probing deeper, the Mayo team discovered that cells in a number of the rodents' tissues had prematurely slid into a state called cellular senescence, in which cells permanently lose the ability to divide and become aberrant in other ways. Such failure of cell division would explain the bone, muscle, eye and skin abnormalities observed by van Deursen's group.

The investigators then went beyond explanations and did something about the symptoms: by adding a second genetic alteration to their mice, they eliminated senescent cells as they formed and thereby slowed various aspects of the animals' fast aging. The finding, reported last November, brought the field of cellular senescence to the fore of aging science and breathed new life into a controversial idea proposed more then 50 years ago: that the loss of cells' ability to divide causes the body to deteriorate with time. Other recent research is also drawing new attention to the process for a related reason. Long believed to be a defense against cancer, cellular senescence has been exposed as two-faced—blocking tumor growth in some ways but promoting it in others.

The new findings suggest that slowing our cells' entry into senescence might help postpone late-life cancers and other diseases. Because deletion of senescent cells in the Mayo mice required complex genetic manipulations, the same treatment will not be offered to people anytime soon. Yet all is not lost. A number of simpler interventions could potentially fit the bill.

OLD, TIRED CELLS

THE STUDY OF SENESCENT CELLS has been a story of provocative surprises and extensive revisions. Initially biologists thought of them as cells that simply had exhausted their ability to reproduce. Leonard Hayflick, co-discoverer of the senescent state, established in 1961 that some kind of molecular counter triggers senescence after about 50 replication cycles in human cells. He theorized that this "Hayflick limit" on replication might underlie whole-body aging because stalled proliferation would prevent cells from replacing those lost in damaged tissues. He also posited that cells are programmed to run out of dividing power after some number of replication cycles because having a built-in limit would prevent damaged cells from proliferating uncontrollably and becoming cancerous. Cellular senescence's contribution to aging, in other words, was seen as the price we pay for its help in defending us against cancer.

The theory that senescing cells drive aging gained ground af-

IN BRIEF

Senescent cells—which have permanently lost the ability to divide—were once assumed to contribute to aging by undermining tissue repair. Cells were thought to enter senescence to avoid becoming cancerous when damage put them at risk of proliferating uncontrollably.

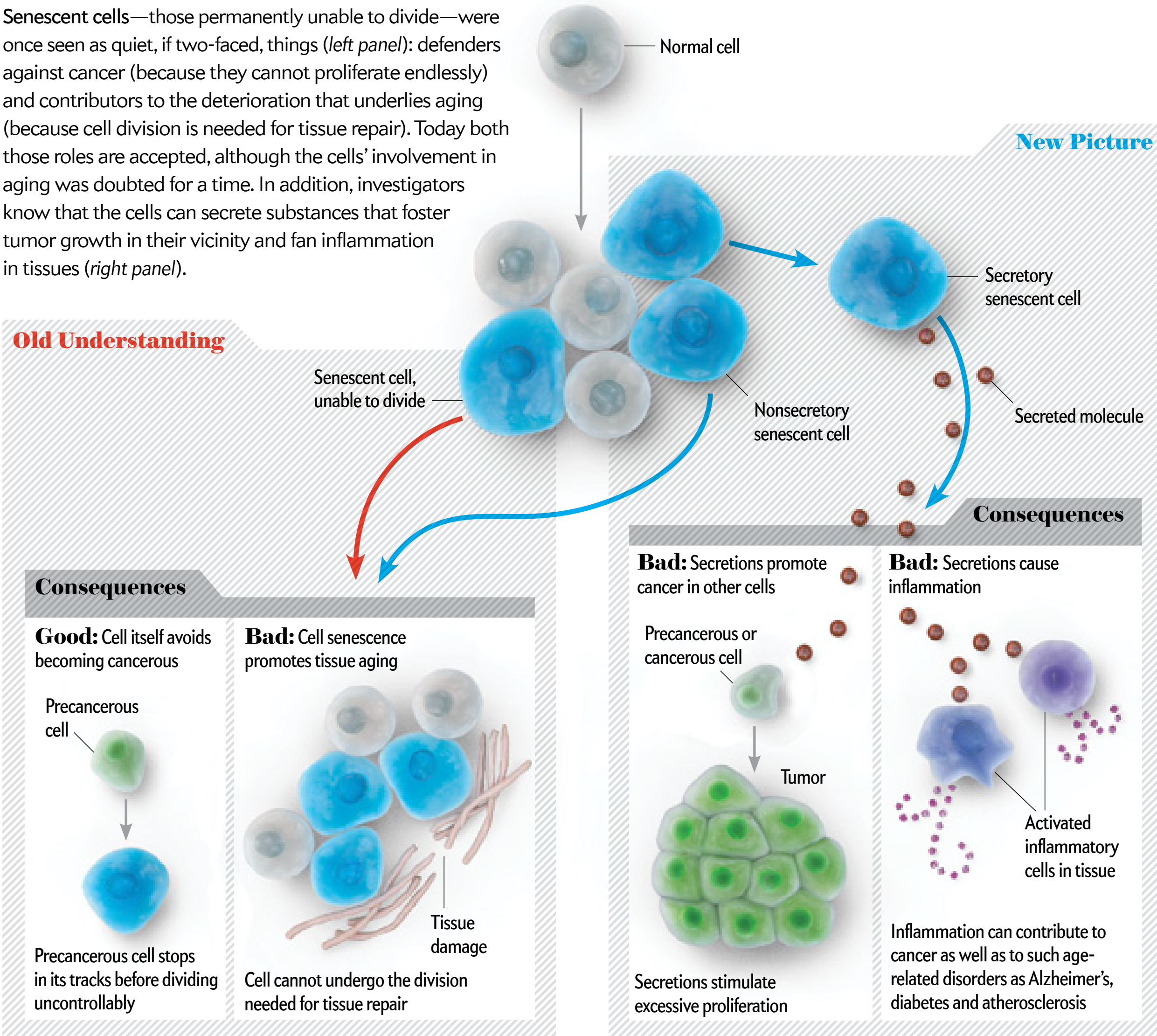
Later, the notion that senescent cells play a part in the aging of tissues and bodies fell out of favor. More recently, though, that idea has gained new support.

Recent research indicates that the cells can contribute to aging in the originally proposed way and also by spurring inflammation. Plus, they can harm nearby cells in ways that promote cancer.

Some evidence in mice suggests that retarding cellular senescence may help slow aging and delay some of the ills associated with it.

Good Cells Gone Bad

Senescent cells—those permanently unable to divide—were once seen as quiet, if two-faced, things (*left panel*): defenders against cancer (because they cannot proliferate endlessly) and contributors to the deterioration that underlies aging (because cell division is needed for tissue repair). Today both those roles are accepted, although the cells' involvement in aging was doubted for a time. In addition, investigators know that the cells can secrete substances that foster tumor growth in their vicinity and fan inflammation in tissues (*right panel*).



ter studies beginning in the 1970s uncovered a molecular clock behind the Hayflick limit. Each time a cell divides, its telomeres—stretches of DNA at the tips of chromosomes—shorten; cells stop dividing when their telomeres shrink beyond some set length. Our cells, it seemed, were programmed to become senescent if we lived long enough.

Later research undercut the theory, though. Multiple laboratories reported in the late 1990s, for instance, that the ability of skin cells to proliferate did not significantly decline with age—a sign that the Hayflick limit was not necessarily reached frequently enough to significantly disrupt tissue repair in a person's lifetime. In line with this view, others established that mice have very long telomeres, apparently preventing their proliferative cells from clocking out before the animals died. In 2001 two gerontologists, Harriet and David Gershon, bluntly declared in a review article that the telomere theory of aging should "be considered irrelevant."

As the tick-tock theory of aging was running down, evidence in favor of cell senescence's other apparent role—as a defense against cancer—was accumulating. By the 1990s it was well known that certain kinds of damage to cells, such as genetic mutations, could trigger uncontrolled proliferation and other changes characteristic of cancers. And, it turned out, various forms of cellular injury could induce senescence—presumably to prevent the damaged cells from becoming malignant. Dousing cells with DNA-damaging oxidizing chemicals, for example, could induce its hallmark proliferative arrest. Tellingly, in 1997 a team led by Manuel Serrano, now at the Spanish National Cancer Research

Illustration by Gert Nielsen

Center in Madrid, found that senescence can be established by a sustained surge of signals within a cell urging it to divide. Oncogenes—mutated genes that help to drive tumors' unchecked growth—are known for pounding out such relentless go-go beats.

These and other discoveries suggested that an anticancer mechanism within cells continually scans for signs of damage that can tip them toward uncontrolled growth. If such signs are sustained and surpass a critical threshold, the mechanism can permanently arrest cell division by triggering senescence, which allows the cell to repair the damage, if possible, and carry on in a kind of semiretired state.

CANCER PROMOTERS

THEN CAME A SHOCK: researchers discovered that senescent cells could sometimes spur on cancer. Among them was Judith Campisi, now at the Buck Institute for Research on Aging in Novato, Calif. She then came up with a hypothesis that has helped quash the idea that senescent cells merely sit quietly in their dotage. The hypothesis holds that the cells can actively both foster tumor growth and cause widespread damage of other kinds.

The first hints that senescent cells might play such an insidious role arose in the late 1990s, as evidence emerged suggesting that senescent cells can disrupt the cells and tissues in their immediate vicinity—in their "microenvironments"—possibly turning the regions into bad neighborhoods that could abet tumor growth. In 2001 Campisi's lab corroborated this idea with a groundbreaking study showing that senescent cells maintained in a culture dish can stimulate precancerous cells in the same culture to form unusually aggressive tumors when injected into mice. The bad-neighborhood effect appeared to stem from the tendency of many senescent cells to secrete a mix of potentially hazardous molecules, including ones that promote cell proliferation and others that break up extracellular proteins surrounding and supporting cells. (Spreading tumor cells are thought to employ the same degradative enzymes to melt through tissues' structural boundaries.) In 2008 Campisi published further support for what she calls the "senescence-associated secretory phenotype," or SASP, using the term to highlight that, in certain contexts, senescent cells secrete hurtful molecules, behaving like catatonic zombies drooling poison.

Why, scientists wondered, would the cells long pictured as cancer preventers actively promote the very malady they seem to have been evolved to block? Campisi drew on studies about wound healing, among other lines of research, to help explain how they came to acquire this role.

One line of work showed that cancer and wound healing, strangely enough, are similar in some ways. Tumors and partly healed wounds, for instance, are both laced with fibrous proteins that form when the precursors of clotting proteins leak from blood vessels and polymerize into a matrix to support rebuilding. Struck by this similarity, in 1986 Harvard Medical School pathologist Harold Dvorak speculated that tumors harness and subvert the body's wound-healing response to aid their abnormal growth. Because of this Machiavellian jujitsu, he concluded, tumors appear to our bodies as an "unending series of wounds that continually initiate healing but never heal completely."

Another line of work demonstrated that senescent cells participate in wound healing. When tissues are damaged, certain cells in the vicinity respond by senescing, after which they fuel an inflammatory phase that initiates healing. The phase involves secretion of chemical messengers called cytokines that attract immune cells and activate them to fight infections and remove dead cells and debris. Later, healthy cells proliferate to replace lost ones, and then the proliferative phase gives way to a remodeling one, during which senescent cells secrete degradative enzymes to tear apart fibrous proteins laid down as an initial scaffold; this destruction limits scar formation.

Fitting these pieces together, Campisi postulated that beyond harnessing cellular senescence to block excessive proliferation by damaged cells, evolution turned to it for wound repair, which entailed adding SASPiness to its repertoire. Unfortunately, the secretory mode makes senescent cells perfect partners in crime for tumors bent on co-opting the wound-healing program for their own growth. Equally regrettable, their ability to fan inflammation may turn the entire body into a bad neighborhood—low-level inflammation is thought to promote the progression not only of cancer but also of atherosclerosis, Alzheimer's disease, type 2 diabetes and many other diseases of aging.

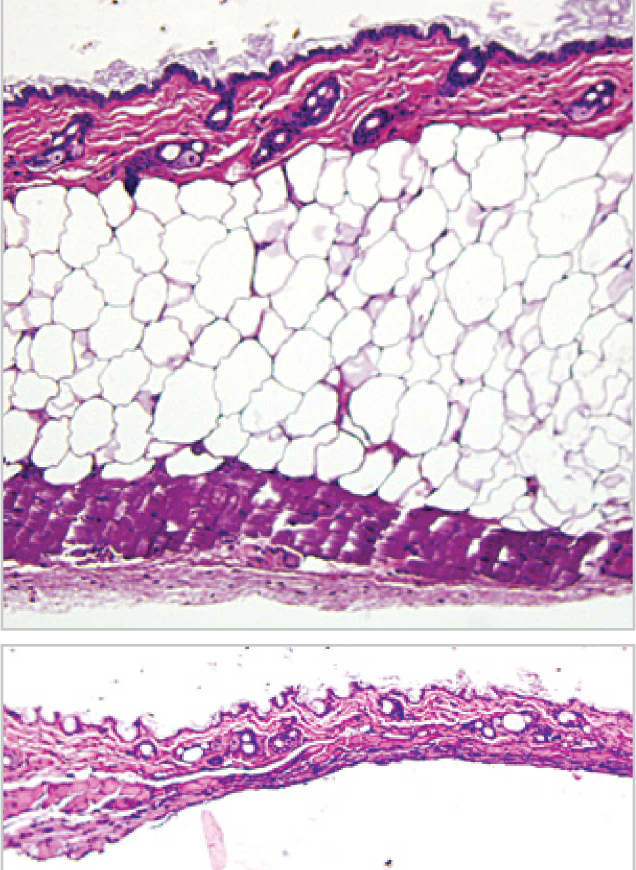
AGING AGENTS, AFTER ALL

INDEED, AS INVESTIGATORS REALIZED that senescent cells could behave in ways that fostered cancer, they also began to accrue fresh evidence for a role in aging. In particular, they found that senescent cells turn up with suspicious frequency in tissues of rodents and humans where things have gone badly awry, as well as in aging bodies as a whole. In 2006, for example, researchers showed that the normal decline of immune function in older mice occurs in tandem with an age-related increase in the senescence of the stem cells that continually generate various kinds of immune cells.

A number of these findings were made possible in part by discovery of features that identify cells as having become senescent. One of the most useful senescence markers is an elevated level of a protein encoded by a gene called $p16^{INK4a}$ (*p16* for short). Discovered in 1993 by David Beach of Queen Mary, University of London, *p16* activity was later found to help force cells to stop dividing when they sense various kinds of damage.

Norman E. Sharpless of the University of North Carolina at Chapel Hill School of Medicine and his colleagues conducted a number of studies correlating p16 protein levels and aging. They demonstrated, for instance, that levels rise with age in rodent and human cells and that this senescence-inducing rise is tied to a diminished ability of the cells to proliferate and repair damaged tissues. In 2004 the team reported that p16 increases markedly in almost all rodent tissues with advancing age and can be slowed by calorie restriction—a form of stringent dieting known since the 1930s to extend life span and promote healthy aging across various species. Five years after the 2004 finding, the Sharpless lab showed that getting older is accompanied by sharply increasing p16 levels in the human immune system's T cells. Intriguingly, p16 levels in the T cells are higher in smokers and people who are physically inactive, suggesting that those behaviors might promote cellular senescence. Anecdotally, Sharpless cheerfully told me that after his lab developed an easy-to-use test for measuring p16, he discovered that his own levels were twice as high as those of his graduate students. He is a young-looking 45-year-old.

Beyond correlating p16 and cellular senescence with features of aging, Sharpless and his colleagues have published a series of experimental findings supporting the idea that cellular senes-



EVIDENCE OF A ROLE IN AGING: **In mice able to eliminate senescent cells, the fatty layer in the skin stays lush (*white in top image*), but it dwindles in other mice over time (*bottom*).**

COURTESY OF VAN DEURSEN LABORATORY

cence contributes to tissue and organismic aging. In 2006 they reported that aging mice with disabled *p16* genes and thus, presumably, a much reduced tendency to form senescent cells resemble younger mice in their enhanced ability to regenerate pancreatic cells knocked out by exposure to a toxin; that aging mice with suppressed *p16* activity are better able than normal peers to regenerate neurons in certain parts of their brain; and that dialing back p16 levels in blood system stem cells—the ones that give rise to immune and red blood cells—retards the usual aging-related decline in the stem cells' regenerative power.

Other studies conducted over the past five years have suggested that genetic differences affecting the amount of p16 protein people make—and therefore the rate at which their cells become senescent as they age—help to determine their risks of many age-associated diseases, among them atherosclerosis and Alzheimer's. Sharpless says that these "superinteresting" findings have galvanized medical researchers' interest in p16 and that they are the "key to knowing that something real is going on" in research implicating cellular senescence as a culprit in aging-related decline.

Last year's Mayo Clinic study, though, provided the most direct evidence that interfering with cellular senescence might be beneficial, and van Deursen's group did it by taking advantage of p16's role as an ID tag for such cells. The team genetically engineered its mice both to have chromosomal defects that led to premature cellular senescence in various tissues and to carry a gene that made cells susceptible to killing by a particular drug if their *p16* genes were switched on; nonsenescent cells, whose *p16* genes were not activated, were not affected. Drug treatment throughout life erased the senescent cells and delayed the thinning of fat under the skin, loss of muscle, development of cataracts and the onset of other aging-related deterioration that occurred prematurely in untreated mice. Treatment begun later in life slowed age-related losses of fat and muscle.

As exciting as the Mayo findings are, they do not, by themselves, demonstrate that eliminating senescent cells during normal aging will be helpful in people or will extend life. Campisi cautions, for instance, that the study did not definitively prove that senescent cells drive normal aging; the mice in the study suffered from accelerated aging. And not all aspects of their accelerated aging involved rapid cellular senescence. In fact, erasing the senescent cells did not help avert the rodents' main cause of death—early onset of heart and blood vessel dysfunction—and so their life spans were not substantially stretched out.

SIMPLE STEPS

STILL, SUPPOSE THAT at some point scientists find that reducing cellular senescence in people does turn out to retard aging or at least delay wrinkling and some more serious age-related disorders. How might one intervene safely in the senescence process?

Replicating the Mayo study in people would require editing their genomes before birth, so that option that will not be tenable anytime soon, if ever. Simply blocking the activity of *p16* genes with a drug would probably backfire by increasing the risk of unwanted cell proliferation and cancer. Some surprisingly simple options might be open to us, however.

That smokers and sedentary people tend to have higher p16 levels suggests that not smoking and exercising regularly may help prevent the kind of molecular damage that promotes cellular senescence. Losing weight may be another way. Indeed, van Deursen and his Mayo colleague James Kirkland theorize that fat cell precursors called preadipocytes may induce a condition akin to accelerated aging in obese animals and people because the cells tend to become senescent in large numbers and, in keeping with Campisi's theory, promote chronic, low-level inflammation throughout the body.

Some preliminary evidence also hints that a drug called rapamycin can inhibit cellular senescence without fostering cancer. Interestingly, chronically feeding rapamycin to mice has been shown to extend their life spans. And recently Campisi's lab showed that certain anti-inflammatory drugs suppress senescent cells' destructive SASP mode. Yet for the time being, Sharpless says, the most prudent way to oppose deleterious cellular senescence is: "Don't smoke, eat reasonably and take exercise."

No one knows yet whether braking cellular senescence can slow normal aging. The theory that senescent cells are important contributors to age-related deterioration at the tissue and organ levels is, however, now aging with remarkable grace. It seems increasingly likely that this insight will one day lead to potent new ways to promote healthy aging. SA

MORE TO EXPLORE

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Clearance of p16^{Ink4a}-Positive Senescent Cells Delays Ageing-Associated Disorders. Darren J. Baker et al. in *Nature,* Vol. 479, pages 232–236; November 10, 2011.

SCIENTIFIC AMERICAN ONLINE
See researcher Judith Campisi talk about cellular senescence at **ScientificAmerican.com/aug2012/senescence**


Spotted Tree
Rockhopper
O'BRIEN

WHICH SPECIES WILL LIVE?

Like battlefield medics, conservationists are being forced to explicitly apply triage to determine which creatures to save and which to let go

By Michelle Nijhuis

Illustration by Tim O'Brien

Michelle Nijhuis is a Colorado-based journalist who writes about science and the environment for many publications. As a 2011 Alicia Patterson Foundation Fellow, she researched strategies for protecting critically endangered species.

THE ASHY STORM-PETREL,

a tiny, dark-gray seabird, nests on 11 rocky, isolated islands in the Pacific Ocean off the coasts of California and Mexico. Weighing little more than a hefty greeting card and forced to contend with invasive rats, mice and cats, aggressive seagulls, oil spills and sea-level rise, it faces an outsize fight for survival. At last count, only 10,000 remained. Several other species of storm-petrels are similarly endangered.

Yet at least one conservation group has decided to ignore the petrel. In the winter of 2008 the Wildlife Conservation Society was focusing its far-flung efforts on a small number of animals. The society's researchers had spent months analyzing thousands of declining bird and mammal species around the world and had chosen several hundred that could serve as cornerstones for the organization's work. They then turned to people with decades of experience studying wildlife to further narrow the possibilities.

Dozens of these experts gathered in small conference rooms in New York City, southwestern Montana and Buenos Aires to make their choices. They judged each species for its importance to its ecosystem, its economic and cultural value, and its potential to serve as a conservation emblem. They voted on each animal publicly, holding up red, yellow or green cards. When significant disagreement occurred, the experts backed up their reasoning with citations, and the panels voted again. By the middle of the first day most panels had eliminated more than half the species from their lists.

At some point in the afternoon, however, in every meeting, the reality of the process would hit. As entire groups of species, including storm-petrels, were deemed valuable but not valuable enough, a scientist would quietly shut down, shoulders slumped and eyes glazed. "I'm just overwhelmed," he or she might say. Panel members would encourage their colleague, reminding him or her that these choices were necessary and that the science behind them was solid. John Fraser, a conservation psychologist who moderated the panels, would suggest a coffee

IN BRIEF

Conservation groups can no longer afford to try to protect as many animals and plants as they have in the past, so they are increasingly turning to new systems of triage to explicitly determine which species to save and which to leave to die.

Function-first forms of triage favor species that perform a unique job in nature, such as whitebark pines, which provide vital food for grizzly bears.

Evolution-first approaches seek to preserve genetic diversity—from the two-humped Bactrian camel to the Chinese giant salamander—which can help all the world's species survive and adapt in fast-changing environmental conditions.

Other methods refine the popular hotspots approach, which focuses on saving whole ecosystems but may give short shrift to human needs.

break. "I'd say, 'I'm sorry, but we have to stop. This is a very important part of the process,'" he remembers. "It was important to recognize the enormity of what we were doing—that we were confronting loss on a huge scale."

The experts knew that all conservation groups and government agencies were coping with similar choices in tacit ways, but the Wildlife Conservation Society process made those decisions more explicit and more painful. As budgets shrink, environmental stresses grow, and politicians and regulators increasingly favor helping the economy over helping the planet, many scientists have come to acknowledge the need for triage. It is time, they say, to hold up their cards.

TRIAGE: A FOUR-LETTER WORD

THE CONCEPT of conservation triage is based loosely on medical triage, a decision-making system used by battlefield medics since the Napoleonic Wars. Medical triage has several variations, but all of them involve sorting patients for treatment in difficult situations where time, expertise or supplies, or all three, are scarce. The decisions are agonizing but are considered essential for the greater good.

SOONER OR LATER A VULNERABLE SPECIES WILL BE TOO HARD TO SAVE. YET MANY CONSERVATIONISTS REMAIN UNCOMFORTABLE MAKING THE FINAL, FATEFUL DECISIONS THAT TRIAGE REQUIRES.

In 1973, however, when the U.S. Congress passed the Endangered Species Act, the mood was not one of scarcity but of generosity. The act, still considered the most powerful environmental law in the world, stipulated eligibility for protection for all nonpest species, from bald eagles to beetles. Later court decisions confirmed its broad reach. In their book *Noah's Choice,* journalist Charles C. Mann and economist Mark L. Plummer describe the act's reasoning as the Noah Principle: all species are fundamentally equal, and everything can and should be saved, regardless of its importance to humans.

Trouble arose in the late 1980s, when proposed endangered-species listings of the northern spotted owl and some salmon varieties threatened the economic interests of powerful timber and fishing industries, setting off a series of political and legal attempts to weaken the law. Environmentalists fought off the attacks, but the bitter struggle made many supporters suspicious of any proposed changes to the law, even those intended to increase its effectiveness. In particular, proponents feared that any overt attempt to prioritize endangered species—to apply the general principle of triage—would only strengthen opponents' efforts to try to cut species from the list. If such decisions had to happen, better that they be made quietly, out of political reach.

"The environmental community was always unwilling to talk about triage," says Holly Doremus, a law professor at the University of California, Berkeley. "Even though they knew it was going on, they were unwilling to talk about it."

Today triage is one of the most provocative ideas in conservation. To many, it invokes not only political threats to laws such as the Endangered Species Act but an abandonment of the moral responsibility for nature implied in the Noah Principle. "Triage is a four-letter word," conservation biologist Stuart Pimm recently told Slate's Green Lantern blog. "And I know how to count."

PINE TREES OR CAMELS

CONSERVATIONISTS who are pushing for explicit triage say they are bringing more systematic thinking and transparency to practices that have been carried out implicitly for a long time. "The way we're doing it right now in the United States is the worst of all possible choices," says Tim Male, a vice president at Defenders of Wildlife. "It essentially reflects completely ad hoc prioritization." Politically controversial species attract more funding, he says, as do species in heavily studied places: "We live in a world of unconscious triage."

In recent years researchers have proposed several ways to make triage decisions, with the aim of providing maximum benefit for nature as a whole. Some scientists argue for weighting species according to their role in the ecosystem, an approach we might call "function first." Threatened species with a unique job, they say, or "umbrella" species whose own survival ensures the survival of many others, should be protected before those with a so-called redundant role. One example is the campaign to protect the Rocky Mountains' high-elevation whitebark pines, trees stressed by warming temperatures and associated beetle outbreaks. Because high-fat whitebark pine nuts are an important food source for grizzly bears in the fall and spring, many conservation groups view the pine as a priority species.

The advantage of this function-first approach is that it focuses on specific ecological roles rather than raw numbers of species, giving conservationists a better chance at protecting functioning ecosystems. The approach, however, is useful only in well-understood systems, and the number of those is small. An exclusively function-first analysis would almost certainly leave many ecologically important species behind.

As an alternative, the EDGE (Evolutionarily Distinct and Globally Endangered) of Existence program run by the Zoological Society of London argues for prioritizing species at the genomic level, an approach we might call "evolution first." Rather than focusing on well-known species with many near relatives, the EDGE program favors the most genetically unusual threatened species. Examples include the two-humped Bactrian camel; the long-beaked echidna, a short, spiny mammal that lays eggs; and the Chinese giant salamander, which can grow to six feet in length.

The evolution-first approach emphasizes the preservation of genetic diversity, which can help all the world's species survive and adapt in fast-changing environmental conditions by providing a robust gene pool. But as University of Washington ecologist Martha Groom points out, exclusive use of the approach could miss broader threats that affect entire taxa, leaving groups of species vulnerable to wholesale extinction. "What if a whole branch of the evolutionary tree is endangered?" she asks. "What do we do then?"

Of course, species are valuable for many different reasons. Some play a vital role in the ecosystem, some have unique genes, some provide extensive services to humans. No single criterion can capture all these qualities. The Wildlife Conservation Society combined different triage approaches in its analyses: it gave priority to threatened species that have larger body size and wider geographic range, reasoning that protection of these creatures would likely benefit many other plants and animals. It also gave higher rankings to species with greater genetic distinctiveness. The expert panels then considered more subjective qualities, such as cultural importance and charisma, which, like it or not, are important to fund-raising.

Groom, who helped to lead the society's analysis, says it opted for the combined approach because much of the information she and her colleagues needed was unknown or unquantifiable. "There's an awful lot of uncertainty and ignorance about all species," she says. But with a combination of available data and expert opinions, the analysis identified a small group of "global priority" species that the organization can focus on.

ECOSYSTEMS OVER SPECIES

GIVEN THE IMPORTANCE of protecting not simply individual animals but also the relations among them, some researchers say that triage approaches should select among ecosystems instead of species. In the late 1980s British environmentalist Norman Meyers proposed that his global colleagues try to protect the maximum number of species by focusing on land areas that were full of plants found nowhere else on the planet and that were also under pressing environmental threats.

POSTER CHILDREN

Winners and Losers

Conservationists are trying different forms of triage to help them decide which species to save and not to save. Each method favors certain priorities, such as an animal's role in preserving a food chain or in maintaining genetic diversity. Serving those priorities ultimately deems species winners or losers; some samples are shown below.

Function First
Favors species that perform a unique job in nature. Gray wolves control animal populations; Chinese river dolphins serve no meaningful role.

Evolution First
Seeks to preserve genetic diversity. California condors are rare relics of the Pleistocene era; Gunnison sage grouses are related to other grouse species.

Hotspots
Prefers ecosystems rich in species. Sequoia forests house many unique plants and animals; mangrove forests are less diverse.

TOP TO BOTTOM: TIM FITZHARRIS, KONRAD WOTHE, AND YVA MOMATIUK AND JOHN EASTCOTT *Minden Pictures* (*winners*); TOP TO BOTTOM: MARK CARWARDINE, GERRIT VYN AND KAZUMA ANEZAKI *Minden Pictures* (*losers*)

Meyers called such places hotspots. He and his partners at Conservation International eventually identified 25 hotspots worldwide, from coastal California to Madagascar, that they thought should top priority lists. In a sense, the approach combines the function-first and evolution-first processes: it protects ecological relations by focusing on entire ecosystems, and it protects genetic diversity by prioritizing endemic species. The idea caught on and influences decisions by many philanthropists, environmental organizations and governments today.

Nevertheless, in recent years researchers have criticized hotspots for oversimplifying a global problem and for giving short shrift to human needs [see "Conservation for the People," by Peter Kareiva and Michelle Marvier; SCIENTIFIC AMERICAN, October 2007]. "It was brilliant for its time," says Hugh Possingham of the University of Queensland in Australia. "But it used just two criteria."

In an effort to refine the concept, Possingham and his colleagues developed Marxan, a software program that is now in wide use. It aims to maximize the effectiveness of conservation reserves by considering not only the presence of endemic species and the level of conservation threats but also factors such as the cost of protection and "complementarity"—the contribution of each new reserve to existing biodiversity protections. Mangrove forests, for instance, are not particularly rich in species and might never be selected by a traditional hotspot analysis; Possingham's program, however, might recommend protection of mangrove forests in an area where representative swaths of other, more diverse forest types had already been preserved, resulting in a higher total number of species protected.

Protected areas and parks, however, can be difficult to establish and police, and because climate change is already shifting species ranges, static boundaries may not offer the best long-term protection for some species. In response, Possingham has created a resource-allocation process that goes well beyond the selection of hotspots, allowing decision makers to weigh costs, benefits and the likelihood of success as they decide among different conservation tactics. "You do actions—you don't do species," Possingham says. "All prioritizations should be about actions, not least because in many cases actions help multiple species."

The New Zealand Department of Conservation has used the resource-allocation process to analyze protection strategies for about 710 declining native species. It concluded that by focusing on the actions that were cheapest and most likely to succeed, it could save roughly half again as many plants and animals from extinction with the same amount of money. Although some scientists worry that the process places too much emphasis on preserving sheer numbers of threatened species and too little on preserving ecosystem function, resource-allocation analysis is now under way in Australia, and Possingham has spoken with U.S. Fish and Wildlife Service officials about the process.

"People think triage is about abandoning species or admitting defeat," says Madeleine Bottrill of Conservation International, who is a colleague of Possingham. To the contrary, she argues: by quantifying the costs and payoffs of particular actions, the trade-offs become explicit. Agencies and organizations can identify what is being saved, what is being lost and what could be saved with a bigger budget, giving them a much stronger case for more funding.

SUCCESS BREEDS SUCCESS

IT IS POSSIBLE that the very act of setting priorities more overtly could inspire societies to spend more money on conservation efforts. Defenders of Wildlife's Male says prioritization schemes, far from exposing nature to political risks, offer practical and political advantages. "If we focus more effort on the things we know how to help, we're going to produce more successes," he says. "More successes are a really compelling argument—not just to politicians but to ordinary people—for why [conservation programs] should continue."

Trailing behind such successes, however, are undeniable losses, and true triage must acknowledge them. "We're very good as humans, aren't we, at justifying any amount of work on anything based on undeclared values," says Richard Maloney of the New Zealand Department of Conservation. "We're not very good at saying, 'Because I'm working on this species, I'm not going to fund or work on these seven or eight species, and they're going to go extinct.'" And yet Maloney himself is reluctant to name the species likely to lose out in his agency's resource-allocation analysis. Rockhopper penguins—whose vital supply of krill has declined because of shrinking sea ice driven by climate change—fall to the bottom of the department's list because of the costly, long-shot measures needed to protect them. Yet the species' low priority, Maloney argues, should be seen not as a death sentence but as a call to action by other groups.

Sooner or later, though, a vulnerable species or habitat—the rockhopper penguin, the whitebark pine ecosystem—will require measures too expensive for any government or group to shoulder. What then? Do societies continue to pour money into a doomed cause or allow a species to die out, one by one, in plain sight? Even though the conversation about triage has come a long way, many conservationists remain uncomfortable taking responsibility for the final, fateful decisions that triage requires.

The central difficulty is that, just as with battlefield triage, the line between opportunity and lost cause is almost never clear. In the 1980s, when the population of California condors stood at just 22, even some environmentalists argued that the species should be permitted to "die with dignity." Yet others made an evolution-first argument, calling for heroic measures to save the rare Pleistocene relic. With heavy investments of money, time and expertise, condors were bred in captivity and eventually returned to the wild, where 217 fly today, still endangered but very much alive.

"We can prevent extinction; we've demonstrated that," says John Nagle, a law professor at the University of Notre Dame who has written extensively about environmental issues. But "knowing that an extinction was something we could have stopped and chose not to—I think that's where people kind of gulp and don't want to go down that road," he adds.

Similarly, by creating what prominent restoration ecologist Richard Hobbs calls a "too-hard basket" for species that would cost too much to save, a triage system could allow societies to prematurely jettison tough cases, choosing short-term economic rewards over long-term conservation goals. The Endangered Species Act itself has one provision for such a too-hard basket—it allows for a panel of experts that can, in unusual circumstances, permit a federal agency to violate the act's protections. But the so-called God Squad is deliberately difficult to convene and has so far made only one meaningful exemption to the act: letting the Forest Service approve some timber sales in habitats of the struggling northern spotted owl.

As climate change, population expansion and other global pressures on biodiversity continue, however, more and more species are likely to require heroic measures for survival. Prioritizing species by ecological function, evolutionary history or other criteria will help shape conservation strategies, but for the greater good of many other species, societies will almost certainly have to consciously forgo some of the most expensive and least promising rescue efforts.

In the U.S., legal scholars have suggested ways of reforming the Endangered Species Act to reckon with this reality—to help the law bend instead of break under political pressure. Yet Nagle says that the essence of the law, the Noah Principle, remains acutely relevant. Given the temptations that accompany triage, he says, the exhortation to save all species remains a worthy, and perhaps even necessary, goal. Just as a battlefield medic works unstintingly to save lives, even while knowing that he or she cannot save them all, societies should still aspire to the Noah Principle—and stuff the ark to the brim. SA

MORE TO EXPLORE

Noah's Choice: The Future of Endangered Species. Charles C. Mann and Mark L. Plummer. Knopf, 1995.

Optimal Allocation of Resources among Threatened Species: A Project Prioritization Protocol. Liana N. Joseph et al. in *Conservation Biology,* Vol. 23, No. 2, pages 328–338; April 2009.

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SCIENTIFIC AMERICAN ONLINE
More examples of species that could win or lose under different triage systems can be seen at **ScientificAmerican.com/aug2012/nijhuis**

BACTERIOLOGY

Phage Factor

Long ignored by mainstream researchers, the viruses that infect bacteria have a role to play in modern medicine, Vincent Fischetti says

Interview by Brendan Borrell

INSIDE A THIRD-FLOOR OFFICE A FEW BLOCKS FROM THE HUDSON RIVER IN YONKERS, N.Y., a small biotechnology company called ContraFect prepares to test a remarkable new way to kill bacteria in humans. Antibiotics, after many years of use and overuse, have lost their edge against rapidly evolving bacteria, with everything from staph infections to tuberculosis becoming more devastating, deadly and difficult to treat. Whereas traditional antibiotics have mostly been derived from chemicals produced by soil bacteria and fungi, ContraFect has found an alternative in bacteriophages: viruses that infect bacteria and hijack their internal machinery. In nature, phages produce enzymes called lysins, causing the bacteria fall to pieces and new phages to tumble out by the hundreds. ContraFect believes it can harness these lysins to treat bacterial infections in humans.

The first trials for patient safety are expected to start this year. It is a moment that Vincent Fischetti, a 71-year-old microbiologist at the Rockefeller University, has been approaching for decades. A child of working-class parents on Long Island, he once thought he would be a dentist before getting hooked on microbiology as an undergraduate. Studying for his master's degree by night and paying his bills as a technician on a scarlet fever project by day, he became fascinated by phages. After years of work, he demonstrated, in 2001, that lysins could help mice fight strep throat infection. The military also sees potential in lysins, which could be administered before surgery to prevent infection or spread over surfaces to clean an area contaminated by an anthrax attack.

More broadly, researchers are showing renewed interest in delivering cocktails of phages to treat stubborn infections. That strategy was nurtured in the former Soviet Union and all but ignored stateside. Some technical and practical challenges stand in the way of their widespread adoption in human therapeutics,

IN BRIEF

WHO
VINCENT FISCHETTI

VOCATION | AVOCATION
Microbiologist

WHERE
Rockefeller University

RESEARCH FOCUS
Finding an alternative to overused antibiotics.

BIG PICTURE
Could viruses that attack bacteria be used to treat and prevent infections?

Photograph by Spencer Heyfron

although several U.S. companies have Food and Drug Administration approval to include *Salmonella-* and *Escherichia coli*–killing phages in packaged meats and other food products.

Scientific American spoke with Fischetti to learn more about the promise and peril of phages in human health. Excerpts follow.

Scientific American: How did you first become interested in science?
FISCHETTI: I grew up on Long Island, and my family had a landscaping business right next to a pond. When I was around 12, my parents bought me a microscope. There was no Internet or anything to distract me, so I would take water samples from the pond and spend evenings looking at the microbes swimming around in the water samples: *Euglena, Paramecium* and all kinds of things. I spent hours just fooling around with that. When I took my first microbiology course at Wagner College on Staten Island, I realized this is really what I love to do, and I stayed with it.

When did you first learn about phages?
In my first job, I was a lab technician at Rockefeller working with John Zabriskie, a physician-scientist. At that time, scientists at New York University had recently discovered that pertussis toxin—the toxin that causes whooping cough—was produced by a bacteriophage carried by a bacterium. We wondered whether the toxin that caused scarlet fever was also controlled by a bacteriophage. We found that it was. In this case, the *Streptococcus* bacterium carries a bacteriophage that has the gene for the scarlet fever toxin. When the phage replicates inside a streptococcal organism that has infected a person, it produces the toxin, which causes the reddening of the skin and high temperature associated with scarlet fever. We now know phages are responsible for most of the toxin-associated diseases.

How important are phages in the environment?
Every gram of soil, every cubic centimeter of water, has at least 10 million to 100 million phages. Phages are the most numerous biological entities on earth. They are in everything we touch, we eat, we drink. We ingest phages all the time. They are found in our gut, on our mucous membranes, everywhere in our body. Bacteriophages continuously infect and kill bacteria. Then resistant bacteria grow out again, and the process continues. Every two days half the bacteria on earth are killed by bacteriophages.

It's a hugely dynamic process, where both bacteria and bacteriophages need each other to survive. And it's my view—and I don't know if anyone actually believes this view—that because there are 10 times more bacteriophages than there are bacteria, what's really in control of the planet are the bacteriophages. They control everything.

When did scientists realize that phages could be used in medicine?
About 100 years ago, when bacteriophages were first identified, antibiotics did not exist, and it was felt that here was the substance that kills bacteria—we could now harness this to kill bacteria causing infection. In the U.S., Pfizer was one of the first companies to start developing phages as a therapeutic, and it had a facility in Brooklyn to grow bacteriophages for controlling infection. But right around the same time, antibiotics were discovered, and we dropped bacteriophages as a means for controlling infection here in the U.S. We went with the antibiotic approach.

And the Soviet researchers went the other route?
That's right. A couple of institutes, including one in Tbilisi, Georgia, still have an active bacteriophage program. People who have infections, mostly diabetic foot ulcers, not cured by ordinary antibiotics can go there and be treated with a cocktail of bacteriophages. It works, but it's really a boutique-type treatment. Unlike antibiotics, which can kill lots of different organisms, bacteriophages are unique in that they kill only specific bacteria. Basically, when you go to Tbilisi, they'll culture the bacteria in your foot, they'll develop a cocktail of phages that will target those bacteria, and you will be treated there for several weeks. In the U.S., Randall Wolcott of the Southwest Regional Wound Care Center in Lubbock, Tex., has also been using bacteriophages to treat resistant bacteria in wound infections.

Is the rise of antibiotic resistance contributing to renewed interest in phage-related therapies?
Yes. Antibiotic resistance is a very serious problem that presents two issues. First, bacteria are now becoming resistant to multiple current new-generation antibiotics. The biggest problem right now is methicillin-resistant *Staphylococcus aureus,* or MRSA, and vancomycin-resistant staph bacteria are emerging. It's already a problem for patients undergoing surgery who have compromised immune systems. But it won't be long before you and I could go into the hospital for a minor procedure, get infected by one of these organisms and become seriously ill. There's not much that can be used to treat you, and this type of infection is becoming more prevalent not only in the hospitals but also in the community.

The second issue is large drug companies are no longer in the antibiotics business. It's too expensive for them to develop an antibiotic for which the organism will become resistant very rapidly. This is disturbing because they are the best equipped to develop antibiotics, and I think it's their duty to continue.

What are the obstacles to phage therapy?
First off, the successes in Russia [and the former Soviet Union] have not been well documented. Where two individuals have a similar type of wound, the wounds are not necessarily treated with the same exact phage. So it's difficult to document a success in a true, scientific way.

Another problem is you need to use a cocktail of phages to kill a single organism. Complex mixtures may have trouble receiving FDA approval. Bacteriophages also pick up DNA from bacteria, so the FDA will want to know what DNA they are picking up. Phage therapy companies are trying, and that's not to say it'll never

PHAGE is a virus that infects bacteria. It has a capsid, or head (*top*), tail (*pink*) and tail fibers (*bottom blue appendages*).

PHOTO RESEARCHERS, INC.

be achieved, but they really have an uphill battle to try to get phage therapy approved for human use.

Are there any other ways to take advantage of phages in medicine?
We've developed one way, which is to use phage lytic enzymes. When phages enter a bacterium, they take over the cell to produce new virus particles. At the end of the cycle, the bacteriophages have to get out of the bacterium. They do this by producing a lytic enzyme that degrades the bacterial cell wall, causing the bacteria to explode. We've purified that enzyme, and we add it back to our bacterial cells. It will drill a hole in the cell wall, causing the bacteria to die virtually instantly. In humans, lysins can be applied directly on the skin or mucous membranes or injected into the blood. Because they are quickly cleared from the body and cannot break down human tissue, we anticipate that they will be safe.

How did you realize that these enzymes could be used therapeutically?
I purified one of these lysins for my Ph.D. thesis about 40 years ago. At that time, I used this enzyme to degrade the cell walls of *Streptococcus* bacteria to study surface proteins, but my real medical breakthrough came around 10 years ago. I had mice with group A strep throat. When I delivered the lysin in the throats of these mice, I found it killed the strep quickly. Then I realized that these enzymes could be used in a therapeutic way. It was an aha! moment. This was the first time anyone had ever used a lysin in an animal model and showed a therapeutic effect.

Since then, we have used lysins in lab animals to treat endocarditis, an infection of the heart valves, and we have used them to study meningitis, an infection of the brain. We also have used lysins to treat pneumonia, group B streptococcal infection and bacteremia, a blood infection. These enzymes are very stable and can be frozen or dried for many years and still retain their activity.

That's impressive. Did other scientists see that same therapeutic potential?
It was tough. People said, "That's interesting but—" The pharmaceutical industry was worried our immune systems would make antibodies to these lysins and neutralize them. Also, it was concerned we had enzymes that were very specific: the strep enzyme killed only strep, the pneumococcal enzyme killed only *Pneumococcus* and the anthrax enzyme killed only anthrax. People said, "You know, these are too targeted. We need broadly active enzymes."

We now have enzymes that have fairly broad activity, but broad activity is not the way to go, because you kill too many good bacteria. When you kill good organisms, you run into other problems. You're better off only killing the organisms that you want to kill without collateral damage and killing the organisms that are necessary for health and well-being. I think that everything is starting to turn in that direction: to try to kill only what you want to kill without destroying everything that you have in your body.

And these lysins can be used in other ways to protect human health?
That's right. We developed an enzyme that kills anthrax. It took 10 years for the government to realize that if there's an anthrax terrorist event, where anthrax spores are spilled in a city, it will take decades to safely remove all those spores from that environment. And to do so, you need to use corrosive materials. What we've been able to do in the lab is take the anthrax lysin and combine it with a natural chemical that tricks anthrax to germinate. Within 20 minutes, you can kill 99.99 percent of the spores. It's all-aqueous, it's all very safe, and so it could be used to decontaminate wide areas of contaminated surfaces of spores.

You can imagine this could be used for killing bacteria in agriculture or for controlling MRSA in hospitals by swabbing patients before and after surgery. Bacteriophages are also being used to kill bacteria on packaged meats.

Couldn't bacteria develop resistance to lysins?
So far we haven't found any resistant bacteria to these enzymes. I think it's really based on the way these enzymes have evolved over billions of years to stick to parts of the bacteria that the bacteria can't change. Never say never, but it would be a very rare event for resistance to develop.

The first ContraFect clinical trial against MRSA begins this year using a lysin you discovered, CF-301. Is that the first human trial with lysins?
Exactly. That will be the first time lysins will be used in humans.

I guess you're pretty excited about that?
Very excited. It took 10 years of hard work to get to this point. SA

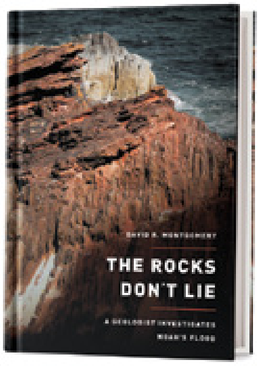
Brendan Borrell, *based in New York City, writes frequently for* Scientific American *and* Nature.

MORE TO EXPLORE

View animations depicting how bacteriophages work: http://tinyurl.com/btxzr2f

SCIENTIFIC AMERICAN ONLINE
Read more about Fischetti's research at ScientificAmerican.com/aug2012/phage

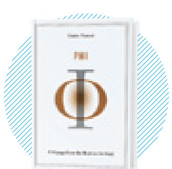
BOOKS



The Rocks Don't Lie: A Geologist Investigates Noah's Flood

by David R. Montgomery.
W. W. Norton, 2012 ($26.95)

This thought-provoking book explores the interplay between science and mythical tales of great floods. Montgomery, a University of Washington geomorphologist and MacArthur fellow, digs into the evidence for Noah's flood, among other legendary deluges, and finds that it may refer to the formation of the Black Sea some 8,000 years ago. In that catastrophic event, rapid sea-level rise caused the Mediterranean to overflow into what was then a low-lying freshwater lake, inundating some of the earliest farming communities. He also traces the emergence of modern creationist thinking, which rejects geologic evidence for the age of the earth and for Noah's flood being a local, rather than a global, calamity.



Phi: A Voyage from the Brain to the Soul

by Giulio Tononi.
Pantheon Books,
2012 ($30)

Tononi, a leading researcher on consciousness and sleep at the University of Wisconsin–Madison, imagines Galileo on a Dantesque journey of exploration to discover the fundamental nature of consciousness. His meditation on the meanderings of Galileo, who is accompanied at times by scientists resembling Francis Crick, Alan Turing and Charles Darwin, serves as a vehicle for explaining his own theory that consciousness can be quantified. The brain, Tononi postulates, consists of billions of neurons: think of them as transistorlike elements that represent bits with a particular value. When tallied, they add up to more than the sum of their parts. That increment above and beyond—Tononi calls it "phi"—represents the degree to which any being, whether human or mule, remains conscious.

—Gary Stix

Curious Behavior: Yawning, Laughing, Hiccupping, and Beyond

by Robert R. Provine.
Harvard University Press, 2012 ($24.95)

Provine, a professor of psychology and neuroscience at the University of Maryland, has written a charming ode to "Small Science"—science that does not require a large budget or fancy equipment but that is interesting nonetheless. Taking examples from his own research, some of which involved nothing more complicated than stalking graduate students and observing how and when they laugh, he explains the origins of some of the most prevalent, but often overlooked, human behaviors.

When Can You Trust the Experts? How to Tell Good Science from Bad in Education

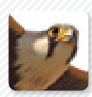
by Daniel Willingham.
Jossey-Bass, 2012 ($24.95)

Parents increasingly come face-to-face with important educational decisions that they feel ill prepared to make. Whether they are choosing among schools, math programs or early interventions for a learning disability, this book will help them figure out which options are backed by the best science. Educators and administrators faced with adopting new curricula and policies will likewise find it of value.

COURTESY OF MICHAEL OBERHOFER, COPYRIGHT © 2012 BY MITCH WAITE GROUP

ALSO NOTABLE

APPS

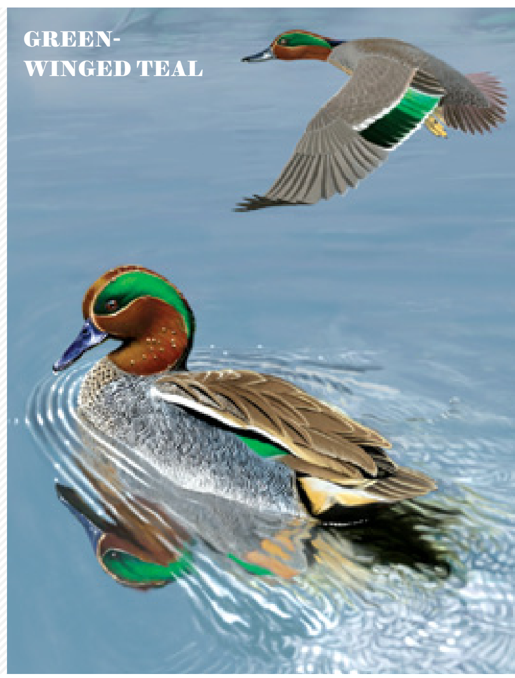


iBird Explorer PRO. Mitch Waite Group, 2011 ($2.99). For iPhone/iPad. This top-rated app for bird lovers (*right*) features 924 North American and Hawaiian birds and their songs.

LeafSnap. Columbia University, University of Maryland and Smithsonian Institution, 2011 (free). For iPhone/iPad. Snap a picture of almost any leaf, and this cool app will help you identify it by bringing up images and names of possible matches.

Particle Zoo. Richard Burgess, 2011 (free). For iPhone/iPad. Mainly for kids but also a handy primer for adults, this app describes all the particles and antiparticles—including those that have not yet been discovered.

Planets. QContinuum, 2012 (free). For iPhone/iPad. An addictive real-time map of the sky showing when the planets and moon are, or will be, visible, plus great data on each planet's mass, orbit and moons.



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

Free Won't

Volition as self-control exerts veto power over impulses

At a restaurant recently I faced many temptations: a heavy stout beer, a buttery escargot appetizer, a marbled steak, cheesecake. The neural networks in my brain that have evolved to produce the emotion of hunger for sweet and fatty foods, which in our ancestral environment were both rare and sustaining, were firing away to get me to make those selections. In competition were signals from other neural networks that have evolved to make me care about my future health, in particular how I view my body image for status among males and appeal to females and how sluggish I feel after a rich meal and the amount of exercise I will need to counter it. In the end, I ordered a light beer, salmon and a salad with vinaigrette dressing and split a mildly rich chocolate cake with my companion.

Was I free to make these choices? According to neuroscientist Sam Harris in his luminous new book *Free Will* (Free Press, 2012), I was not. "Free will is an illusion," Harris writes. "Our wills are simply not of our own making." Every step in the causal chain above is fully determined by forces and conditions not of my choosing, from my evolved taste preferences to my learned social status concerns—causal pathways laid down by my ancestors and parents, culture and society, peer groups and friends, mentors and teachers, and historical contingencies going all the way back to my birth and before.

Neuroscience supports this belief. The late physiologist Benjamin Libet noted in EEG readings of subjects engaged in a task requiring them to press a button when they felt like it that half a second before the decision was consciously made the brain's motor cortex lit up. Research has extended the time between subcortical brain activation and conscious awareness to a full seven to 10 seconds. A new study found activity in a tiny clump of 256 neurons that enabled scientists to predict with 80 percent accuracy which choice a subject would make before the person himself knew. Very likely, just before I became consciously aware of my menu selections, part of my brain had already made those choices. "Thoughts and intentions emerge from background causes of which we are unaware and over which we exert no conscious control," Harris concludes. "We do not have the freedom we think we have."

True enough. But if we define free will as *the power to do otherwise,* the choice to veto one impulse over another is *free won't.* Free won't is veto power over innumerable neural impulses tempting us to act in one way, such that our decision to act in another way is a real choice. I could have had the steak—and I have—but by engaging in certain self-control techniques that remind me of other competing impulses, I vetoed one set of selections for another.

Support for this hypothesis may be found in a 2007 study in the *Journal of Neuroscience* by neuroscientists Marcel Brass and Patrick Haggard, who employed a task similar to that used by Libet but in which subjects could veto their initial decision to press a button at the last moment. The scientists discovered a specific brain area called the left dorsal frontomedian cortex that becomes activated during such intentional inhibitions of an action: "Our results suggest that the human brain network for intentional action includes a control structure for self-initiated inhibition or withholding of intended actions." That's free won't.

In addition, a system has "degrees of freedom," or a range of options that may result from its complexity and the number of intervening variables. Ants have a few degrees, rats more, chimps many more still, humans the most. Some people—psychopaths, the brain-damaged, the severely depressed or the chemically addicted—have fewer degrees than others, and the law adjusts for their lowered capacity for legal and moral accountability.

These vetoing neural impulses within a complex system with many degrees of freedom are part of the deterministic universe. Thinking of volition as a component of the causal net lets us restore personal responsibility to its rightful place in a civil society. SA

SCIENTIFIC AMERICAN ONLINE
Comment on this article at ScientificAmerican.com/aug2012

Illustration by Brian Taylor

The ongoing search for fundamental farces

Steve Mirsky has been writing the Anti Gravity column since Derek Jeter had a total of 12 base hits in the major leagues. He also hosts the *Scientific American* podcast Science Talk.

Good Chappe

The author discovers his similarities to a great 18th-century astronomer

As the 2012 transit of Venus rolled around, I got caught up in the excitement. Which led me to read *The Day the World Discovered the Sun,* a new account of the arduous attempts by the scientific community to observe the two Venus transits of the 1760s. (My ensuing audio interviews with author Mark Anderson are archived at www.ScientificAmerican.com/podcast.)

Until I read the book, I never knew how much I had in common with 18th-century French astronomer Jean-Baptiste Chappe d'Auteroche. Well, we had one big thing in common. In 1769 he traveled to the Sea of Cortez, between the Baja peninsula and mainland Mexico, to observe the transit. His data collection, combined with those of other sky watchers at different latitudes, would enable astronomers to calculate the distance from Earth to Venus and the sun. In 1991 I went to the same location, which lay in the narrow band that would experience another spectacular astronomical event, a total eclipse of the sun.

Let's compare the two journeys.

In September 1768 Chappe sails from France to Spain, schlepping enough equipment to construct an observatory in his ultimate destination, Cabo San Lucas, which won't be a hopping resort town for another two centuries. On July 4, 1991, I leave New York City on a train for Los Angeles with a couple of astronomically interested friends—we figured we'd see the country along the way from our sleeper cars. I pack a couple of Hawaiian shirts.

It takes Chappe three weeks to get to Cádiz. Twenty hours after leaving New York, my amigos and I arrive in Chicago, where we're forced to change trains and endure a six-hour layover. Fortunately, there's a food fair along the lakeshore.

In December 1768 Chappe begins a 77-day transatlantic voyage onboard what he called "our little nutshell." On July 5, 1991, my group leaves Chicago on a double-decker superliner train for L.A.

On March 6, 1769, Chappe's ship sets anchor near Veracruz. The vessel sits there for two days before local officials send a skiff to bring Chappe to shore. A hurricane almost destroys the anchored ship and its cache of astronomical equipment. Two days after leaving Chicago, my team pulls into the City of Angels, having taken in a lovely traverse of the Colorado River from the observation car. We head to a nice hotel.

In mid-March, Chappe begins traveling over land to the Pacific side of Mexico, which he will reach on April 15. On July 7, 1991, my buddies and I find a decent Mexican restaurant for dinner.

On April 19, 1769, Chappe sets sail onboard a small vessel called *La Concepción*. Unfriendly currents and winds keep him and his mates at sea for a full month before they reach Baja. On July 8, 1991, my friends and I leave the Port of Los Angeles onboard the cruise ship *Viking Serenade*. Built in 1982, it had been the world's largest cruise ferry and was later converted into a luxury cruise ship. Other passengers include moon-walking astronaut Harrison Schmitt and amateur astronomer John Astin, television's Gomez Addams. Me and the boys rough it in our windowless interior cabin.

For a week and a half in late May 1769, Chappe and his crew build their observatory in San José del Cabo. For three days onboard the cruise ship, as it sails down Baja and up into the Sea of Cortez, my crew attends astronomy lectures, plays Ping-Pong under bright blue skies on the top deck, and eats from dawn till the midnight buffet.

On June 3, 1769, Chappe lucks out—perhaps his first and last brush with good fortune on this journey—and gets a clear day to make his observations of the Venus transit. His data will help scientists determine the dimensions of the solar system. On July 11, 1991, an overcast sky threatens our eclipse watching. But using satellite weather images, the captain speeds to a cloudless spot, where we observe six minutes and 53 seconds of totality, just 38 seconds less than the theoretical maximum. It's very cool.

Following the transit, Chappe and many of his men fall victim to a typhus epidemic. Following the eclipse, we set sail back to L.A. Rough seas make me a bit queasy.

On August 1, 1769, Chappe passes away. Among his last words: "I have fulfilled my purpose, and I die happy." On July 14, 1991, my friends and I arrive back in Los Angeles and head to the train station. Among our last words there before another three-day train trip: "Maybe we should have flown." SA

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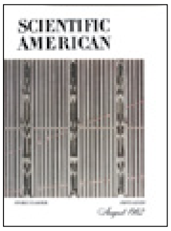
Illustration by Matt Collins

Innovation and discovery as chronicled in *Scientific American*

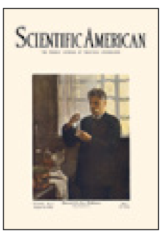


August 1962

Bee Jargon

"For almost two decades my colleagues and I have been studying one of the most remarkable systems of communication that nature has evolved. This is the 'language' of the bees: the dancing movements by which forager bees direct their hivemates, with great precision, to a source of food. In our earliest work we had to look for the means by which the insects communicate and, once we had found it, to learn to read the language. Then we discovered that different varieties of the honeybee use the same basic patterns in slightly different ways; that they speak different dialects, as it were. This led us to examine the dances of other species in the hope of discovering the evolution of this marvelously complex behavior. —Karl von Frisch"

Von Frisch shared the 1973 Nobel Prize in Physiology or Medicine.



August 1912

Sahara Sea

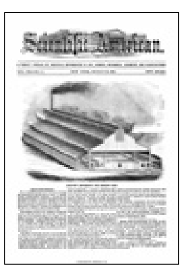
"A sensation was recently caused in Paris by the daring proposal of Prof. Etchegoyen, a distinguished scientist, who declares that France ought to lose no time in converting the vast desert of Sahara into an inland sea. He claims that, since 'about a quarter of the whole desert area lies below sea level, the construction of a canal some fifty miles long through the higher land of the north African coast would immediately create a Sahara Sea equal in size to about half the extent of the Mediterranean.' Millions of human beings could then support themselves in comfort, who now lead a miserable existence on the verge of starvation. Moreover, a great new colony could be added to the possessions of France."

SICILIAN ELEMENT: Young miners in a labor-intensive industry stand on molded blocks of sulfur, 1912

SCIENTIFIC AMERICAN, VOL. CVII, NO. 7; AUGUST 17, 1912

Sulfur Mining

"Sicily's sulphur production comprises an area about equal to that of the State of Connecticut. A population of 350,000 ignorant, ill-nourished peasants, called *carusi,* labor in the mines [*see photograph*]. Exceedingly crude and simple methods prevail, and have prevailed since the days of the Romans, in the mining of Sicilian sulphur. The Sicilian industry, debilitated by ages of market speculation, usury and local *vendette,* late in the last century, staggered under the shock of news of the opening up of an immense deposit of sulphur on the gulf coastal plain of Louisiana. By Herman Frasch's invention of a process for liquefying sulphur in the ground, at a depth of 1,000 feet, and pumping it to the surface in fluid form, sulphur is produced at an average cost of $3.68 per ton, as against $12 per ton, the cost of mining sulphur in Sicily."



August 1862

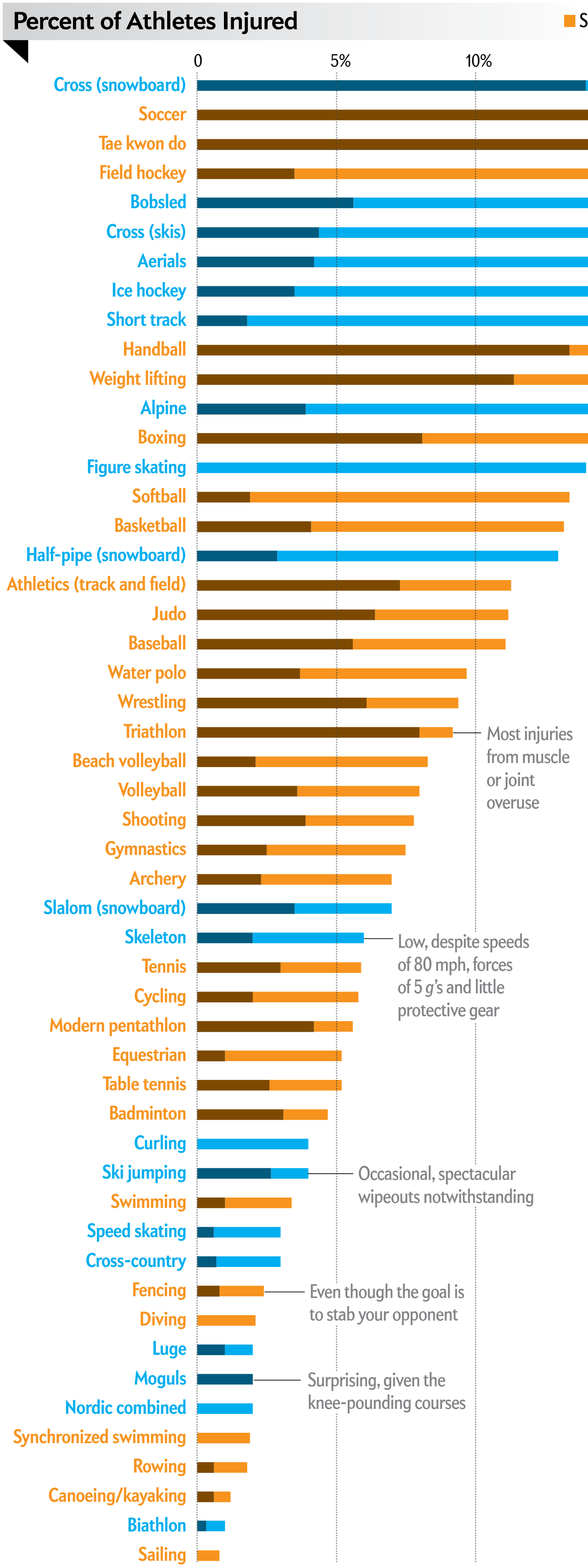
Civil War Shipbuilding

"A number of our engineering establishments are engaged at present in constructing ironclad steamers of various kinds. Contracts have been made by the Navy Department with Capt. Ericsson for building several on the general plan of the *Monitor.* Five are being constructed at Greenpoint, Brooklyn, where a force of nine hundred men are employed upon them. All will be furnished with revolving turrets of greater thickness than that of the *Monitor,* and most of them are to be armed with 15-inch guns."

Some images of the technology of warfare, taken from our archives of 150 years ago, can be viewed at www.ScientificAmerican.com/aug2012/civil-war

Tiger Hunt

"Many of the natives of Cochin China [southern Vietnam] obtain their livelihood by tiger catching, the skin of this animal being valuable. They use a novel mode of ensnaring those savage beasts. The snare consists of large leaves, sometimes pieces of paper, covered on one side with a substance of the same nature as bird-lime, and containing a poison, the smallest portion of which, getting into the animal's eyes, causes instant blindness. They are laid about thickly, with the bird-lime side upward, in the track of a tiger, and as surely as the animal puts his paw upon one of the treacherous leaves, he becomes a victim; for, finding it stuck to his foot, he shakes it, and while scratching and rubbing himself to get free, some of the bird-lime poison gets into his eyes and blinds him. He growls and roars in agony, and this is the signal for his captors to come up and dispatch him."



Olympic Hurtfuls

Athletes are injured frequently—badminton players more so than ski jumpers

We rarely see it happen on television, but one in 10 Olympians will get hurt during the games, if the past is any guide (*left*). About three quarters of the injuries occur during some phase of competition and one quarter during warm-ups or on-site training, according to Lars Engebretsen of the University of Oslo in Norway, who compiled the data. Summer athletes tend to ruin their legs; winter athletes bang their heads (*below*). The causes vary greatly: collisions (soccer), stick strikes (field hockey), high-speed wipeouts (bobsledding). The damage leader—snowboard cross—involves frequent contact between boarders in a free-for-all downhill race. Sailing is nearly harm-free. Engebretsen says injury rates in most professional sports, such as football and soccer, are higher, although data are inconsistent. —*Mark Fischetti*

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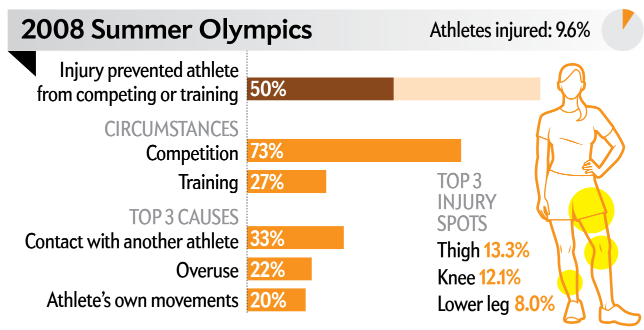
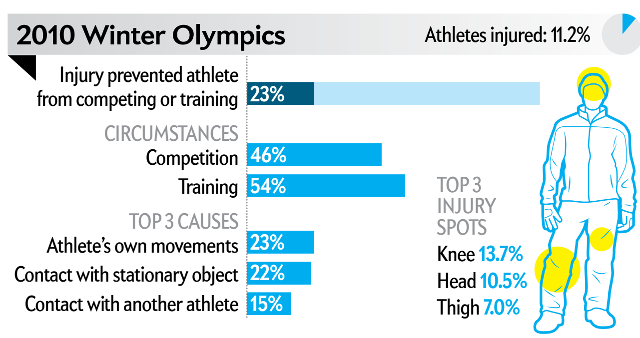
Find a review of leading injuries in specific sports at
ScientificAmerican.com/aug2012/graphic-science





SOURCE: LARS ENGEBRETSEN *University of Oslo*

Graphics by Jen Christiansen, Illustrations by MCKIBILLO