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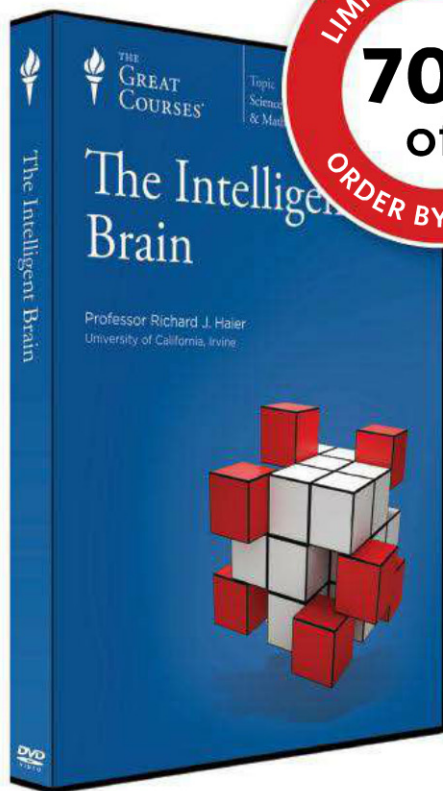
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Removing Antarctica's ice reveals mountains, lakes and rivers, all elements of our Invisible Planet.

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Kellie Jaeger/DISCOVER

Cover photo:
Doug Armand/
Getty Images

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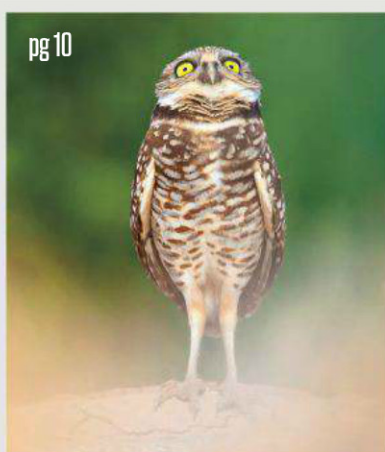
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The apple of Newton's eye and the focus of Einstein's work, gravity is weaker than you probably think and weirder than you probably imagined.

By Bill Andrews



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Though no one in the air knew where he was, there were people on the ground tracking Maultsby's flight path. Unfortunately, they were the wrong people. The voice that had come over the radio was, unbeknownst to him, a Soviet voice.

Amy Shira Teitel, in the Crux blog post "How the Aurora Borealis Nearly Started World War III" DiscoverMagazine.com/Aurora

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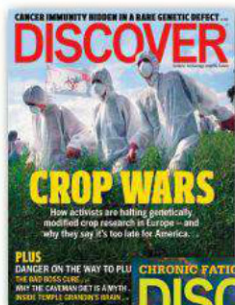
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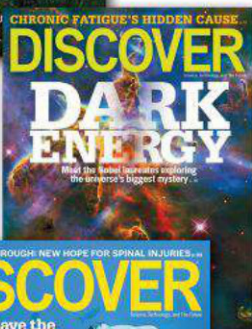
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April
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May
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June 2013

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Mavericks, Mothering and More

Maverick of Art and Science

Steve Nadis profiled
scientist-artist Joe
Davis and his portfolio
of work in the April
issue (page 52).

"A Scientific Method to His Madness" is weirdly wonderful. I want to join the Joe Davis Fan Club, not because of his unusual style, but because the treatment of it is refreshing in these times of herd-following, "don't rock the boat" official science.

Patricia Folley
Noble, OK

Family Inheritance

In "Trait vs. Fate" (May issue, page 48), Dan Hurley explains how our ancestors' lives — be they rough or privileged — might be reflected in our genetics.

Very good article and explanation of the mechanics of epigenetics chemistry. I did wish there was not so much emphasis on mothering, which seems like a throwback to a bad time when all childhood problems were blamed on the mother. Seems like the article just got going to the more interesting part of this field that was briefly mentioned — infection, toxins, other environmental exposures

— when it quit! Gee, I would like to have known more about epigenetics and cancer, for instance.

Lou Overman
Oakwood, GA

"Data" Assessment

May's Data section included stories on health and behavior predictions determined by index-to-ring-finger length ratios ("Finger Findings," page 16) and a reduction in the size of the hole in the ozone layer ("Is the Ozone Hole Shrinking?" page 14). "Finger Findings" — the new phrenology. I am not sure that all concerned should not be ashamed of themselves. I, with a finger quotient well under 1, am wondering where my improved athletic ability and risk taking went. Notwithstanding, the hopeful news about the ozone layer was most welcome.

Robert De Lisle
Battle Creek, MI

Questioning the Dark

Zeeya Merali's May cover story, "Confronting the Dark" (page 38), explores the discovery of "dark energy" that pushes space apart. In your very interesting article, mention is made of the early universe expanding faster than the

speed of light. How would this have been possible? I thought nothing could exceed light speed.

Dennis Gaunt
Iowa City, IA

DISCOVER Associate Editor Bill Andrews answers: *While you're right that nothing can go faster than the speed of light, making it a kind of universal speed limit, that rule doesn't apply to the universe itself. Space-time, the fabric of the universe, can indeed stretch out at speeds exceeding light's.*

Predicting the Future

In his Editor's Note for the June issue, Steve George asks readers what "gifts from the future" — advances in technology — they'd like to see.

I come from a family of engineers all the way down and understand about gifts from the future. What I would really love, since I am over 70 and travel is getting more difficult for me, is true "virtual presence." I know it is sort of here, and I love the idea of the iPad on teleoperated robotic wheels, but I don't think it would satisfy my family in the U.K. A holographic me would be nice.

Anne Fletcher-Jones
Palm Desert, CA

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Invisible Planners

FOR THOSE OF YOU WHO REGULARLY DROP IN ON DiscoverMagazine.com, parts of our Antarctica coverage (page 48) might jingle a faint bell. See, back in January, DISCOVER had a writer posting online dispatches from the scene when scientists peered for the first time into the interior of a lake that has sat undisturbed beneath the Antarctic ice sheet for perhaps a million years.

It was news, but it wasn't the whole story — nor the only story we wanted to run on Antarctica. But reviewing the online coverage of that event made me realize that now, as we bring you our annual Invisible Planet issue, it would be fitting to have you meet a few of the folks who work tirelessly, if somewhat invisibly, to bring you the stories that make our website special.

Senior Editor Tasha Eichenseher may edit magazine features and our Notes From Earth column (page 32), but she's also involved daily with the website. With several years' experience in digital media, Tasha helps DISCOVER plan content that bridges both the print and digital worlds, allowing us to cover stories in each medium in ways that are both timely and comprehensive.

Although she's dedicated — in every sense of the word — to DiscoverMagazine.com, Associate Editor Lisa Raffensperger is very much involved in our editorial planning process for the magazine, identifying elements of forthcoming stories that work to best effect online, be they photo galleries, expanded interviews or, as in the case of our Antarctica coverage in January, news dispatches in the website's Field Notes section.

Last but not least in this triple crown of talent is Staff Writer Breanna Draxler. Breanna's writing appears so frequently on D-brief, our news blog, you'd be forgiven for thinking the D stands for "Draxler" and not "Discover." And when she's not cranking away at the science news of the day, Breanna's work turns up in the magazine in anything from feature sidebars to book reviews.

As you dig into this extra-large issue and scroll through our stories online, I think it's ironic that this page is one of the few places where you'll see Tasha, Lisa and Breanna's names. But you'll see their impact — and that of all the invisible planners who make DISCOVER possible — as they work behind the scenes to bring you not just "the science you don't see" but science editorial you don't see every day.



Time to meet
a few folks
who work
tirelessly,
if invisibly,
to bring you
great stories.

SCG

STEPHEN C. GEORGE, EDITOR IN CHIEF

WILLIAM ZUBACK/DISCOVER



DATA





SKYWALKER

A stroll through the clouds turns out to be a walk on water only inches deep at Salar de Uyuni, a vast salt flat in the high plains area of southwestern Bolivia. During the rainy season, this 4,000-square-mile, virtually flat expanse of salt is often covered in shallow water that creates a mirror-like vista stretching to the horizon. Photographer Kazuyoshi Nomachi said conditions have to be exactly right for such a vista. Too much water, and the surface gets choppy. A clear sky has far less drama. Although the salt has been mined since antiquity, the slushy brine beneath it may contain more than 50 percent of the world's lithium, an essential element for efficient batteries used in aircraft, hybrid vehicles, computers and cell phones.

ERNIE MASTROIANNI



WATCH THE BIRDIE

A burrowing owl looks skyward near the Salton Sea in Southern California. Photographer Floris van Breugel noticed that it seemed to watch a red-tailed hawk circling overhead. Burrowing owls nest in the ground instead of trees, using holes dug by prairie dogs, but they also find or dig suitable burrows on golf courses and open flatland. The owls place mammal droppings around their habitat to attract dung beetles, which the owls capture and eat. The bird's numbers are declining due to habitat loss to development, and the U.S. Fish and Wildlife Service considers the owl a Bird of Conservation Concern. They can be found in western North America, large parts of South America outside the Amazon Basin, and Florida.

ERNIE MASTROIANNI

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BIG IDEA

SEQUENCING AN ENTIRE COUNTRY

Personalized medicine has been hot for the past decade. Now, the remote Faroe Islands aims to be the first to integrate complete genomes into its health-care system.

GROWING UP IN THE FAROE ISLANDS in the North Atlantic, Edmund Jensen battled an overpowering sense of fatigue. At age 10, he developed seizures in which his limbs would stiffen and his eyes would roll back in his head, but local doctors could never diagnose his condition. In August 2008, Danish doctors identified the genetic defect that prevented his body from maintaining adequate levels of carnitine, which plays a critical role in metabolism. By then, Jensen was 21, had close-cropped brown hair and a silver hoop through his upper ear. The day before he went to get his first prescription, he died of cardiac arrest. “Again and again, I look at his picture and cannot believe that it is true,” his father, John, wrote afterward.

Jensen’s death was followed by the death of his third cousin Margretha, along with a string of macabre news articles about this undiagnosed genetic condition that had been shattering families in the Faroes for decades. The deaths became a call to action for the country’s Health Ministry, which persuaded some 30,000 citizens — about three-fifths of the total population — to submit blood samples to its new Genetic Biobank. They were all screened for Jensen’s disease, called carnitine transporter deficiency (CTD), improving and potentially saving dozens of lives. The earlier deaths

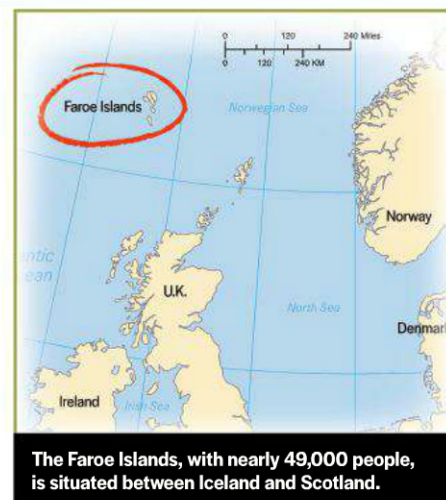
would have a larger impact, though, changing the very face of health care in the Faroes and setting it on a path to become a leader in genomic medicine.

Identifying the Genes of Disease

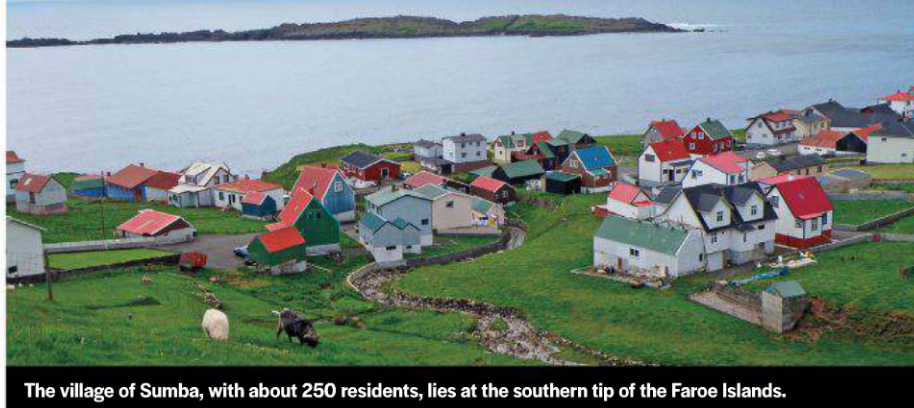
The 18 islands of the Faroes lie in a tight cluster between Iceland and Scotland and are just about the last place in the world you might imagine for a genome revolution. Like other remote islands, a limited gene pool has led to a greater prevalence of certain diseases. “I don’t call it inbreeding, but line breeding,” says Gudrid Andorsdottir, who runs the biobank. “There is the implication that you are strengthening some factors, rather than inbreeding, which is a more negative word.” The prevalence of CTD in the Faroes is now known to be the highest in the world, and hundreds of times higher than in nearby regions.

Last year, the Health Ministry announced plans to perform whole genome sequencing on every citizen who wants it. During the pilot phase over the next year or so, they aim to sequence 1,000 individuals, focusing on those with CTD, along with other conditions, such as schizophrenia, cystic fibrosis and diabetes. Project director Bogi Eliassen envisions the database growing each year.

The country has already adopted



The Faroe Islands, with nearly 49,000 people, is situated between Iceland and Scotland.



The village of Sumba, with about 250 residents, lies at the southern tip of the Faroe Islands.

electronic medical records with data on treatments, prescriptions and their success rates, and the Genetic Biobank has finished digitizing the past 200 years of genealogical histories. Adviser Paul Flicek of the European Bioinformatics Institute says we shouldn't necessarily expect immediate scientific breakthroughs to come out of this effort, called FarGen. We should view it in the short term as the ultimate experiment in improving clinical care: helping physicians prescribe the right medications at the right dosages and advising patients on the best way to prevent health problems to which they may be predisposed.

In other words, FarGen will be just as much about health care as it is about furthering clinical research. "How you deliver genomic medicine to real people is going to be a problem we're facing in the next few decades," says Hank Greely, director of the Center for Law and the Biosciences at Stanford Law School. "Why the Faroes? That's harder to answer, but if they are enthusiastic and can find the money, then that's fine. You take your experiments where you can find them."

Ethical Challenges

In 2009, Eliassen began touring conferences abroad and gathering a group of top genome scientists to serve on a scientific advisory board. The bottom line was that genetic breakthroughs made in the United States or China may not be especially useful to isolated populations with rare genetic variants. Countries like the Faroes needed to do the work themselves.

So far, officials in the Faroes are moving cautiously, but FarGen raises a slew of ethical questions. Even if the project leaders find the estimated \$50 million to fully fund the sequencing, it will take hundreds of millions more to determine the meanings of the genomes, and to train and support

genetic counselors, Greely says. Which conditions will be disclosed to people and at what age? How often will a person's genome be reviewed as new science comes in? Then there's the looming question that lingers from Jensen's untimely end: Who is responsible for a death that could have been prevented? That knowledge, after all, will likely be archived on government servers.

In summer 2012, Eliassen braced himself for the prick of a needle on his forearm. Afterward, a technician from the main hospital in the Faroes squirted about 2 milligrams of blood into a special tube with buffers to purify and stabilize his DNA, so that it could be sent to a laboratory to sequence the 3 billion letters that make up the code of his genome. "It was a matter of trust," Eliassen says. "I wanted to be among the first to show that I believe in this approach."

BRENDAN BORRELL

PRIVACY TEST

The Faroes have been a promising test bed for initiatives in medicine. In the late 1990s, a Delaware-based company called deCODE Genetics hoped to create a genetic biobank of the islands' entire population to identify disease-related genes and develop drugs. The Faroes government rejected deCODE, but it spurred the country to pass legislation on genetic privacy and eventually led to the creation of its own biobank.

In the meantime, deCODE pursued its agenda in Iceland. It became a debacle. The company's slow-motion crash began as privacy concerns made their way to the country's Supreme Court, which in November 2003 barred deCODE from building the database of citizens' health records. DeCODE declared bankruptcy in 2009, but the genome revolution carried on. While the first whole genome sequence was completed in 2001 at a cost of \$500 million, by 2014, we may finally see the \$999 genome.

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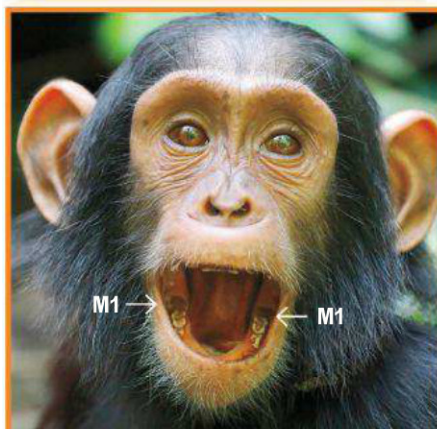
The Yawns Have It

A few smiles, yawns and grimaces into the camera were all it took for Tanya Smith to shatter one of the longest-held truisms in primate studies — that a young chimpanzee's molar development can be used as a proxy for developmental milestones such as age of nursing and weaning.

For decades, researchers assumed that chimps, like other nonhuman primates, weaned their young once the back teeth started coming in. The belief was so ingrained that paleoanthropologists and others investigating human evolution figured that if they saw molar eruption in the fossilized skull of a young human ancestor, they'd assume they knew the age and feeding behavior.

But Smith, an evolutionary anthropologist at Harvard University, wanted to test the theory by looking at wild chimpanzees. First, she wanted to see if molar development in wild chimpanzees was analogous to their captive counterparts, something she was dubious about.

But she also wanted to see whether chimpanzees also stopped weaning when their teeth came in. "It's what I was taught," she says. "So it was surprising to



A young female chimp shows off her first molars.

see that it didn't bear out."

Smith had two nature photographers follow five young chimpanzees at a field site in Uganda's Kibale National Park for nearly a year and a half. The photographers took pictures of the inside of the young chimps' mouths when they vocalized, yawned or gaped.

Smith and a team of researchers then studied the pictures. The first thing they noted is that wild chimpanzees and captive chimpanzees are similar in terms of age of molar eruption, usually occurring

when the animals are slightly older than 3.

They also found that those first molars generally appeared nearly a year before the young chimps stopped nursing. Indeed, the young chimpanzees actually showed an unexpected uptick in nursing behavior after their grinders appeared. "Our research actually suggests that M1 (first molar) appearance may have more to do with adult feeding patterns than nursing or weaning," says Smith.

She and her team believe that before 3 years old, chimpanzees are almost completely dependent on their mothers for survival. But as they approach 3, and their molars begin to appear, they have also learned some of the fundamentals of food gathering.

The research is "extremely creative and inventive," according to Gary Schwartz, a paleoanthropologist at the School of Human Evolution and Social Change at Arizona State University.

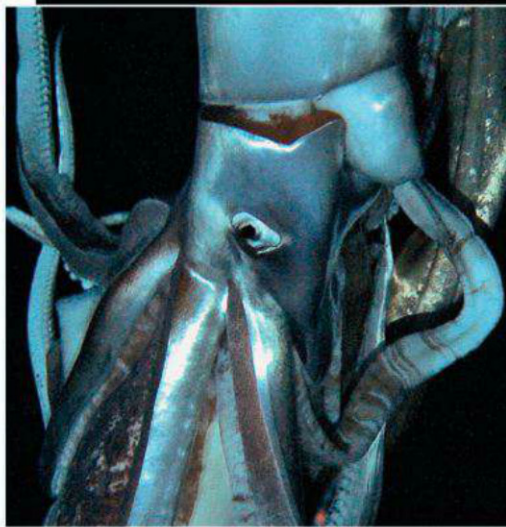
"It now focuses the lens just a bit more on what life history, energetic and ecological attributes we should examine in other well-studied ape populations," Schwartz says.

SUSANNE RUST

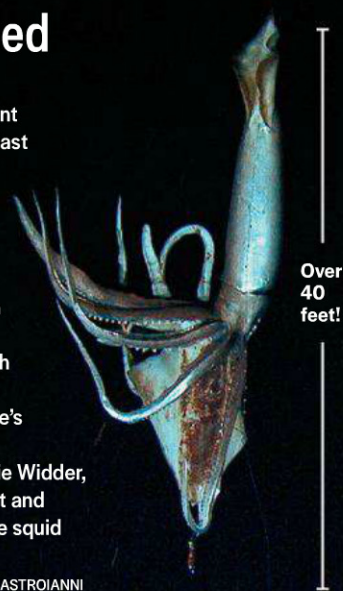
Deep Sea Creature Revealed

More than 2,000 feet below the surface of the Pacific, scientists off the coast of Japan photographed a giant squid (*Architeuthis*) in its native habitat for the first time last summer. These high-definition images were taken from within a submersible vehicle exploring near the Ogasawara Islands in an effort led by Japan's National Science Museum, the Ocean Research and Conservation Association (ORCA), the Japan Broadcasting Corp. (NHK) and the Discovery Channel. The squid is more than 40 feet long with eyes the size of dinner plates. The team made 55 dives, reaching depths of 3,000 feet in its search for the elusive marine animal, and used a novel globe-like device called an electronic jellyfish to capture the creature's attention. To frighten predators, some jellyfish will emit bioluminescence when attacked, and marine biologist Edie Widder, the CEO of ORCA, reasoned that the squid would see light and think that food was nearby. "We paid attention to what the squid paid attention to," said Widder in a television interview.

ERNIE MASTROIANNI



Never before has a giant squid been photographed in its native habitat, deep under water.



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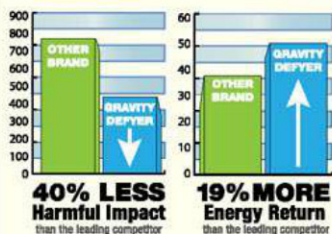
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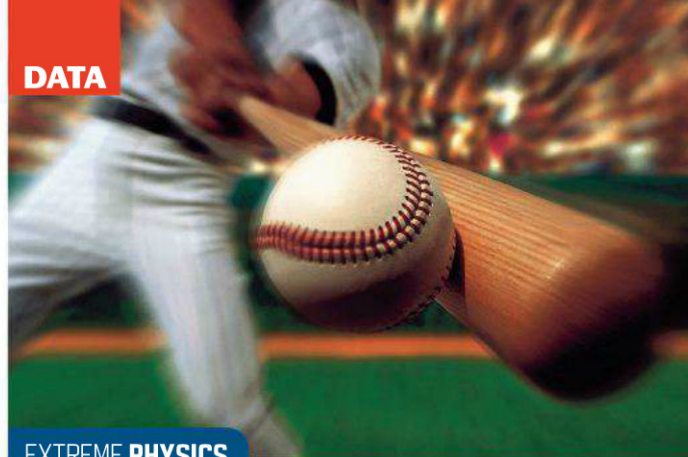
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EXTREME PHYSICS

Silencing the Sting

Anyone who has ever hit a baseball off the wrong part of the bat knows the shot of pain that courses through your hands. Now, thanks to acoustics engineer Daniel Russell of Pennsylvania State University, that unpleasant jolt could become a relic of the game's past.

Russell, who has been devising baseball-centric experiments for years, recently helped solve the physics mystery at the heart of the infamous sting. Nearly a decade ago, baseball equipment manufacturer Marucci Sports put a vibration damper inside its aluminum bats to eliminate the pain, but the technology was not working as well as hoped, so the company recruited Russell.

After interviewing several college players, Russell learned they all felt pain in the same spot: the fleshy tissue between the thumb and forefinger in the upper hand of their grip. They all held the bat in roughly the same place, so Russell analyzed the corresponding region in his lab. He used two rubber bands attached to either end of a frame that suspended the bat horizontally. Then he struck the bat at various points with a hammer. An accelerometer affixed to the barrel of the bat

tracked the vibrations while a transducer in the hammer's tip measured the force applied.

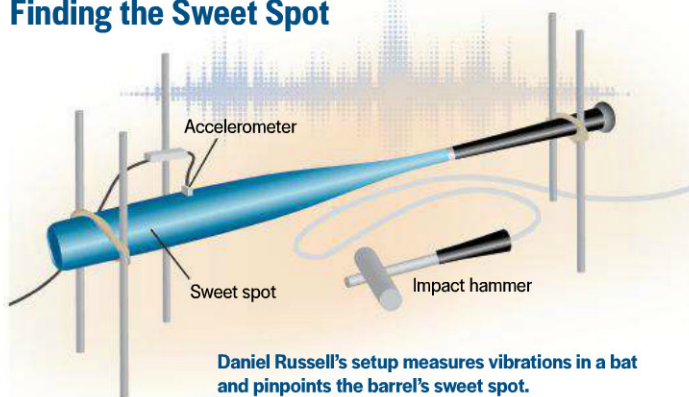
Striking the bat five to six inches from the tip, an area known as the sweet spot, generated virtually no vibration. Smacking it outside the sweet spot, on the other hand, forced 450 to 700 vibrations per second to pulse at the bat's grip, thereby causing the sting. And these vibrations peaked in intensity right where the player typically holds his upper hand.

Russell realized nothing was wrong with the damper, which consists of a rubber-spoked wheel that transfers vibrations to a brass weight set inside the knob of the bat. The idea was right — the weight should have absorbed the pulses — but the device was tuned to the wrong frequency.

Marucci adjusted its dampers and later used Russell's findings to develop a new Kevlar-based grip that also cancels the sting. Recently, other companies have begun using the dampers. Now a poorly hit ball isn't so painful. "This little brass piece vibrates like crazy, but you don't feel it in the hands at all," Russell says.

GREGORY MONE

Finding the Sweet Spot

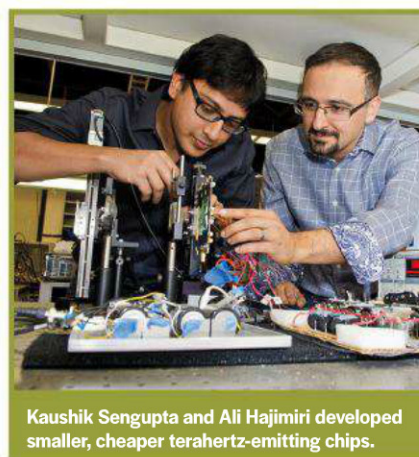


TOOLS

See the Invisible With "T-Ray" Vision

Call it the "X-ray vision" app: In several years, smartphones could come equipped with a microchip that lets users peer through boxes, walls and other objects. Rather than dangerous X-rays, however, the chip beams out waves in the harmless terahertz frequency, a little-used portion of the electromagnetic spectrum between microwaves and far-infrared.

Terahertz generators historically have been bulky, expensive affairs. But now Caltech researchers have succeeded in crafting terahertz-emitting silicon chips that are smaller than a dime using a standard, inexpensive electronics manufacturing technique. The researchers harnessed an array of tiny transistors operating in unison and designed the whole chip to act essentially as a terahertz antenna. "We took a holistic approach and combined generation and radiation in one place," says Ali Hajimiri, co-developer of the chip and an electrical engineer at Caltech.



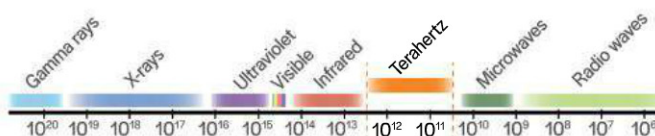
Kaushik Sengupta and Ali Hajimiri developed smaller, cheaper terahertz-emitting chips.

Terahertz waves, sometimes called T-rays, can penetrate fabrics, cardboard and skin but cannot pass as readily through harder, denser materials such as metal and bone. So T-rays encountering contraband handguns concealed within a container would bounce back

to the microchips, which function as a dual transmitter and receiver. This "reflectance pattern" can then be rendered visually through software, allowing an inspector with a handheld device to "see" inside a box without opening it.

Besides security-related applications — and the privacy concerns that such technology might raise — everyday electronics could also make use of terahertz chips to enable all sorts of technical wizardry, much like the cameras, accelerometers and gyroscopes in today's cell phones. "If you include this as yet another versatile sensor on your smartphone," says Hajimiri, "you can develop a lot of different apps." Examples include noninvasive cancer screening, ultrafast data transmission and, for gaming, refined motion-sensing and gesture recognition.

ADAM HADHAZY



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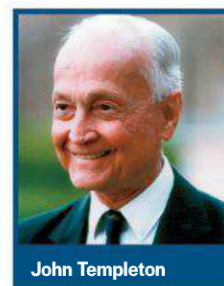
SCI-FI MONEY

GRANTS FUND RESEARCH FROM EXTRATERRESTRIAL POWER TO IMMORTALITY

John Templeton, once called “arguably the greatest global stock-picker” of the 20th century, may now best be known for the foundation that bears his name. The Templeton Foundation often funds research into questions that seem a far cry from the grounded, data-driven realms of high finance: immortality, the nature of evil, the power of prayer and the possibility of alien life, to name just a few.

Templeton, a devout Presbyterian, established the foundation in 1987 to serve as a “philanthropic catalyst for discoveries relating to the Big Questions of human purpose and ultimate reality,” according to its mission statement. Although financing such research may raise scientific eyebrows and hackles, there’s no question that much of Templeton’s money — \$71 million in 2011 — has funded legitimate and important science.

With an endowment of \$2.5 billion in 2012, the foundation’s research efforts have expanded in recent years to cast a wide net. In 2012, the Templeton Foundation awarded 178 grants, averaging \$970,446 each. Below is our deliberately oversimplified guide to these unusual and myriad efforts.



John Templeton

ADAM PIORE

PURPOSE: To investigate how interacting with infants alters unrelated adults’ behavior.

RECIPIENT: C. Sue Carter, co-director of the Brain Body Center at the University of Illinois at Chicago

AMOUNT: \$50,000 (via the Institute for Research on Unlimited Love)

Oxytocin, the so-called “love drug,” has been shown by Carter and others to promote healing in the body and create a sense of profound well-being, in addition to establishing a bond between parent and child. Carter looked at what effect exposure to newborn prairie vole cubs had on adult voles, related and unrelated. “We found that indeed, in a naïve male who was not the father, encountering the baby caused them to release oxytocin, and it also quickly inhibited stress hormones and had a whole series of other physiological effects,” Carter says.

The implications for humans? “Babies make us fall in love with them.”

PLAUSIBLE

• The neuroscience of multitasking

How do infants affect the brain chemistry of unrelated adults?

• The genetics of higher cognitive ability

PURPOSE: Data collection of DNA from 4,000 individuals with extremely high IQs

RECIPIENT: Robert Plomin, professor of behavioral genetics at the Institute of Psychiatry, King’s College London

AMOUNT: \$924,292

“Many people have studied genetics in the area of cognitive ability,” says Plomin. “But everybody studies disability. Nobody had studied high ability. We are looking at the other end of the continuum. There are many genes involved in intelligence. The only way to have a ‘super intelligence’ IQ is if you have most everything going for you. You have to have most of the genes associated that have a positive effect, and very few of the negative.”

• How do brain chemicals like oxytocin and testosterone affect our financial decisions?

• Does belief in an afterlife predict work behavior?

• What motivates generosity?

• The neuroscience of creativity

• Why do soldiers commit war crimes, and should they be held responsible?

• Do positive memories help Holocaust survivors stay alive?

• What is prayer and how do we engage in it?

• What is the nature of forgiveness?

HELPS YOU

HELPS THE WORLD

• What are the origins of the universe?

• Does going to church help the mentally ill?

• Searching for the power stations of intelligent extraterrestrials

PURPOSE: To find evidence of massive orbiting solar power stations constructed by advanced extraterrestrial civilizations.

RECIPIENT: Geoff Marcy, professor of astronomy at the University of California, Berkeley

AMOUNT: \$200,000

NASA’s Kepler observatory has identified hundreds of new planets by focusing on the slight dimming of light signals from specific stars, caused when large masses pass in front of them. Marcy, a member of the Kepler team, is combing the Kepler data to search for light variations that might come from a wholly different source: massive orbiting solar-power stations. “Just think of a big metal structure with slits, like blinds — you might see the blinds open and close,” explains Don York, the University of Chicago astrophysicist overseeing more than \$4 million in Templeton grants awarded to explore fundamental, big questions in astronomy and cosmology. “It would have to be large enough to have a detectable influence on the light of the star.”

• How might we detect multiple universes, or multiverses?

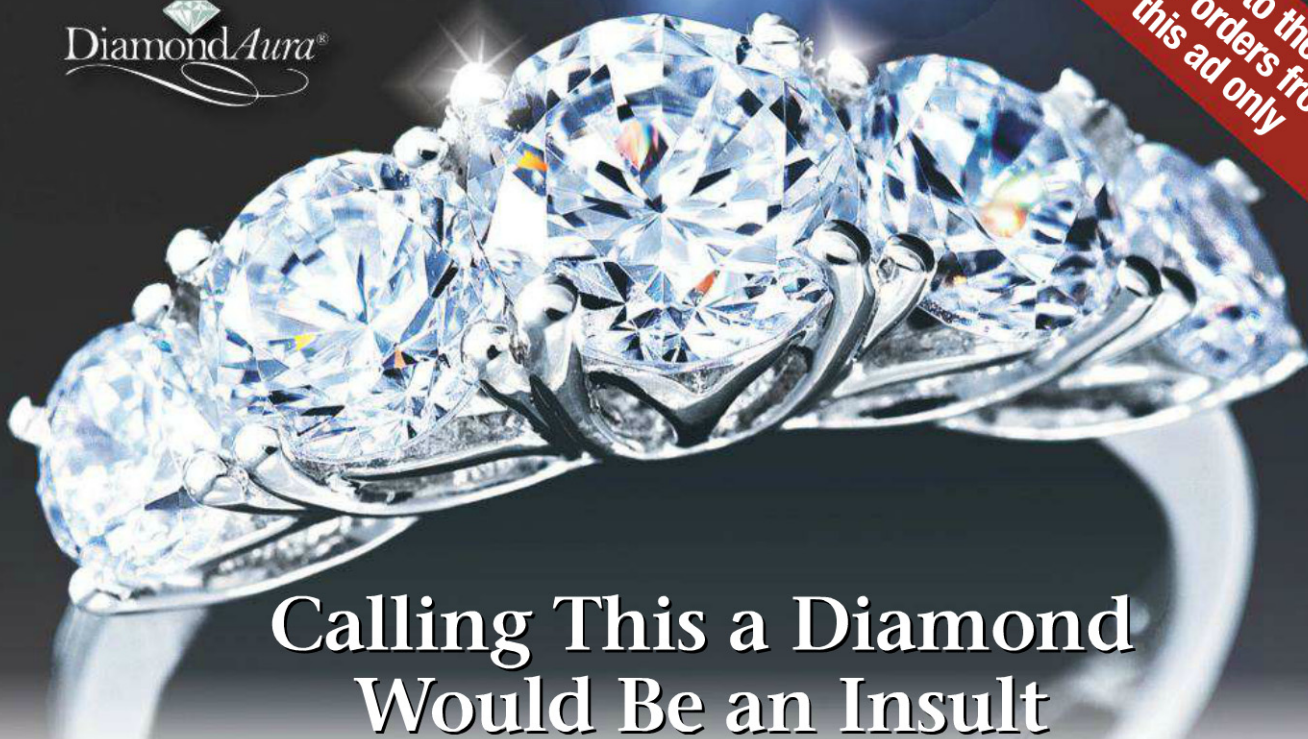
• Is there a purpose to the universe?

• Does faith healing work?

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Joshua Akey of the University of Washington recently explored the average age of our species's gene variants, finding that most are very young. About three-quarters of single nucleotide variants — a mutation that substitutes just one nucleotide (an A, C, T or G) in the long string of DNA — occurred within the past 5,000 years, surprising considering that our species may be 200,000 years old. Using several techniques to gauge the effects of these mutations, which are the most common type of variant in the human genome, Akey estimated that more than 80 percent are probably harmful to us.

All of these mutations — roughly 100 billion for each generation in the entire population — potentially accelerate the pace of evolution by giving it more raw materials with which to work. A small percentage may be beneficial; abilities such as digesting milk in adulthood and living at high altitude are recent acquisitions of the human genome. Given how many mutations are now circulating among living humans, we may be evolving new capabilities already.

Akey says determining the age of our mutations is made possible only by the stupendous increase in gene sequencing speed and power. Just a few years ago, this kind of experiment was inconceivable.

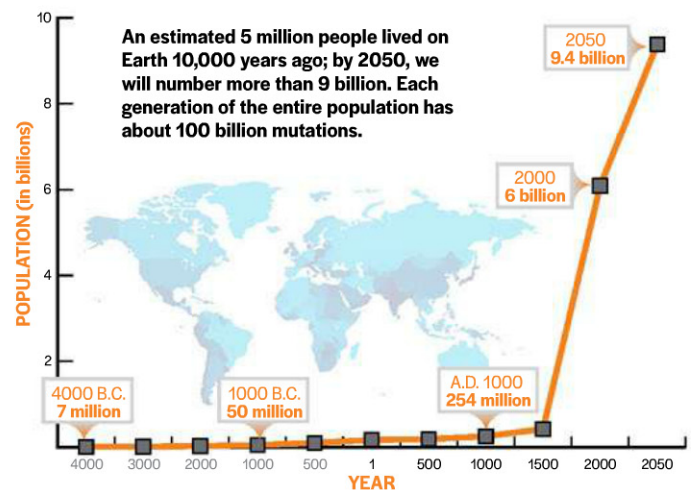
KAT MCGOWAN

Humans have five times as many rare gene variants as would be expected

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CONTRARY VIEW

Legalizing the trade in rhino horns is our best chance to save the species.



The white rhinoceros (left), or square-lipped rhinoceros, is one of the few remaining megafauna species. The dehorning of a white rhino (right) was deliberate to protect it against poaching.

Purported to treat a variety of ailments, from fevers to measles to epilepsy, rhinoceros horns have been prized ingredients in Chinese medicines for thousands of years. Sought after for their horns, white rhinos saw their population fall to 100 animals in South Africa by 1910, and only 2,410 black rhinos remained there in 1995. In South Africa and Namibia, a strong conservation ethic — coupled with financial incentives for ownership, management and protection of rhinos for tourism and legal trophy hunting — gradually helped to reduce poaching and restore rhino numbers. But today, Africa's rhinos once again are facing extinction, despite a 1977 ban on the selling of rhino parts by the Convention on International Trade in Endangered Species (CITES).

Ironically, legalizing a highly regulated trade in rhino horns might actually end up saving the animals. “The trade ban is failing because of persistent and growing demand for horn,” says Duan Biggs, a conservation biologist at the University of Queensland in Australia who argued for lifting the ban earlier this year in the journal *Science*. “The ban artificially restricts supply in the face of this demand growth, which pushes up the price for horn and the incentives for poachers.”

Purveyors of traditional medicine, Internet hucksters and back-alley dealers are taking advantage of Asia's growing wealth and culture of conspicuous consumerism, claiming new rhino remedies, like curing cancer and hangovers, to drive up demand. As of last year, the horns were fetching an aston-

ishing \$65,000 per kilogram on the black market, up from \$4,700 in 1993. Rhino horns are worth more than their weight in gold. In April, masked men stole four rhino heads from Ireland's national museum. The eight horns could be worth more than \$650,000 on the black market.

Rhino horns can be cut or shaved without injuring the animals, and they grow back. Biggs argues that horn cuttings from South Africa's 5,000 white rhinos on private conservation lands, along with stockpiles of confiscated black-market horns and those collected from rhinos that die naturally, could satisfy the current demand if tightly controlled by a single centralized organization. Each legal horn could carry a traceable transponder and have a recorded DNA signature, which would allow tracking of the precious cargo from South Africa to Vietnam and China, where most of the horns are sold.

The increase in poaching in South Africa has more than doubled every year over the past five years. More often,

skilled marksmen kill the beasts with one shot from high-caliber rifles. Or they shoot paralyzing darts at the rhinos from unmarked helicopters — then take the horns and leave the stunned animals to bleed to death. Last year alone, 668 rhinos were killed in South Africa. A 2012 report by researchers there predict that both rhino species will become extinct in the wild in just two decades if poaching continues to accelerate. Policing poachers is expensive and dangerous — game wardens have been murdered in shoot-outs — and it takes conservation resources away from other species.

Another popular tactic, education, hasn't helped curb demand. The horns are simply keratin, like our fingernails, and Western studies have shown no health benefits, but that hasn't dissuaded sellers. “This is not a matter of ‘education,’ but one of changing a fundamental belief system that has been around for longer than Christianity,” says conservation economist Michael ‘t Sas-Rolfes, who is based in Cape Town, South Africa.

The increased supply from legal trade would likely bring prices down, reducing the incentive for poachers to continue slaughtering rhinos. Biggs believes the trade would protect rhinos — a portion of profits could be funneled into continuing to police poachers — and bring jobs to the surrounding areas. And if demand were to keep going up, areas that hold white rhinos could be expanded to grow the population. In the end, a tightly regulated legal horn trade might do the most good.

IS LEGALIZATION VIABLE?

- Early this year the South African government approved an investigation into legalizing the rhino horn trade.
- The option was discussed in “side events” at a CITES meeting in Bangkok this March, but no formal proposal was made.
- The South African government is now undertaking a comprehensive feasibility study, and it could make a formal proposal to legalize the trade in 2016.

JENNIFER ABBASI

BOTH IMAGES: GETTY IMAGES

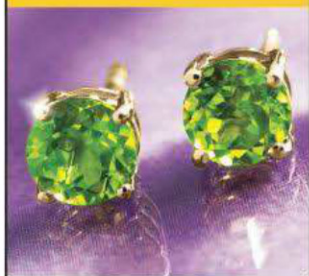
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Hot Science

What to read, view and visit this month



MUSEUM COMING SOON

OHHHH, MAYAN!

**Science Museum of Minnesota,
St. Paul, Minn.**

The Maya of Mesoamerica thought big: Consider the monumental architecture left behind at Tikal, Palenque and other sites. So it's fitting that Minnesota's Science Museum built its world premiere exhibit, *Maya: Hidden Worlds Revealed*, on a grand scale. At 15,000 square feet, it's billed as the largest traveling exhibit on the Maya ever mounted in the U.S. Hundreds of artifacts reveal both the art and everyday experience of the culture, while multimedia and hands-on displays give visitors a glimpse into ongoing field research that will further our understanding of this fascinating civilization. Opens June 21. smm.org

GEMMA TARLACH



CLOCKWISE FROM TOP LEFT: SHUTTERSTOCK; HEATHER QUINN/EOKR/PORTLAND STATE UNIVERSITY; NATIONAL INSTITUTE OF CULTURE AND HISTORY

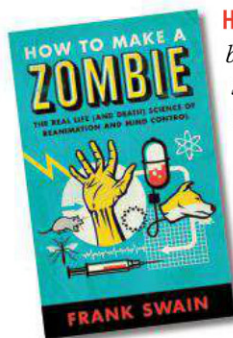
**ROCKET GIRL**

by George D. Morgan

After Sputnik's successful 1957 launch, the U.S. was desperate to get ahead of Russia in the space race. Subpar rocket fuels held the Americans back

until the Army put Mary Sherman Morgan on the problem. Without a college degree, Morgan concocted the right ratio of propellants and then pressurized the mix. Not long after Morgan pioneered the top-secret fuel, she gave up research and became a recluse, isolated even from her children. While writing her 2004 obituary, her playwright son George stumbled upon his mother's classified contributions as the first female rocket scientist and reveals them here, taking dramatic license with dialog and details.

BREANNA DRAXLER

**HOW TO MAKE A ZOMBIE**

by Frank Swain

Science Punk blogger

Swain connects the undead dots from Haitian folktales to CIA mind-control research as he hunts for definitive proof of zombiism.

Swain's search covers a lot of ground, from early historical accounts of whole armies defeated by mind-altering honey to modern experiments reanimating severed dog heads and chilling whole dogs to a "controlled death state." (Man's best friend seems to be man's favorite zombification study subject.) But the most disturbing theme to emerge from this often darkly funny book is our species' apparent eagerness to control each other: alive, dead or otherwise. —GT

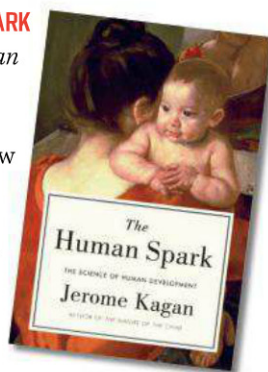
THE HUMAN SPARK

by Jerome Kagan

What governs whether an infant will grow up to cheat at poker, win a Nobel Prize or dominate at karaoke? In this revision

of his classic 1984 volume *The Nature of the Child*, Kagan explores new evidence in the nature vs. nurture debate. He adds material on moral development, emotion and mental illness in children and adolescents. Jargon-heavy at times, Kagan makes a strong case that personality is more elastic, and resilient, than we may think: Even toddlers who experience extreme abuse or deprivation can become well-adjusted adults.

SIRI CARPENTER

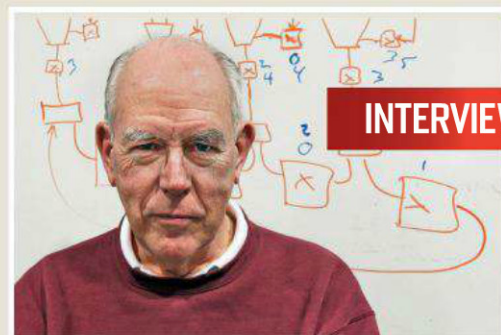
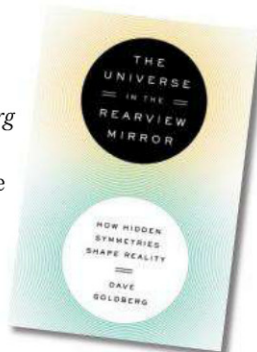
**THE UNIVERSE IN THE REARVIEW MIRROR**

by Dave Goldberg

You shouldn't exist. Don't take it personally — *nothing* should exist.

But at some point, around 10^{-35} of a second after the Big Bang, there was a slight shift in balance and, long story short, all of the "stuff" of the universe was born. Physicist Goldberg takes a road trip through time and space trying to answer the big questions about existence, including why any of us are here. Mathematical symmetries lie at the heart of many of the answers, but Goldberg offers math-free guideposts along the way in this witty and accessible read. Tip: Don't skip the copious footnotes, packed with geek humor.

ALISON MACKEY

**A Computing Pioneer Looks to the Next Frontier**

Among the big guns of computer science, Ivan Sutherland is a bazooka. Fifty years ago, Sutherland's Sketchpad program arguably launched the field of computer graphics. In the '90s, the Nebraska native's "logical effort" method optimized circuitry speed. Sutherland is currently focused on asynchronous computing, which he believes will revolutionize his field. Now at Portland State University, he spoke with DISCOVER Associate Editor Gemma Tarlach about his place in history and biggest source of pride.

Computing today runs, well, like clockwork:

A circuit's signal is forced onto a pathway made of regular intervals. But you've been developing asynchronous computing, which allows signals to progress at different speeds. Why is this method the next big thing?

All computing systems today march to the beat of a clock. It's a very rigid design form we used. That's why computer designers are struggling. If you cast aside the clock paradigm, you get a lot of advantages. When we learned to add in second grade, we learned there were easy additions and hard additions, and the hard additions required carries and took a little longer. Asynchronous computing allows hard cases to take a little longer. It allows you flexibility. Physics tells you asynchronous computing must happen. But it's hard. There are legions of engineers who believe the clock paradigm is the only way to go.

What do you think of calls for digital literacy, teaching children how to create code as well as how to read and write?

Not necessary. Do kids need to learn to drive? Probably. But do they need to know how to repair an engine? No. Give people the opportunity to learn the skills they'll find useful.

Then how will today's students become tomorrow's Sutherlands?

It's about investment. My parents made very substantial efforts and investments in the rearing of children. That's the answer.

You feel education is up to parents?

I learned algebra from the "I'm thinking of a number game," in the back of a car with my brother, both of us bored. Our mother or our father would say, "I'm thinking of a number, I'm the square root of 18 if you subtract 2." We did endless games like that, and that's how I knew algebra before I even went to school. I just didn't know it was called algebra.

What's your greatest achievement?

Four grandchildren. They all still talk to me. I like them, and they like me. I'd say that's a big achievement.

HotScience DESTINATIONS

Stone Laboratory, Ohio State University

Put-In-Bay, Lake Erie

41d 39' 28.2"N 82d 49' 15.8"W
stonelab.osu.edu

THE 6.5 ACRES OF TINY GIBRALTAR ISLAND ON LAKE ERIE'S south edge are crammed with reasons to visit, including Stone Laboratory, the oldest freshwater biology research station in the U. S. Tour the island, soak up the science and then rent a kayak to explore more of this scenic slice of the Great Lakes region. —GT



FISH TALES: Start your trip just a few hundred feet away from Gibraltar on nearby South Bass Island, at Stone Lab's sister facility, the Aquatic Visitors Center. It's open Wednesdays through Saturdays from June 19 through Sept. 7. Learn about Stone Lab's ongoing research into algal blooms and invasive aquatic species.

BAD HAB-ITS: Lake Erie's harmful algal blooms (HABs) are a growing problem for its ecosystem. A new water-quality lab under construction on Gibraltar will augment research already underway; public tours of the island include a discussion of HABs, their causes and possible remedies.



NAVAL-GAZING: Sept. 10 marks the 200th anniversary of the Battle of Lake Erie, when Oliver Hazard Perry and a few hundred other Americans took on the British Navy near Put-In-Bay — and won. Visit during Labor Day weekend to watch tall ships and re-enactors commemorate the event. battleoflakeerie-bicentennial.com

GO: Getting to Gibraltar Island is half the adventure of visiting Stone Lab. All visitors check in at the site's field office in Put-In-Bay on South Bass Island. Catch the water taxi to Gibraltar at the town's public boardwalk on Wednesdays for tours and Thursdays for lectures in the summer. Put-In-Bay also offers the nearest public accommodations. Get directions, find lodging and learn more about events in the area at putinbay.com.

ISLAND LIFE: Gibraltar, now property of OSU, was owned by a series of money men, including Civil War financier Jay Cooke. His elegant Victorian residence, Cooke Castle, still stands on the island, which has had a working marine research station since 1895.

R-E-SSS-P-E-C-T: Gibraltar Island is a center of study for the threatened, non-venomous Lake Erie water snake, often mistaken for the dangerous cottonmouth. Learn more at respectthesnake.com.

GET GROOVE-Y: Rock formations with evocative names such as Needle's Eye dot the island, but Gibraltar's most famous geological feature may be the deep grooves on its western shore, carved by glaciers more than 10,000 years ago.

GO DEEPER: Stone Lab offers courses for college and graduate students as well as various programs for educators and high school students. A seasonal lecture series is open to the public.

TECHNOLOGY

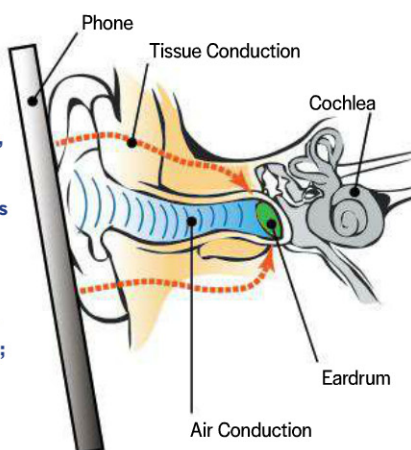


Now *That's* Using Your Head

While Kyocera's rugged Torque is marketed as the sort of thing you could drop, dunk or summit a mountain with, it's the phone's tissue-conduction technology that caught our eye, er, ear.

The Torque is the first smartphone sold in the U.S. that conducts sound through tissue in your head, a technology originally developed for use in hearing aids. You can hold a conversation on the Torque while wearing earplugs, even with someone aiming a hair dryer into your other ear. (Yes, we went there.) As long as the phone's screen is in contact with your head, it doesn't need to be near your ear: We tried the base of the skull, forehead and even nose. It's weird, but it works. —GT

HEAR YE, HEAR YE: On the phone or otherwise, the process of hearing usually begins when airborne sound waves travel through the ear canal and then hit the eardrum, causing it to vibrate. A trio of small bones linked to the eardrum picks up the vibrations and sends them to the inner ear's fluid-filled cochlea. As the cochlea's fluid moves, about 15,000 hair cells sitting in it, each tuned to a particular frequency, pick up the motions; the cochlear nerve translates the movements into auditory messages that are sent to the brain.



DE-SURROUND SOUND: Ambient, airborne sound can wreck a phone conversation, whether you're in a helicopter, on a construction site or surrounded by screaming toddlers. With tissue conduction, in a noisy setting you can wear earplugs or noise-canceling headphones (or go low-tech and use your fingers) and still hear because the sound waves of the conversation are traveling through your head.

GET IT THROUGH YOUR THICK SKULL: Bone conduction devices already on the market, such as some Bluetooth headsets, work on a similar principle; the vibrations travel only through bone, however, so they bypass the soft tissue of the eardrum. Because the eardrum is more adept at conveying tone, bone-only conduction can have a muddy sound.

(SOUND) WAVE OF THE FUTURE: Tissue conduction is turning up in other consumer devices, too. Panasonic plans to roll out a set of tissue-conducting headphones soon, and the much-anticipated Google Glass reportedly uses similar technology.

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10

Jul 4

A black and white portrait of a young man with dark hair and a mustache. He is wearing a dark suit jacket over a white shirt with a high collar. The portrait is set against a light background.

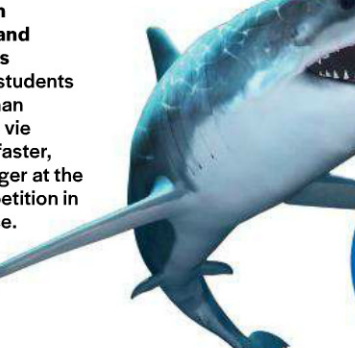
24-25

Jul 27-Aug 5

2 & 4

International
based on
comedy and
physics
School students
more than
countries vie
calculate faster,
stronger at the
competition in
Greece.

13.gr



Shark
Week
The D
Channel
festival of
Check
list

11-12

10-11

Shark Week

A black and white photograph of the atomic bombing of Nagasaki. A massive, billowing mushroom cloud rises from the city, its base obscured by a thick, dark column of smoke and debris. The cloud spreads out at a high altitude, covering a large portion of the sky. The foreground shows the dark, jagged silhouette of the atomic bomb's impact point.

6 & 9

Commence Summer Reading!

11-12



10-11

A close-up photograph of a large, vibrant green stick insect (Phasmatodea) being held gently by a person's hand. The insect's body is elongated and segmented, with a mottled green pattern. Its long, thin legs are spread out, and its antennae are visible at the head. The background is slightly blurred, showing more of the insect's habitat.

Dawn of the Atomic Age
In 1945, the U.S. became the only country to use the nuclear bomb in warfare, annihilating the Japanese cities of Hiroshima on Aug. 6 and Nagasaki on Aug. 9.
www.global-peace.go.jp/en

Calendar compiled by Elisa Neckar. Submit your events to thismonth@DiscoverMagazine.com

This month's calendar is produced in affiliation with the National Science Teachers Association nsta.org

Released to the Public: Bags of Vintage Buffalo Nickels

Historic 1920-1938 "Buffalos"
by the Pound



2013 marks the 100th anniversary of an American Classic: the Buffalo Nickel. To honor this milestone, New York Mint is releasing to the public bags of original U.S. government Buffalo Nickels not seen in circulation for decades. Now they can be acquired for a limited time only—not as individual collector coins, but by weight—just \$49 for a full Quarter-Pound Bag.

100% Valuable Collector Coins—GUARANTEED!

Every bag will be filled with collectible vintage Buffalos from over 70 years ago, GUARANTEED ONE OF EACH:

- 1920-1929—"Roaring '20s" Buffalo
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- Mint Marks (P,D, and S)
- ALL Collector Grade Very Good Condition
- FREE Stone Arrowhead with each bag

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Head Nickel (1883-1912), a valuable collector classic!

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Millions of these vintage Buffalo Nickels have worn out in circulation or been recalled and destroyed by the government. Today, significant quantities can often only be found in private hoards and estate collections. As a result, these coins are becoming more sought-after each day. In fact, the market price for Buffalo Nickels has risen 76% in the last ten years alone!

Supplies Limited—Order Now!

Supplies of vintage Buffalo Nickels are limited as the availability continues to shrink. And the 100th anniversary is certain to drive demand up even further! They make a precious gift for your children, family and friends that will be appreciated for a lifetime.

NOTICE: Due to recent changes in the demand for vintage U.S. coins, this advertised price may change without notice. Call today to avoid disappointment.

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The Nitrogen Underground

Scientists trace nitrogen through the soil in a quest to tame pollution from agriculture.



With the assistance of microbes, a nitrogen-fixing soybean seedling helps to enhance soil quality.

ON THIS GRAY, DRIZZLY WINTER morning, the California coastal mountains in the distance look like a mirage hovering over a flat swath of fields at Russell Ranch, a 300-acre experimental farm in the Sacramento Valley. One of the researchers in charge is Martin Burger, an angular, intense-looking Swiss ecologist. He steps out of his Ford F-150 pickup and leads me down a gravelly path to a field covered in neat rows of lime-green triticale — a cereal grain — and bean shoots.

Above ground, the scene looks orderly and static. But Burger and his colleagues at the University of California at Davis are interested in what lies hidden below the surface. Down there, it's a highly dynamic and far-from-predictable scene. To get a glimpse, they have buried an array of instruments that can trace the trajectory of nitrogen. They are trying to help solve the many ecological and human health problems caused by this troublesome element while helping farmers grow crops more efficiently.

Nitrogen has many faces. It is an essential element on the periodic table. No organism, plant or human, can survive without it. Yet there is a short supply of accessible nitrogen in the world. In fact, had scientists not created synthetic, mostly natural-gas-based fertilizer decades ago to improve nature's method of "fixing" nitrogen — a process of breaking nitrogen molecules apart to make them available to plants — neither you nor I, nor most of the 7 billion people crowding the planet, would be here today.

But here's the rub: Chemical companies turn nitrogen found naturally in the atmosphere into ammonium and nitrate

compounds that make up fertilizer. Soil microbes eventually transform the ammonium into more nitrate. This water-soluble form of nitrogen is a source of food for plants, but it makes a Jekyll-and-Hyde-like transformation when excess leaks into lakes and streams or groundwater. Nitrate can go from helpful to harmful, choking fish and their habitat by stealing oxygen, and contaminating human drinking water. Exposure to high levels of nitrate in groundwater has been linked to "blue baby syndrome," which can kill by

blocking the blood's ability to carry oxygen. The EPA also has linked nitrate in drinking water with thyroid cancer, respiratory tract infections, birth defects and premature births.

To make matters worse,

some of those excess nitrate molecules in the soil undergo another chemical change: Microbes help turn nitrate into gaseous nitrous oxide, which has roughly 300 times the global warming potential of carbon dioxide. In the end, crops use less than half of the nitrogen that farmers apply to the soil, on average.

On average, crops use less than half of the nitrogen that farmers apply to the soil.

Back at the Ranch

At Russell Ranch, scientists are uncovering how nitrate migrates. To start, they are studying how commercial crops, including tomatoes, wheat and almonds, can use nitrogen more efficiently without leaving excess nitrate to percolate into aquifers or run off fields. What makes nitrate such a vexing subject is that so many variables — including crop type, soil characteristics, field gradient and precipitation — dictate the speed, flow and amount that escapes. Sometimes it can take decades, even centuries, for it to move from a farm to a

Did you ever consider that when people keep their balance, it is not by their intent? Instead, consider that they are acting on the intent of a natural law we call gravity.

Extend that concept to all the laws of physics and realize that to be safe, people must act on the intent of all applicable laws of physics, as each law's intent dictates what people should do.

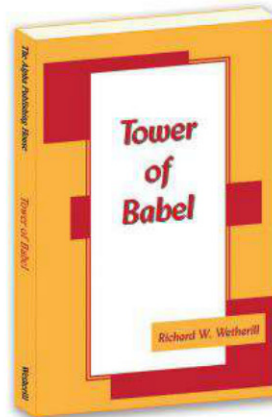
Decades ago the late Richard W. Wetherill identified a natural law that defines its intent for the behavior of the human race, and he called it the **Law of Absolute Right**. Lacking knowledge of that law caused the ancients and every following generations to live by their intent and to judge that people's deaths were inevitable.

The seven displayed books define the *intent of nature's behavioral law as calling for rational and honest thinking and behavior* to be humanity's way of life.

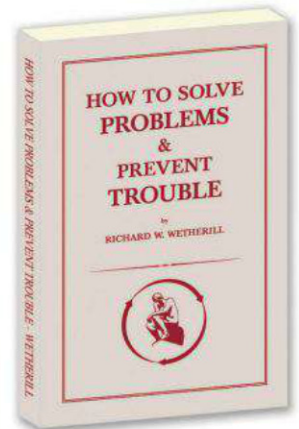
Thanks to Wetherill's insight, this generation has the opportunity to change their former thinking and behavior to the intent of an inviolable, self-enforcing natural law with the same compliance they accord to the laws of physics.

People who accept the logic of the above explanation live by the intent of the behavioral law, to the best of their ability. They know that when any wrong, troublesome results occur, it indicates they have deviated from right action. Eagerly they return to the safety of acting in accord with the intent of the creator's natural law of right behavior.

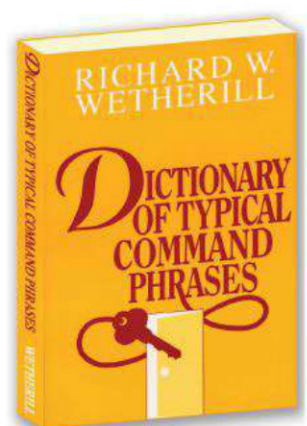
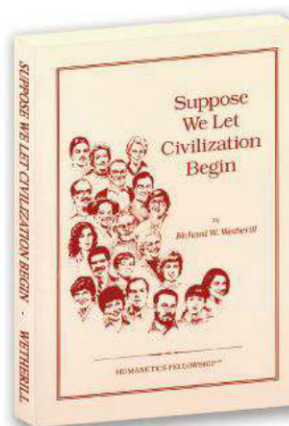
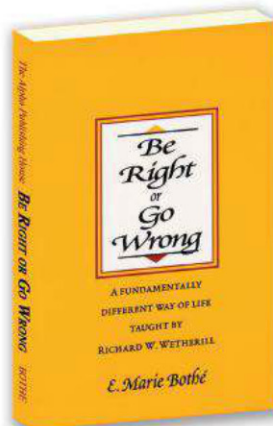
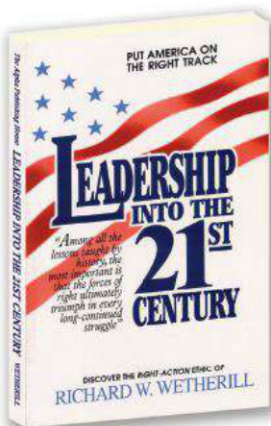
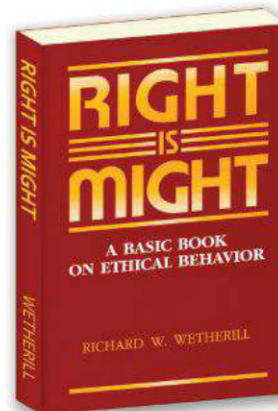
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"I have finished reading the book How To Solve Problems. So simple, yet so profound and powerful. Thank you." - Alex





An aerial view of Russell Ranch, an experimental farm in California's Sacramento Valley.

distant well used for drinking water, making it hard to pinpoint exactly which farm is a source of nitrate pollution.

In fall 2011, Burger and UC Davis hydrologist Jan Hopmans started a three-year experiment, comparing how different cover crops, which are seasonally rotated with cash crops such as tomatoes, can be used to improve soil quality and reduce fertilizer use. Some cover crops, such as fava beans, “fix” atmospheric nitrogen. They help the soil stockpile nitrate, allowing farmers, in theory, to apply less nitrogen fertilizer on the next set of crops planted in that field. Other types of cover crops bring excess nitrate to the surface, keeping it away from groundwater.

There is also the issue of irrigation. When Burger and Hopmans started, they knew tomatoes weren’t capturing a lot of nitrogen, especially when they were watered with furrow irrigation. That is when water runs through channels alongside each raised row. The researchers suspected different, more targeted, irrigation methods would help reduce nitrate runoff and improve plant efficiency.

With new insight about potential cover crop benefits and irrigation pitfalls, what still eluded the UC Davis nitrogen sleuths was precisely how nitrate travels once it



Ecologist Martin Burger checks on instruments that help measure water flow and nitrogen concentration underground.

flows into the soil and through the root zone of various crops.

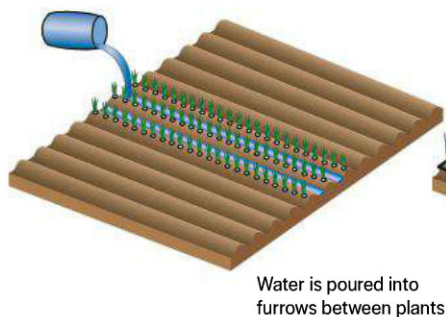
To answer this question, they took their previous research to new depths, literally. They designed instruments that would accurately and continuously measure nitrate concentration and water flow farther down into the soil than what had been measured before. Their machinery is spread out over six one-acre plots scattered across 70 acres. Several thousand units of data pour wirelessly into a computer in Burger’s lab from the field’s central nervous system. Burger unlatches the door of a solar-powered metal cabinet perched on a pole at the edge of a field. A spaghetti of multicolored wires is inside. Some of the wires are connected to sensors under the crops. “Too much information,” he quips, shaking his head. He will enter it all into a computer model that simulates water flow and nitrogen transport under various

irrigation and weather conditions, so that researchers can get the full picture of what is happening underground.

Soil moisture sensors show, over time, how much water has gone into the ground, and how much has left, either from drainage or in the form of evapotranspiration from plants. Burger points out some small red flags among the triticale in one of his plots. They mark where instruments called lysimeters, ceramic plates about 1 foot in diameter, are buried at various depths down to about 47 inches. They measure the amount of water flowing past.

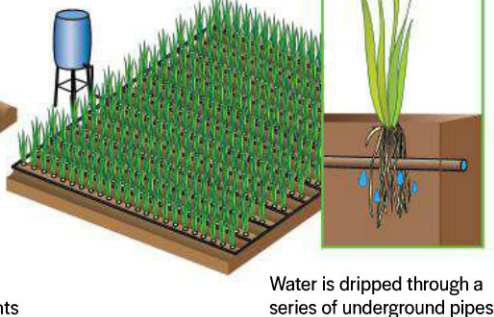
Another set of sensors measure electrical conductivity, which Burger says can be used as a proxy for measuring nitrate. (Nitrate increases electrical conductivity.) The researchers can trace the nitrate using stable (non-radioactive) isotopes, which are essentially unique atomic signatures for nitrate from different sources. They grab water samples by applying suction to ceramic cups buried at various levels in the soil. Each sample is brought to the surface, analyzed for its nitrate concentration and labeled with an isotopic signature. Nitrate sitting on the fields at the beginning of the rainy season is also labeled. Much of this has been left over from last year’s fertilizer use. Later in the spring, they can measure how much of the leftover nitrate on the surface ended up in cover crops and how much made its way into each soil layer.

Furrow irrigation



Water is poured into furrows between plants

Drip irrigation



Water is dripped through a series of underground pipes

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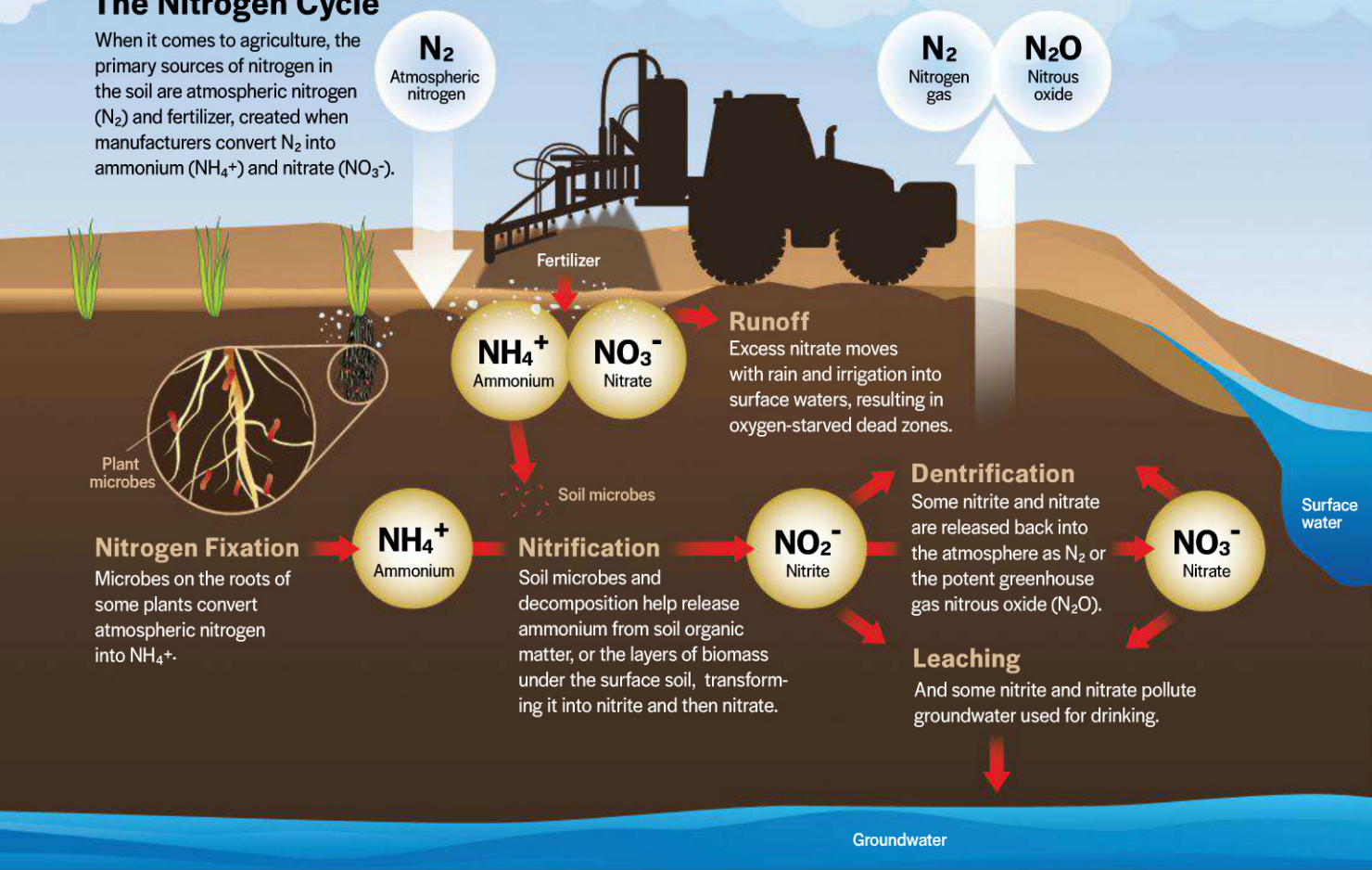
GHR

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The Nitrogen Cycle

When it comes to agriculture, the primary sources of nitrogen in the soil are atmospheric nitrogen (N_2) and fertilizer, created when manufacturers convert N_2 into ammonium (NH_4^+) and nitrate (NO_3^-).



Burger gazes across his plot to the south toward the nearby creek that feeds into the Sacramento River and finally into the Pacific Ocean. “From the label, you can see how far the nitrate is traveling,” he says.

Sowing Solutions

As he strokes a slim triticale shoot at his feet, Burger talks about his experiment’s initial results. “We do know that nitrate is leaching past the root zone during the tomato growing season,” even though applying fertilizer and irrigation water together has helped reduce runoff, he says. What has surprised Burger is that triticale has deeper roots — about two feet deeper — than fava beans. So, despite not being nitrogen-fixing, triticale may be better at capturing leftover nitrate.

Burger hopes his research can apply to farmers and scientists facing similar challenges as far away as Chesapeake Bay and the Mississippi River Basin, where there are enormous dead zones. Based on

the results, Burger and Hopmans will ultimately be able to offer recommendations for irrigation methods, fertilizer use and cover-crop plantings that help curb nitrate contamination and increase yields.

Hydrologist Thomas Harter, also from UC Davis, posits that even these best-management practices can only go so far. For many crops that need a lot of nitrogen, such as vegetables, corn and nuts, “we don’t know today whether farming practices will ever be good enough to produce drinking water quality recharge,” he says. (Recharge refers to water that escapes from fields into groundwater.) But farmers can learn to contain nitrate within their systems more carefully, he says. And regulators can step in. He has recommended that California lawmakers consider imposing economic penalties and incentives for farmers, such as excise fees on nitrogen fertilizer applications, with higher rates applied to areas declared to be at risk for nitrate contamination.

In recent years, some growers already have dramatically reduced the amount of water and synthetic fertilizer they use by practicing precision farming techniques, such as drip irrigation, which reduces the overall amount of water used and therefore nitrate runoff. They have managed to achieve these reductions without sacrificing profits. Despite facing what seems like a challenge made for Sisyphus, Harter harbors far more hope than dread for the future. “If we can get the worse half (of growers) to operate like the best half over five years, and then do it again, in 10 years everyone will operate as the best, and we’ll have come a long way,” he says.

Back at Russell Ranch, Burger continually contemplates the connection between farming practices and distant households. “It would be great if we made a contribution toward safer drinking water,” he says.

Susan Moran is a Colorado-based journalist covering agriculture, energy and climate science.

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Unknowing Host

An old man's liver holds a startling secret

WHAT WOULD YOU DO IF YOU had huge parasitic cysts?

That could burst at any moment? And spill thousands of babies?

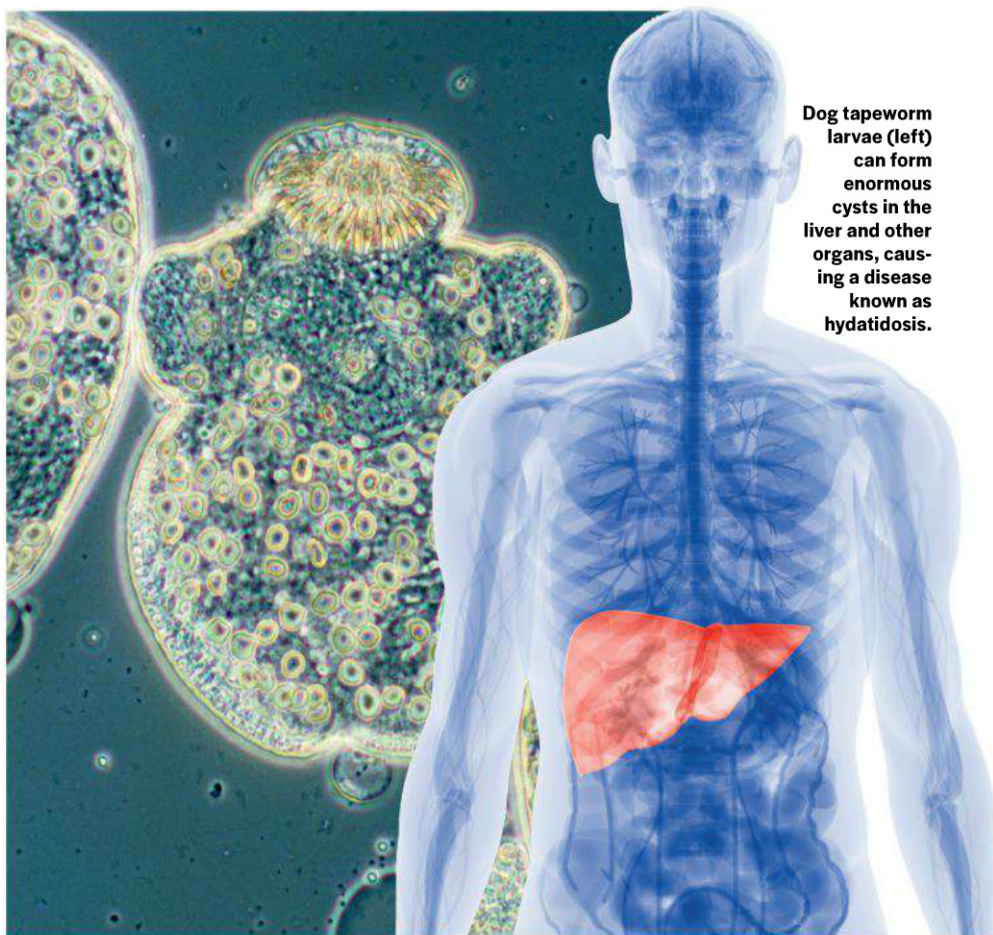
My new patient, an elderly Armenian who recently moved to the United States, didn't speak much English. He didn't need to. His penetrating gaze — anxious, wary and pleading all at the same time — revealed his inner thoughts. He had one overriding goal: to make his problem go away ASAP.

I also wanted to vanquish his parasitic invader and restore his peace of mind. But major abdominal surgery in a man nearing 80? About that, I wasn't so sure.

After trading emails with a local radiologist, I was finally meeting Mr. Kazaryan face to face. From his CT scan, I already knew the bulging landscape of his liver. His X-rays revealed a textbook case of *Echinococcus granulosus*, or dog tapeworm infection. Within two huge sacs (called hydatid cysts) that occupied two-thirds of his liver, Kazaryan harbored hundreds, if not thousands, of budding tapeworm larvae. In my 30 years as an infectious diseases specialist, I had never seen such a huge cache of parasites.

"Is it true you've never experienced any discomfort?" I asked, marveling at the scope of his infection. Yes, he nodded, until a few weeks earlier when an internist discovered his massive, rubbery liver. At that point, Kazaryan started to suffer fretful, sleepless nights — not, as far as I could tell, from physical pain. Just old-fashioned fear.

I clipped Kazaryan's X-ray films to the light box in my consultation room. Moments later, he and his wife and their daughter-in-law, who was his translator, huddled close as I pointed out the two watery gray-and-white silhouettes in his liver. The largest shadow was as big as an eggplant. Its nearby satellite resembled a ring of bell pepper. Scattered



Dog tapeworm larvae (left) can form enormous cysts in the liver and other organs, causing a disease known as hydatidosis.

On the X-ray films, the largest shadow was as big as an eggplant.

through the remaining tissue were other dots and blots. Were they more larvae waiting to bloom? I wished I knew.

The most immediate threat to my patient was not continued invasion, but a forceful blow to his belly. I could picture him slamming his brakes in a big-city traffic jam, hitting the steering wheel, bursting the capsule of his megacyst and — seconds later — his blood pressure

falling to zero. Rapid leakage of echinococcal parasite proteins into the human bloodstream can trigger dramatic allergic collapse, even death.

"Well, Mr. Kazaryan," I began, feeling three pairs of eyes on me. "These certainly look like hydatid cysts. Just to make sure, we'll do a blood test. Assuming it's positive, you'll then start an anti-parasitic drug called albendazole. The drug won't cure you, but it should prevent further growth of the cysts."

Kazaryan's daughter-in-law, a nursing student, spoke up. "In Armenia, we have learned, they often operate on this condition. Is that another possibility?"

"Yes," I replied. "But it could be risky. Let's talk about surgery after we've confirmed the diagnosis, OK? We have time. I know it's hard to believe," I added. "But your father-in-law has had this disease for decades."

She looked a bit dubious but remained polite. "Of course, doctor. We'll start with the blood test."

How to Vanquish a Worm

Mention tapeworms, and most people think of the fully grown variety: long, ribbonlike creatures slithering in someone's gut. Most commonly contracted by eating undercooked pork, beef or freshwater fish containing larval blebs, adult intestinal tapeworms spark fanciful lore. Can they really scarf calories and make people svelte? Don't count on it. They may absorb a few nutrients through their delicate skin, but their metabolic needs are surprisingly low.

Larval tapeworms, on the other hand, are acquired by ingesting tiny eggs passed in the stool of animals or humans carrying adult parasites. Silently breaching the intestinal lining, then morphing into juvenile stages, the microscopic parasites eventually find their way into a congenial organ. Then they slowly grow ... and grow ... and grow. Pork tapeworm larvae typically lodge in the human brain and can eventually cause seizures, severe headaches and blockage of cerebrospinal fluid. In contrast, larval dog tapeworms, the kind my patient harbored, most commonly seed the liver and lungs.

There's a good reason why dog tapeworm infections are relatively rare in industrialized nations. The surprisingly puny adult *E. granulosus* (in a dog's gut, it measures a mere quarter-inch) is found mainly in rustic locales throughout the world where dogs still herd sheep and sometimes consume their viscera. Eating the parasitized sheep flesh allows canines to acquire their own intestinal worms. Paradoxically, Kazaryan told me, he never liked dogs. Of course, he didn't have to. To acquire his blight, he needn't nuzzle one; he merely needed to swallow a tiny egg passed in the animal's stool. That egg,

in turn, might have lived for weeks or months in soil or vegetation before it ever entered him. I was sure of one fact, however: The fateful swallow of the wee ovum occurred in Kazaryan's native Armenia.

After his blood test came back showing he was indeed infected with *E. granulosus*, I started him on daily albendazole to halt the progression of his disease, as we had discussed. But that was just a prelude to a more definitive solution. Over the next week or two, I weighed the latest data and treatment options for a massive *E. granulosus* liver cyst. Recent studies confirmed that anti-parasitic drugs like albendazole could sometimes melt smallish echinococcal cysts without further intervention. Alternatively, combining albendazole with trans-abdominal cyst puncture followed

During surgery, even a spatter of cyst contents could plant many more.

by a killing flush of alcohol or concentrated saline had successfully shrunk cysts of various sizes in several thousand sufferers residing in low- and middle-income countries. But albendazole plus classic surgical excision remained the treatment of choice for patients with really large or complex masses — especially those whose cysts were on the verge of rupture.

Well, I decided: That describes Mr. K. It was time for him to meet my colleague, Ron Busuttill, a surgeon at the University of California at Los Angeles.

Mass Exit

Living in the United States, it's easy to take surgery for granted. By surgery, I don't just mean the elegant craft itself, but all the ancillary care — from anesthesia to blood replacement to skilled post-op management — that helps assure a happy surgical outcome. Surgeons in developing countries often lack such support, while patients in rural areas where *E. granulosus* is endemic may lack access to hospitals altogether. This explains the ongoing need for less-invasive treatments for many of the 2 million to 3 million echinococcal sufferers worldwide.

Mr. Kazaryan was lucky. He was not

only at a gleaming, modern medical center — he was about to become a patient of the best of the best, a world-famous liver transplant surgeon who over the years has operated on dozens of echinococcal patients. Busuttill didn't blanch at Kazaryan's advanced age or his enormous cysts. On the other hand, he never forgot a paramount risk of any echinococcal operation: During surgery, even a spatter of cyst contents could plant many more.

"We go on red alert as soon as we're in the OR and take every precaution against spillage," my colleague told me recently. He also described his careful search for the fibrous plane separating cyst wall from healthy liver. When a surgeon dissects along that plane, his scalpel is far less likely to trigger bleeding.

In Kazaryan's case, the operation went as planned. After surgically exposing the liver, Busuttill vacuumed 2.5 liters of larvae-laced fluid

from the huge carbuncle distending the organ's surface. He then irrigated the cyst cavity with concentrated saline to kill additional embryonic larvae, trimmed tissue from the inner so-called "brood" lining of the cyst and, finally, using an argon laser device, he vaporized the remaining parasite membrane. Then he removed the second, smaller cyst entirely.

Before closing, he repaired minor bile leaks and controlled bleeding vessels. Kazaryan returned to the recovery room in stable condition.

Five days later, Kazaryan suffered a cardiac setback, corroborating my fear that major surgery in a man his age might have unintended consequences. Fortunately, a delicate procedure corrected the problem, and he soon left the hospital.

Today, I see him every few months, admire his well-healed scar, check his blood tests and refill his prescription. When we meet, he always smiles and gives me a firm handshake. God willing, he'll now live well into his 90s, just like his dad. 

Claire Panosian Dunavan is a professor of medicine and infectious diseases at UCLA. The cases described in Vital Signs are real, but names and certain details have been changed.

MUSHROOM

A crusading mycologist says fungi are key to human and environmental health –



by KENNETH MILLER

MANIFESTO

and can clean up everything from **OIL SPILLS** to **NUCLEAR MELTDOWNS**



Paul Stamets shows off mushrooms in a growing room at Fungi Perfecti, his family business and farm. Work done there has inspired potential solutions to such global problems as radioactive waste, global warming, oil spills and cancer.

Left: Pioppino mushrooms (*Agrocybe aegerita*) induced tumor regression, reversing cancer in lab mice. The species also controlled blood sugar in diabetic mice.

photography by STUART ISETT, *except where noted*

For Paul Stamets, the phrase “mushroom hunt” does not denote a leisurely stroll with a napkin-lined basket. This morning, a half-dozen of us are struggling to keep up with the mycologist as he charges through a fir-and-alder forest on Cortes Island, British Columbia. It’s raining steadily, and the moss beneath our feet is slick, but Stamets, 57, barrels across it like a grizzly bear heading for a stump full of honey. He vaults over fallen trees, scrambles up muddy ravines, plows through shin-deep puddles in his rubber boots. He never slows down, but he halts abruptly whenever a specimen demands his attention.

This outing is part of a workshop on the fungi commonly known as mushrooms — a class of organisms whose cell walls are stiffened by a molecule called chitin instead of the cellulose found in plants, and whose most ardent scientific evangelist is the man ahead of us. Stamets is trying to find a patch of chanterelles, a variety known for its exquisite flavor. But the species that stop him in his tracks, and bring a look of bliss to his bushy-bearded face, possess qualities far beyond the culinary.

He points to a clutch of plump oyster mushrooms halfway up an alder trunk. “These could clean up oil spills all over the planet,” he says. He ducks beneath a rotting log, where a rare, beehive-like Agarikon dangles. “This could provide a defense against weaponized smallpox.” He plucks a tiny, gray *Mycena alcalina* from the soil and holds it under our noses. “Smell that? It seems to be outgassing chlorine.” To Stamets, that suggests it can break down toxic chlorine-based polychlorinated

biphenyls, or PCBs.

Most Americans think of mushrooms as ingredients in soup or intruders on a well-tended lawn. Stamets, however, cherishes a grander vision, one trumpeted in the subtitle of his 2005 book, *Mycelium Running: How Mushrooms Can Help Save the World*. Mushroom-producing fungi, he believes, can serve as game changers in fields as disparate as medicine, forestry, pesticides and pollution control. He has spent the past quarter-century preaching that gospel to anyone who will listen.

If his data were less persuasive, he might be dismissed as an eccentric myco-utopian. Stamets has no regular academic or institutional affiliation; his research is funded mostly by the profits from his private company, Fungi Perfecti, which sells gourmet and medicinal mushrooms (along with growing kits, mushroom-derived supplements and mushroom-related books and knickknacks) by mail order and at health food stores. With his Woodstockian hirsuteness and frank enthusiasm for mushrooms of the psychoactive sort, Stamets often comes across more as a hippie mystic than a dispassionate scientist. “Our bodies and our environs are habitats with immune systems,” he writes in *Mycelium Running*, and fungi “are a common bridge between the two.” He describes mycelium, the web of fibrous tissue from which mushrooms spring, as “the neurological network of nature,” a

Mycelia change their behavior in response to the environment. When you walk through the forest, they leap up. They know you’re there.

“sentient membrane” that has “the long-term health of the host environment in mind.” To some, such language seems uncomfortably metaphysical.

Yet Stamets’ ideas have gained an expanding audience among mainstream scientists, environmental engineers, federal officials and Silicon Valley investors. His 2008 talk at the TED Conference, the annual hajj of tech barons and thought leaders, has snagged more than 1.5

million hits since it was posted online; it also earned Stamets invitations to brainstorming sessions with Bill Gates, Amazon CEO Jeff Bezos and the guys who run Google.

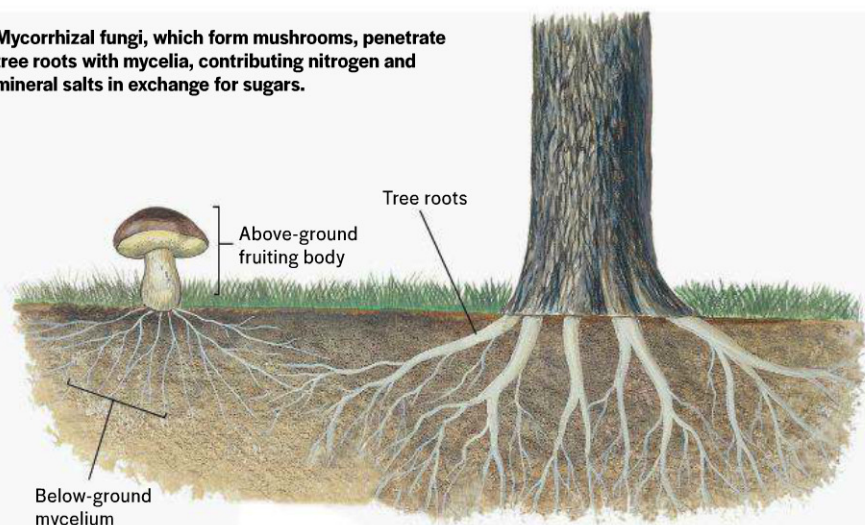
“It helps that he’s brilliant,” says Eric Rasmussen, a former Defense Department scientist and disaster expert collaborating with Stamets to decontaminate the zone around Japan’s Fukushima nuclear reactor with mushrooms. Rasmussen compares Stamets to visionary entrepreneur-scientists like Thomas Edison or “some of the truly fine amateur naturalists or astronomers of the 17th and 18th centuries — people who were experts in their fields, but had other ways to occupy their days.”

Stamets occupies some of his days teaching fungus aficionados and would-be mycotechnologists, both here at the eco-oriented Hollyhock Lifelong Learning Centre and at his mushroom farm in Washington state. He runs a business that has 47 employees and ships goods worldwide. Somehow, he also manages to juggle a diverse array of experiments — often in tandem with researchers at universities or nonprofit outfits — aimed at finding fungal solutions to global problems. “The path to the future,” he likes to say, “is the path of the mycelium.”

A PLANETARY WEB

However poetically expressed, Stamets’ notion that mushrooms bridge human and environmental immune systems is grounded in solid biology. On the evolutionary tree, the animal and fungal kingdoms sprout from the same branch,

Mycorrhizal fungi, which form mushrooms, penetrate tree roots with mycelia, contributing nitrogen and mineral salts in exchange for sugars.



splitting from each other long after plants diverged. And fungi knit together the lives of plants, animals and the Earth itself in some very concrete ways.

There are an estimated 1.5 million species of fungi, comprising yeasts and molds along with mushroom-producing macrofungi. All these organisms share certain basic traits with animals: They inhale oxygen and exhale carbon dioxide, as we do, and they are susceptible to many of the same germs. Like us, they get their energy by consuming other life forms rather than by photosynthesis.

But a fungus's body is radically different from an animal's. Yeasts are unicellular, while molds and macrofungi take the form of mycelia, networks of threadlike membranes, each a single cell thick, that can infest a rotting orange, infiltrate acres of woodland or fuse together to make a mushroom. Mycelia absorb nutrients from their surroundings and can rapidly change their growth patterns and other behavior in response to the environment.

"They have cellular intelligence," Stamets says. "When you walk through the forest, they leap up in search of debris to feed on. They know you're there."

When fungi colonized land a billion years ago, some established a niche as Earth's great decomposers — key to the creation of soil. Their mycelia exude enzymes and acids that turn rock into biologically accessible minerals and unravel the long-chain molecules of organic matter into digestible form. Fungal mycelia hold soil together, help it retain water and make its nutrients available to vegetation. Species known as mycorrhizal fungi use their mycelia to envelop or penetrate plant roots, contributing nitrogen compounds and mineral salts in exchange for sugars from the host organism. (When a sapling is languishing in the shade of a larger tree, these fungi can sense the problem and send the youngster extra nourishment.) Mushroom-producing fungi feed animals; animals return the favor by spreading fungal spores.

To ward off pathogens, fungi have developed an arsenal of antibacterial and antiviral compounds — a resource that traditional peoples harnessed in the form of mushroom teas and foodstuffs. Alexander Fleming exploited them in more

THE FUNGAL MIND

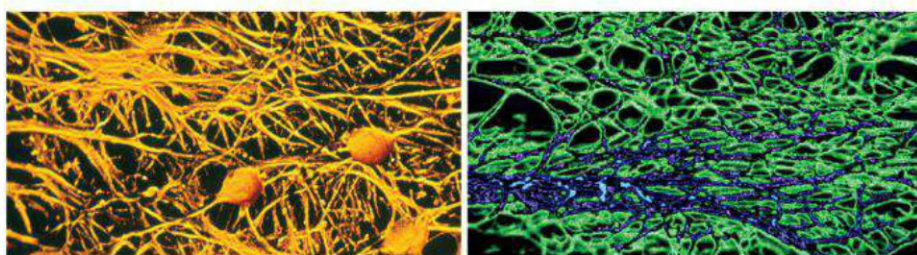
When you look at a mushroom, what you're seeing is a fungus's fruit. It emerges from a mass of fibrous tissue known as mycelium, which penetrates whatever material the mushroom is growing on. To the naked eye, mycelium resembles cottony fluff or cobwebs. Viewed through an electron microscope, however, it's an intricate weave of branching, threadlike membranes whose structure, Stamets notes, resembles a network of brain cells. And that, he argues, is evidence that fungi possess a kind of intelligence.

The analogies are striking. Brains and mycelia grow new connections, or prune existing ones, in response to environmental stimuli. Both use an array of chemical messengers to transmit signals throughout a cellular web. (One part of a mycelium, for example, can order another to send nutrients from hundreds of feet away.) The similar structures of fungal and neural networks, Stamets believes, reflect the fact that both systems evolved to do similar jobs — and do them with maximum efficiency.

But he doesn't stop there. Stamets perceives mycelium-like patterns in the information architecture of the Internet, in the matrices of string theory, in computer models of the web of dark matter suffusing the cosmos. Such recurrences, he believes, are signs of an evolutionary intelligence governing reality itself. "Nature tends to build on its successes," he writes in his book *Mycelium Running*. "The mycelial archetype can be seen throughout the universe." — KM



The cottony mycelium of a Garden Giant mushroom grows on fermented wood chips.



Scanning electron microscope images of human brain cells (left) and mushroom mycelium.

modern fashion when he isolated penicillin from the *Penicillium rubens* mold in 1929. Fungi can also parasitize and kill insects, including those troublesome to us.

For millennia, humans have exploited microfungi (molds and yeasts) to create edibles such as cheese, bread, beer and wine. But in Western culture, Stamets observes, the powers of macrofungi have been largely ignored, an attitude he refers to as "mycophobia" or "biological racism." Mushrooms were relegated to the Campbell's can, or outlawed when they blew too many minds. They were discounted, devalued, shunted aside.

Just as Paul Stamets was, before he found his own mycelial path.

THE MYCELIAL PATH

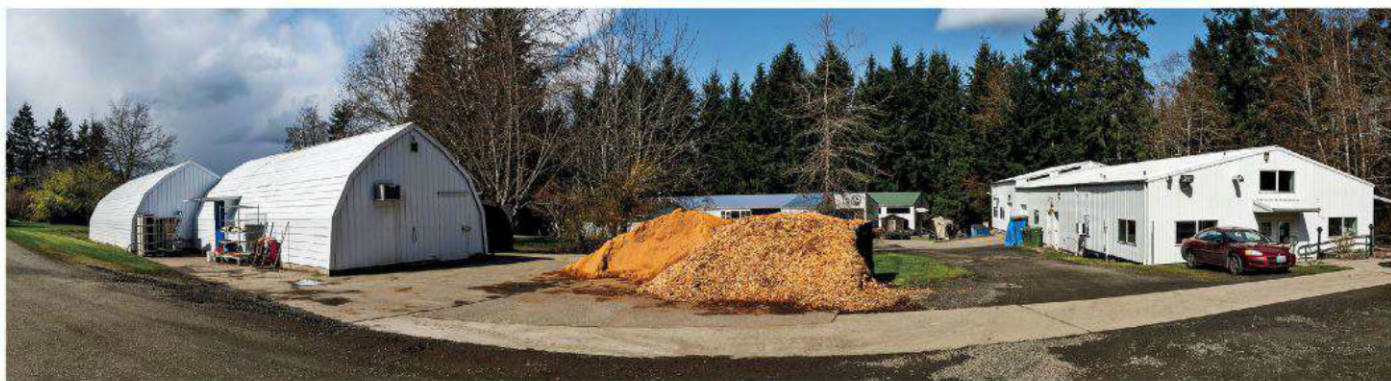
To understand how Stamets came to believe mushrooms could save the world, it helps to know how they saved Stamets.

He was born in 1955 in Salem, Ohio, one of four brothers. His father, an engineer, owned a firm that oversaw construction projects for the U.S. Army. Stamets was a

shy kid with a crippling stutter who dreamed of becoming a trailblazing scientist. "We lived in a big house with a lab in the basement," he recalls, "and I looked up every experiment I could find." He nearly blew the place up on several occasions while tinkering with chemicals.

Then, when he was 12, his father's business failed and the family splintered. Stamets' mother decamped with him and his twin brother to a small apartment in Columbiana, Ohio, where they lived in poverty. Eventually, she moved with the boys to her own parents' vacation home near Seattle and sent them on scholarship to a boarding school in Pennsylvania. Stamets felt like a misfit among preppies. He threw himself into martial arts (later earning black belts in both tae kwon do and hwa rang do) and identified with the counterculture that was reaching its crest.

During his senior year, Stamets and his brother were expelled for selling marijuana to fellow students. They hitchhiked back to Seattle, where they finished high school at a public institution. Stamets spent a summer



Against a backdrop of evergreens in Shelton, Wash., Fungi Perfecti supplies mushrooms to a growing market.

toiling as a sawmill hand before enrolling at Kenyon College in Ohio. But he still felt out of place and spent hours wandering in the woods off campus.

That's where he headed the day he tried hallucinogenic psilocybin mushrooms for the first time. He climbed a tree, but was too intoxicated to climb down. Soon a thunderstorm blew in, and he was lashed by rain and wind. As lightning struck nearby, he realized he could die at any moment, yet the scene was overwhelmingly beautiful. He felt part of the forest and the universe as never before. He reflected on his life and how to change it. "Stop stuttering now, Paul," he told himself, repeating the phrase like a mantra.

When the weather calmed, he climbed down and hiked home. On his street, he ran into a neighbor whose attractiveness had always intensified his stammer. "Hi," she said. "How are you today?"

"Fine, thanks," he answered, with an ease that astonished him. "And you?"

From that moment, Stamets' tongue began to come untied, and he devoted himself to learning about the fungi that he credited with the change. With the help of a mushroom-identification book, he found psilocybes growing wherever he looked, and he began to probe the mysteries of other species as well.

The following summer, he dropped out and took a logging job. But the more fascinated he became with mushrooms (hallucinogenic and otherwise), the worse he felt about helping to destroy their habitat. After three crew buddies were killed in logging-related accidents, Stamets decided to try school again, this time at Evergreen State College in Olympia, Wash. He wanted to become a mycologist.

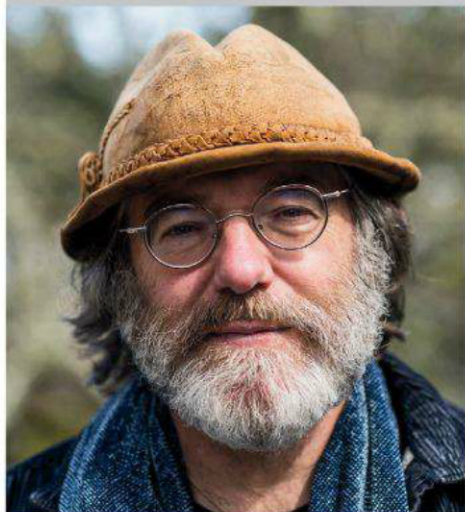
Evergreen didn't have a mycology department, but it encouraged indepen-

dent study. An environmental chemist named Michael Beug offered a course on mushrooms, and Stamets badgered him into becoming his adviser. "I've never had a student who was more driven," says Beug, who intensified his mycology research to keep up with Stamets. (Beug also secured a license from the Drug Enforcement Administration allowing him and his students to work with psilocybin mushrooms.) Stamets learned to run the school's scanning electron microscope — a rarity in the 1970s — and was soon photographing the cell structures of mushrooms, mycelia and spores for scientists nationwide.

By the time he graduated in 1979, Stamets had been tutored by some of America's leading academic mycologists. He was an accomplished field scientist, laboratory researcher and taxonomist. He had discovered several new *Psilocybe* species and published a book on the genus. He was an expert cultivator, too. Yet grad school seemed economically out of reach. Stamets had recently married a woman with three kids of her own, and the couple's first child was on the way. To support his family, he remained at Evergreen as an adjunct professor and started a business with a research arm on the side.

Fungi Perfecti's first lab and grow room occupied the basement of Stamets' rented house. He began selling exotic culinary mushrooms and holding seminars for the paying public. Then, after a 1983 trip to China with two of his mentors (mycologist Gary Lincoff and physician Andrew Weil, on his way to fame as a natural-health guru), Stamets became one of the first U.S. cultivators to branch into Asian medicinal varieties. Later that year, he published *The Mushroom Cultivator*, a book still widely

THE MAN WHO MISTOOK HIS MUSHROOM FOR A HAT



Although he's obsessed with finding new uses for mushrooms, Stamets is also a passionate scholar of ancient mycotechnology. He often wears one example: a traditional Transylvanian hat made of amadou, the spongy inner layer of horse's hoof fungus (*Fomes fomentarius*), which can be processed into a warm, feltlike fabric. Highly flammable, amadou has also served as tinder for flintlock guns and prehistoric campfires. (Ötzi, the 5,000-year-old "ice man" found in an Alpine glacier, was carrying the stuff in his pouch.) Its absorbent and antimicrobial properties made it ideal for dressing wounds and preserving foods. And amadou was the first medicinal mushroom on record: "Hippocrates described it in 450 B.C. as an anti-inflammatory," Stamets notes. — KM

considered essential for home and commercial growers.

In 1984 Stamets dove into his business full time. Aided by loans from relatives, he bought a 20-acre farm on Kamilche Point, a few miles northwest of Olympia. And it was there where he began to discover the macrofungi's planet-changing powers.

THE FUNGI PERFECTI FARM

Stamets' land came with a sagging farmhouse, a half-dozen cows and 400 feet of waterfront overlooking Skookum Inlet off the Puget Sound. Soon after he moved in, the sheriff rang his doorbell. "I thought, that was quick, I haven't had a chance to do anything illegal yet," he recalls. The officer informed Stamets that *E. coli* from sewage runoff was contaminating the local oyster beds, and served him with a court order requiring landowners to install updated septic systems in two years.

Stamets couldn't afford a new system. But he had suspected that mushroom mycelium could function as a natural filter the first time he saw its microscopic structure. In college, he confirmed his theory by testing the mycelia of various common species for absorbency; they all beat cotton hands down. He also knew that mycelia exude antibacterial compounds. So he decided to conduct a (literal) field test.

A marshy depression called a swale followed the gentle slope of Stamets' property, running downhill for 800 feet and ending just above the inlet. At the top of the swale, he dumped several truckloads of wood chips, which he covered with mycelium-infused growing medium — known to cultivators as spawn. Within weeks, mycelia had fully enmeshed the bed. By summer, Stamets had his first harvest of tasty Garden Giant (*Stropharia rugosoannulata*) mushrooms. A year after the planting, when water quality inspectors checked his runoff, they found his septic system was no longer a source of pollution; fecal bacteria levels measured a hundred times less.

Technicians from a Seattle-based bioremediation company, Enviro, learned of Stamets' success and asked him for advice on using fungi to clean up oil-soaked soil. At the time, many experts were betting on hydrocarbon-eating



Garden Giant mushroom: Mycelial wastewater filtration system and culinary delight.

bacteria as an eco-friendlier alternative to the conventional way of cleaning up such contamination — which was to truck the affected soil to a landfill and replace it with clean dirt. But bacteria can have trouble breaking down petroleum's largest molecules, and they're finicky about ambient temperature and oxygen levels.

A few researchers had begun experimenting with fungi instead. It had long been known that mold and mushroom species called "white rot" fungi could eat the lignin in wood, using enzymes to convert its complex hydrocarbons into nutritious carbohydrates. Molds also sometimes colonize fuel tanks, where they use those same enzymes to consume petroleum products. In the lab, a white-rot mold called *Phanerochaete chrysosporium* had shown particular thoroughness at digesting oil, but it often failed to perform under outdoor conditions. The Enviro staff hoped to find a hardier fungus, and

Stamets suggested they try oyster mushrooms (*Pleurotus ostreatus*), an aggressive white-rotter that could grow practically anywhere. He sent them some oyster mushroom spawn. The technicians covered it with oil, most of which was consumed within three weeks; mushrooms were popping up through the muck. But Enviro went bankrupt before the work could proceed further.

Meanwhile, Stamets began installing experimental mycelial wastewater filtration systems for other farmers (eventually with funding from the county and the state), improving on his initial design by encasing *Stropharia* spawn and wood chips in burlap sacks and packing them into ditches placed to catch maximum runoff. He began touting the method in environmental journals, and in 1996 he was approached by Pacific Northwest National Laboratory, operated by the Battelle Memorial Institute, known



Petroleum-eating oyster mushrooms resembling those above can remediate soil contaminated by oil spills.

for technological solutions to energy and environmental issues. Although initial interest was in Stamets' wastewater work, excitement grew when he mentioned his foray into oil-spill remediation.

Stamets and the Battelle team began lab work to maximize the mushroom's petroleum-eating efficacy. From his research on psilocybes, he knew that different strains of a single mushroom species can have wildly varying levels of chemical activity. So the team grew a few dozen strains of oyster mushroom, testing each for oil-digesting ability in petri dishes in the lab.

The strains that consumed oil fastest were selected for further trials, and in 1998, the team used the top performers in an experiment sponsored by the Washington State Department of Transportation at a maintenance yard in Bellingham. Soil at the site was contaminated with diesel fuel at up to 20,000 parts per million, similar to concentrations on Alaskan beaches after the Exxon Valdez oil spill. That spring, WSDOT scooped out four piles of dirt.

Stamets' team added layers of myceliated wood chips to one pile and covered it with a shade cloth. Two of the piles were treated only with bacterial cultures or chemical fertilizers. One pile was left as a control.

Four weeks later, the myceliated sample was light brown, sweet-smelling and bursting with mushrooms — some more than 12 inches in diameter. Insects came to eat the fungi, and their larvae attracted birds, which likely deposited seeds. After nine weeks, the pile was covered with flourishing plants. Aromatic hydrocarbons had dropped to less than 200 ppm, suitable for freeway landscaping.

"The other piles," Stamets recalls, "remained dead, dark and stinky."

The mushrooms had won.

HOW MUSHROOMS CAN SAVE THE WORLD

By then, Stamets was obsessed with the possibilities of what he called "mycorestoration," a nascent field encompassing his own and other researchers' work in mycofiltration, mycoremediation,

mycoforestry and mycopesticides (most of which are terms he coined). He began amassing a genetic library of hundreds of mushroom strains — gathered on hikes through the old-growth forests of the Northwest and on trips to Europe, Asia, South America and Australia — that could be used for environmental as well as medicinal healing.

The EPA asked Stamets to help the Coast Guard find ways to clean up waterborne oil spills. In response, he invented the mycoboom, a burlap tube filled with oyster mushrooms designed to break down petroleum while floating on a slick or barricading a beach. Battelle researchers tested his fungal strains against neurotoxins and found one potent variety of psilocybin mushroom highly effective at breaking down VX nerve gas. Stamets collaborated with the Washington State Department of Natural Resources on another successful field experiment, planting mushrooms on old logging roads to prevent silt and pollutants from clogging streams. He improved



Growing room manager Justin Tulloss inspects Lion's Mane mushrooms (*Hericium erinaceus*) at Fungi Perfecti. At right, mycorestoration project coordinator Katie Brownson works in the production facilities.



Mushroom cultures are propagated at the Fungi Perfecti farm and sold as part of its growing kits.



crop yields on farms and sped up reforestation in woodlands by adding mycorrhizal fungi to soil. In one case he planted broccoli together with elm oyster mushrooms; in another, he dipped Douglas fir seedlings into a slurry of puffball mushroom spores. He invented the Life Box, a cardboard carton impregnated with tree seeds and symbiotic fungi. After use (for shipping shoes bought online, for example), the box could be torn apart and planted to replace the trees used in its manufacture.

But the invention with the greatest immediate impact on Stamets' own environment grew out of his relationship with herbal medicine practitioner Carolyn "Dusty" Yao, which began in 1997 after his first marriage fell apart. (Stamets and Yao were married, with Andrew Weil officiating, four years later.) When Yao moved in, she was dismayed to find that Stamets' old farmhouse was infested with carpenter ants — attracted, ironically, by a white-rot fungus that was crumbling the floor joists. Stamets, who had ignored the problem for years, promised to take care of it.

He wanted to use a natural pesticide that was nontoxic to humans; unsurprisingly, he began looking for one derived from fungi. He knew that a few mold species could infect insects with their spores, killing them in the process. (In some cases, a tiny mushroom pops

through the corpse's skull.) Yet existing mycopesticides worked poorly against social insects, which could smell the spores and stop workers carrying them from entering the nest.

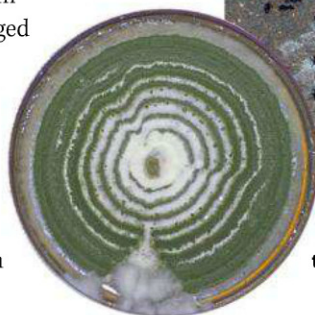
Stamets smelled a challenge. He sent away for a sample of *Metarhizium anisopliae* mold, known to kill termites and carpenter ants when its spores are sprayed on them directly. His idea was to train the fungus, which normally produces spores nonstop, to hold off until the ants had carried it into the nest. In its pre-sporulating form, he thought, the insects might be attracted to *Metarhizium* as a source of nutrition. Once they ate it, the mycelium would consume them in return.

When Stamets cultured the mold in his lab, a white circle of mycelium spread over the petri dish from the point of inoculation; it was soon covered with green spores. He transferred bits of the mold to other dishes, where they reproduced for several generations. Eventually, white stripes emerged amid the green in one dish, where the mycelium (perhaps due to a damaged gene) was lagging in its spore production. He then took some of the white material and cultured it over many more generations, breeding a mutant strain

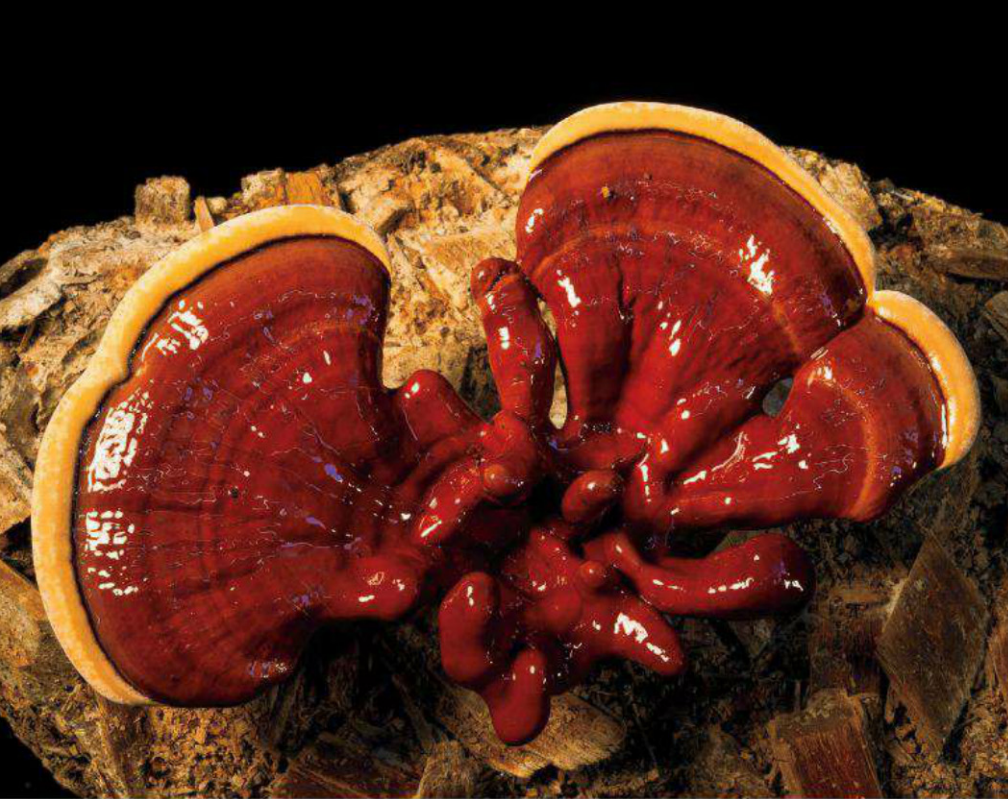
of *Metarhizium* whose sporulation cycle was delayed for days or longer.

Stamets grew his developmentally delayed mycelium on rice. When it was ready, he put a teaspoon of the spawn on a dollhouse dish belonging to his then-teenage daughter, LaDena, and placed it on the kitchen floor. That night, she ran to his bedroom yelling, "Wake up! You've got to see this!" The dish was swarming with ants, which were carrying grains of myceliated rice back inside the walls. Two weeks later, the house was ant-free, and remained that way from then on. After the insects died, Stamets hypothesized, the smell of their moldy bodies warned others away.

Further testing showed that other strains of *M. anisopliae* and another mold, *Beauveria bassiana*, could also be modified to attract and then exterminate a wide variety of bugs. In 2003, Stamets patented



Ants succumb to the pesticide power of green *Metarhizium* fungus, grown in the petri dish at left and disguised as food.



Reishi mushrooms are used to produce the antibiotic ganomycin.



Lion's Mane mushrooms might be useful for regenerating nerves and treating Alzheimer's.

his method and licensed it to a company that planned to bring it to market.

He used the proceeds to tear down his decaying house and build a new one, with cedar walls, a soaring roofline and a geothermal heating system. A stained-glass window dominates the living room, depicting the cosmos entwined with a mycelium-like network of dark matter.

MUSHROOMS FOR HEALTH

Across the meadow from Stamets' home sits a cluster of hangar-size white metal sheds and Quonset huts: Fungi Perfecti's offices, labs and grow rooms. Inside, workers tend to fruiting maitake mushrooms for medicinal teas, stuff plastic bags with oyster mushroom spawn for home-growing kits, or propagate fungal cultures in clean rooms equipped with airlocks and laminar-flow benches. These days, however, the company's fastest-growing product line (co-created by Yao, now his partner in virtually all enterprises) is a line of nutraceutical mushroom extracts, sold through another facility a few miles away.

According to FDA regulations, a nutraceutical manufacturer can't claim its products are able to treat any particular illness. So Fungi Perfecti markets its tinctures as general immune-system boosters and antioxidants. But mush-

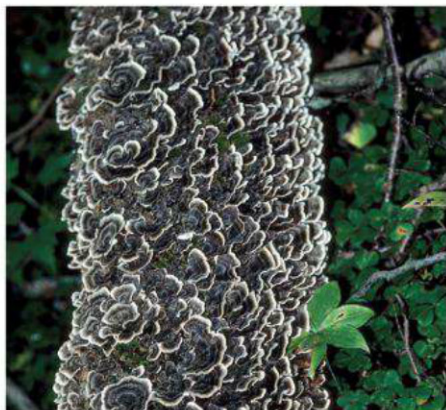
rooms are known to contain a host of proven disease-fighting chemicals, including polysaccharides, glycoproteins, ergosterols and triterpenoids, as well as antimicrobial and antiviral compounds, all varying according to species and strain. Indeed, a handful of pharmaceutical medications are derived from mushrooms, including the antibiotics ganomycin (from reishi mushrooms) and camp-estrin (from meadow mushrooms) and the chemotherapy drugs calvacin (from giant puffballs) and Illudin S (from the glow-in-the-dark jack-o'-lantern mushrooms).

Stamets is working aggressively to add to that list, and over the past decade, he has initiated or consulted on a dozen laboratory and clinical trials aimed at deriving novel mushroom-based drugs. After the 9/11 attacks, for example, he sent hundreds of samples to the federal Bioshield program, whose mission is to develop defenses against biological weapons. Several of his proprietary strains of Agarikon (*Fomitopsis officinalis*) showed strong activity against H1N1 swine flu and H5N1 bird flu, as well as viruses in the smallpox family. Stamets furnished capsules of freeze-dried fungus for a seven-year, NIH-funded study by Bastyr University and the University of Minnesota to determine whether turkey tail mushrooms could help breast cancer patients whose immune systems had been compromised by radiation therapy. Last year, the researchers announced that natural-killer cell activity, CD8 T-cell counts and other immune functions improved significantly with the treatment.

Stamets' mother, by coincidence, was diagnosed with stage IV metastatic breast cancer in 2009, at age 83. Although she was ineligible for the trial, he put her on turkey tail capsules to supplement her conventional chemotherapy drugs, Taxol and Herceptin. After six months, Patricia Stamets' tumor disappeared, and today she remains cancer-free. Though a single anecdote falls far short of proof, the deeply religious woman credits prayer as well as mushrooms for her return to health.

RENEWING A NUCLEAR FOREST

Divine intervention notwithstanding, progress toward Stamets' mycotechnological promised land has been slow. His



Turkey tail mushrooms: Stamets sent these to his mother when she was diagnosed with breast cancer.



medical research has yet to produce a marketable drug. His mycopesticides are held up in product development. His mycorenewal ideas still haven't been applied on a large-scale basis. When he proposed using mycobooms to battle the 2010 Deepwater Horizon oil spill, officials never even responded.

Yet momentum may be building. Last year, the EPA awarded Stamets \$80,000 to design a mycofiltration system for managing storm water runoff. A global environmental consulting firm, New-Fields, has adapted some of the techniques Stamets pioneered to remediate polluted soil. In Ecuador, the nonprofit Amazon Mycorenewal Project, run by an alumna of Stamets' seminars, plans to use mushrooms to clean up oil waste left by drillers. In New York, another nonprofit is experimenting with mycobooms to help cleanse the Newtown Creek toxic-waste Superfund site. In Grafton, Mass., renowned environmental engineer John Todd is using a Stamets-designed mycofilter to scrub petrochemicals from an old mill canal.

And then there's Stamets' plan to redeem the devastated landscape around Fukushima. Shortly after the 2011 tsunami-driven meltdown, he posted an online manifesto called "The Nuclear Forest Recovery Zone," which was predicated on a little-known fact about mushrooms: Many species are able to remove and absorb heavy metals, including radioactive isotopes, from soil.

Stamets' proposal was simple. First, fence off the contaminated area around the reactors. Then chip the wood debris from ruined buildings and trees, and spread it over the area to make substrate.

Replant native trees along with mycorrhizal fungi, which will help the trees grow while drawing radioactive material from the soil. Harvest the mushrooms as soon as they form, and dispose of them as nuclear waste. Repeat as necessary for several decades or even centuries until the Geiger counters stop screaming. The alternative, he pointed out, was to cart away millions of tons of soil and bury it as nuclear waste, taking up far more landfill space and depriving Japan of some of its best farmland and forestland forever.

The blog post went viral, although even many hardcore mycophiles assumed the plan was hypothetical. Eric Rasmussen, however, believed it was worth a try. The veteran disaster-relief coordinator had met Stamets nearly a decade earlier at a conference Rasmussen organized on environmental issues in refugee camps. "Paul had a lot of clever ideas that seemed both benign and effective, which is a rare combination," Rasmussen recalls. The two became close friends.

Last year, aiming to make the Nuclear Forest Recovery Zone a reality, Stamets partnered with Battelle researchers at the Energy Department's former nuclear production facility in Hanford, Wash., to test various mushroom species for their ability to take up cesium. Results are expected within the next few months.

Stamets, as usual, is optimistic. "I know some of my hypotheses sound rather extraordinary," he says. "I may be a little weird, but I'd rather be weird and right than normal and wrong."

Kenneth Miller is a Los Angeles freelance writer who contributes frequently to DISCOVER.

MUSHROOMS TO THE RESCUE

Stamets is researching a wide variety of ways in which fungi could help solve human problems. Here is a partial list:

Environmental cleanup Mushrooms could be used to break down petrochemicals or absorb radiation from contaminated soil and water.

Wastewater filtration Mushroom mycelia could cleanse runoff from storm drains, farms or logging roads. They could be used to filter out the nitrates, endocrine disrupters and pharmaceutical residues that disrupt ecosystems and damage human health.

Pesticides Fungal bug-killers could be used to target troublesome species while remaining nontoxic to others.

Medicines Mushrooms could provide new antibiotic, antiviral and immune-boosting compounds and even chemotherapies.

Forestry Planting symbiotic mushroom species could speed reforestation in clear-cut woodlands.

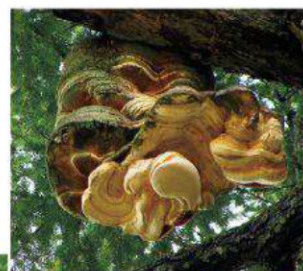
Agriculture Adding mycorrhizal fungi to soil could improve crop yields without the need for toxic chemical fertilizers.

Famine relief Mushrooms could be grown rapidly in refugee camps and disaster zones, using just wood chips or saltwater-soaked straw.

Biofuels Growing mushrooms for biodiesel could require far less soil and other resources than commonly cultivated fuel crops.

Space travel Because of their usefulness in soil creation, and the tolerance of many species for radiation, mushrooms could be grown by interstellar voyagers and used to terraform other worlds. — KM

Agarikon (*Fomitopsis officinalis*) mushrooms could protect against bird flu, swine flu and smallpox.



Slimy spike-cap mushrooms (*Gomphidius glutinosus*) can uptake radioactive cesium-137.



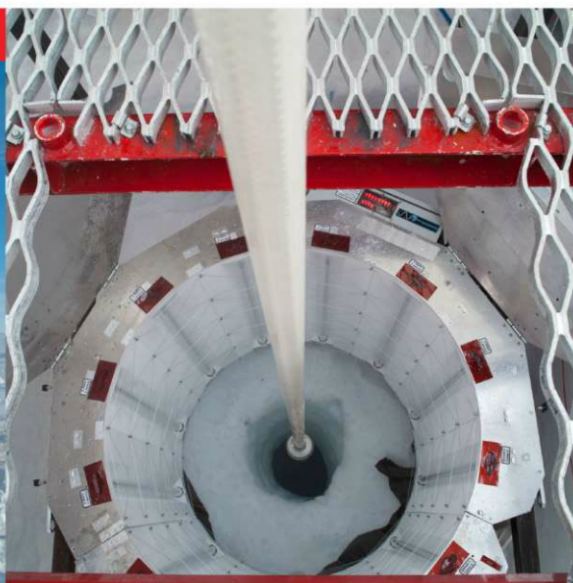
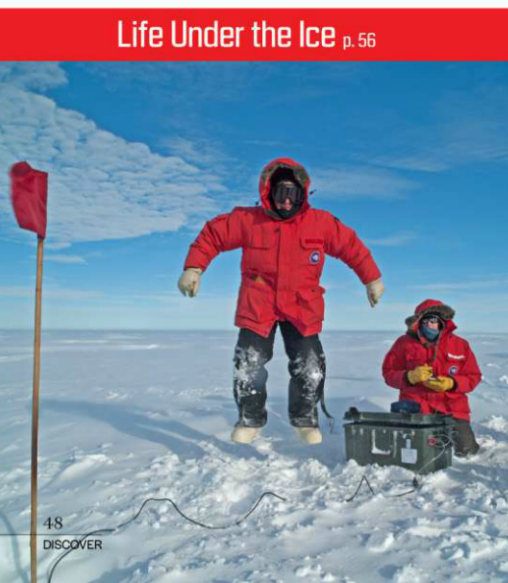
See more pictures from the mushroom farm at www.DiscoverMagazine.com/Mushrooms



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A INSIDE OUT



FROM ANCIENT ICE TO HIDDEN LAKES, NEW RESEARCH REVEALS THE FROZEN CONTINENT AS NEVER BEFORE. TWO DISCOVER WRITERS TAKE YOU THERE.

Above: Central Beacon Valley lies at the heart of Antarctica's Dry Valleys; buried under the valley's rubble is 8-million-year-old ice, believed to be the world's oldest. Photographer Keith Heyward of Prehensile Productions created this 180-degree panorama of the area from 35 separate exposures. From left: In these photos taken by JT Thomas, Dan Sampson from the University of California in Santa Cruz jumps to test seismic sensors that are buried in the West Antarctic Ice Sheet, nearly 650 miles and a world away from the Dry Valleys; a 2,626-foot borehole leads to Subglacial Lake Whillans; Reed Scherer, a geology professor from Northern Illinois University, stands by as drilling work continues; researchers extract mud from the lake; geomicrobiologist Andrew Mitchell, now with Aberystwyth University in England, prepares lake-water samples.



Dry Valleys Diary

In 1903, explorer Robert F. Scott and his team stumbled on an anomaly in the frozen, white expanse that is Antarctica: the Dry Valleys, fields of exposed rock with virtually no visible ice. Since 1986, geologist David Marchant of Boston University has spent nearly every Antarctic summer here, decoding a unique landscape. Journalist Jennifer Berglund, assisting Marchant in the field, kept a diary of her adventure.

Tuesday, Nov. 13, 2012 | McMurdo Station to Upper Friedmann Valley

This morning, four of us hopped on a helicopter at McMurdo Station, the United States Antarctic Program's base, near the spot where Scott's men built a hut in 1902 to wait out the long winter. Along with my fellow field assistant Keith Heyward, I was joining Marchant and his graduate student, Sean Mackay, flying 60 miles across the sea ice to the Dry Valleys, a series of valleys and ridges that lie roughly east to west and largely free of the ice that covers 98 percent of the continent.

Most glaciers are wet-based: A layer of water beneath the ice makes the glacier mobile, capable of creating steep fjords and other dramatic features that we associate with glacially sculpted terrain. The Dry Valley glaciers are cold-based: Too frigid to melt, their geological footprint is more subtle.

Marchant, with support from the National Science Foundation, is a veteran of Dry Valley expeditions, and this is Mackay's fourth season. As a rookie, I have no idea what to expect. I've done my share of adventuring, but this is a whole new level. I'm wondering if I'm really up for this. For six weeks, I will be without a shower, peeing in a bottle and sleeping in a tent in the coldest, driest place in the world.

From the helicopter, the land below resembled a massive explosion of white cake frosting over mountainous terrain. It was covered with glacial ice — the East Antarctic Ice Sheet. It is the largest in the world. In parts, it's nearly three miles thick, and, with the nearby West Antarctic Ice Sheet, it blankets an expanse roughly the size of the United States and Mexico combined. If both ice sheets melted — a process already underway at an alarming rate in West Antarctica — global sea

levels would rise 200 feet.

We flew over a break in the mountains, and the ice ended abruptly, revealing a flat valley. It looked like a dry, rocky riverbed. Mackay nudged me and pointed down. "That's Beacon Valley," he yelled, "our next campsite." For now, we continued farther south to a smaller inlet called Friedmann Valley.

When we reached our campsite, we unloaded our gear. The helicopter took off in a maelstrom of blowing sand and rock, leaving us in the middle of a giant boulder field stretching several miles north toward Beacon.

It's now evening, and we're surrounded by craggy walls banded with ruddy bedrock and tawny sandstone. Farther north, buttes and mesas resembling the American Southwest flank a flat valley floor. Beyond Beacon, the shelf of Taylor Glacier shows hints of baby blue. The cliffs surrounding us are glowing red. During the austral summer — October through February — the sun never sets here, but it does fall closer to the horizon, which spreads a narrow spectrum of warm light across the landscape, drawing out vivid, contrasting hues.

written by JENNIFER BERGLUND

photography by KEITH HEYWARD AND JENNIFER BERGLUND



Left: The design of the famously sturdy Scott Tent, such as this pair in Upper Beacon Valley, is a key feature of the Dry Valleys. Right: A helicopter takes off with a sling full of gear destined for a remote field camp.



Rocks weathered by wind over millions of years cover Friedmann Valley. Taylor Glacier, one of the few glaciers in the Dry Valleys, is believed to be the oldest ice on Earth, most of it buried beneath a layer of sand and rock.



in Valley, has changed little in more than a century. Center: At McMurdo camp. Right: geologist David Marchant (photo by Sean Mackay).



Glacier glints in the distance. Although Marchant and other geologists have accumulated rubble, they have not yet identified its upper age limit.

Wednesday, Nov. 14, 2012 | Upper Friedmann Valley

We woke up this morning to a different Antarctica. This was more like the one I'd read about — blustery and frigid at zero degrees Fahrenheit. The wind rumbled through the mountain peaks like distant thunder. Seconds later, it struck — a furious explosion that threatened to blow down our only shelter. But I was relying on a Scott Tent, designed by its famous namesake more than a hundred years ago and little changed since, a testament to its ability to withstand hurricane-force winds not uncommon on the continent. Scott Tents are large, tepee-like structures, with an array of guy lines that can be fastened to boulders or metal anchors buried and secured in the snow.

Because there were such strong winds today, it wasn't optimal for digging pits. That meant Mackay couldn't do his fieldwork, so he offered to take us on a walk while Marchant spent some time reading the landscape in solitude. Over his many seasons here, Marchant has found he does his best work alone. The veteran Dry Valleys expeditioner is a master, Mackay says, of pulling tiny pieces of evidence together to tell a much grander story.

Mackay, a tall, fit, 37-year-old climber, moved effortlessly across the rugged terrain while Heyward and I struggled. Covering the ground as far as the eye could see were large rocks and boulders, constantly tripping me in my cumbersome standard-issue "bunny boots" — white, clownlike shoes with a sole about an inch thick and little valves on the side to restrict the outflow of warm air.

We walked 50 feet down a steep slope to a flat area. Mackay explained that we had just been on top of relatively young glacial ice buried beneath the rubble. The slope was the edge of the glacier, but now we were walking on solid ground. We continued north toward Beacon while Mackay explained that the farther we got, the older the buried ice became.

The terrain beneath our boots was a time capsule. Roughly 14 million years ago during the Middle Miocene Climate Transition, ice stopped melting in Antarctica's southern Dry Valleys. Temperatures plummeted to about 14 degrees Fahrenheit, never again to rise above freezing at high elevations. The air dehydrated, leaving a frozen landscape with less humidity than the Sahara. From that

time forward, the landscape has remained largely unaltered.

Once we reached Beacon Valley, Mackay scoured the ground and knelt down. Using his hands, he dug through the rock and sand, and hit something solid. Hammering at it with a rock, it chipped — ice! He gave Heyward and me a couple of pieces to suck on. Mackay estimated the ice could have been as old as 800,000 years, making it roughly the same age as the oldest ice ever core-sampled from anywhere in the world.

Marchant and colleagues have found that pockets of slow-moving buried glacier ice can persist for millions of years — 8 million years for ice found in central Beacon. Some ice in the valley could be even older. Not long ago, it was thought impossible for ice to remain intact for millions of years: Scientists assumed it would eventually sublimate, transforming in the frigid, dry air directly from ice to vapor. But new modeling studies by Marchant and his team have shown that sublimation of deeply buried ice is extremely slow, less than a tenth of a millimeter per year. Under certain conditions, the buried ice can persist almost indefinitely.

Friday, Nov. 23, 2012 | Camp move to Central Beacon Valley

We moved our camp north today to Central Beacon Valley. It was an all-day affair of packing, unpacking, organizing, loading and unloading the helicopter. The landscape here is different from what I imagined it would be. The boulders are much smaller than the ones in Friedmann, and the terrain is easier to navigate. In parts, the rocks fit together like a Roman road in a multicolored mosaic of rock types: sandstone, volcanic dolerite and granite. Judging from the rocks' small size and smooth texture, Marchant told me it would have taken the snow and wind millions of years to whittle them down. They must have remained in the same position for thousands more to fit together like puzzle pieces.

Saturday, Nov. 24, 2012 | Central Beacon Valley

We had our first real snow today! I've never seen anything quite like it. The flakes were massive. They looked and sounded like little balls of Styrofoam as they fell. Marchant said they would accumulate for only a short while before being either blown away by

What Flavor Will the Gene Popsicle Be?

In the desolate landscape of Antarctica's Dry Valleys, it is nearly impossible to imagine life could exist, much less thrive. Yet buried beneath the frozen boulder fields, tucked between grains of sand and buried ice, there is a surprising amount of biodiversity.

In search of microscopic life, molecular ecologist Kay Bidle of Rutgers University looked for microbial DNA in the soil and ice core samples Marchant gathered for him during one of his expeditions. Though degraded, multitudes of ancient microbial DNA fragments, some 8 million years old, were suspended inside the ice samples. Bidle found the Dry Valley soil microbes were not much different from those found elsewhere in the world.

For a genome to survive in a cell, it needs a chain of at least 160,000 base pairs of DNA

fragments intact — the largest soil microbes have about 12.2 million. Bidle didn't see lengths like that; the largest segments he found in the ice core specimens were just tens of thousands of base pairs long. Older core samples contained even smaller, more degraded chains. And yet, when Bidle cultured his samples, they grew into living organisms — even the oldest ones. Hiding among the masses of ancient, degraded DNA, there must have been a few intact specimens that persevered all those millions of years. They had survived, Bidle hypothesizes, in a dormant state, a sort of hibernation.

If the Dry Valleys ice melts, entirely new life forms could spring up. They would be created through the process of lateral gene transfer, in which microbes incorporate loose bits of genetic material from other microbes into their own. The melting of the oldest ice would expose DNA fragments entombed millions of years ago,

creating a sort of gene Popsicle: Existing microbes could incorporate the released genetic fragments, leading to new species.

Many believe something like this happened 570 million years ago, when our planet may have been completely covered in ice — Snowball Earth, it's called. That ice encased microbes, just like Bidle's specimens from the Dry Valleys. When the Snowball melted, there was an explosion in the diversity of microbial species in the fossil record. The gene Popsicle effect may be why.

With more ice melting in this era of global warming, could we have an alien microbial invasion on our hands again? Not likely, Bidle said. Any species released via the gene Popsicle effect probably won't make a dent in the established microbial order. Instead, complex modern microbes, which would vastly outnumber any new Antarctic life forms, would probably just gobble up the more primitive organisms. — JB



The sky clears after a rare snow in Upper Beacon Valley. With average summer temperatures around 14 degrees Fahrenheit and less than 10 percent humidity, the Dry Valleys of Antarctica are too cold and too dry for significant snowfall. Any dusting that accumulates is quickly blown away or sublimates, turning to vapor.

the wind or sublimating. Low clouds covered most of the landscape, but occasionally they cleared just enough to reveal a lacy layer of snow covering the mountainsides.

Heyward and I spent most of the day in the cook tent readying equipment for the field. Despite being out of the wind, a day like this, with little strenuous activity, is just about the worst thing when you're trying to stay warm. Without much movement, the cold hits your fingers and toes first, making your bones ache and shooting pain all the way up your extremities. Several times, I had to run out of the tent and up a nearby hill to get my blood pumping. I hope tomorrow is more active.

Friday, Dec. 7, 2012 | Camp move to Upper Beacon Valley

Another camp move today. We're now just a few miles south of Central Beacon. It's our final campsite, which is bittersweet. Aside from the cold, life out here is simple: eat, sleep, work hard, chat. There is a kind of camaraderie that grows from working in the field, particularly within a small group of four. One more week, and I'll be heading back to a bustling city. I think I'm more worried about assimilating back into normal society than I was about living outside in the middle of Antarctica.

Monday, Dec. 10, 2012 | Upper Beacon Valley

We are camped at the point where Friedmann and Mullins Valley meet Beacon. The ice here is younger and cleaner than ice farther north in Central Beacon, so it's a good place to drill for an ice core sample. The bubbles of atmospheric gas trapped inside a sample can be analyzed to reveal information about past conditions and, by extension, past temperatures. Marchant estimates the ice here could be 4 million years old, five times older than the oldest cores taken from elsewhere. If we manage to drill a good sample, it would help place ongoing climate change within a long-term geo-

logical framework and provide compelling evidence for past changes in the atmosphere and global ice volume. Access to that information would enable scientists to predict future change more precisely.

"In the next 50 to 100 years, we're going to see carbon dioxide levels in a realm that we have never observed in the records we have, which really only date back 800,000 to 1 million years," Mackay told me. "We've just never seen levels that high."

Scientists believe there are earlier periods in Earth's history with comparably high levels of the gas. The trouble is, ice cores are the gold standard for estimating past atmospheric carbon dioxide levels, and Marchant says the Dry Valley glaciers are the only ones known to contain ice that old.

Although samples from previous seasons have been useful for other research, Marchant has yet to obtain a core with a pristine carbon dioxide record. Drilling a good core — while not impossible — is challenging and takes time. Drills designed to cut through rock use warm water to rinse the blades during the process, which can destroy an ice core. For the best chance of an intact sample, researchers must hunt for areas of solid ice that can be cored with drills used specifically for that purpose. Even when a prime, rock-free site is found, samples can be contaminated with microbial activity or by modern air that seeps in when temperature changes cause the ice to crack.

Thursday, Dec. 13, 2012 | Upper Beacon Valley

I woke up to a surprisingly hot day in Upper Beacon Valley. It was about 30 degrees, and I was burning up. I made a sweaty exit from my sleeping bag and stripped down a few layers to my long underwear. It still seemed hot.

Today we had to excavate an ice core from a patch of buried ice we uncovered yesterday. For once, I wished for cold.



Left: Sean Mackay uses a manual drill to obtain an ice core sample while Marchant looks on. Coring in the Dry Valleys is challenging: Many drills use hot water, which destroys the ancient ice. **Right:** Mackay walks on a ridge high above the Labyrinth, formed in a devastating subglacial flash flood 12 million years ago.

Exposed ice glistened as it melted from the surrounding dark rocks heating in the sunshine. Mackay and Heyward took turns twisting the manual, cylindrical drill into ice and rock. It's a low-tech version of the drills they usually use, and it is typically employed to test core quality at a site before large-scale drilling. Mackay pulled it up. Fractured pieces of ice fell out of it. It was certainly not the solid piece we needed. We sighed in disappointment. It wasn't good enough for science, but Mackay had something else in mind. He bagged it, and we took it back to camp.

That night, bad weather came in again, but this time without wind. It was snowing; a thick cloud covered the mountaintops and much of the landscape. It was much colder now. We huddled

in our cook tent and listened to some music on a pair of battery-powered speakers while Mackay made us a treat: a dash of rum with Raro, a Tang-like powder drink popular in New Zealand, the last civilized port of call for researchers heading to the Dry Valleys. Mixing in the crumbled bits of ancient ice, Mackay poured us all a glass, and we toasted the adventure.

Fog surrounded our campsite. We could have been on a mountaintop, a freezer, a studio — it was impossible to tell. You could see nothing but a fuzzy white wall a football field away in every direction. Mackay's kite, which, for fun, he had tethered to the tent, was high above us — a black speck, with the long, dotted line of a tail hovering in a white void.

Solving the Puzzle of the Labyrinth

Beneath a glacier in the Transantarctic Mountains some 12 million years ago, the downhill flow of a massive, growing reservoir of meltwater was restrained by walls of ice. As the reservoir grew, it became too heavy for the walls to hold. They gave way, releasing an explosive surge of water nearly 13 times the volume of water draining through the Amazon River.

As it ripped through the valley below, the water gushed into the bedrock, tearing away chunks of rock the size of refrigerators, hurling them miles down Antarctica's Wright Valley. In its wake, the subglacial flash flood left a spectacular maze of channels, some hundreds of meters deep, incised into the stone, an intricate complex of meandering pathways called the Labyrinth.

It wasn't easy to decode the history of this mysterious place. It may never have been understood were it not for the Channeled Scablands, a strikingly similar landscape in eastern Washington state, and a bit of meticu-

lous sleuthing by geologist David Marchant and his graduate student, Adam Lewis.

A megaflood theory for the Scablands first appeared in the 1920s, but it wasn't widely accepted until the 1970s, when geologist Victor Baker described the physical processes of major floods around the world. Features like giant gravel current ripples and displaced 65-foot-wide boulders in the Scablands could not be explained by changes in the nearby Columbia River, he wrote — the flow and volume of whatever water source formed them would have to be exponentially larger. In 2005, when Marchant and his team were exploring the Labyrinth, they noticed scouring patterns on the walls within the channels, hinting at a massive surge of water below a glacial surface. It was then they pieced the story together.

The subglacial megaflood, Marchant believes, occurred during the middle Miocene, a period 12 million to 16 million years ago. Antarctica cooled from a temperate climate with wet glaciers to the

frigid climate and cold-based glaciers it has today. During the transition, ice sheets expanded, and meltwater accumulated below the ice at the edge of mountain divides, creating lakes below the glaciers. As the climate cooled, ice dams formed in mountain passes, including one above what is now the Labyrinth. As the lake beneath the glacier grew, pressure overcame the strength of the ice dam. Once the water broke through, nothing could stop its flow.

Smaller, so-called "proto-Labyrinths" exist elsewhere in Antarctica, suggesting catastrophic floods were probably not rare in the continent's geologic history. Marchant suspects more of these landforms are buried under ice, which covers more than 98 percent of the continent.

— JB

Jennifer Berglund is a journalist, photographer and multimedia producer based in Boston. She travels the world to tell stories about science.



Life Under the Ice

Hundreds of lakes and rivers lurk beneath Antarctica's expansive ice sheet. Writer Douglas Fox joined a cadre of researchers seeking signs of life in the frozen deep.

Sunlight glared off of the Antarctic Ice Sheet. Slawek Tulaczyk, a 46-year-old glaciologist, squinted in the slanted summer rays as he watched a drama unfold 600 feet away.

A Hercules military cargo plane sat stranded, unable to take off. Its skis had frozen to the snow. The plane had just dropped off Tulaczyk along with 12 workers and 10,000 pounds of gear. They were here to probe one of the last unexplored places on Earth. Beneath the snow's deceptively flat surface, under 2,600 feet of ice, lay a mysterious lake that human eyes had never seen. Tulaczyk, from the University of California in Santa Cruz, had waited six years for a chance to investigate this hidden body of water, called Subglacial Lake Whillans.

Now, as he watched the Herc make its second attempt to take off, he worried. Tulaczyk's flight was the first to shuttle expedition scientists, engineers, technicians and gear to the field, and a stranded plane could prevent the rest of the crew and the last of the equipment from arriving in time.

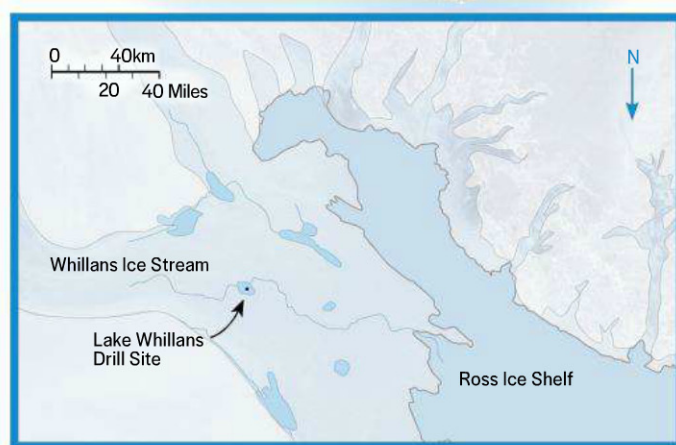
The Herc's four propellers roared, kicking up a blizzard of snow. The plane did not move.

Four men shoveled around the Herc's skis, trying to free them. This cold-blooded butterfly could stay alighted on the ice sheet for only so long. If its engines were shut down for more than a few minutes, they might not restart in the cold.

Lake Whillans had likely not seen the light of day for hundreds of thousands of years, but Tulaczyk and the others who landed that day intended to see what was under the ice. They intended to drill into the lake and sample its water and mud. They intended to lower a camera into its belly. And they intended to find out what, if anything, might live there.

As Tulaczyk watched the Herc on Jan. 17, 2013, the lake remained a mere silhouette pieced together from noisy geophysical measurements involving radar, lasers shot down from satellites and the seismic echoes of shock waves released by explosives detonated in shallow holes in the ice.

But for scientists around the world, tapping into this humble lake had come to symbolize a major milestone in exploration. Almost 10 percent of the planet's land area sits locked under glacial ice, where humans have never ventured. Exploring subglacial lakes could help answer many important questions: whether, for example, global warming might accelerate as Antarctica's



ice recedes. Sampling Lake Whillans could also provide hints about what kind of life might survive in icy worlds elsewhere in the solar system.

Getting into the lake represented a monumental task. A convoy of tractors had already towed 1.2 million pounds of drilling gear 600 miles from the coast of Antarctica, where McMurdo Station served as a base. Testing of the drill in McMurdo, and subsequent weather delays, had forced the expedition onto a critically tight schedule. Even as drilling was about to begin, the Antarctic summer and workable conditions were nearing an end — giving the team no more than 14 days. "Often fieldwork in this part of Antarctica is like trench warfare," where you dig in and work for months, said Tulaczyk a few days before. "What we are trying to do is a blitzkrieg."

Tulaczyk considered this as he watched the Herc rev its engines a third time. Its body shuddered. Its skis broke loose. The 125,000-pound plane lumbered forward, plowing the airstrip in both directions — a maneuver that lightened the plane's load by incinerating several thousand pounds of fuel.

As the Herc traversed the skiway a fourth time, eight solid-fuel rockets mounted on its sides ignited, heaving the plane into the air.

Tulaczyk sighed with relief. The team's goal lay tantalizingly

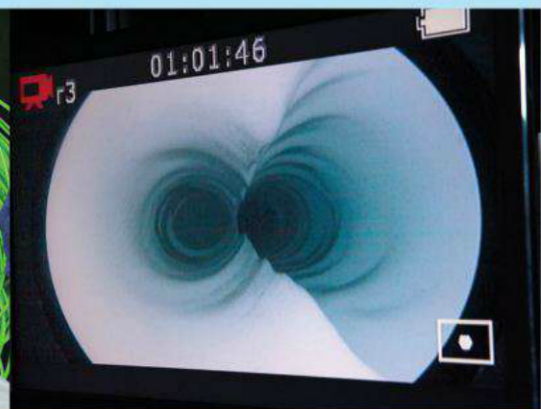
written by DOUGLAS FOX *photography by* JT THOMAS



Left: Members of the Lake Whillans research team board a ski-equipped cargo plane at McMurdo Station. Center: A convoy of shipping containers on sleds carries gear 600 miles from McMurdo to the drilling site. Right: Researchers set up sensors to monitor movement of the Antarctic Ice Sheet.



Left and center: Graduate student Grace Barcheck, from the University of California in Santa Cruz, buries a seismic sensor in the ice sheet above Subglacial Lake Whillans. Right: Scientists prepare to unwrap a sanitized scientific instrument that will measure water currents and temperature in the lake.



Left: Another UC Santa Cruz graduate student, Ken Mankoff, tests a geothermal probe at McMurdo Station. Center: Team members prepare fiber-optic cable that will eventually connect a camera in the borehole to a live video feed at an equipment control center. Right: Video footage reveals an accidental double borehole.



Left: Chad Carpenter, a hot water drill system specialist from the University of Nebraska in Lincoln, secures the drill frame. Center: A researcher prepares a remotely operated vehicle to send down the borehole. Right: Chief driller Dennis Duling, from the University of Nebraska, checks in with his equipment.

close, only half a mile directly below. But, as the plane's departure had showed, in these conditions even seemingly straightforward tasks, like melting a hole in the ice, often prove difficult.

PATH TO EXPLORATION

The story leading to Lake Whillans extends back more than 50 years. For most of the 20th century, the Antarctic Ice Sheet was viewed as timeless, unchanging. A few scientists even suggested that nuclear waste be stored permanently inside it.

But in the latter half of the 20th century, a new technique, called ice-penetrating radar, allowed scientists to see through broad swaths of the ice and revealed entire buried mountain ranges, as tall as 9,000 feet. In the late 1960s and throughout the 1970s, Hercules aircraft with downward-looking radars flew thousands of miles of survey lines across the continent to map the subglacial landscape. This view changed the way scientists thought of Antarctica. Glaciologists also noticed that, in some places, the ordinarily jagged landscape beneath the ice was perfectly flat and the radar reflection unusually bright — indicating water instead of rock.

People didn't expect to find lakes under the ice, but today, over 200 are known to exist in Antarctica. The lakes are fed by geothermal heat that seeps up from the Earth's interior, melting away the bottom of the ice sheet at a rate of several dime-thicknesses per year and liberating water from the ice.

In the mid-1990s, a lake containing 1,300 cubic miles of water (as much as Lake Michigan) was detected 12,000 feet below the surface of the ice in East Antarctica, beneath where the Russians had spent years drilling into the ice sheet to study its history. When the Russians' drill came within 600 feet of the underlying lake, now called Lake Vostok, the ice that they were bringing up suddenly changed, from transparent to dirty, dotted with specks of mud. This dirty ice represented muddy water from Lake Vostok that had frozen back onto the bottom of the ice sheet.

John Priscu, a lake biologist from Montana State University in Bozeman, got his hands on a pound and a half of this dirty ice. Priscu had already found bacteria and algae thriving in small lakes along the coast of Antarctica. Only the upper 10 to 30 feet of water in these lakes was frozen as ice, so sunlight filtered through, allowing life to power itself through photosynthesis. But a lake as deeply buried as Vostok would be entirely dark, so any life there would have to use some other energy source.

At that time, the question of what life might inhabit Lake Vostok was becoming increasingly relevant to people who were looking for life elsewhere in the solar system. Space probes had found an ocean of water inside Jupiter's moon Europa, locked

beneath a shell of ice five to 10 miles thick. Scientists speculated whether life might inhabit that dark ocean — a breathtaking possibility, says Priscu, when you consider that the ice-covered oceans of Europa and other moons orbiting Jupiter and Saturn actually contain five to six times as much water as all the oceans on Earth. Lake Vostok was the perfect analog on Earth to investigate what life, if any, might survive in these sunless, extraterrestrial oceans.

Sure enough, Priscu found dead or dormant cells in the dirty Vostok ice — up to 600,000 per cubic inch. Skeptics speculated that the cells had come not from the ice itself but from the 100,000 pounds of kerosene drilling fluid that the Russians kept inside the borehole above Lake Vostok, to keep it from freezing shut. Priscu never got to sample Vostok directly to confirm his find because drilling the rest of the way into it was delayed. People feared that kerosene in the borehole would spill into the pristine lake when it was finally penetrated.

By 2007, though, another plan was taking shape. Satellite measurements had just revealed the existence of Lake Whillans under half a mile of ice in West Antarctica. The lake was 7.5 miles long, 5 miles wide and 25 feet deep.

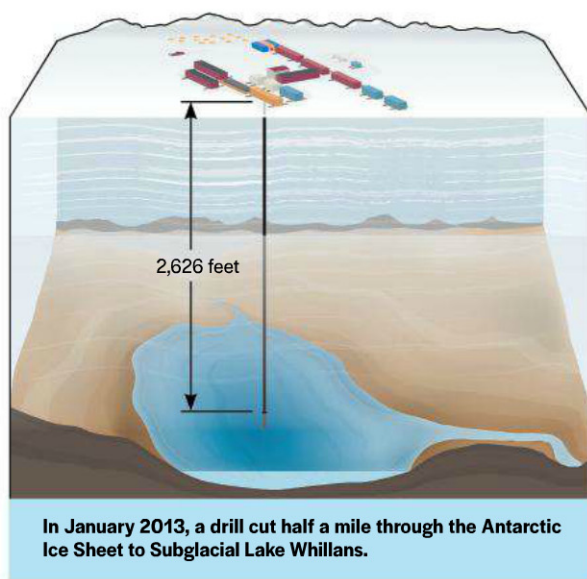
Tulaczyk became the first researcher to visit Lake Whillans in November 2007. A glaciologist rather than a biologist, he wanted to investigate a question critical to climate change: Do subglacial rivers and lakes lubricate the movement of ice over land — and might they somehow accelerate a glacier's flow into the ocean, triggering rapid

sea level rise? Tulaczyk's team installed instruments on the ice surface above Lake Whillans to monitor movement of the ice sheet. ("Iceman cometh," DISCOVER, September 2008.)

That expedition was an important first step, but understanding the physics and biology of Lake Whillans would ultimately require drilling into it. Tulaczyk, Priscu and dozens of other scientists made plans. They would bore through the ice with a jet of hot water instead of a metal drill surrounded by kerosene.

Hot water drilling still posed challenges: A borehole filled with water would quickly refreeze, and the hole could still collapse shut under the sheer weight of the surrounding ice sheet. The National Science Foundation funded the ambitious project, and starting in November 2012, more than 30 scientists, drillers and technicians made their way to McMurdo Station on the coast to prepare for their push to Lake Whillans. The group included separate teams of biologists, geologists and glaciologists from a dozen institutions. Several flights in January 2013 would transport them and some scientific instruments (too fragile to be towed in the convoy) from McMurdo to Lake Whillans.

The first flight, the one carrying Tulaczyk, finally landed at Lake



Whillans on Jan. 17; due to weather, it was 13 days later than planned. Such delays, together with uncertainties about how quickly drilling would go, increased the chances that the lake wouldn't be reached, or that efforts to sample it would be crippled. But over the next five days, three more flights managed to deliver most of the remaining scientists and gear. All that remained was the task of boring through the ice and keeping the narrow, ephemeral portal open for several days.

INTO THE ABYSS

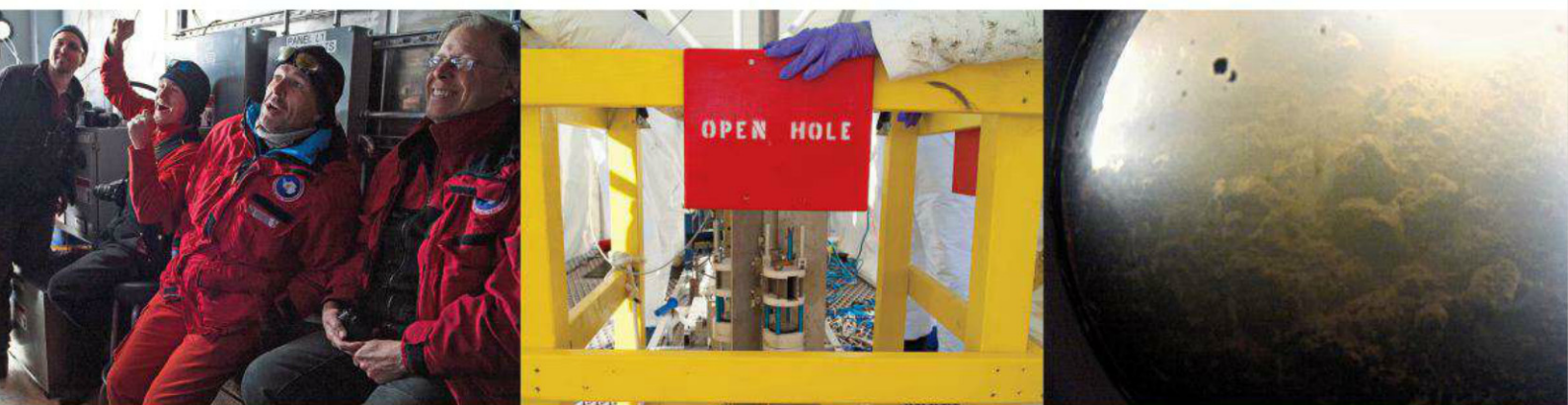
Whillans drill camp sits 380 miles from the South Pole, a constellation of faint dots nearly invisible through the membrane of mist that often cloaks West Antarctica during the summer. Up close, the camp is industrial in scale.

Each dot represents a truck-size shipping container welded onto a massive sled. The drill comprises a dozen of these sleds, arranged end to end like a segmented, metallic organism. Seg-

the mechanical equivalent of a blocked coronary artery.

At 6:30 p.m. Jan. 25, after two days of drilling, the final approach into Lake Whillans began. The drill hose dangled 2,480 feet down a 20-inch-wide hole in the ice. The lead driller, Dennis Duling, a 61-year-old former farmer with a gray beard, sat in the control room, his calloused hand on a mouse, surveying sensor readings on a computer. Those readings encompassed his secondhand knowledge of the world half a mile below — a world he must navigate by feel rather than sight.

Because of harsh conditions in the borehole, Duling and his men have no camera on the drill itself. They must infer what is happening thousands of feet below using proxy measurements from three sensors. One sensor counts the revolutions on the spool reeling out the drill hose (this data is used to estimate the depth of the hole); another sensor measures the weight of the dangling hose, revealing if the hose goes slack because it has bumped against an obstruction; a third sensor monitors pres-



Left: Researchers in a control room, above Lake Whillans, cheer as they get confirmation that the borehole has broken through the ice and reached the lake. **Center:** Scientists prepare instruments at the top of the borehole. **Right:** A submerged camera reveals what Lake Whillans looks like.

ments one, two and three, at the head of the beast, house generators and transformers that convert jet fuel into 450,000 watts of electricity. In segment four, water (from melted snow) is sterilized using ultraviolet radiation and filtration. The water then flows through woven Kevlar-reinforced hoses to segments five and six, where it is heated and pressurized. Then in segment seven, the water enters a section of hose more than half a mile long, coiled around a spool as wide as a school bus. As drilling began on Jan. 23, the hose was gradually unspooled into a hole in the ice sheet. Hot water gushed from the nozzle.

This machine was built by seven ice drillers from the University of Nebraska in Lincoln: a motley crew of college-educated guys who fled the reliable monotony of NASA or biomedical engineering jobs in search of adventure. Dressed in battered Carhartt overalls and grease-stained gloves, they operate the drill, patrolling its far-flung appendages on foot, communicating by handheld radios as they turn valves to adjust the flow of water.

"You just want to keep everything warm and moving as much as you can," said driller Dar Gibson, a former meteorologist, one night as the drill was halted for repairs. Shutting down is a race against time: Slowdowns can cause clots of ice to form in hoses,

sure and detects if the water level in the hole rises or falls — potential evidence that the lake has been reached.

Eying this data from the sensors, Duling ordered the drilling slowed to a crawl, worrying that they were nearing the lake and trying to avoid stirring up mud. "We don't want to blast our way in," he said. On the night of Jan. 25, no one knew at what exact depth they would break through. It would become a vexing question.

BREAKING THE SURFACE

The drill appeared to break into the lake at 12:10 a.m. Jan. 26; the hose was pulled up so a camera could be lowered down the hole to confirm the break-in. Unfortunately, that camera never reached the bottom: At 2,300 feet, the hole split into two branches, preventing the camera from being guided deeper.

The camera was withdrawn from the hole and the drill hose lowered down to the point of the branch. Hot water was pumped in with the goal of melting the branch into a single, wide passage through which the camera could later be lowered.

At 7 p.m. Jan. 26, the camera was lowered a second time. People crowded into the control room to watch the live feed. The camera encountered the same branch at 2,300 feet; the hot water drill had

failed to solve the problem. This time, though, in a lucky break, the camera was successfully jostled down past the intersection. People in the control room cheered.

The camera eased down 50 feet. The hole expanded, contracted, then widened again. Then the camera came to rest. A second or two passed before people understood what they were seeing.

The camera lay on a floor of white. Of ice. The hole had dead-ended. "Holy cow," said someone, in disappointment.

The drillers soon figured out the problem. A sensor on the drill hose wasn't calibrated properly and had overestimated the length of hose fed into the hole. The drill was stopped at least 100 feet short of the lake.

"When you come down here, you get your nose bloodied up," said Duling. "It's all right. We can handle it." He appeared tired, resigned. "We will drill one more time."

Twenty-four hours later, on Jan. 27, a banter of dry gallows humor circulated among the drillers. "You guys want to watch

knitted in rows of grainy pixels, echoed the first-ever pictures of the Martian surface beamed back by the Viking lander 36 years ago — an image of a place never before seen by humankind.

Contrary to expectations, the water itself was only 5 feet deep, not 25 feet. Radar surveys had overestimated the lake's depth by mistaking 20 feet of gooey mud forming the lake bed for water, said Tulaczyk during a hastily called meeting. "This lake is old enough to have filled with sediments for the most part." Notwithstanding that surprise, the team would finally have a chance to look for life beneath the ice sheet.

At 6:20 a.m. Jan. 28, half a dozen people in sterile white suits gathered at the drill platform, awaiting the first sample of Lake Whillans water.

A taut cable inched out of the borehole. Brent Christner, a microbiologist from Louisiana State University, chipped globs of frost off the cable with a hammer. An opaque bottle rose into view. Priscu carried it into a laboratory. People crowded in as the



Left: Lake biologist John Priscu, from Montana State University, and Louisiana State University microbiologist Brent Christner prepare to sample lake water. **Center:** Technician Jeremy Lucke wears Lake Whillans mud. **Right:** More mud, which contained the crushed shells of microscopic aquatic organisms.

Thelma and Louise?" crackled one of them over the radio, a dude with a heavy wrench and thick beard deflecting feelings of anxiety with a chick-flick reference.

"Only if we can hold hands and cry," replied Gibson into his handheld. Gibson sat in the control room, where people gathered to see the camera descend a third time down the hole, after another round of drilling.

The camera passed 1,600 feet. Undulations in the hole's circular walls scrolled over the monitor like contours of a cosmic wormhole. Then, the image dissolved in haze. All sense of motion ceased.

A conversation sprang up in the dark room. Was the water cloudy, or had the camera malfunctioned? "Are we still going down?" Gibson asked into his radio.

"We are," crackled the reply. "Just coming up on 640 meters [2,100 feet]."

Minutes trickled past. The blur on the monitor darkened to brown. Cable "just went slack," crackled the radio. "We just hit the bottom." The camera rested 2,626 feet below.

Swirling silt settled. A view of the lake coalesced.

The camera lay on its side, its lens gazing across a muddy floor strewn with clumps. Wisps of mud drifted in the water. The image,

first water from Subglacial Lake Whillans was decanted into a clear tube.

The liquid was honey-colored. An electrode was dipped in — a number flashed onto an LCD. The water conducted electricity strongly, evidence that it was laden with mineral salts that could serve as food for microbes. A whoop of excitement went up.

THE SEARCH FOR LIFE

The subglacial environment is often described as extreme. But Lake Whillans has turned out to be surprisingly hospitable.

The lake registered at just 31 degrees Fahrenheit, slightly warmer than the coastal seas near McMurdo Station, which teem with sea stars, 100-pound toothfish and other living things. Pressure from the ice sheet overhead keeps the subglacial water liquid by lowering its freezing point several degrees.

Lake Whillans also contains oxygen, which is injected into the subglacial space by air bubbles released as the ice sheet melts. It would be enough oxygen, in some cases, to support worms, starfish and other marine invertebrates on the seafloor.

The spot where Lake Whillans sits today was once a shallow seafloor. Reed Scherer, a marine micropaleontologist from North-

ern Illinois University, saw evidence of this when he smeared mud from the lake onto a glass slide.

Scherer placed the slide under a microscope and twisted a knob. A glassy object snapped into focus — a round disk, serrated on the edge, perforated with dimples — the shell of an aquatic microscopic organism called a diatom. “Probably Miocene,” he said. “Likely 10 to 15 million years old.” The slide contained around a hundred crushed diatom shells.

What is now Lake Whillans was probably covered and uncovered by the ice sheet dozens of times as the climate swung back and forth over the past 20 million years. The ice most recently rolled over the lake sometime between 120,000 and a million years ago, depending on which of several warming episodes the ice sheet did or didn’t withstand. Any life that exists in the lake today may represent hangers-on from its ice-free time.

But any survivors needed to overcome a major challenge. The ice cut off sunlight and photosynthesis — the main source of

It will provide a glimpse of what taxonomic groups they belong to.

Christner’s and Priscu’s teams are also growing microbes from more than 500 cultures collected from the lake. “We may be coming up with cultures that people study for the next 50 years,” says Christner.

Understanding microbial life and the mineral breakdown that it incites under the ice sheet could help answer some momentous questions about whether global warming will speed up as Antarctica’s ice recedes. Some scientists believe that microbes under the ice may have produced billions of tons of methane — a potent greenhouse gas that could escape as the ice retreats, causing warming to accelerate.

On Feb. 1, Tulaczyk and his students made one last use of the borehole. They lowered a string of vibration sensors into it. The bottom sensor hung 60 feet above the lake. Those sensors, which the ice would encroach on and eventually envelop, would document the private life of Lake Whillans over time, recording rum-



Left: Microbiologist Jill Mikucki from the University of Tennessee in Knoxville inspects Lake Whillans water samples. **Center:** A researcher labels sediment samples. **Right:** Biologist John Priscu celebrates the team’s successful attempt at reaching Lake Whillans through half a mile of ice.

energy for most ecosystems on Earth’s surface. So subglacial life, if present, would have to power itself through the chemical breakdown of minerals instead.

The honey color of that first sample of Whillans water provided a hint: a sign of tiny mineral grains (pulverized by glaciers), some smaller than a red blood cell. That glacial grinding turned the minerals into good microbe food, much as the milling of wheat into flour makes it more digestible to humans.

On Jan. 28, Trista Vick-Majors, one of Priscu’s Ph.D. students, took a long-awaited step: She added DNA-sensitive dye to a sample of lake water — the first attempt to detect life in Lake Whillans. As she viewed it through a microscope, she saw specks of green shining against a background of black — cells glowing in response to the dye — as many as 1.6 million cells in each cubic inch of water. Those cells were the first ever found unambiguously in a subglacial lake.

A BALANCING ACT

A portrait of life beneath Antarctica’s ice will take time to emerge. Louisiana State University microbiologist Christner is using DNA sequencing to census hundreds of microbe species from the lake.

bles of turbulence and tumbling rocks as currents washed through the lake. This information would help Tulaczyk understand whether subglacial water lubricates the flow of ice, and whether it might play a role in the runaway acceleration of glaciers that has occurred in some parts of Antarctica. The hole was covered in plywood, and snow piled on top.

A mile west stood 21 squat silhouettes, backlit in the afternoon sun. The team had bulldozed these snow platforms into existence. Twenty sleds and 700,000 pounds of gear would soon be parked atop them for winter, safe above the snowdrifts that would unfurl for half a mile in their wakes.

As winter darkness falls and the mercury drops to 50 degrees below zero, those parked sleds remain a gesture of hope: If budgets allow, Tulaczyk and Priscu will return next year, drill more holes and continue exploring Antarctica’s hidden world. 

Douglas Fox has written for numerous publications, including *Scientific American*, *Esquire*, *Popular Mechanics*, *The Christian Science Monitor* and *High Country News*. His February 2008 DISCOVER story, “Did Life Begin in Ice?” appeared in *The Best American Science and Nature Writing 2009*.

 Watch video of life under the ice and see more pictures of the Lake Whillans expedition at www.DiscoverMagazine.com/Antarctica

CANCER

The Long Shadow

We think of cancer as a modern-day scourge, but the fossil record reveals a disease that may have been with us since prehistoric times.

by GEORGE JOHNSON

WHEN LOUIS LEAKEY sat down to recount the discovery of what may be the earliest sign of cancer in the genus *Homo*, the first thing he remembered was the mud. It was March 29, 1932, midway through the Third East African Archaeological Expedition, and it had rained so long and so hard that it took an hour to drive the four miles from the campsite in Kanjera, near the shore of Lake Victoria, to the Kanam West fossil beds. By the time he and his crew had slogged their way through, they were covered with mud, and before long, Leakey, who was just beginning an illustrious career as an anthropologist, was on hands and knees scouring the ground for newly exposed bones.

He was coaxing the remains of an extinct pig from the muck when one of his Kenyan workers, Juma Gitau, walked over with a broken tooth he had just extracted from a cliff side. *Deinotherium*, Leakey noted, a prehistoric elephantlike creature that roamed Africa long ago.

Gitau went back to look for more, and as he was scratching away at the cliff face, a heavy mass of calcified clay broke loose. He chopped it with his pick to see what was inside: more teeth, but not *Deinotherium*. These looked like what a dentist might recognize as human premolars, still set in bone, yet they came from a layer of sediment deposited, Leakey believed, in early Pleistocene time, about a million years ago.

The Kanam mandible quickly became a sensation. "Not only the oldest known human fragment from Africa," Leakey proclaimed, "but the most ancient fragment of true *Homo* yet discovered anywhere in the world." It was, he insisted, a direct precursor of us all.



In 1932, anthropologist Louis Leakey, top, and his crew discovered a fossilized jawbone in Kenya with an abnormal-looking growth, at left. At the time, Leakey claimed it was the oldest evidence of early human ancestors. While that view has changed, the fossil is still considered remarkable for the possible tumor it carries on its left side. Now housed at the Natural History Museum in London, the bone is known as the Kanam mandible, named after the fossil bed where it was found.

Like many of Leakey's enthusiasms, this one proved controversial. Anthropologists remain divided over whether *Homo kanamensis*, as Leakey called it, was as old as he believed. Some of them have come to consider the specimen a more recent jawbone — mid- to late Pleistocene — that had washed into much older surroundings. Whatever its pedigree or precise age, Kanam Man is no longer considered remarkable for its antiquity but for an abnormal growth on the left side of the jaw.

At the time of the discovery, it had seemed like a bother, detracting from Leakey's find. He was working in his rooms at St. John's College at the University of Cambridge, carefully cleaning the specimen, when he felt a lump. He thought it was a rock. But as he kept picking, he could see that the lump was part of the fossilized jaw. He sent it to a specialist on mandibular abnormalities at the Royal College of Surgeons of England, who diagnosed it as osteosarcoma — a cancer of the bone.

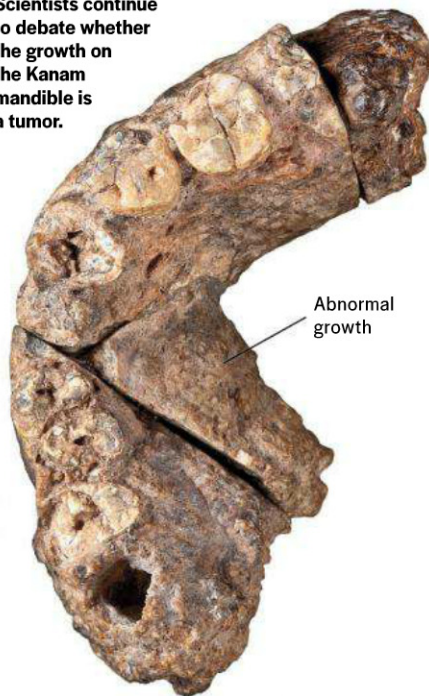
Others have not been as certain. As recently as 2007, scientists scanning the mandible with an electron microscope concluded that this was indeed a case of "bone run amok" while remaining neutral on the nature of the pathology.

HANDS-ON HISTORY

I first came across a mention of the Kanam jaw in a history-of-cancer timeline somewhere on the web. That sent me digging into Leakey's old books and papers, and after several email exchanges, I tracked down the fossil at the Natural History Museum in London, where it had been in storage for decades. As far as I could tell, it had never been on display.

On a spring day I arrived, as previously arranged, at the museum's staff and researcher entrance on Exhibition Road. The man at the guard desk called ahead to Robert Kruszynski, curator of vertebrate paleontology. He came out to greet me and

Scientists continue to debate whether the growth on the Kanam mandible is a tumor.



then led me into the museum's inner sanctum. Waiting for me on a table by a window was a brown cardboard box he had retrieved from museum storage. The handwritten label identified the contents:

M 16509
KANAM MANDIBLE.

M stood for mammal. In the upper right-hand corner of the label were two colored stickers — a red sunlike symbol and below that a blue star — indicating that the specimen in the box had been analyzed at various times by radioassay and X-rays. Mr. Kruszynski carefully removed the lid. Inside was a smaller box, fashioned from balsa wood and cardboard and covered with a glass lid, and inside that was the Kanam jaw.

He placed it on a padded mat, to cushion it from the hard surface of the table. "All yours to look at," he said, and he went off to search for another fossil I hoped to see: a femur retrieved from an early medieval Saxon grave in Standlake, England, with an enormous growth that had also been diagnosed as a cancerous bone tumor.

I had thought I would be content just glimpsing the Kanam jaw. I never expected to be left alone with it and to be able to hold it in my hand. It was dark brown and unexpectedly heavy and dense. That

shouldn't have been surprising. It was a rock really, petrified bone. Once it had been part of a prehistoric man, or a proto-man. Two yellowed teeth were still in place, and there was a deep hole where the root of another tooth had been.

Just below that, on the left inside curve of the jaw, was the tumor. It was bigger than I had expected, reminding me perversely of a type of candy from my childhood called a jawbreaker.

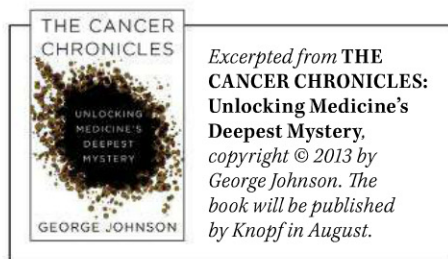
There was also a slight swelling on the outside of the jaw, and I could understand how people might argue endlessly over whether it was the remnant of a modern chin, as Leakey himself believed, or just part of the tumor. I could see where Leakey had sliced through the mass (some of his colleagues considered this sacrilege) to remove a section for further analysis. I could almost picture the rest of the head, its vacant eyes pleading for relief from inexplicable pain.

Mr. Kruszynski returned half an hour later to see how I was doing with the fossil. "Don't bring it too close to the edge," he warned. I suddenly realized that the protective pad on the table was sloping toward my lap and how easily a sudden movement might have sent the Kanam mandible dropping onto the linoleum floor.

In the end, he was unable to find the cancerous femur I'd inquired about. "For another time," he said. He escorted me back across the barrier to the public portion of the museum. Hundreds of visitors of all ages coursed through the hallways. Some of them inevitably would get cancer, or they would love somebody who did. I wondered if anyone had been there for Kanam Man.

ANCIENT ONCOLOGY

Not much has been written about the obscure discipline of paleo-oncology. Although research had gone on sporadically for decades, the word was introduced only in 1983 when a small group of Greek and Egyptian oncologists (from the Greek *onkos* meaning "mass" or "burden") began planning a symposium on human cancer in earlier times. The gathering took place the following year on a voyage to the island of Kos, where Hippocrates was born. What emerged was an elegantly published, sparsely printed little book,



Palaeo-Oncology. I felt lucky to find a copy on the Internet for \$100. Its 58 pages are bound in a blue cover with gilded print, and below the title is a drawing of a crab.

Crab in Greek is *karkinos*, and Hippocrates, in the fifth century B.C., used the word for the affliction whose Latin name is *cancer*. It became the root of *carcinogen* and *carcinoma*.

Some 600 years later, the ancient physician Galen speculated on the etymology in an old text: “As a crab is furnished with claws on both sides of its body, so, in this disease, the veins which extend

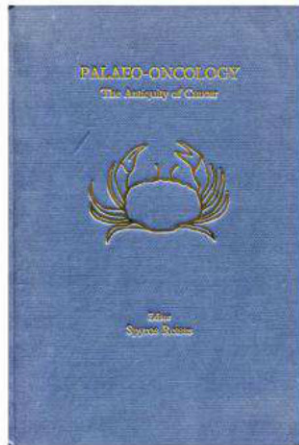
from the tumour represent with it a figure much like that of a crab.” The story is repeated in almost every history of cancer.

Very few tumors, however, look like crabs. Paul of Aegina, a seventh-century Byzantine Greek, suggested that the metaphor was meant to be taken more abstractly: “Some say that [cancer] is so called because it adheres with such obstinacy to the part it seizes that, like the crab, it cannot be separated from it without great difficulty.” The word *karkinoi* was also applied to grasping tools, like calipers.

All but forgotten is a very different derivation from Louis Westenra Sambon, a British expert on parasitology who, before his death in 1931, turned his attention to the study of cancer. There is a parasite, *Sacculina carcini*, that feasts on crabs in a manner eerily similar to the feasting of a cancerous tumor. The process was described in a 1936 report by pathologist Sir Alexander Haddow to the Royal Society of Medicine:

[I]t attaches itself to the body of a young crab, and casts off every part of its economy save a small bundle of all-important cells. These penetrate the body of the host and come to rest on the underside of the latter’s intestine, just beneath the stomach.

Crab in Greek is *karkinos*, and Hippocrates, in the fifth century B.C., used the word for the affliction whose Latin name is *cancer*.



Left: *Palaeo-oncology* as a discipline was formalized by the publication of this report in 1983. Right: A drawing from a 1904 book, *Kunstformen der Nature*, depicts a bulb-shaped parasite called *Sacculina carcini* that feasts on crabs like a cancer.

Here, surrounded by a new cuticle, they shape themselves into the “*sacculina interna*,” and like a germinating bean-seedling, proceed to throw out delicately branching suckers which, root-like, extend through every portion of the crab’s anatomy to absorb nourishment. Growing in size, the parasite presses upon the underlying walls of the host’s abdomen, causing them to atrophy, so that when the crab moults, a hole is left in this region corresponding in size to the body of the parasite. Through this opening the tumour-like body finally protrudes and becomes the mature “*sacculina externa*.”

Long before Galen, disciples of Hippocrates, dining on crabs, may have noticed the similarities between the ways the parasite overtakes its host and the invasion of a cancer.

Whatever the reason for the name, ancient Greek texts describe what sound like cancer of the uterus and the breast. Driven by a belief in sympathetic magic, some physicians would treat a tumor by placing a live crab on top of it. They also recommended powders and ointments (sometimes made from pulverized crabs) or cauterization (burning closed the ulceration). As for patients with internal

tumors, Hippocrates warned that they might best be left alone: “With treatment they soon die, whereas without treatment they survive for a long time.” The principle is part of the Hippocratic oath: First do no harm.

There is something comforting about knowing that cancer has always been with us, that it is not all our fault, that you can take every precaution and still something in the genetic coils can become unspun. Usually it takes decades for the microdamage to accumulate — 77 percent of cancer is diagnosed in people 55 or older. With life spans in past centuries

hovering around 30 or 40 years, finding cancer in the fossil record is like sighting a rare bird. People would have died first of something else. Yet in spite of the odds, cases continue to be discovered, some documented so vividly that you can almost imagine the ruined lives.

After my visit to London, I received from the Natural History Museum photographs of the Saxon skeleton whose tumorous femur I had hoped to examine. I had read that the growth was large — 10 inches by 11 inches — but I was astonished to see what looked like a basketball grafted onto the young man’s leg. The tumor shows a sunburst pattern that pathologists recognize as a sign of osteosarcoma, a cancer so rare that one would have to comb through the bones of tens of thousands of people to find a single example.

Yet ancient cases continue to turn up. There were signs of the cancer in an Iron Age man in Switzerland and a fifth-century Visigoth from Spain. An osteosarcoma from a medieval cemetery in the Black Forest mountains of southern Germany destroyed the top of a young child’s leg and ate into the hip joint. Bony growths inside the roof of the eye sockets indicated anemia, which may have been an effect of the cancer. The authors of the report speculated on the cause: contamination from a nearby lead and silver mine.

Maybe it helped to believe there was a reason. But no one knows what causes osteosarcoma. Then, as now, a few cases probably were hereditary, traced to chromosomal abnormalities. In modern times, speculation turned for a while to fluoride-treated water and, more plausibly, radiation — therapeutic treatments for other diseases or exposure to radioactive isotopes like strontium-90, which is spread by nuclear fallout. Strontium sits just below calcium in the periodic table of the elements and imitates its behavior, incorporating itself tightly into bone. But most often, osteosarcoma strikes for no apparent reason, leaving parents grasping to understand what remains as inexplicable as a meteor strike.

Another malignancy, nasopharyngeal carcinoma, which affects the mucous membrane in the nose, can scar adjacent bone. Signs of it have been found in skeletons from ancient Egypt. One woman's face had been all but obliterated, and I tried to imagine her stumbling through life. "The large size of the tumor, which caused such extensive destruction, suggests a relatively long-lasting process," observed Eugen Strouhal, the Czech anthropologist who documented the case. "Survival would be impossible without the help and care of the patient's fellow-men." Here was another case where the horrors of cancer punched through the flat veneer of scientific prose.

Osteosarcoma and nasopharyngeal carcinoma — these are primary cancers, those found at the site of origin. They are debilitating enough. Most skeletal cancers by far come from metastases, tumors that migrate from elsewhere. They also show up with greater frequency in the fossil record, leaving a distinctive signature. Metastatic bone cancer has been discovered in Egyptian tombs, in a Portuguese necropolis, in a prehistoric grave in the Tennessee River Valley and in a leper skeleton from a medieval cemetery in England. Buried near the Tower of London, the skeleton of a 31-year-old woman was marked with metastatic lesions. We even know her name from a lead coffin plate: Ann Sumpter. She died May 25, 1794.

In 2001, archaeologists excavated a 2,700-year-old burial mound in the Russian Republic of Tuva, where nomadic horsemen



The skeleton of an early medieval Saxon man uncovered in Standlake, England, shows a basketball-size cancerous growth on his left leg.

called the Scythians once thundered across the Eurasian steppes, their leaders exquisitely dressed in gold. Digging down through two wooden ceilings, the scientists came upon a subterranean chamber. Its floor, covered with a black felt blanket, cushioned two skeletons. Crouched together like lovers, both man and woman wore what remained of their royal vestments. Around the man's neck was a heavy band of twisted gold decorated with a frieze of panthers, ibex, camels and other beasts. Near his head lay pieces of a headdress: four gold horses and a deer. Golden panthers, more than 2,500 of them, bedecked his cape.

His riches couldn't save him. When he died — he appeared to have been in his 40s — his skeleton was infested with tumors. A pathological analysis, including a close look with a scanning electron microscope, concluded that the nature of the lesions and the pattern of their spread were characteristic of metastatic prostate cancer. Biochemical tests revealed high levels of prostate-specific antigen, or PSA. For all the false positives these tests can produce, this one was apparently genuine.

While prostate cancer tends to be osteoblastic, adding unwanted mass to the skeleton, breast cancer is osteolytic, gnawing mothlike at the bone. A middle-aged woman with osteolytic lesions was excavated from the northern Chilean Andes where she died around A.D. 750. Her body was buried in a mummy pack along with her possessions: three woolen shirts, some feathers, corncocks, a wooden spoon, a gourd container and a metal crucible. She was no Scythian queen. Her hair reached down her back in a long braid tied with a green cord. There were lesions in her spine, sternum and pelvis. On top of her skull, cancer had chomped a ragged hole 35 millimeters across. Cancer had feasted on her right femur, shortening her leg.

COUNTING CANCERS

Altogether I counted about 200 suspected cancer sightings in the archaeological record. I was left to wonder how big an iceberg lay floating beneath the tip.

Ninety percent of human cancers are carcinomas, which arise in the epithelial tissues that line the organs and cavities of the body and envelop us with skin. As the layers are worn by the passage of food and waste or exposure to the elements, the outer cells are constantly dying. The cells beneath must divide to form replacements. And with every division there will be mistakes in the copying of genes — spontaneous mutations, or ones caused by carcinogens in food, water and air. For children, who are just beginning to withstand life's wear and tear, only a fraction of cancers are carcinomas.

When it comes to hunting ancient cancer, primary carcinomas would almost always be lost with the decomposing tissues. And those that had metastasized would have often spread first to the lung or liver, killing the victim before a record was left in bone. Egyptian medical papyri make ambiguous references to "swellings" and "eatings," and some evidence has survived in mummies. A rectal carcinoma in a 1,600-year-old mummy was confirmed with a cellular analysis of the tissue. Another mummy was diagnosed with bladder cancer.

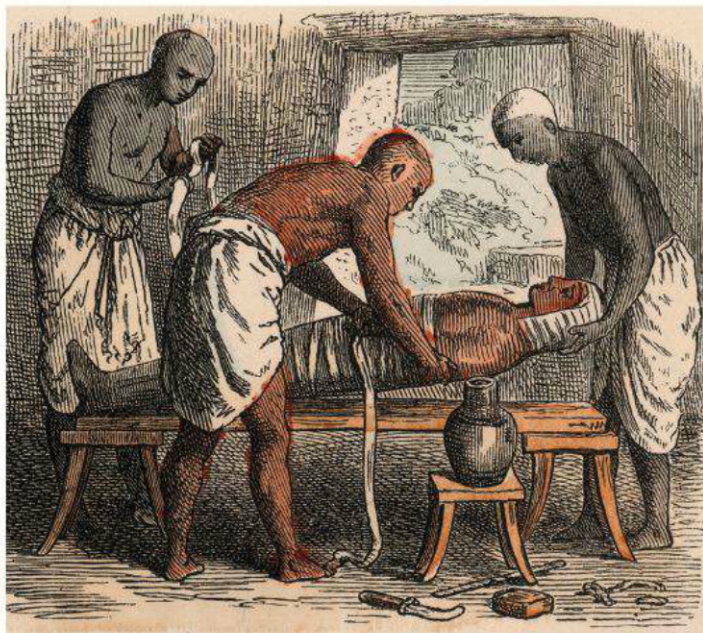
Other evidence of ancient cancer may have been destroyed by the invasive nature of Egyptian embalming rituals. To prepare

a pharaoh for passage to the afterlife, the first step was removing most of his organs. The brain was pulled out through the nostrils. The torso was sliced open to take out the abdominal and chest organs (except for the heart, which was believed necessary for the ethereal voyage). To slow the process of decay, a turpentine-like solution was sometimes injected as an enema to dissolve the digestive tract.

Mummies are a curiosity, and most skeletal evidence is stumbled on by chance. Only recently have anthropologists really begun looking for cancer — with CT scans, X-rays, biochemical assays and their own eyes. What they will never see, even in bone, are clues lost through what anthropologists call taphonomic changes. In digging and transporting skeletal remains, markings can inadvertently be erased. Bone-eating osteolytic lesions can cause a specimen to crumble and disappear. Through erosion, decomposition and the gnawing of rodents, taphonomic changes might also create the illusion of metastasis — pseudopathology — a possibility that must be taken into account along with alternative diagnoses like osteoporosis and infectious disease. But on balance, it seems likely that the evidence of ancient cancer is significantly underreported. Most skeletons, after all, are incomplete. Metastases are more likely to appear in certain bones like the vertebrae, pelvis, femur and skull. Others rarely are affected. No one can know if a missing bone happened to be the one that was cancerous.

Hoping to cut through the uncertainty, Tony Waldron, a paleopathologist at University College London, tried to get a feel for how much cancer archaeologists should expect to find. First he had to come up with an estimate, no matter how imperfect, of the frequency with which primary tumors might have occurred in earlier times. There wasn't much to go on.

Evidence of ancient cancer may have been destroyed by the invasive nature of Egyptian embalming rituals.



Egyptian medical papyri make ambiguous references to “swellings” and “eatings,” and some evidence of cancer has survived in mummies.

The oldest records that seemed at all reliable came from the Registrar General of Britain for causes of death between the years 1901 and 1905. Using that as his baseline, he took into account the likelihood that various cancers would come to roost in the skeleton where they might be identified. The numbers, a range of approximations, came from modern autopsy reports. For colorectal cancer, the odds were very low, 6 to 11 percent, as they were for stomach cancer, 2 to 18 percent. On the high side were cancer of the breast (57 to 73 percent) and prostate (57 to 84 percent).

From these and other considerations, Waldron calculated that (depending on age at death) the proportion of cancers in a collection of old bones would be between zero and 2 percent for males and 4 and 7 percent for females. (The numbers were higher for women because of gynecological cancer. In the next century, cancer in men would come to dominate because of smoking.) No matter how hard you looked, cases of ancient cancer would be sparse — even if the rate had been as high as that of industrial Britain. To test if his numbers

were plausible, he tried them out on the remains of 623 people from a crypt at Christ Church, Spitalfields in the East End of London between 1729 and 1857. Relying solely on visual inspection, Waldron found one case of carcinoma among the women and none among the men.

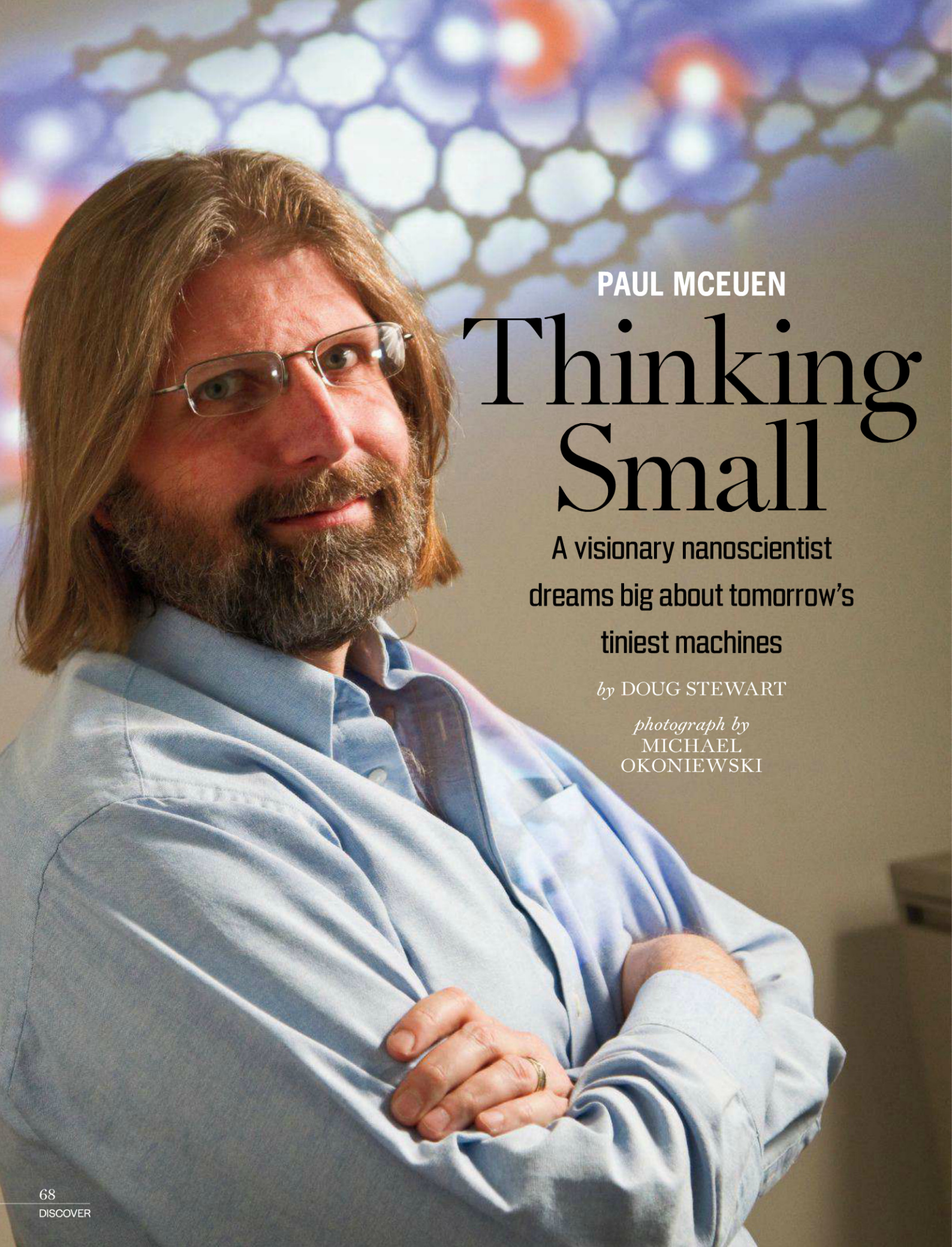
That was within the range of his formula, encouragement that it was not wildly wrong. The next step was to try the predictions on much older and larger populations: 905 well-preserved skeletons buried at two sites in Egypt between 3200 and 500 B.C., and 2,547 skeletons placed in a southern German ossuary between A.D. 1400 and 1800. (The church cemetery was so small and crowded that remains, once they had decomposed, were periodically removed and put into storage.) Using X-rays and CT

scans to confirm the diagnoses, pathologists in Munich found five cancers in the Egyptian skeletons and 13 in the German ones — about what Waldron's formula predicted. For all the differences between life in ancient Egypt, Reformation Germany and early 20th century Britain, the frequency of cancer appeared to be about the same.

Since then, the world has grown more complex. Longevity has soared along with the manufacture of cigarettes. Diets have changed drastically, and the world is awash with synthetic substances. The medical system has gotten better at detecting cancer. Epidemiologists are still trying to untangle all the threads.

Yet running beneath the surface there has been a core rate of cancer, the legacy of being multicellular creatures in an imperfect world. There is no compelling evidence that this baseline is much different now than it was in ancient times. **D**

George Johnson writes for *The New York Times*, *National Geographic* and other publications. *The Cancer Chronicles* is his ninth book.



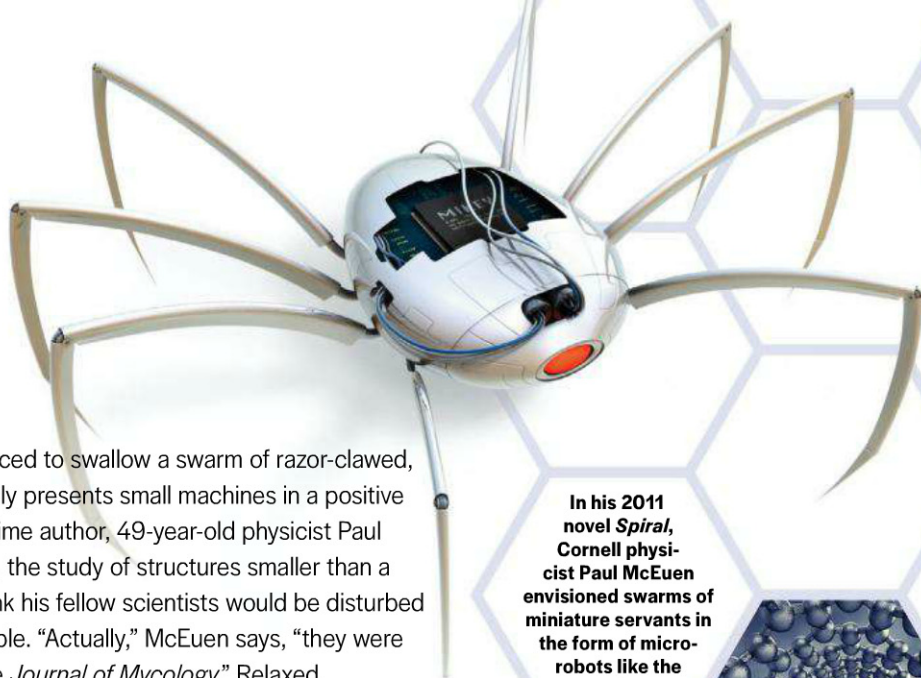
PAUL MCEUEN

Thinking Small

A visionary nanoscientist
dreams big about tomorrow's
tiniest machines

by DOUG STEWART

photograph by
MICHAEL
OKONIEWSKI



In the 2011 thriller novel *Spiral*, a scientist is forced to swallow a swarm of razor-clawed, fungus-tending micro-robots, a scene that hardly presents small machines in a positive light. So it may seem odd that the book's first-time author, 49-year-old physicist Paul McEuen, is a leader in the field of nanoscience, the study of structures smaller than a micron, or a millionth of a meter. One might think his fellow scientists would be disturbed that he mined his field for gory ways to kill people. "Actually," McEuen says, "they were very supportive. I even got a good review in the *Journal of Mycology*." Relaxed, thoughtful and highly literate — in a recent academic article he cited Hume, Joyce and Beckett along with Nobel Prize-winning physicists Richard Feynman and Niels Bohr — McEuen is a man of wide-ranging interests who has narrowed his scientific focus to the very, very small.

McEuen was already a leading authority on carbon nanotubes, naturally occurring cylindrical structures smaller than a billionth of a meter in diameter, when he was lured to Ithaca, N.Y., in 2001 to direct Cornell University's Laboratory of Atomic and Solid State Physics. In 2010, he also took over as director of the prestigious Kavli Institute at Cornell for Nanoscale Science. Today, he spends many of his workdays exploring the properties of graphene, the world's thinnest material at just one atom thick. Sixteen faculty and their research groups are involved in the institute he runs, creating tools that will one day build and control nanobots and other atomic-scale machines still the stuff of science fiction. One ambitious multibillion-dollar effort that McEuen is helping to plan will use nanomaterials to listen in on millions of brain cells at once.

When he's not investigating atomic-scale objects in his lab, McEuen tinkers with his next thriller manuscript in the home he shares with his psychologist wife, Susan Wiser, and their six dogs. DISCOVER sent writer Doug Stewart to Ithaca to ask McEuen about where nanoscience is headed. The nonfiction future, to hear McEuen tell it, is a world of bloodstream submarines; tiny, flexible computers; and thinking small.

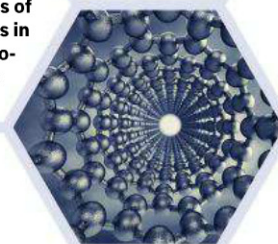
QA+ **Have you always been drawn to tiny things?**

I remember being fascinated by ants and wasps and other bugs when I was a kid. I'd set out a Coke can and stand back 20 feet and use my telescope to watch wasps land on it. Here were these amazing little bitty machines that could do all sorts of things. I think it's very telling: I got this telescope to look at the stars, but I ended up using it to look at small things. Even at the time that's where my interests lay — that extra universe that exists at the small scale rather than the big scale.

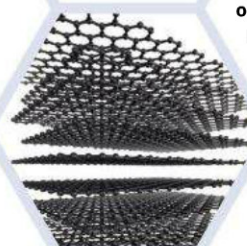
But you didn't end up deciding to become an entomologist.

No. As an undergrad, I studied engineering physics at the University of Oklahoma, and all my degrees are from engineering departments. My father wanted me to join him in the oil-field business in Oklahoma, but I wanted to be a scientist. Later, when I was thinking about graduate school, I read about a professor at Yale named Robert Wheeler, who was making tiny one-dimensional conductors and transistors — really skinny wires, basically. I didn't know what that was, but I thought it sounded really cool. He became my Ph.D. adviser in the late 1980s.

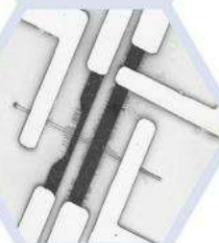
In his 2011 novel *Spiral*, Cornell physicist Paul McEuen envisioned swarms of miniature servants in the form of micro-robots like the one above.



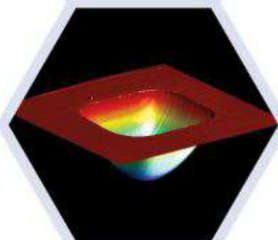
A carbon nanotube (rendered above in 3-D) is a naturally occurring cylinder composed of hexagonally arranged carbon atoms, called graphene.



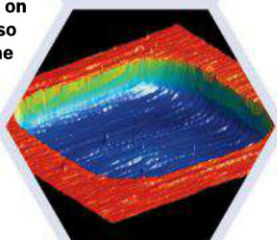
Graphite (above), another form of carbon, is made from stacked sheets of graphene. It is used in the manufacture of batteries, lubricants and pencil lead.



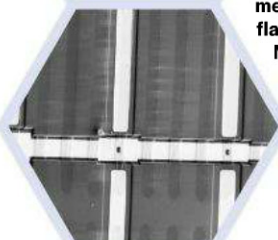
A nanotube transistor with graphene electrodes. All-carbon transistors allow for the creation of thin, bendable electronics, such as flexible displays.



In McEuen's nanodrums, a graphene membrane one atom thick is pressurized on one side (above), so that the membrane forms a bowl shape.



When pressure is released from the drum (above), the membrane reverts to a flat-bottomed surface. Nanodrums can be used as pressure sensors.



A graphene strip (horizontal bar, above) suspended over a trench. Contact with the bars (vertical) allows it to act as an electromechanical switch.



Nanoscience could someday yield tiny machines such as "nanosubmarines" designed to navigate the bloodstream (artist's conception above).

What excited you about the skinny wires?

There was a sense that an unexplored world was just opening up. If devices are small enough, the effects of a single electron start to matter. At MIT, where I did postdoctoral work, we made transistors that were so small there were only one or two or maybe three electrons in them. Transistors are used to turn on and off the flow of electrons through a device, and also to amplify that flow so that you can send one signal to many devices. They're the building blocks of computers. The smaller you can make a transistor, the faster it is.

This was your first foray into atomic-scale technology. What does nanotechnology encompass, and why does it matter?

Nanotechnology is the idea that we can create devices and machines all the way down to the nanometer scale, which is a billionth of a meter, about half the width of a human DNA molecule.

In the case of electronics, nanoscience has already pushed it down to the nanoscale — we've been able to pack incredibly dense arrays of devices on chips. The goal is to make machines at that scale that will do real work.

After you joined the faculty of the University of California at Berkeley in 1992, your attention turned to carbon nanotubes, carbon cylinders 10,000 times narrower than a human hair. What happened?

Carbon nanotubes occur naturally — we now know you find them in soot. When I was at Berkeley, Richard Smalley, a Rice University chemist, was learning how to grow large quantities of carbon nanotubes in his lab. We thought, "Let's try wiring up some of those."

What was it about these nanostructures that excited you?

Carbon nanotubes are amazing because they're really good electrical conductors, yet they are only a few atoms in diameter. You can make transistors out of them in the same way you can with silicon. At Berkeley, we made the narrowest device anybody had ever made. It was basically a single molecule. It is fundamental

science like this that underpins the applications that are coming.

Can you describe those applications? How might carbon nanotubes be used?

One approach is to use them to make high-performance, small devices that would replace silicon. You could use them the same way as you would a silicon transistor but with higher performance — like silicon transistor chips. IBM is working on things related to that. And because they're so flexible, you can use them for high-performance, flexible electronics, so if you want your electronics to be on a flexible screen, it might be useful for that. They might also be useful for nanoscale sensors: They're so small that even if a single molecule sticks to them, it can change the conducting properties, allowing you to sense the presence of individual molecules.

Since 2001, you've been at Cornell. What are you investigating?

Lately we've been working on graphene, which is a sheet one atom thick, made entirely of carbon atoms arranged in a hexagonal structure like chicken wire. You can think of it as a carbon nanotube that's been rolled out flat. Unlike nanotubes, you can make it cover large areas, you can make it more uniform, and it's much easier to work with as a material — it's as different [from nanotubes] as a sheet of paper is from a stick.

Graphene is a phenomenal material in almost every way. It's electrically conducting, so it could be useful in electronic devices. It's incredibly flexible, so something that handles like a piece of paper could actually be an electronic display. When you push a single sheet of graphene with a probe, it crinkles up a little like cellophane, but it doesn't rip. In fact, both graphene and carbon nanotubes are extremely strong. You can do all sorts of nasty things to them — pour acid on them, keep them underwater — and they don't mind.

How is graphene's durability useful?

It means it can survive all kinds of environments and not break down, which is hard to do at the nanoscale. Most of the

nanomachines in your body — by that, I mean biological machines like enzymes — don't last more than a few hours. They're constantly replaced in your body as they break down chemically. If you want a device to work inside your body for years, like a brain implant, durability is essential.

What kinds of nanomachines could arise out of basic research on graphene?

Since nanomachines don't exist yet, we can't say what they'll look like. You might think that they would look like miniature versions of machines we know, so if you were building a tiny machine that was going to move around in the bloodstream and look for cancerous cells, it might look like a little submarine. But it's more likely that it would look like its biological equivalent: a bacterium, with soft movable parts that flex to cause it to swim, and a little propeller.

What are you working on?

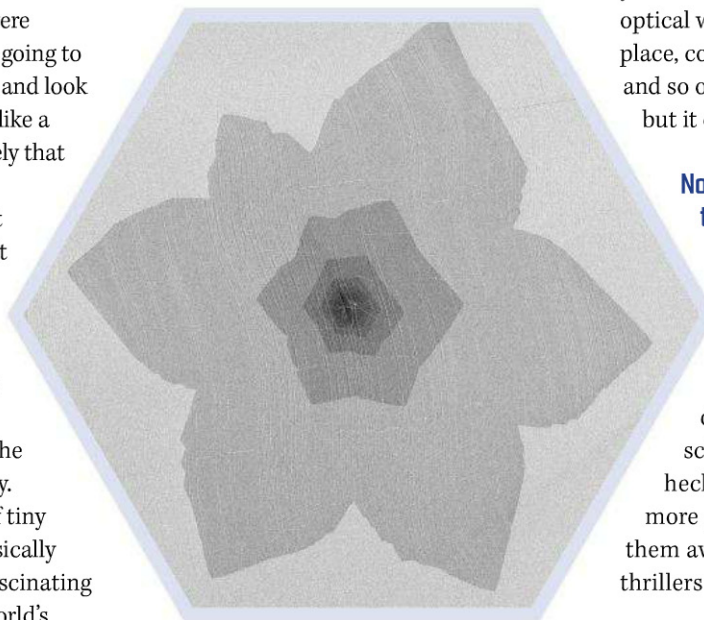
The structures we work with are the elements out of which you would build these machines — the panels and screws, you might say. Lately, we've been making lots of tiny graphene resonators. They're basically drumheads an atom thick. It's fascinating to make what amounts to the world's thinnest drum, to see if you can put it into vibration and play it and listen to it. You can tune nanodrums just like a real drum, depending on how much tension you put in the membrane. They vibrate at the frequency of an FM radio signal, so they could be used for miniaturized communications systems. For example, if you wanted to make a bloodstream submarine, you'd need to get information in and out. A graphene resonator on board could tune to signals at a particular frequency, the way a cell phone does, but it would be extraordinarily tiny and use very little power.

You've also been designing hinges made of graphene, which would be a necessary part of any kind of nanoscale machine. How do graphene hinges work?

A traditional door hinge is a complicated device with a lot of parts, so it's hard to

build — you have to build all those pieces and know how to put them together, and that's not easy to do. A graphene hinge is more like a paper fold. We made one hinge that we tested by opening and closing it about 10,000 times to show that it's indestructible with normal use.

With hinges like that made out of silicon, you might build an array of tiny steerable mirrors that would change the colors and reflectivity of pixels in a new kind of TV screen. Or, if you built a



A pattern of nested stars shows how graphene is grown, with lighter regions representing a single layer and progressively darker areas depicting additional layers.

nanosubmarine, you might want to seal a drug inside for delivery to a cancer cell that you wanted to kill. A hinged graphene door could then open and release the drug on the spot. You could plan multiple folds, like an origami design.

You've been involved in designing ways to use nanoscience tools to understand the brain better. What is the main goal?

The medical world would like flexible brain implants so they can shove them between the brain's ridges or corrugations and get back signals from deep inside the brain. A flexible electronic implant might help a person control a prosthetic limb, for

example. We've done no actual work on this yet — we're thinking ahead.

What's a key challenge in designing such brain implants?

One is that you want the wires to be small enough that they don't cause brain damage when you jam them in. But if they're too small, it's hard to insert them — it's like pushing a rope. What you really need is a little semi-autonomous device that knows how to crawl down into the crevices in your brain, dragging its little electrical or optical wire behind it, attach it to the right place, come back out, grab another wire, and so on. This is science fiction right now, but it could happen.

No wonder you've begun writing in the science fiction genre. Your novel *Spiral* features homicidal "MicroCrawlers." Did you worry about damaging nanotechnology's image?

I probably worried more about damaging my own reputation as a scientist. But I figured what the heck — *Jurassic Park* probably drew more people to science than scared them away. Anyway, people expect thrillers to be over the top.

Did you see your MicroCrawlers as benign machines gone astray, or did you intend them to be creepy?

I definitely went for creepy. They are basically robotic spiders. In fact, my wife has a fear that if she sleeps with her mouth open, a spider might drop in. That might be where I got the idea of these tiny robots getting inside people.

Did you yourself ever accidentally inhale a nanodevice?

They're so small I wouldn't notice. In any case, if I lose something or it doesn't work, there's always another one. That's an advantage of working with tiny things: You make them by the millions. 

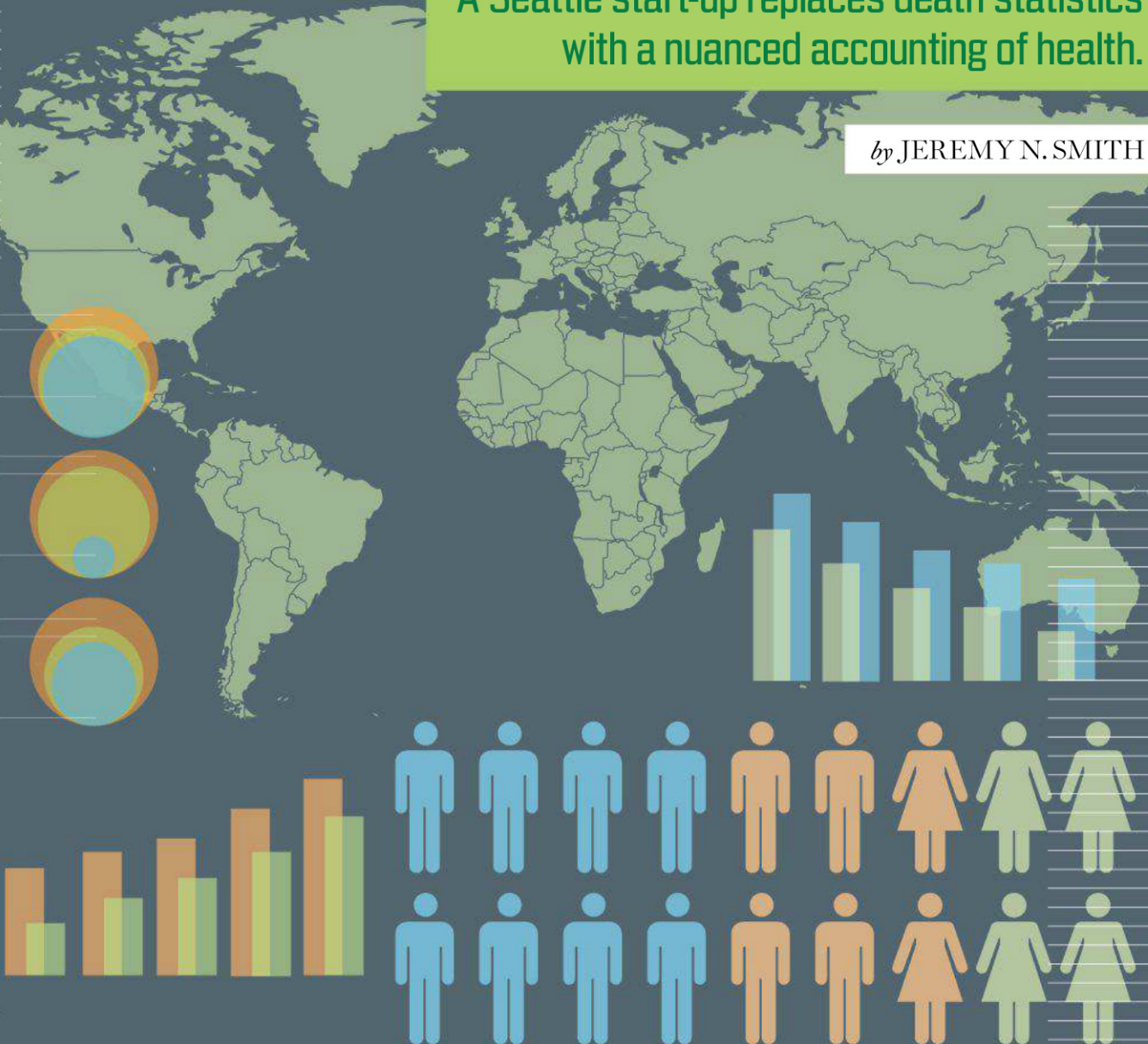
Doug Stewart's articles have appeared in *Smithsonian*, *New Scientist* and *National Wildlife*. He lives in Massachusetts.



THE NEW BOOK OF LIFE

A Seattle start-up replaces death statistics
with a nuanced accounting of health.

by JEREMY N. SMITH



It's Monday morning in Seattle, and Christopher Murray and I are glued to his computer screen, watching how the world dies. A drop-down menu offers choices from measles and cirrhosis to eating disorders and self-harm. I choose road traffic injuries and see a map divided into 187 countries, each color-coded by incidence: blue for safest, fire engine red for most deadly. Commuting in Sweden or Singapore? Go ahead, gas up. Traversing Gabon or Angola? Buckle up and pray.

The maps represent the ascendance of a new accounting of life and death led by Murray, a still-boyish-looking salt-and-pepper-haired 50-year-old who is the director of the Institute for Health Metrics and Evaluation. Rather than focus only on how many people were killed by a particular malady, as others measuring death and disease do, IHME emphasizes the number of years of healthy life lost.

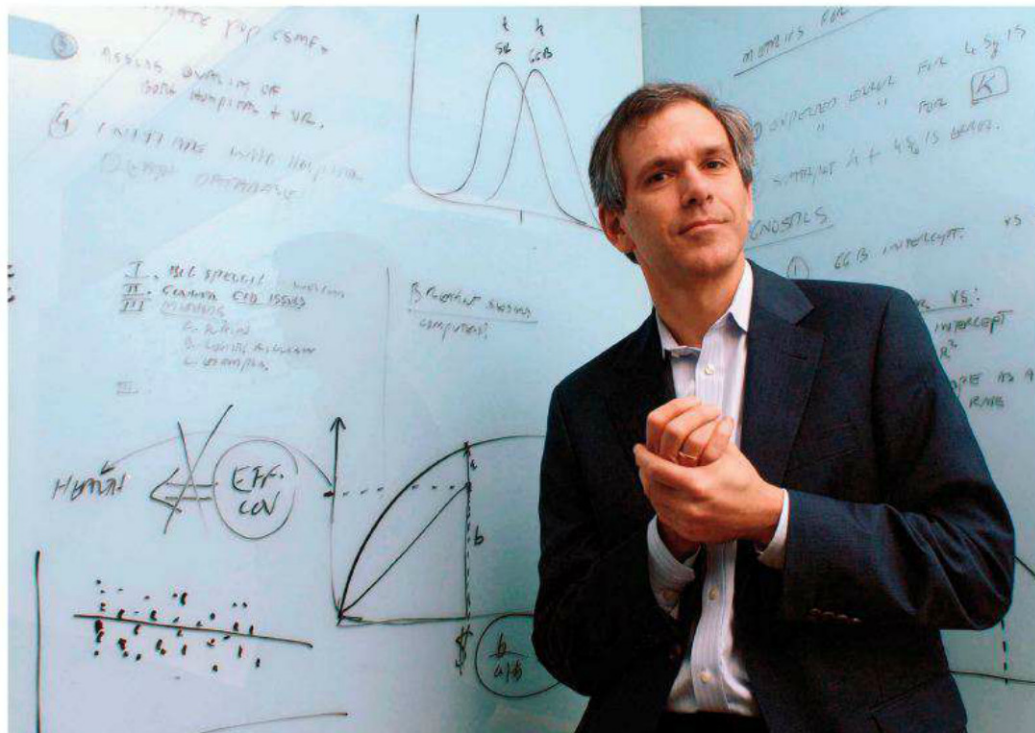
Take the traffic maps in front of me. Using data released in December 2012, Murray and his colleagues have calculated that road accidents in 2010 cost humanity 75 million years of healthy life — more than measles, lung cancer, tuberculosis or iron-deficiency anemia. “If someone dies of cancer at age 75, maybe the disease has taken five years of his life,” explains Murray, whose group’s massive study, entitled “Global Burden of Diseases, Injuries, and Risk Factors Study 2010,” shares the tolls by age, sex and country for 291 different health problems and 67 risks. “If he dies of a car crash at age 25, though, that has taken 55 years. And if he survives the car crash but suffers a severe spinal injury and then dies at age 60, that is both 20 years of life lost and 35 intervening years lived with disability.”

All of a sudden, asphalt might be worse for you than cigarettes.

OUT OF AFRICA

Murray was all but born to a career in international public health. When he was 10 years old, his family raised money, bought a couple of Land Rovers and moved from Minneapolis to eastern Niger for a year. There, his father, a professor of medicine at the University of Minnesota, and his mother, a microbiologist, took over an empty hospital. “There was just us,” Murray says. “Dad was chief — and only — physician. My mother and 14-year-old sister ran the inpatient nursing services. My 18-year-old brother ran the lab and helped my dad with surgery. I was the pharmacist and run-around boy.”

Niger was, and remains, one of the poorest places on Earth, and



IHME Director Christopher Murray drills into the math of life and death in his Seattle office. One key find: Traffic accidents cost us more years of healthy life than lung cancer.

the 10-year-old witnessed locals carrying sick boys and girls his own age in from the desert, wrapped up in brightly colored cloth. These children had their ribcages sticking out. Some screamed. Others didn't have the energy even for that. Then there were the adults.

“I remember a guy who walked out of the hospital,” Murray says. “He was very proud. He didn't want to show people he was sick. But I was a kid. He dragged me over and showed me where he had vomited blood in the sand.”

The direct medical work made a difference, Murray recognized. It saved lives. But his father was the kind of academic who encouraged his children to be skeptical of conventional wisdom. Year after year, the family returned to Africa. As Murray grew older, he questioned whether saving someone's life and sending him back into the desert, still vomiting and sick, was the best science could do.

Murray went to Harvard for college. He became a Rhodes scholar and earned a doctorate in international health economics. While writing his dissertation at Oxford in the mid-1980s, he saw resi-

dents of some low-income countries — China, Costa Rica, Sri Lanka and the state of Kerala in India — repeatedly trumpeted as healthier than others and, in terms of mortality rate improvement, doing even better than those in many wealthy Western nations. For instance, the Rockefeller Foundation published a highly influential report, “Good Health at Low Cost,” promoting China’s patriotic health campaign, Costa Rica’s universal health insurance, Sri Lanka’s land reform movement and Kerala’s rural nurse-midwives as reasons residents of these areas were living better. Hard data was sketchy, however, and largely limited to average life expectancy. Who was really extraordinary, and what specific interventions did the greatest good?

“There was incredible expertise in the world on malaria or tuberculosis or any other given disease or problem, but there was nobody standing back and saying, ‘What is the landscape?’” Murray says. Say you believed the data and wanted to help other countries follow the examples set by China, Costa Rica, Sri Lanka and Kerala. Should you focus limited time and money on safer birth conditions or lower hospital copays? On improved nutrition or better drinking water? What if none of the above is as important as the number of years young women spend in school — or, returning to road traffic, how safe it is to cross the street? “If you don’t have the big picture,” says Murray, “it’s incredibly easy for groupthink to lead you to focus on a limited number of things and miss what’s really important.”

The ideal life not only lasted the longest, he thought, but also experienced the least illness. “Obviously, being in good health is avoiding dying, but it’s also being able to move around well, being able to see and hear, being able to think clearly and not being in pain, not suffering from anxiety and not being depressed,” Murray says. “These things really matter to how you live your life. But if you just focus on death, you miss them.”

DUELING DEATHS

When it comes to advocating his ideas, Murray has always been brash. Demographer Alan Lopez, Murray’s close collaborator for three decades, recalls meeting him in 1984 at the World Health Organization in Geneva: “A young man knocked on my door. He said, ‘Is this Alan Lopez?’ I said yes. He said, ‘My name is Chris Murray, and everything you’ve written about mortality in Africa is wrong.’”

Murray’s interest and intellect thrilled Lopez, himself a young demographer taking piecemeal mortality information from around the world and trying to estimate what killed whom where. An Australian trained in statistics and epidemiology, Lopez recognized not

only the limits of his own mortality measurements, but those of the WHO as a whole. Every year, researchers in each program of the organization calculated the annual number of deaths attributable to their specialty: malaria, pneumonia, diarrhea and the like. When Lopez added them all up for the first time, the total was over 50 percent higher than U.N. estimates of overall mortality —

akin to saying a family with four children has three girls and three boys. It meant that the leading global authority on life and death was either missing or misdiagnosing tens of millions of sick people a year.

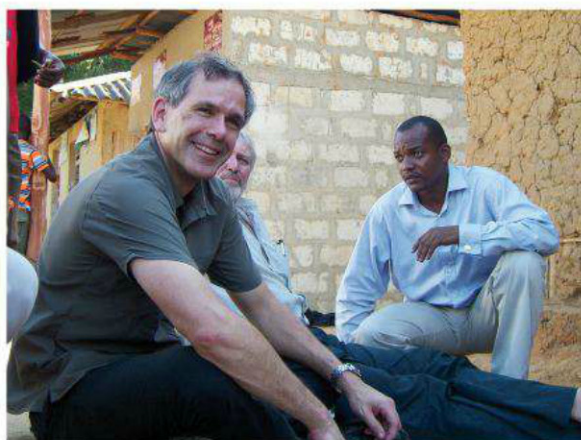
“These were well-meaning advocates doing the calculations, but because there was no central oversight, they were using different methods, different degrees of rigor and databases of different quality,” Lopez remembers. “When they made their estimates, there was no constraining them. No one was saying, ‘Hold on a minute, you’re saying a million deaths from diarrhea. The people down the corridor are saying 5 million deaths from pneumonia. Are any of these the same deaths?’”

Such double-counting could be deadly. “The whole purpose of doing

the numbers is to correctly describe the comparative importance of different diseases,” Lopez says. Diarrhea and pneumonia were the two leading causes of child deaths in the 1980s. They have completely different treatments. “So if you had 9 million deaths between the two of them and you said there were 4 or 5 million each, but in reality there were 3 million from diarrhea and 6 million from pneumonia, you would end up with a lack of pneumonia treatment,” says Lopez. “That potentially could cause many more child deaths.” When he brought his concerns to colleagues, most just disregarded him and continued to promote the numbers that they themselves had produced.

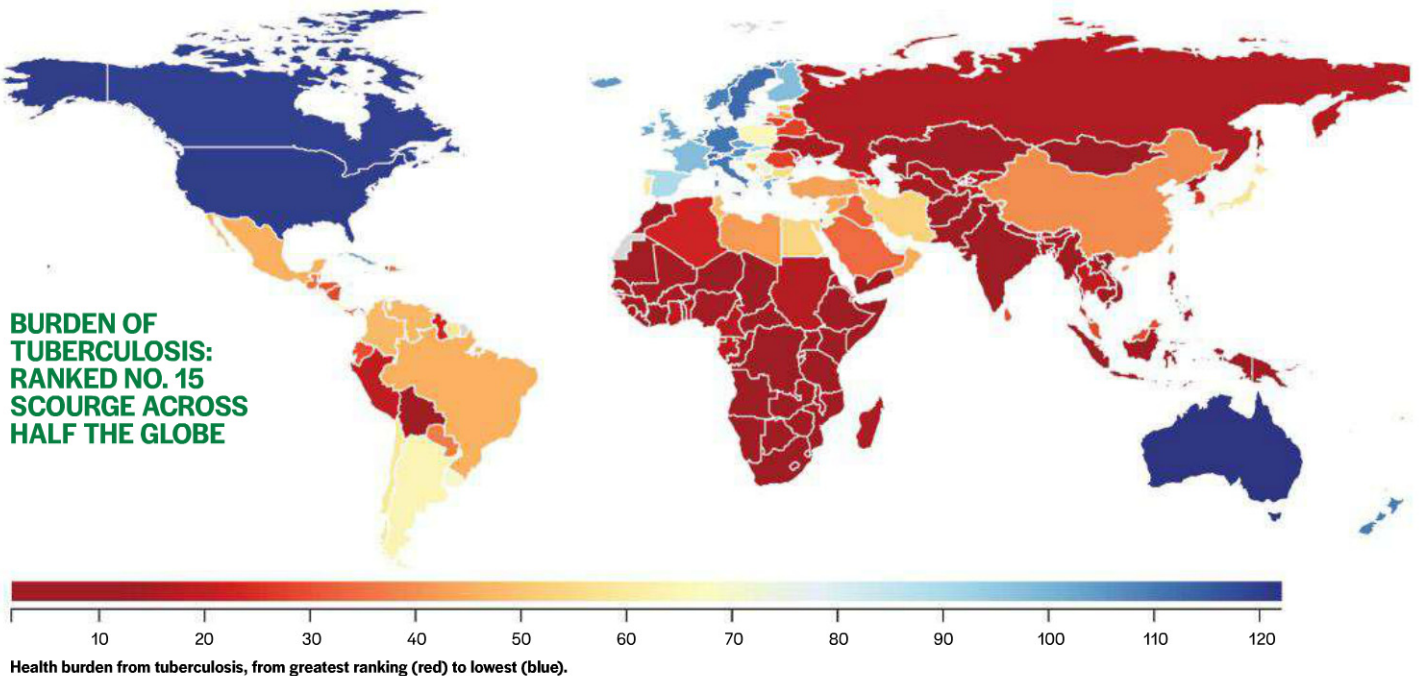
Murray argued for change. First, rather than rely on researchers studying one specific ailment or area, decision-makers needed an independent team consistently and comprehensively tallying how bad each disease was, for whom, everywhere. Second, it wasn’t fair to concentrate only on mortality. How many 10-year-olds from eastern Niger ended up as Oxford grad students? How many ended up injured by a car accident? How many didn’t have enough to eat? How many would suffer an obstetric fistula giving birth? How many would cough blood? “At that time, the global public health community was very much focused on child survival,” says Lopez. “He was one of the first people who started to think that mortality and health actually mattered for adults as well.”

Murray and Lopez began corresponding and kept in contact even after Murray returned to the United States for medical school. While



Murray (foreground) and demographer Alan Lopez (behind him) challenged the way the U.N. determined mortality rates.

BURDEN OF TUBERCULOSIS: RANKED NO. 15 SCOURGE ACROSS HALF THE GLOBE



still a resident in internal medicine at Brigham and Women's Hospital in Boston and a junior faculty member at the Harvard School of Public Health, the economist-turned-doctor researched various attempts since the 1960s to create a combined measure of impairment, illness and death. "The original idea was you want a metric that can also be used in economic studies: If you spend X amount of money, this is how much health you'll get." In 1991, he and Lopez started working on the global burden of disease.

A SIMPLE SUM

Murray defined burden with a two-part sum remarkable for its simplicity. The first part was about everything that kills people. Let's say, as was true in 1990, that men and women in the healthiest places on Earth could expect to live about 80 years on average. Then if you died at any age short of 80, you had "lost" that many years of healthy life — at least compared with the ideal. Demogra-

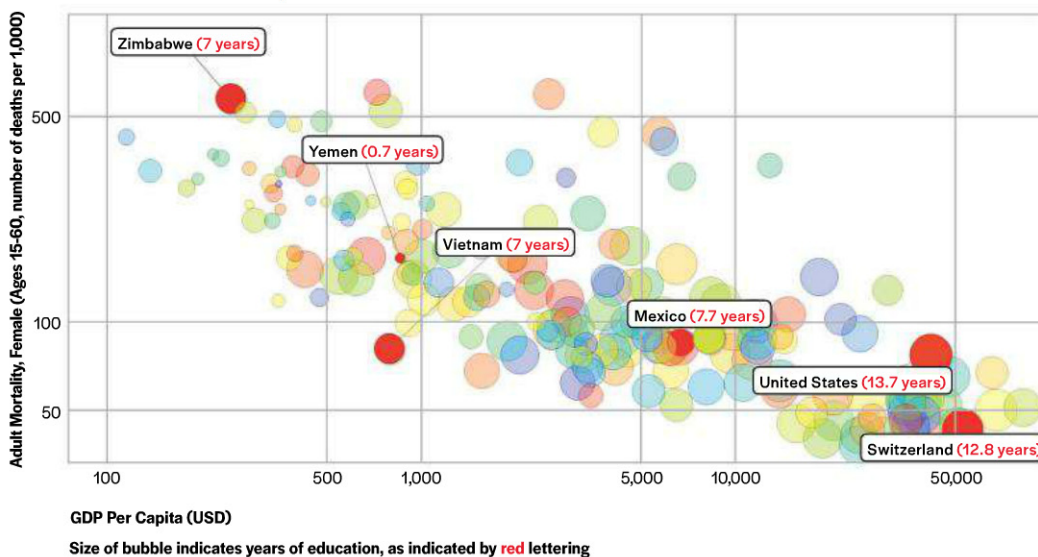
▲ Footprint of a Disease

When Americans imagine an epidemic, they are most likely to think of HIV. But as the dark red swath on the map above shows, in much of the world an equally formidable foe is tuberculosis, a bacterial disease characteristically concentrated in the lungs. Globally, the burden of disease from TB in 2010 ranked 13th overall, ahead of drug use, suicide, diabetes or any kind of cancer. In Southeast Asia, TB was second only to strokes. Based in part on an early global burden analysis, The Global Fund to Fight AIDS, Tuberculosis and Malaria was started in 2002.

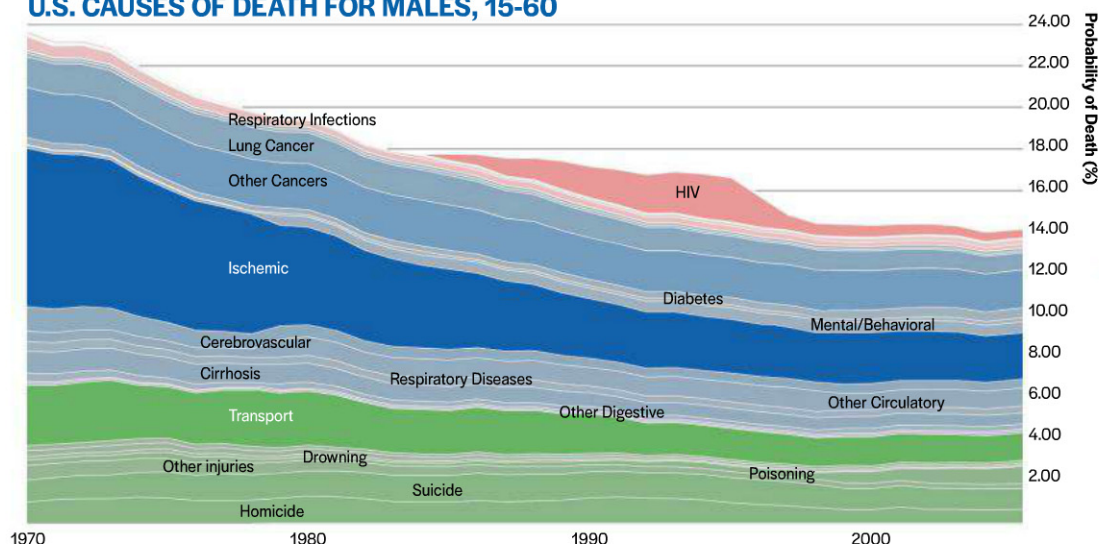
▼ The Power of Education

To live the longest and healthiest life possible, get smarter. IHME data show that past a certain threshold, health and wealth (as indicated by female adult mortality rate, vertical axis, and per capita gross domestic product, or GDP, horizontal axis) are just weakly correlated. However, overall health is closely tied to how many years people spend in school (indicated by circle size). Mexico, for instance, has a fifth the per capita GDP of the United States, but, for women, more than 50 percent of the latter's schooling. In line with the trend, Mexico's female adult mortality rate is only narrowly higher. Vietnam and Yemen have roughly equivalent per capita GDP. Yet Vietnamese women average 6.3 more years in school and are half as likely to die between the ages of 15 and 60. Outliers are Switzerland and Zimbabwe, with one of the world's lowest and highest female adult mortality rates, respectively, and a 200-fold difference in per capita GDP. "Economic growth is also significantly associated with child mortality reductions, but the magnitude of the association is much smaller than that of increased education," comments Emmanuela Gakidou, IHME's director of education and training. "One year of schooling gives you about 10 percent lower mortality rates, whereas with a 10 percent increase in GDP, which is huge, China has achieved it for a few years, your mortality rate would go down only by 1 to 2 percent."

FEMALE MORTALITY, 2010: EDUCATION IMPROVES THE ODDS



U.S. CAUSES OF DEATH FOR MALES, 15-60



How American Men Die

IHME visualizations allow easy comparison between patterns of disease, injury and death over periods of time. At left, a stream graph depicts the shifting probability that a 15-year-old male in the United States will die before reaching the age of 60, broken down by cause. According to the institute's research, the probability of adult men dying early from traffic accidents or cerebrovascular disease more than halved between 1970 and 2006, while death by suicide held relatively steady through the years. Newly published data point to seven causes that accounted for more than 40 percent of years of life lost to premature death in the United States in 2010. Ischemic heart disease tops the list, followed, in order, by trachea, bronchus and lung cancers; stroke; chronic obstructive pulmonary disease; road injuries; suicide; and diabetes. Rising fast were kidney and other urinary organ cancers as well as Alzheimer's disease and other dementias. A deep dive into the numbers reveals the U.S. lagging behind other wealthy and even middle-income nations in wide-ranging aspects of health, from preterm birth and maternal mortality rates to life expectancy.

phers called this shortfall potential years of life lost (YLL).

The second part of the sum concerned nonfatal health problems, weighting each on a scale from 0 (perfect health) to 1 (death) — blindness being worse than deafness, moderate dementia being worse than autism, neck pain being worse than infertility and so on, as rated originally by a panel of experts and now by statistically representative surveys of the general public around the world. If you think of blindness as a fifth less healthy than perfect health — 0.2 on the 0-to-1 scale — then living with 10 years of blindness could be thought of as equivalent to dying two years early. In the same manner, living a decade with mild neck pain was roughly equivalent to dying one year early, and living a decade with moderate depression was about the same as losing four years of healthy life. Multiply each condition's weight by the number of years people suffer it, and you have what Murray called years lived with disability (YLD).

The beauty of his formulation for death and infirmity is that both parts of the sum share the same unit: years of healthy life lost. Add them up, and you have what Murray termed the number of disability-adjusted life years, or DALYs, attributable to any health problem. Expressed as an equation, $DALYs = YLL + YLD$.

In plain English, the number of disability-adjusted life years (DALYs) is the sum of years of life lost because of premature death (YLLs) and equivalent years lived with disability (YLDs). DALYs, aptly enough, rhymes with tallies, and the metric allowed important new comparisons: not only between what kills you and what merely makes you sick, but also between, say, life in Latin America and the Caribbean; between homicide and heart disease victims; and between the relative risks of iron deficiency and alcohol abuse. At a glance, given the right background data and analysis, one could say that in 2010 premature deaths were responsible for two-thirds of all DALYs lost and disabilities for one-third; that 25 percent of all DALYs lost worldwide were due to death and disability in children younger than 5; and that sexually transmitted diseases and tuberculosis added together contributed 5.7 percent of the global burden of disease.

Risky Business

Relatively few risk factors account for a large proportion of the global burden of disease. Smoking and indoor and outdoor air pollution together lead to more than 13 percent of total years of healthy life lost — and they wreck the body almost identically. "Particulates get inhaled, go into the lung, and the harm they do seems the same," Murray says. Dietary risks in aggregate top the rankings worldwide: In the U.S., too little fruit is the lead factor. In Italy, it's high sodium. Murray says Americans could alter diet, tobacco use and exercise to powerful effect. "Where it's good for you and it's easy, why not do it?" he says. Risk varies by region. Household air pollution is the fourth-highest-ranked risk worldwide, but of much less consequence in the United States and Canada, where it's ranked 24th and marked on the grid in coral green.

GLOBAL RISK: RANKING HEALTH DANGERS BY REGION

	Global	High-income Asia Pacific	Western Europe	Australasia	High-income North America	North Africa and Middle East	South Asia	Southeast Asia, East Asia and Oceania	Central Europe, Eastern Europe and Central Asia	Latin America and Caribbean	Sub-Saharan Africa
Dietary risks	1	1	1	1	1	1	1	1	1	1	7
High blood pressure	2	2	3	4	4	2	4	2	2	2	6
Smoking	3	3	2	3	2	4	3	3	4	6	8
Household air pollution	4	24	24	24	24	16	2	4	11	11	2
Alcohol use	5	5	7	8	7	13	11	7	3	4	4
High body-mass index	6	7	4	2	3	3	13	8	5	3	15
High fasting plasma glucose	7	6	6	6	5	5	8	6	8	5	12
Childhood underweight	8	21	20	19	21	14	5	16	20	17	1
Ambient PM pollution	9	8	9	16	10	7	7	5	9	16	13
Physical inactivity	10	4	5	5	6	6	12	10	6	7	17

"That," comments Lopez, "is an extraordinarily beautiful and extraordinarily useful policy tool."

Murray and Lopez brought the idea to the World Bank and then the World Health Organization, which together published the first preliminary "Global Burden of Disease" in 1993.

RECALCULATING RISK

Young, influential, confident and contrarian, Murray and his growing research unit at Harvard attracted critics. Contention only increased in 1998, when the team shifted headquarters to the WHO. As a U.N. agency, the WHO is inherently political. When member nations didn't like what was said about their country, they made protests to the executive board. Pakistani and Brazilian leaders, for instance, were upset when the 2000 World Health Report, overseen by Murray, estimated their health systems' performance to be much lower than they thought was the case. In response, an independent scientific committee was established to review Murray's results. "There were very diverse opinions, a lot of emotions, a lot of anger," Lopez recalls.

Likewise, aid organizations and WHO staff working to control individual diseases like pneumonia and malaria didn't necessarily appreciate having their numbers challenged. "For every disease and every risk factor, there's a constituency out there," Murray says. Altering the story an advocacy group tells can create cataclysmic change.

With such powerful tools, policymakers soon followed "Global Burden's" techniques. At the vanguard was Julio Frenk, the current dean of the Harvard School of Public Health. From 2000 to 2006, Frenk served as the minister of health in Mexico, and that nation performed the first country-level burden of disease assessment. "It completely changed the perception and sense of priorities in Mexico," he says. "Before DALYs, we assessed the importance of health problems by the number of deaths. Obviously, there are a lot of diseases that don't kill people but produce a lot of disability. That's the case with mental illness." For the first time, not only depression, but osteoarthritis, arthritis and lower back pain were seen as vital state concerns, each nonfatal yet among the 10 biggest DALY-ranked health problems facing adults in Mexico. Also newly emphasized were road traffic accidents for men and breast and cervical cancer for women. These struck young people disproportionately, costing more life years.

Frenk used the analysis to drive national health policy in the Congress of Mexico. "For what was given priority, and in what

order, we used the national burden of disease," he says. Medications for breast cancer and cervical cancer and for arthritis are covered in the new national insurance plan, for instance. Where emergency care after a car accident was once an out-of-pocket expense, now it, too, is part of the insurance. So is treatment for mental illness. "I doubt such comprehensive reforms would have

been approved if we hadn't had that evidence," Frenk says.

Country-level burden studies for Mauritius, Colombia, Chile, Uruguay, Japan, Australia and India's Andhra Pradesh followed Mexico's. Murray found himself invited to the World Economic Forum in Davos, Switzerland, and to social events with U2 rocker-turned-humanitarian Bono. When Bill and Melinda Gates, the world's richest couple, made global health their family foundation's top priority, the Microsoft founder invited Murray to dinner at his house. "He was incredibly well-read and very detail-oriented," Murray says of the initial 1999 encounter.

One extreme numbers enthusiast had met another. DALYs, Murray was told, would guide much of what the Gates Foundation funded, and how they determined if it worked. "We use global burden estimates to prior-

itize not only work in the field, but also research and development: Where should we invest?" says Stefano Bertozzi, who leads the foundation's efforts to prevent, treat and cure HIV. "For the pharmaceutical industry, it's expected return on investment, measured in dollars. For us, it's expected return on investment, measured in improvement in global health." DALYs had changed the debate.

In 2007, the Bill and Melinda Gates Foundation and the state of Washington offered Murray \$125 million to fund the creation of IHME. The first task before him was building the skilled team necessary to complete a new, far more detailed and nuanced version of the "Global Burden of Disease" study.

Emmanuela Gakidou, Murray's wife and colleague, was crucial to the effort, helping to hire faculty and overseeing a fellowship program where recent college graduates can earn a master's degree in public health. Today the institute employs 139 people, including 24 faculty, 35 fellows and 14 data analysts. Staff members are interdisciplinary and international. The director of data development is a former media executive from Germany. An American mathematician designed the software program to model levels of impairment from each illness or injury. Rafael Lozano, lead author of the original Mexican burden of disease study, leads the global cause of death analysis group.

Official "Global Burden" results began appearing in the British



"There were very diverse opinions, a lot of emotions, a lot of anger," Lopez says about U.N. countries who disagreed with Murray's results.

medical journal *The Lancet* late last year in an unprecedented triple issue of the weekly publication, the first in its 190-year history. “In total, there are 650 million individual results to be reported,” Editor-in-Chief Richard Horton, not exaggerating, told Twitter followers. If he tried to run them all, he joked, “that would be six years of *The Lancet* with nothing but the Global Burden of Disease.”

The publication was celebrated with a daylong scientific symposium at the Royal Society in London, open to the public and attended by many of the study’s 486 co-authors from 302 institutions in 50 countries. The audience included Christine Kaseba-Sata, the first lady of Zambia; Jane Halton, secretary of the Department of Health and Ageing in Australia; Mickey Chopra, chief of health for UNICEF; and Mark Dybul, executive director of the Global Fund to Fight AIDS, TB and Malaria. Murray and colleagues discussed a few of the startling findings filling the global burden ocean.

Around the world, for example, chronic obstructive pulmonary disease claimed roughly twice the number of lives as HIV/AIDS in 2010, but HIV/AIDS was much more fatal to young people, and therefore appears higher in the DALY ranking. Likewise, as risk factors, not eating enough fruit out- rivals illicit drug use. For years, experts have said that most of the world’s major childhood diseases could be eliminated with clean water. What global burden suggests is that while lack of access to water and sanitation is a concern, five times worse for the world is indoor smoke from cookstoves, a major contributor to respiratory illnesses, communicable diseases, cardiovascular problems and cancers.

The concept of global burden upsets entire categories of thought, not the least of which is the old distinction between “developing” and “developed” nations around the world. For example, high blood pressure is the top risk factor in nations as diverse as Germany, Brazil, Indonesia, Egypt, China and Russia. Conversely, the No. 1 cause of ill health varies widely, even among close neighbors. “In Venezuela, it’s homicide. In Mexico, it’s diabetes,” says Murray. “Tuberculosis is big in Indonesia; in Malaysia and Thailand, it’s ischemic heart disease, same as in Western Europe.”

“What is exciting about this is that it’s the most up-to-date information,” says Lisa Cohen, executive director of the Washington Global Health Alliance, representing many of the world’s leading global health nonprofit organizations, including the Bill and Melinda Gates Foundation. “Where should we put our program resources?” In some nations, health spending may be as little as \$2 or \$3 per person. “That is infinitely precious money,” says

Cohen. And with guidance from global burden data, government officials can allocate money to save and improve the most lives.

Simple comparisons suggest tomorrow’s priorities. Back pain costs men more years of healthy life than malnutrition; depression and suicide hurt women more than tuberculosis and cirrhosis; glaucoma was one of the fastest-growing contributors to health

loss between 1990 and 2010. While Swiss males outlive even the Japanese, life expectancy in the United States has slipped by comparison with other nations of wealth. Depending on the county, men and women may have the same average life expectancy in Indiana and Panama, Nevada and Vietnam, Michigan and Syria. “What we have found is that America has wonderful health care services for those who enjoy them,” says Lopez, today an IHME affiliate professor and the Rowden-White Chair of Global Health and Burden of Disease Measurement at the Melbourne School of Population and Global Health at the University of Melbourne in Australia. “But you have large proportions of the population who don’t have access to those services.”

What countries do with the data is up to political leaders, not IHME. But Murray is committed to making global burden datasets a constantly updated, freely available public resource rather than a once-every-other-decade publication. In January and February of 2012, even as he and his team raced with collaborators to ready the entirety of their research for publication, Murray traveled to Washington, D.C., Brasilia, Dhaka and Beijing to share preliminary findings and demonstrate interactive visualizations. And this year, IHME has put the same tools online for use by anyone in the world. Murray’s energy and impatience to measure life and death just may prove infectious.

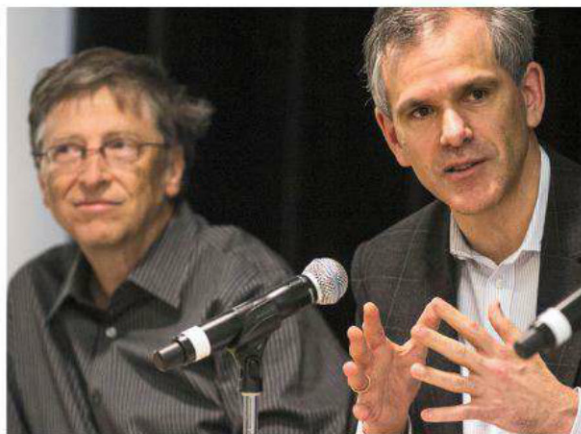
Back in Murray’s office, we click again at the computer, and the display shifts to a series of nested rectangles showing the top global causes of DALYs in 2010. The bigger the rectangle, the worse the problem; the darker the rectangle, the more it has changed recently in percentage terms. Especially dark is “exposure to forces of nature.”

Murray swivels in his chair to face me. “That’s Haiti,” he says.

I ask if numbers can tell the whole story.

We already fit vast human tragedies into little rectangles, Murray responds. “People walk around with a mental map that’s different for every one of us. A real map has got to be a better guide.”

Jeremy N. Smith is writing a book about health metrics and the “Global Burden of Disease” study, to be published by HarperCollins in 2014.



For Bill Gates, global health is a priority. Murray’s accounting system guides the Bill and Melinda Gates Foundation in allocating grants.



Breathless

by LINDA MARSA

California's dirty air is driving rates of asthma, allergies and premature births sky high. Is it too late to change course?



Haze fills the sky around Los Angeles, whose air quality is among the worst in the United States.

Martha Cota awakened one morning to find her infant son, Jose Miguel, gasping for air, his lips and the skin under his fingernails blue from lack of oxygen. Terrified, she rushed him to her local hospital in Long Beach, Calif., where doctors stabilized the toddler and sent him home with medications to control his fever and an inhaler to help him catch his breath. The cycle went on for more than five years — Jose turning blue and barely able to breathe, Cota frantically strapping him into his car seat and racing through traffic, spending countless days and nights sitting in hospital emergency rooms.

Like so many other kids in their working-class neighborhood not far from Long Beach's massive port, Jose had severe asthma, and it took doctors years to hit on a regimen that controlled his symptoms. "He could have died at any time," Cota told me, her eyes brimming with tears, when we conversed one April morning through an interpreter at a coffee shop near her office in Long Beach. "At least once a month, I'd get a call from his school threatening to send me to jail because he was absent so much."

Tall and attired in an elegant black suit, Cota, who is now in her late 40s, has a long mane of dark hair shot through with

auburn highlights and large, expressive eyes. She was a social worker in her native Mexico and now works as a community educator for the Long Beach Alliance for Children with Asthma. When she first discovered that many other women and children in her community were having trouble with respiratory illnesses, she was determined to find out why living downwind of the nation's largest port complex was making so many people sick.

Even at noon on this otherwise sunny day, the sky was blanketed in hazy toxic smog from the ports of Los Angeles and Long Beach, the entry points for more than

heavily congested highways to the rest of the country. Since the 1970s, the massive port complex has exploded to five times its original size, transforming the surrounding area into what one local physician called "an environmental nightmare."

California may have a reputation as a sun-kissed paradise with some of the world's most photographed real estate — Southern California's sparkling white beaches, the celebrated rocky coastline along Big Sur and the epic grandeur of Yosemite and the Sierras. But the reality is that the nation's most populous state is an industrial colossus — the world's ninth-

Since the 1970s, the massive port complex has exploded to five times its original size, transforming the surrounding area into what one local physician called "an environmental nightmare."

half of the goods shipped into the United States and the largest source of air pollution in California. Every day, idling cargo ships carrying 30,000 containers from Asia and the Pacific basin are unloaded by construction cranes towering more than 200 feet high on the docks. Then the containers are dispatched from the rail yards alongside the harbor onto 1,200 diesel-powered freight trains that ferry goods up and down the coast, and 35,000 semi tractor-trailers that speed along

largest economy — with the worst air quality in the nation, according to annual report cards issued by the American Lung Association. The Los Angeles metropolitan area, with nearly two cars per household, has the dubious distinction of having the highest vehicles-per-capita ratio in the world; more than 12 million cars travel on the extensive freeway system every day. But all this commercial activity exacts a heavy toll on residents' health. The exhaust-filled industrial corridor that stretches from the ports of Los Angeles and Long Beach to Riverside — a city of 300,000 residents and a distribution hub that sprouted up next to the freeways where trucks and trains transporting goods belch dark clouds of diesel dust — is what environmentalists call the "diesel death zone."

Cota's first encounter with the environmental cause that would come to consume her life was at a parents' workshop held at her son's school, situated about a mile northeast of the waterfront. There, she met a team of physicians connected with the Children's Environmental Health Center at the University of Southern California who were conducting a long-term study on the link between chronic exposure to air pollution from freeway traffic and respiratory illnesses. Called the Children's Health Study, the research project began in 1993 and eventually involved about 5,500



Martha Cota stands with her son Jose Miguel at the Port of Long Beach in California. Cota's community activism started after years of rushing Jose Miguel to the hospital with childhood asthma attacks.



More than half of the goods shipped in the United States arrive through the ports of Los Angeles (foreground) and Long Beach (upper right). The port complex is California's largest source of air pollution.

children in 12 communities in Southern California. Two-thirds of them were enrolled as fourth-graders, and all were followed until they graduated from high school. Cota immediately signed up for the study and learned how to use a particle counter, which measures particulates and toxins in the air, to take samples of ambient air quality surrounding her home. "Every time a truck would go by," she recalled as we sat sipping coffee, "the meter would spike off the charts." Sometimes it measured 7,000 micrograms of particulate matter per cubic meter, which is more than 400 times the maximum level that federal standards consider healthy.

What the USC researchers ultimately uncovered after a decade of meticulous monitoring was eye-opening. The lung development of children who lived near highly trafficked corridors was stunted — about 20 percent smaller than average — which greatly impaired their functioning. These youngsters also suffered from asthma at significantly higher rates — those living within a quarter of a mile from a freeway had an 89 percent higher risk of asthma than kids more than a mile away. Their asthma symptoms also were worse,

and even among those with health insurance, their odds of ending up in the hospital emergency room choking from the bad air was triple that of youngsters in more affluent areas. Worse yet, pregnant women living in these high-traffic areas were more likely to give birth to premature or low-birth-weight infants, setting up the next generation for a lifetime of disabilities and developmental deficits.

Cota hardly needed a study to tell her this. She and two of her other children later developed severe allergies and now use inhalers and an arsenal of medications just to get through the day. "No one in my family had asthma or allergies," Cota told me. She started working for the Long Beach Alliance for Children with Asthma, she said, "so no other mother has to put up with what I had to."

THE OTHER CALIFORNIA

The situation is even worse in California's Central Valley, where a combination of farming, industry, traffic and topography has made the air quality so bad that four regional metropolitan areas rank among the nation's top 10 dirtiest cities, according to the American Lung Association.

Bakersfield, the birthplace of the renegade rockabilly honky-tonk of Merle Haggard and Buck Owens, consistently tops the list. A long, crescent-shaped lick of fertile flatlands that stretches more than 450 miles and covers 22,000 square miles (slightly smaller than West Virginia), the Central Valley is nestled between the coastal mountains on the west and the Sierra Nevada to the east. They call it "the other California," with patches of farmland extending as far as the eye can see and hardscrabble towns originally settled by Dust Bowl refugees now covered with strip malls and fast-food outlets. But this high desert region is also home to 6.5 million people — more than the population of two-thirds of the states in the U.S.

The spreading urban sprawl, coupled with industrial growth, has yielded increasingly tainted air. Dairy farm waste, soil blown from farmlands, pesticides, industrial emissions, vehicle exhaust and dust particles kicked up by cars and the big rigs ferrying produce down Interstate 5 and Highway 99 — the valley's two main arteries — have made this one of the smoggiest places in the nation. The surrounding mountains trap these

10 Dirtiest Cities in the U.S. by Ozone Measurements

- #1: Los Angeles-Long Beach-Riverside, CA
- #2: Visalia-Porterville, CA
- #3: Bakersfield-Delano, CA
- #4: Fresno-Madera, CA
- #5: Hanford-Corcoran, CA
- #6: Sacramento-Yuba City, CA
- #7: Houston-Baytown-Huntsville, TX
- #8: Dallas-Fort Worth, TX
- #9: Washington, D.C.-Baltimore-Northern Virginia
- #10: El Centro, CA

In California's Central Valley (yellow), a combination of farming, industry, traffic and topography has made the air quality so bad that four metropolitan areas in the region rank among the nation's top 10 dirtiest cities.

Source: American Lung Association
2013 State of the Air report

pollutants, and the stagnant air envelops the region in a perpetual cloud of haze. On hot days, locals told me, the toxic smog fills hospital emergency rooms and doctors' offices with children who can't breathe, and schools in Fresno fly color-coded flags to alert students to the air quality: Green means it's OK to be outside, while red is a warning to stay indoors. On average, nearly four Central Valley residents die prematurely every day because of the pollution, and experts predict that within the next few years, as temperatures continue to rise and population growth raises smog levels, one of every four children will have asthma.

"In the past 10 years, I've had to put more kids on steroids than ever before, which terrifies me," said Kevin Hamilton, a respiratory therapist and administrator for Clinica Sierra Vista, a string of medical

centers throughout the Central Valley that cares for about 50,000 low-income youngsters every year. "It can be overwhelming with patients in every room on inhalers and nebulizers" — the heavy artillery of an asthmatic's medicinal arsenal. "These kids never get well, and now we have a generation who are permanently damaged by their constant exposure to pollution," Hamilton, a burly, bearded man in his late 50s, sighed in frustration when we met in his cramped office at the clinic. "The effects are not transient. If they get pneumonia, they're more prone to end up in the hospital. They can't participate in athletics, and when they get older, they're more likely to have heart disease because their bodies can't generate enough oxygen. They get sicker faster, and die younger."

FUTURE SHOCK

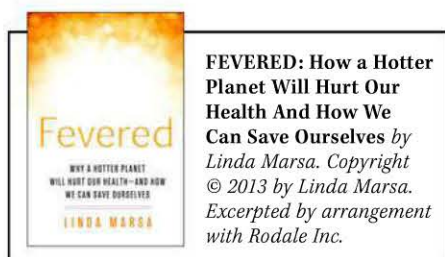
For Californians who live, work and breathe in the state's industrial zones, the future is already here. The disastrous health effects they experience from pollution are a preview of what will happen everywhere as climate change becomes a routine fact of life, and as the planet gets hotter, carbon levels continue

to climb and air quality progressively worsens. To cite one example, the heat-trapping carbon dioxide emitted from tailpipes and factories collects over cities, creating CO₂ "domes" that shroud the urban cores in toxic clouds of pollutants. Research on air quality in New York, Phoenix and Baltimore shows that ambient CO₂ parts per million (ppm) levels can spike into the 400s, 500s and 600s, which climate modelers predict will become the norm in 20 to 30 years. Right now, the global average is 393 ppm. As temperatures rise and more pollutants are dumped into the atmosphere, the plume of that toxic cloud will broaden like ink on a blotter, covering more land under a suffocating carbon canopy. A 2010 Stanford University study found that these domes act like pressure cookers, exacerbating pollution's harmful health effects, and may already be responsible for up to 1,000 excess deaths across the country, the equivalent of two jumbo jet crashes every single year.

And it will just go from bad to worse in the coming decades, as the Earth gets warmer. Two of the chief culprits behind asthma and allergies — air pollution and smog — will only intensify as the temperatures rise. The result is ozone smog, a toxic brew created as sunlight cooks the mix of pollutants and particles in the atmosphere. As the air heats up, more ozone is produced. Increasing levels of ozone, in turn, trap more heat, exacerbating the urban heat island effect: Cities are normally about five to 10 degrees hotter than surrounding suburbs because asphalt and cement absorb sunlight, generating a vicious cycle of escalating pollution and heat.

Higher levels of ozone smog, toxic to the lining of the lungs, will also boost the incidence of respiratory diseases. A 2009 study done by European scientists looked at hospital admission data from 12 major cities including Dublin, London, Barcelona, Athens and Rome from at least a three-year period. They found that for every 1-degree Celsius (about 2 degrees Fahrenheit) temperature increase, hospitalizations from respiratory- and asthma-related illnesses rose by 4.5 percent.

Chronic exposure to elevated levels of ozone has a serious cumulative effect. Ozone in the upper atmosphere normally





More than 12 million cars travel on the Los Angeles metropolitan freeway system every day.



A crop duster flies low over a field in Sacramento County, Calif. The air quality of the Sacramento region ranks as the sixth worst in the nation.

forms a protective layer that shields us from the sun's ultraviolet radiation. But ground-level ozone — the chemical combustion product of factory and vehicle emissions heated by sunlight — can have a devastating effect. Sunbelt cities like Los Angeles, Riverside, Calif., and Houston, with their seemingly endless sunny days, gridlocked urban sprawl and heat-trapping stagnant air masses, contain the highest average concentrations of ozone, according to a 2009 study by University of California, Berkeley scientists. People living in these regions, and in California's Central Valley, have a 25 to 30 percent greater annual risk of dying from respiratory diseases like pneumonia and chronic obstructive pulmonary disease than do residents who enjoy cleaner air in places like San Francisco and Seattle, where fog, rain and cooler temperatures keep ozone levels in check.

In much of California, on the other hand, a witches' brew of pollutants cooked in the atmosphere can sear the delicate tissue lining the lungs and aggravate an astonishing array of other health problems, ranging from heart disease and lung cancer to dementia. The dirty particles accelerate the thickening of arteries, which, in turn, increases the chances of heart attack and stroke and accelerates a decline in cognitive abilities because less oxygen-rich blood is being pumped to the brain.

One 2012 study that followed nearly 20,000 women nationwide revealed that exposure to this type of pollutant greatly

speeds memory impairment and reduces concentration. And women who experienced higher levels of exposure to tainted air for longer periods of time had "significantly" sharper declines in mental acuity, the equivalent of an extra two years of aging. "The same chemical reaction that makes more ozone and goes faster when temperatures are higher also produces chemical compounds that make particles, or particulate matter, in the air," said Anthony Wexler, director of the Air Quality Research Center at the University

of California, Davis.

Big particulate matter — PM10 — is about 10 microns, similar to the thickness of a strand of hair. Typically, these particles are found in windblown or construction dust and are emitted by woodstoves, fireplaces, trash incinerators and wildfires. PM10 particles tend to make up that thick blanket of haze that envelops urban areas, and when inhaled, they stick to the insides of the lungs' small branches that transport oxygen to the gas-exchanging tiny sacs called alveoli. The alveoli are surrounded by thick networks of blood vessels. This is where the crucial switch is made and our bodies perform their miraculous life-sustaining alchemy: Carbon is removed from the blood to be expelled from the lungs and replaced by fresh oxygen, which is then pumped to the heart for circulation. But the pollutants cause the lungs to make

Ozone smog, a mixture of all the pollutants and particles in the air, is created when sunlight cooks pollutants in the atmosphere.

of California, Davis.

to these fine air particles is associated with up to 24,000 deaths every year, according to a 2009 study by the California Air Resources Board, the majority of them in highly populated areas such as the San Francisco Bay, the San Joaquin Valley and the Los Angeles air basins. PM2.5 particles penetrate deep inside the lungs, causing constant irritation that diminishes lung capacity and can lead to cancer. Like PM10 particles, they insinuate themselves inside the walls of blood vessels, which can trigger the formation of the artery-clogging plaques that are the culprits behind strokes and heart attacks. There is evidence that even smaller particles, which are 100 nanometers, can infiltrate the brain through the nasal passages, potentially eroding cognitive abilities.

"What we're seeing now is probably just the beginning of the effects we'll experience from bad air," Jose Joseph, a pulmon-

ologist and asthma specialist at the Fresno campus of the University of California, San Francisco, told me rather ruefully one steamy October afternoon when I visited his tidy office at the university's medical center. "In the years to come, we're going to have major increases in all types of chronic illnesses," he continued, ticking them off on his fingers, "in respiratory illnesses, in heart disease, in increases in heart attacks and strokes because air pollution increases blood clotting, and in its effects on developing fetuses — there is so much fallout from air pollution. In looking at the magnitude of the problem, we really have to do better than this."

SIMPLE JUSTICE

But there is some good news: Even seemingly small changes in curbing greenhouse gas emissions not only can reduce harmful pollutants and clear the air, but also help to slow climate change. In California, local grassroots groups have been successful in pushing polluters to clean up their communities and compelling government agencies to protect residents from the consequences of a warming planet. They're part of the



A 2,500-pound bonnet caps a chemical cargo ship's smokestack and collects toxic pollutants, which are delivered by flexible ducts to a treatment system at the Port of Long Beach.

environmental justice movement, a crusade that grew out of the recognition that it was mainly the poor and people of color who were forced — by circumstance, finances, lack of political power and what activists call "environmental apartheid"

that callously targets the disenfranchised — to live and work in some of the nation's dirtiest environments.

Luis Cabrales, who worked for many years as a campaign director for the Coalition for Clean Air, a venerable green group that was instrumental in the passage of California's historic vehicle Smog Check Program in the early 1970s, has spent most of his adult life fighting for environmental justice. A slight man with a full head of dark hair, a square jaw and the broad-shouldered build of a wrestler, Cabrales possesses the easygoing charm and dogged persistence of a natural-born organizer.

There have long been strands of environmentalism in the civil rights struggle, Cabrales tells me during an interview in the coalition's offices in a high-rise in downtown Los Angeles. Rosa Parks' refusal to move to the back of the bus stemmed from a deep need for adequate public transportation, he points out, while César Chávez pushed to protect farmworkers from the harmful pesticides that were killing them in California's Central Valley. But it wasn't until the late 1970s when people started connecting the

Creating Sustainable Cities

Two of the greenest cities in North America, New York and Vancouver, have hit upon the right recipe for a more sustainable 21st century, and they are investing in infrastructure changes to prepare for the new realities of a hotter world.



Stanley Park, Vancouver

Vancouver: Pedestrian Paradise

Vancouver, British Columbia, is North America's uncontested leader in smart growth and is consistently ranked among the world's most livable cities. Among Northwestern cities, the Canadian metropolis, which is home to more than 2.3 million residents, has the highest population density; the greatest rates of cycling, walking and transit riding; and the fewest cars per capita, plus the highest life expectancy, lowest teen birth rate and lowest poverty rate.

Vancouver also leads the world in the use of hydroelectric power, which makes up 90 percent of its energy supply, and regularly uses renewables like wind and solar. Its pedestrian-friendly, high-density neighborhoods (14,000 people per square mile) are clustered around high-rises, multifamily dwellings, restaurants, groceries, shops and pocket parks, and have wide sidewalks that encourage walking and short blocks that slow traffic. The extensive mass-transit system eases traffic congestion and includes high-capacity diesel buses and electric trolleys, a network of light-rail routes and an elevated train service called SkyTrain. There are hundreds of miles of biking trails. Because of all of these factors, Vancouver has the lowest per-capita carbon emissions of any major city in the Western Hemisphere.

In the future, Vancouver wants to become not just the greenest, but the world's most sustainable city. The city's action plan focuses on even greater use of renewal energy, further upgrades to the existing transportation system and expansion of the city's already considerable green space, including the world-class Stanley Park, which is larger than Central Park. The blueprint also encourages urban agriculture, rethinks sewer and wastewater management and reduces greenhouse gas emissions per capita to the lowest in the world by promoting even higher-density living with smaller multifamily homes, especially along transit corridors in Vancouver's downtown peninsula.

dots and realized that African-Americans resisting attempts to establish garbage dumps in their neighborhoods were essentially fighting the same fight as grassroots activists protecting endangered species. “Better housing, clean water, clean air, safe schools,” said Cabrales, “these all had to do with the environment.”

In the decades since, the environmental justice movement has grown from a scrappy army of the poor and disenfranchised into a powerful coalition that united the mostly white and college-educated traditional environmentalists, trade unionists, blue-collar workers and residents of some of the nation’s most contaminated neighborhoods. It has used its growing political clout and numbers to take its place in the corridors of power. “We’ve changed the paradigm into a green-blue coalition,” said Cabrales. “Years of environmental consciousness-raising are really bearing fruit, and environmentalists are no longer seen as weed-smoking, sandal-wearing tree huggers. Over the last 10 years, the change has been dramatic because a new generation of environmental advocates now hold positions of power in the legislature, on the ports commission

and on the air resources board.”

It is a remarkable sea change that has seen someone like Fabian Núñez of East Los Angeles, one of 12 children born to a gardener and a maid from Tijuana, ascend to the speakership of the California Assembly and co-author of the nation’s most stringent measures to alleviate global warming. The landmark package of laws is considered former governor Arnold Schwarzenegger’s signature legislation and has become a model for the rest of the world. “He was a gardener when he was a kid and pushed around a lawn mower helping his dad,” said Cabrales, with no small measure of pride. “Now he’s helped create the strongest pollution-control standards in the world — a Mexican immigrant.”

In the past decade, the Coalition for Clean Air has waged a successful campaign to begin cleaning up the deadly diesel pollution emanating from California ports. Working in tandem with such groups as the Natural Resources Defense Council and the Coalition for a Safe Environment, along with the Teamsters and Longshoremen’s unions and local activists like Martha Cota, they’ve done

extensive lobbying in Sacramento and community organizing to push for enforcement of the California Environmental Quality Act and compel the Port of Los Angeles to initiate a suite of pollution-reduction strategies that have cleaned up the air. These included the Clean Truck Program, which replaced the port’s fleet of old, dirty diesel trucks with EPA-compliant vehicles equipped with particle filters, and electrifying the ports so ships can just plug in to power their infrastructure while at the dock. A single ship idling in the port — they normally sit at anchor for two to three days while they’re being unloaded — emits more pollution than five diesel school buses in an entire year. Turning off the engines and using electrical power can cut as much as three tons of smog-inducing emissions from each ship. Still, while pollution at the Port of Los Angeles has been reduced by about 70 percent from its height, air quality remains a serious problem. “But at least we’ve made a start,” said Cabrales, and, he added, flashing a toothy smile, “we now have a seat at the table.” **D**

Linda Marsa is a contributing editor at DISCOVER.

New York: Land of a Million Trees

On Earth Day 2007, New York Mayor Michael Bloomberg unveiled PlaNYC, a comprehensive, 127-point blueprint to create a sustainable city. It involves initiatives to revitalize the city’s 580 miles of waterfront, decrease energy costs, cut greenhouse gas emissions by 30 percent by 2030 and upgrade the infrastructure to prevent shorelines from being swamped by flooding and storm surges.

After Superstorm Sandy, long-gestating plans to build three massive surge barriers have been moved to the front burner, along with discussions about raising entrances to flood-prone subway stations and the locations of critical equipment like pumps, transformers and wastewater pipes.

Heavy downpours can overwhelm New York’s antiquated 19th-century sewer systems, the miles of pipes and tunnels that carry away wastewater and, when overtaxed, divert billions of gallons of raw sewage and contaminated urban runoff into the rivers, lakes and the ocean. The city has committed \$1.5 billion to erecting green infrastructure — green roofs, street and sidewalk plantings, porous pavements, cisterns, rain barrels — that will control and absorb storm water and prevent polluted runoff from flowing into waterways by capturing it and filtering it naturally through the soil.

The city has also launched several programs to turn down the climate’s thermostat, such as the Million Trees project (more than half a million have already been planted around the city) and painting flat roofs with a white or “cool” coating that reflects the sun’s energy. More than 2 million square feet of roofs have been covered so far, with the goal of coating them all by 2030.

New York is also an acknowledged world leader in its efforts to create a more sustainable food system. A broad-based coalition of neighborhood activists, social justice and food advocacy groups, top chefs, writers, farmers, fishermen, ranchers, civic leaders and state agencies is revamping the way food is grown, distributed and disposed.

The improvements include ways to preserve and promote regional farming and food production; connect rural farmers with city markets; cultivate urban agriculture; create large-scale municipal composting facilities; and expand food cooperatives and outreach programs to residents in low-income areas, especially through school food and afterschool programs. — LM



A rooftop garden in Brooklyn

No Head for Numbers

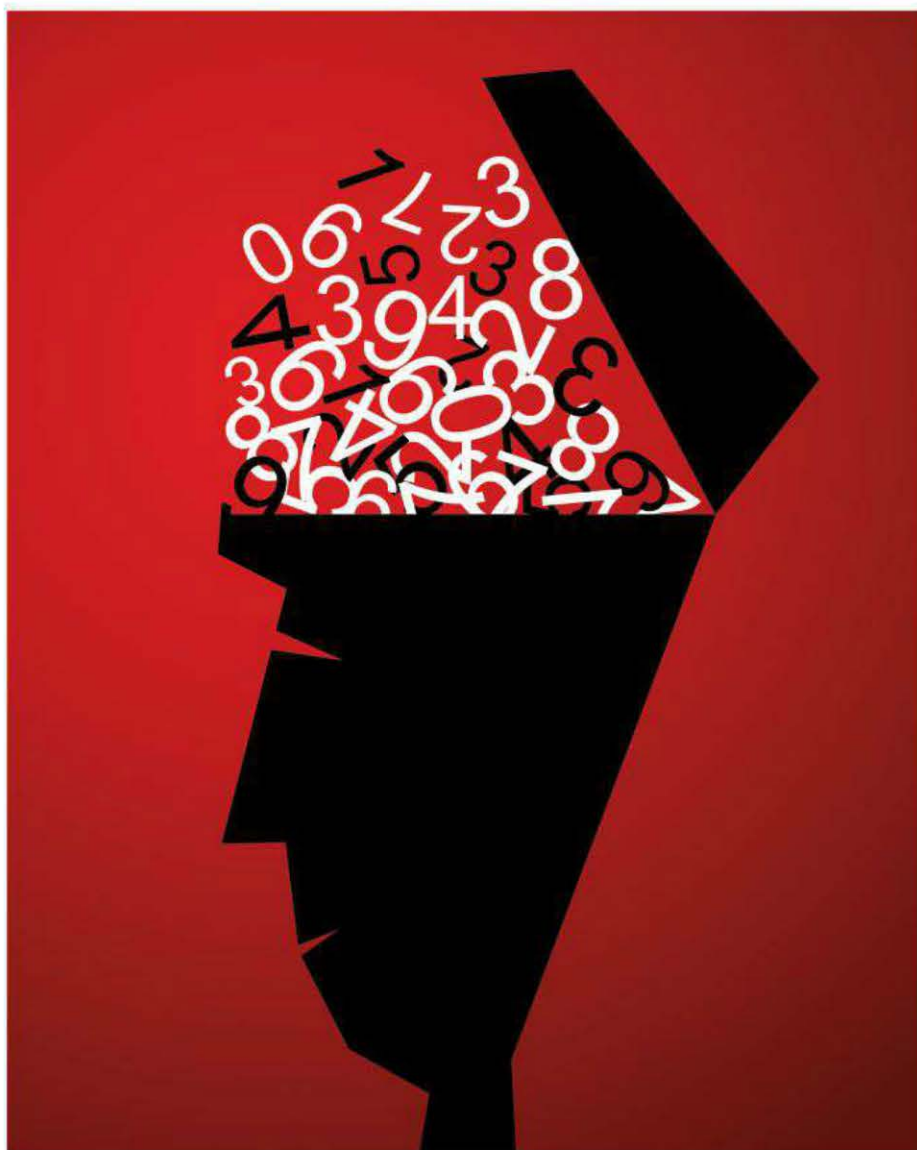
How can such a smart kid be so bad at math?

STEPH ZECH GRADUATED FROM high school this spring with an admirable academic record. She especially loved chemistry, writing and literature — though she has some reservations about Dante. A bright and diligent student, she took two Advanced Placement classes her senior year, sailing through both.

But when it comes to math, Steph has struggled mightily. At age 17, she still counts on her fingers to add 3 and 5. She doesn't know her multiplication tables. She can't understand fractions, process concepts of time such as "quarter after" or read dice without counting the dots. She did recently figure out that if something costs 75 cents, the change from a dollar should be 25 cents. But when asked what the change would be if the price were 70 cents, she considers at length before venturing, "15 cents?"

There are many reasons for a bright student to be bad at math, including poor learning environments, attention disorders and anxiety. But Steph's struggles typify a specific math learning disability known as developmental dyscalculia. "A lot of people say, 'I'm not good at math' because they couldn't handle pre-calculus or something," says cognitive neuroscientist Edward Hubbard of the University of Wisconsin-Madison. "People with dyscalculia struggle to tell you whether seven is more than five."

Although dyscalculia, which affects about 6 percent of people, is about as common as the analogous reading disorder dyslexia, it is far less well-understood. According to one analysis, studies on reading disabilities outnumber those that look at math deficits by a ratio of 14 to 1. One reason for that disparity may be the belief that literacy is more important than numeracy. "People freely admit at dinner parties that they are poor at math, while few would admit that they are a poor reader," notes cognitive neurosci-



entist Daniel Ansari of the University of Western Ontario.

From calculating restaurant tips to navigating investment decisions to following medication instructions, the ability to understand numbers is essential to functional living. In one study conducted in the U.K., researchers found that at age 30, people with low numeracy tended to have less education and were more likely

to be unemployed, in trouble with the law, and mentally and physically sicker than others the same age.

But now, thanks to advances in brain imaging techniques and improved understanding of numerical cognition in general, new insights into the disorder have begun to emerge. Researchers have tracked dyscalculia to a fold in the back of the brain known as the intraparietal sulcus,

or IPS. This area, they've learned, is crucial for perceiving and approximately comparing quantities — say, a group of dots on a page, or spades on a playing card. This core mental capacity, known as approximate number sense, is important for arithmetic and much higher-level math.

New research “helps isolate the potential causes of dyscalculia and points to impairments in very basic number-processing abilities that can be measured before children enter formal schooling,” Ansari says. “This in turn can inform early diagnosis and intervention.”

Numbers Don't Stick

Steph was in second grade when she decided she must be stupid. “We had those little one-minute math tests, and I would always be working till the last second, and everyone else would have [their papers] flipped over,” she says. “I felt extremely isolated.”

Teachers at her school in Wisconsin dismissed her troubles, concluding that because she did well in the rest of her schoolwork, she must have been lazy when it came to math. That assumption still hurts, because Steph knows better: For more than 10 years she and her mother, Susan, have spent countless hours hunched over math homework, trying to make the numbers stick in Steph's brain. They've tried flashcards, computer games, videos, math songs, summer tutors ... but “there's nothing that has particularly helped” her truly understand, Steph says.

While Steph was learning to compensate for her disability, partly through clever memorization tactics and partly through sheer effort, scientists far removed from the school where she struggled were probing the disorder's biological roots. Studies had shown for nearly a century that some brain injuries can cause impairments in quantity processing. Beginning in the late 1990s, neuroimaging studies showed that a specific area of the parietal lobe — the IPS — is important for very basic numerical magnitude processing, such as deciding which of two numbers is larger.

Only a few neuroimaging studies have examined numerical processing in children with developmental dyscalculia. In a

2007 study, Ansari and colleagues scanned the brains of dyscalculic children while they made judgments about quantities of squares presented on a screen. When asked to identify which clustering had more squares, the children made more errors and responded more slowly than those in a control group. In addition, unlike their peers, children with dyscalculia showed no difference in IPS activation when they were comparing pairs of numbers that were closer versus further apart in value, suggesting that their brains were less efficient at discerning the relative distance between numbers. Other studies since have found similar effects.

Recently, some researchers have proposed that in some cases, dyscalculia may

Difficulties in math can lead to more general underachievement.



Steph Zech, who has developmental dyscalculia, will attend Coe College in Iowa this fall.

arise not from a “core deficit” in the ability to compare quantities, but instead from an “access deficit” — a problem in how the brain links perceptions of quantity to number symbols such as Arabic numerals, or in how it maps numbers onto verbal or spatial processes. So far, the evidence for “core” versus “access” subtypes of dyscalculia has been mixed.

Rebooting Number Sense?

Over the years, Steph persevered through multiplication tables and ratios, fractions and decimals. It was never fun — and geometry in particular is an adventure she'd prefer to forget. Her junior year, she transferred to a different school where the teachers were more helpful and willing to make some accommodations, like letting her use a note card to remind her of basic math facts during tests. She stuck with math through high school, earning straight A's in pre-calculus her senior year. Though her performance on some elementary parts of the ACT math test was abysmal, she did fairly well on some of the more advanced parts, which involve more reasoning than arithmetic. Her overall score was respectable — good enough, in fact, to land her a slot at a small private college in Iowa this fall, with academic scholarships.

Steph is more fortunate than many young people with dyscalculia, whose difficulties in math — and the anxiety their troubles tend to stir — can set them on a path of overall underachievement. Many children with dyscalculia, and especially highly intelligent ones, tend to go undiagnosed. By the time someone notices the discrepancy between their math ability and general performance, it may be too late to shore up shaky foundations.

But the advances in understanding how dyscalculia works suggest it might be possible to do better. Recently, researchers have focused their efforts on identifying faulty number sense earlier, in hopes of finding ways to blunt its effects. Ansari and others are designing behavioral tests that evaluate the processing of number symbols and the basic skills underlying math, such as comparison of quantities and numbers, dot counting and relationships between numbers. “These tools move



beyond just testing children on calculation skills to assessing the underlying skills — the basic foundational or scaffolding abilities,” Ansari says.

Several recent studies have shown that rudimentary number sense — an ability to discriminate between varying quantities — emerges by the time infants are 6 months old. In a 2010 study, cognitive psychologists Melissa Libertus and Elizabeth Brannon, then both at Duke University, found that infants gazed longer at images of black circles when the number of circles changed, compared with when the quantity was always the same, as long as the ratio between the number of circles was always at least 2-to-1. And although all infants improved by age 9 months, those whose abilities were keenest at 6 months remained so a few months later.

The study is important, Hubbard says, because “it shows that we can reliably measure something about number sense and that the number sense is stable over time.” As such, he says, individual differences in number sense might predict later math abilities.

Several research groups are testing the prospects for rebooting dyscalculic children’s approximate number sense or their ability to map quantities onto symbols or a mental number line. One example is a computer game called *The Number Race*, developed by Stanislas Dehaene at INSERM (the French National Institute of Health and Medical Research) and his colleague Anna Wilson, now at the University of Canterbury in New Zealand.

In the game, which is designed to strengthen the brain circuits that support number sense, the child tries to beat a cartoon opponent to the end of a number line disguised as a colorful racetrack. Along the way, the child must practice several different foundational math skills, including comparing quantities of objects, counting and ordering numerals, and matching quantities with symbols. The game adapts in difficulty depending on the player’s success, so that it stays challenging without being frustrating.

Initial tests of *The Number Race*’s effectiveness with children who struggle in math have been encouraging, though “not a

slam dunk,” Hubbard says. Young children who play the game do show improvements on basic numerical cognition, but it’s unclear how long these improvements last.

Clues from Dyslexia

Nonetheless, Hubbard is cautiously optimistic that early and intensive training can help children with dyscalculia. Part of that optimism, he says, stems from research on dyscalculia’s sister disorder, dyslexia. Reading research, he observes, has long shown that a key aspect of dyslexia is the child’s difficulty in understanding the sounds of language — a deficit that is similar to the faulty number sense seen in dyscalculia. But even though understanding the sounds of language is key to learning letter

symbols, many studies have shown that learning letter symbols actually improves dyslexic children’s ability to hear the sounds of language.

Hubbard suggests it may be that the same is true with numbers: that learning the symbols of math changes how the brain actually perceives quantities. “Because number symbols are exact — a number is either a 3 or it isn’t — this may help ‘tune up’ the brain networks for non-symbolic numbers,” he says. “Once children are aware of the fact that numbers can be exact, they may then focus more on counting up the right number, which could in turn sharpen their ability to see even non-symbolic quantities more precisely.”

Whether that is true and, if so, exactly what kinds of training might jump-start the process are not yet clear. But what is key, Hubbard says, is that the brain a child is born with “may not be the brain the child is stuck with.”

Last winter, when Steph met with Hubbard to discuss her math problems, an online test (see “How Good Is Your Number Sense?”) confirmed that her number sense was truly impaired. The information provided no fix — just vindication, and the wish that dyscalculia could be more widely understood. “I want math teachers to be educated about it,” Steph says. “Think about all the other kids that don’t have as much motivation, or don’t have as caring parents as I do.”

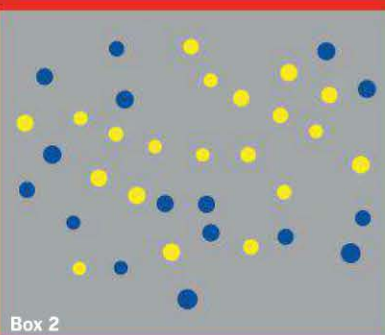
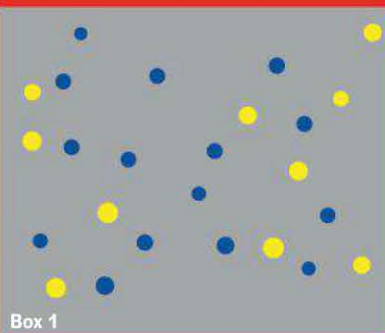
Whether adults with dyscalculia, like Steph, can eventually tap into the tools that researchers are currently developing for children remains unknown. Hubbard says it may be possible, though harder, both because adults have missed opportunities to learn when they’re younger and because with age, the brain changes less in response to learning.

As for Steph, he says, “There are places in life where this will always cause her difficulty. But I get the feeling that she’s a very determined young girl and that she’s going to figure out how to have a very successful life no matter what happens.”

Carlin Flora is the author of *Friendfluence: The Surprising Ways Friends Make Us Who We Are* (2013). She lives in New York.

HOW GOOD IS YOUR NUMBER SENSE?

Number sense, or the ability to quickly ascertain and compare quantities, is correlated with general mathematical ability, and very poor number sense is the hallmark of dyscalculia. One online measure of number sense, the Panamath test (developed by Johns Hopkins University psychologist Justin Halberda and his student Ryan Ly), is freely available at www.panamath.org. For a taste of the test, glance at the first box below and quickly decide whether it has more blue or yellow dots. Then do the same for the other box — a more challenging task.



Answers: Box 1: Blue, Box 2: Yellow

Foundations of Physics

By Joseph M. Brown Ph.D., Purdue University, 1952

- Starts with basic Newtonian particles
- Derives conservation of mass, momentum, and energy
- Derives Newton's equations of motion
- Shows why Maxwell-Boltzmann gas parameters v_r and v_m arranged as $[(v_r - v_m) / v_m]^2 = (\sqrt{3\pi/8} - 1)^2 = 1/137.1$ is fundamental to quantum mechanics
- Shows how neutrinos develop 10^6 newton thrust
- Proves that Newtonian particles can form stable inhomogeneous states – the neutrinos
- Shows why fundamental angular momentum has one value – $\frac{1}{2}$ Planck's constant
- Shows what produces the magnitude of the proton mass
- Shows how hydrogen is formed
- Shows what causes electric charge
- Derives the strong nuclear force
- Shows how matter motion is accomplished
- Shows what causes matter waves and magnetism
- Derives superconductivity
- Derives the neutron and what causes nuclear decay
- Shows exactly what a photon is
- Shows what causes gravitation
- Shows how atoms are formed
- Shows how stars are formed
- Shows why photons decay with travel
- Shows why matter we see was formed 10^{10} years ago

Other books by Dr. Brown

Photons and the Elementary Particles,
ISBN 9780971294455, 2011, \$29.95

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ISBN 9780971294462, 2004, \$29.95

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Darklands of the Cosmos

Has scientific prejudice blinded astronomers to a parallel universe of invisible matter?

I AM A LIGHT-MATTER CHAUVINIST. Don't snicker; you're probably one, too. Almost all of us are.

We think of ourselves, and the world immediately around us, as something special. And by extension we regard our kind of matter — atoms, molecules, rocks, water, air, stars and all of the other things that interact with visible light — as the most important kind of matter in the universe. The only matter that matters, as it were.

Science tells a starkly different story. Last spring, the European Space Agency's Planck spacecraft completed an ultraprecise 15-month census of the composition of the

universe. The kind of matter that we can see makes up 4.9 percent of the total. Another fundamentally invisible type of matter vastly outweighs it, accounting for 26.8 percent. (The remaining 68.3 percent is an even more baffling component that consists of formless energy: That means more than two-thirds of the universe has no substance at all.)

Even the technical language used to describe the Planck result was humbling. Things made of visible atoms are known as baryonic matter, which sounds like something you'd take at the doctor's office. The unseen 26.8 percent, in contrast, is "dark matter" — cool and mysterious.

But cosmologists have a hard time letting go of their prejudices. For years they convinced themselves that although the visible universe may be secondary in mass, it is where all the interesting things happen. Extrapolating from their very limited knowledge of how dark matter works, cosmologists assumed that dark matter consisted of just one kind of substance with a limited range of behavior, tending to gather in giant, diffuse clouds. They generally regarded dark matter as little more than the glue that holds together the visible universe and all its rich diversity.

Two recent advances hint at just how much we have been missing about the dark side. In January 2012, Christoph Weniger, a physicist at the University of Amsterdam in the Netherlands, started noticing hints of a strange type of radiation around the center of our galaxy. To his excitement, he realized that the glow could be a signal of dark-matter particles smashing into each other and, in the process, transforming from something invisible to something visible. If so, it might finally be possible to go beyond simply deducing where dark matter gathers, and start learning how it actually behaves.

The other shoe dropped earlier this year, when a group of Harvard University theorists, including Lisa Randall and Jiji Fan, formulated a new theory of dark matter. One of the oddest things about Weniger's detection, Randall notes, is that it was possible at all. "The signal would be too small for you to see under most reasonable models of dark matter," she says. But Randall and her collaborators realized they could tidily explain the observation if there were a second type of dark matter out there: one that is not as diffuse as the dominant component of dark matter, but can interact with itself, just like visible matter. Clumps of this interacting kind of dark matter could form a disk, collapsing into a plane that could produce a correspondingly concentrated signal like the one Weniger saw.

Acknowledging that dark matter might have some of the same kind of diversity as visible matter may seem a minor adjustment. But it's one that has, as Randall narrates in an excited staccato, "super-

dramatic consequences." If one variety of dark matter can clump together, it could form a panoply of previously unimagined dark structures. It could ball up into dark stars surrounded by dark planets made of dark atoms. In the most extravagant leap of

Cosmologists convinced themselves that the visible universe is where all the interesting things happen.

possibility, this new kind of dark matter might even allow the existence of dark life.

We could be sitting right on top of a whole shadow galaxy and not even know it.

"A Whole New World"

The turnabout shouldn't really come as much of a surprise. Galileo began chipping away at humans' sense of self-importance a full five centuries ago, when he proved that Earth does not sit at the center of the universe, no matter how things look to us. Yet the tendency to judge the cosmos based on appearances (and assumptions of our primacy) has proved tenacious.

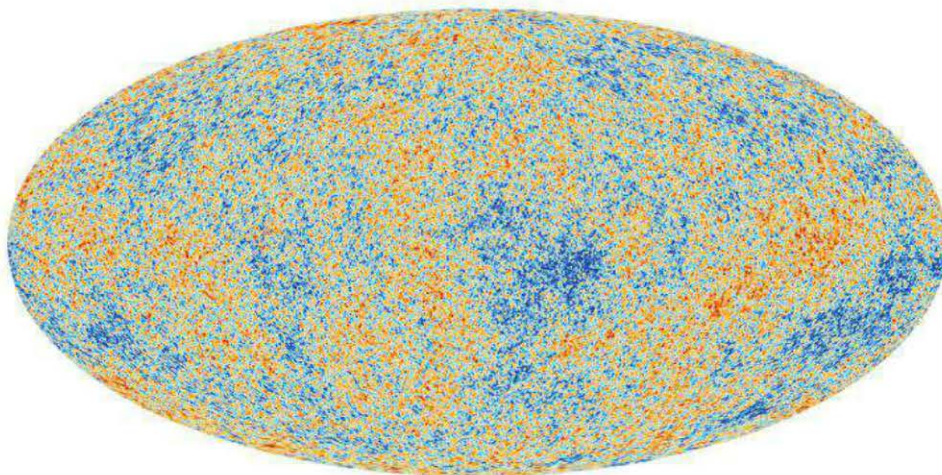
In the 1930s, the iconoclastic Swiss-American astronomer Fritz Zwicky collect-

ed the first evidence for *dunkle Materie* — dark matter. It took another 40 years before his colleagues grudgingly began embracing the idea, persuaded by new evidence that rotating galaxies would fly apart without the stabilizing gravitational attraction of dark matter. Not until the 1980s did nearly all astronomers accept that dark matter is real, and that it substantially outweighs the visible cosmos.

At that point, a small but growing number of researchers began attempting to understand, measure and map the shadow world. One approach, pioneered by astrophysicist Anthony Tyson at Bell Labs in the 1990s, crudely located dark matter by the way its gravity distorted the light of visible galaxies. The next decade, studies of the cosmic microwave background (the relic radiation from the Big Bang) by the Wilkinson Microwave Anisotropy Probe, or WMAP, provided a new way to measure the total amount of dark matter; this is the same technique that the Planck spacecraft built upon to come up with its more precise cosmic breakdown. Meanwhile, an underground Italian lab experiment called the DAMA (Dark Matter) Project sought evidence of dark matter particles colliding headlong into atoms right here on Earth.

And still, none of those efforts did much to alter the basic assumption that dark matter was fundamentally simple and rather dull.

Weniger's research, on the other hand, is seriously shaking things up. In January



The Planck spacecraft created this map of radiation differences left over from the Big Bang. Scientists used it to determine that visible matter makes up only 4.9 percent of the universe.



2012, he and four collaborators were combing through 43 months of data from Fermi, a NASA space observatory that scans the sky for gamma rays — radiation similar to light, but far more energetic. One unusual signal starkly stood apart from the others. Again and again, Fermi recorded gamma rays of a very specific energy, 60 billion times as potent as ordinary yellow light.

Random cosmic violence tends to produce radiation of all different energies, equivalent to the roar of waves on the beach. This signal was totally different. It was more like the beep-beep-beep of a distress call. Weniger kept checking and rechecking his results. The gamma rays looked like the long-theorized flash of dark particles crashing into and destroying each other, which his team described as the “smoking gun signature” of dark matter. Mindful of the grand implications of this claim, Weniger continues to monitor the Fermi data. “It would be truly amazing if this turns out to be a real signal,” he says.

After Weniger announced what he and his team were seeing, more than 100 other papers followed as other scientists tried to confirm that the signal really exists and, if so, figure out what it means. Harvard’s Fan and Randall were inspired by that frenzy. Their key insight was discarding the old idea that dark matter is one thing and one thing only. That was when they recognized that some dark matter might not be so simple. A secondary component (as much as one-sixth of the total dark matter) might be able to interact, collapse and form a hidden, dark disk within the visible disk of our galaxy; the theorists therefore call it “double disk” dark matter.

Double-disk dark matter could do many of the same complex things that ordinary matter does. And there is so much dark matter overall that the secondary kind could weigh as much as all of the visible parts of the universe. “The fact that nobody had thought about this before is incredible,”



The Fermi Gamma-ray Space Telescope saw radiation that looked like the long-theorized flash of dark particles crashing into and destroying each other — a “smoking gun signature.”

Randall says. “What’s really fun about this idea is that it opens up a whole new world.”

Vision From the Other Side

Getting mainstream scientists to move past their light-matter chauvinism and take that shadow world seriously will require some highly convincing evidence. Weniger frets that the Fermi observations are too ambiguous to do the trick. “What one needs is more data with the same experiment to establish that the signal is there,” he says.

Harvard astronomer Douglas Finkbeiner is making an independent analysis of the Fermi data and likewise is finding that his results hang halfway between verification

and falsification. “It’s the most frustrating possible outcome,” he sighs. “One option is that the signal is just not as bright as we thought it was.”

Randall is ready to forge ahead regardless of the fate of this particular observation. “The gamma ray line may not stay, but this just turns out to be independently such an interesting scenario, with so many interesting implications,” she says. And if our galaxy really does live right on top of a shadow galaxy, there are other ways to prove it.

Researchers are working on a new European space observatory called Gaia, scheduled to launch this autumn, which should

perform a particularly telling test. Gaia will map the locations and velocities of about 1 billion stars within the Milky Way. Searching for anomalous motions could shade in the outlines of an invisible, dense disk of dark matter pulling on those stars.

Even then, we will have only scratched the surface of our galaxy’s dark side. The only sure thing is that we will never know unless we explore all the possibilities. In that spirit, Finkbeiner cites an old friend and fellow dark matter visionary, Neal Weiner at New York University. Weiner spins stories about Professor Dark Matter, a researcher from the other side who has formulated a far-out theory about a missing ingredient in the universe called “visible matter.” The professor accurately describes all the details of our world to her incredulous colleagues — with the end result that she fails to get tenure.

“Imagine a dark academic working in a dark lab trying to come up with a detector for visible matter,” Finkbeiner says. “It’d be a pretty difficult thing.” Then he pauses a beat, pondering the fate of the poor professor and still struggling to set aside his own light-matter prejudices. **D**

Corey S. Powell is editor at large of DISCOVER. Follow him on Twitter @coreyspowell, and read his blog at DiscoverMagazine.com/outthere.



ABOUT THE MAP

It depicts the sky from midnorthern latitudes at midnight July 1 and 10 p.m. Aug. 1. West is to the right because this is the view looking up.

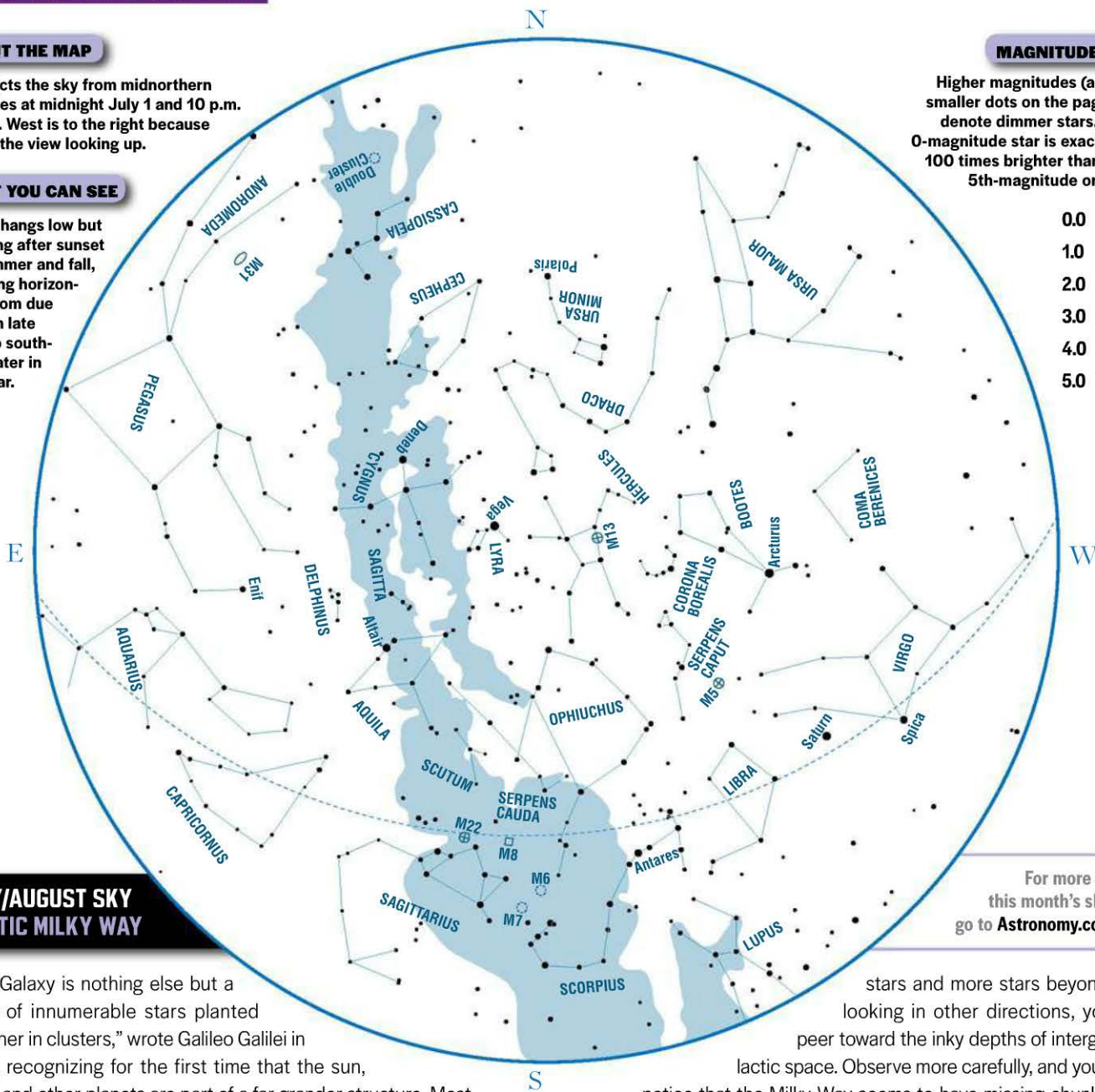
WHAT YOU CAN SEE

Venus hangs low but dazzling after sunset all summer and fall, skidding horizontally from due west in late July to south-west later in the year.

MAGNITUDES

Higher magnitudes (and smaller dots on the page) denote dimmer stars. A 0-magnitude star is exactly 100 times brighter than a 5th-magnitude one.

0.0 ●
1.0 ●
2.0 ●
3.0 ●
4.0 ●
5.0 ●



JULY/AUGUST SKY MYSTIC MILKY WAY

For more on this month's sky, go to Astronomy.com

"The Galaxy is nothing else but a mass of innumerable stars planted together in clusters," wrote Galileo Galilei in 1610, recognizing for the first time that the sun, Earth and other planets are part of a far grander structure. Most of us never get to share Galileo's epiphany because ubiquitous light pollution easily overwhelms the glow of the Milky Way. But not always: Once or twice a year, suburban skies turn beautifully transparent, often after a storm has cleaned up the air. Or perhaps your summer vacation may take you to true dark-sky country. Either way — seize the moment!

Even a quick glance reveals a lot. The Milky Way appears as a confined band of light because our galaxy is flattened like a pancake, and we lie within it. Looking out through the width of the pancake, you see

stars and more stars beyond; looking in other directions, you peer toward the inky depths of intergalactic space. Observe more carefully, and you'll notice that the Milky Way seems to have missing chunks, including a long split — called the Great Rift — which is high overhead this month. (Some Incan and Aboriginal Australian cultures perceived such dark gaps as mythological figures, like negative versions of the bright constellations.) These are the shadows of massive, light-obscuring dust clouds. Because of them, much of our galaxy's 200 billion stars are obscured. But those clouds contain the raw material for the next generation of stars, ensuring that the Milky Way will remain enthralling for billions of years to come.

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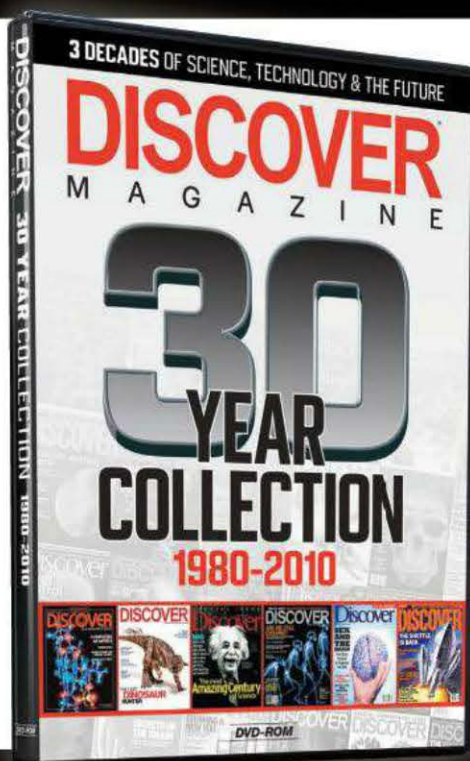
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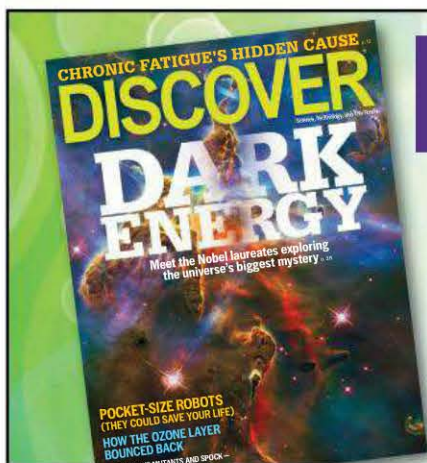


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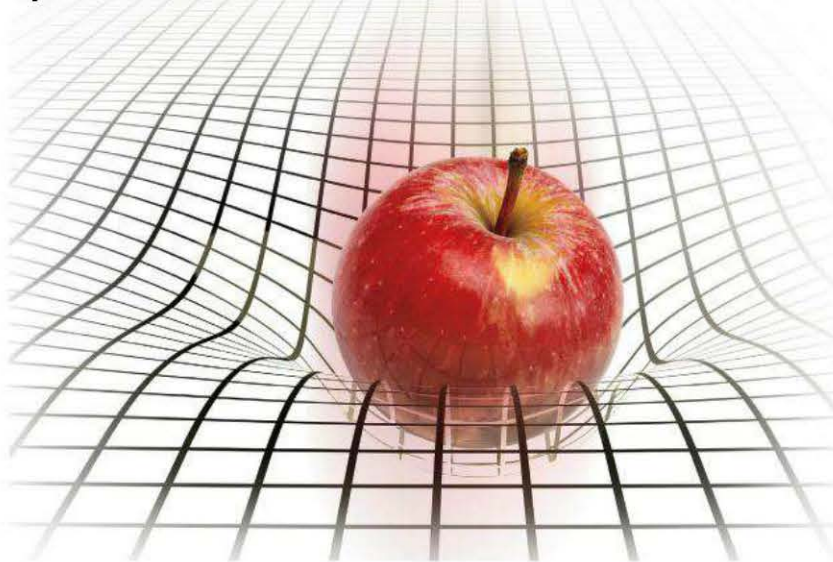
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20 THINGS YOU DIDN'T KNOW ABOUT GRAVITY

By Bill Andrews

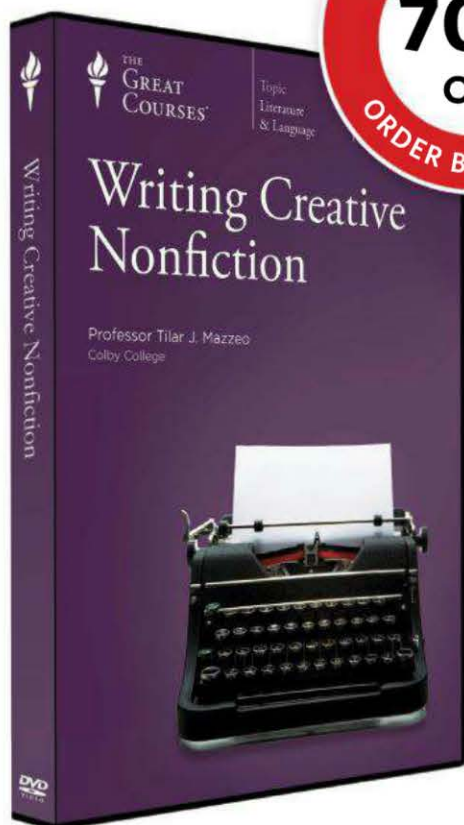


The funny thing about gravity is that it's all relative.

1. *Star Wars'* Obi-Wan Kenobi said the Force “surrounds us and penetrates us; it binds the galaxy together.” He could have been talking about gravity. Its attractive properties literally bind the galaxy together, but it also “penetrates” us, extending physically through us, keeping us bound to Earth. **2.** Unlike the Force, with its dark and light sides, gravity has no duality; it only attracts, never repels. **3.** NASA is trying to develop tractor beams that could move physical objects, creating an attractive force that would trump gravity. **4.** Passengers on amusement park rides and the International Space Station experience microgravity — incorrectly known as zero gravity — because they fall at the same speed as the vehicles. **5.** Someone who weighs 150 pounds on Earth would — if it were possible to stand on Jupiter — weigh a whopping 354 pounds on the enormous gas giant. Larger masses have greater gravity. **6.** To leave Earth's gravitational pull behind, an object must travel 7 miles a second, our planet's escape velocity. **7.** Gravity is by far the weakest of the four fundamental forces. The other three are electromagnetism; weak nuclear force, which governs how atoms decay; and strong nuclear force, which holds atomic nuclei together. **8.** A dime-size magnet has enough electromagnetic force to overcome all of Earth's gravity and stick to the fridge. **9.** An apple didn't

hit Isaac Newton in the head, but it did make him wonder if the force that makes apples fall influences the moon's motion around Earth. **10.** The apple in Newton's eye led to the first inverse square law in science, $F = G * (mM)/r^2$. This means an object twice as far away exerts a quarter of the gravitational pull. **11.** Gravity's inverse square law also means the reach of gravitational attraction is technically infinite. Whoa. **12.** Gravity's other definition — meaning something weighty or serious — came first, originating from the Latin *gravis*, or “heavy.” **13.** The force of gravity accelerates everything at the same rate, regardless of weight. If you dropped balls of the same size but different weights from a rooftop, they would hit the ground at the same time. The heavier object's greater inertia cancels out any speed it might have over the lighter object. **14.** Einstein's general theory of relativity was the first to treat gravity as a distortion of space-time, the “fabric” that physically embodies the universe. **15.** Anything with mass warps the space-time surrounding it. In 2011, NASA's Gravity Probe B experiment showed Earth tugs on the universe around it like a wooden ball spinning in molasses, exactly as Einstein predicted. **16.** When distorting the space-time around it, a massive object sometimes redirects light that passes through it, just as a glass lens does. Gravitational lensing can effectively magnify a distant galaxy or smear its light into a strange shape. **17.** The “Three-Body Problem,” determining all the patterns three objects orbiting each other could take if influenced only by gravity, has puzzled physicists for 300 years. So far they've found only 16 types of solutions — 13 of them just discovered this March. **18.** Although the other three fundamental forces play nice with quantum mechanics — the science of the very small — gravity is stubbornly incompatible with it; quantum equations break down if they try to include gravity. How to reconcile these two completely accurate but opposing descriptions of the universe is one of physics' biggest questions. **19.** To understand gravity better, scientists are looking for gravitational waves, ripples in space-time that result from things like black holes colliding and stars exploding, according to Amber Stuver, a physicist at Louisiana's Laser Interferometer Gravitational-Wave Observatory (LIGO). **20.** Once LIGO researchers successfully detect gravitational waves, they'll be able to use them to see the cosmos as never before. “Every time we've looked at the universe in a new way,” Stuver says, “it revolutionized our understanding of the universe.” Talk about heavy. **D**

Bill Andrews is an associate editor at DISCOVER and has always felt a mutual attraction with the physical sciences.



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