COSMOLOGY
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Magnetic Sensing in Animals

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# SCIENTIFIC AMERICAN

January 2012

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# THE PATHWAY OF YOUTH?

## New insights into the body's aging-control system


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# SCIENTIFIC AMERICAN

January 2012 Volume 306, Number 1


ON THE COVER


What if human aging could be slowed? Beyond giving us more years of life, the intervention should postpone cancer, diabetes and other age-related diseases, keeping us vibrant longer. Recent research has revealed a molecular regulator of aging and raised hopes that medicines might one day act on it to help us achieve those aims. Photograph by Evan Kafka.

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## FEATURES



COVER: HAIR AND MAKEUP BY NIKKI WANG



*Photograph by Christopher Griffith*


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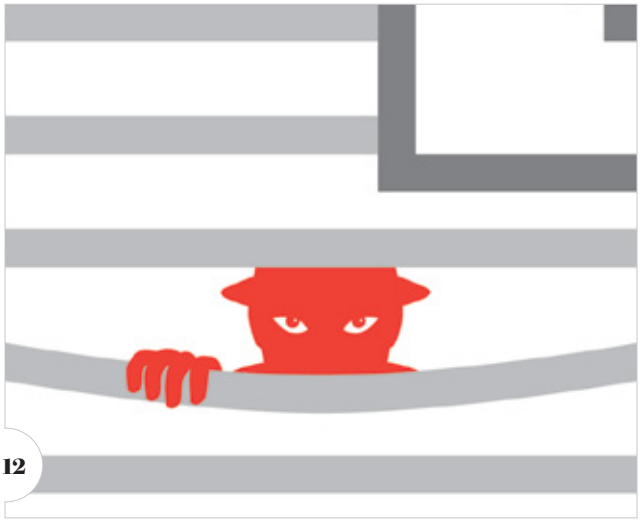

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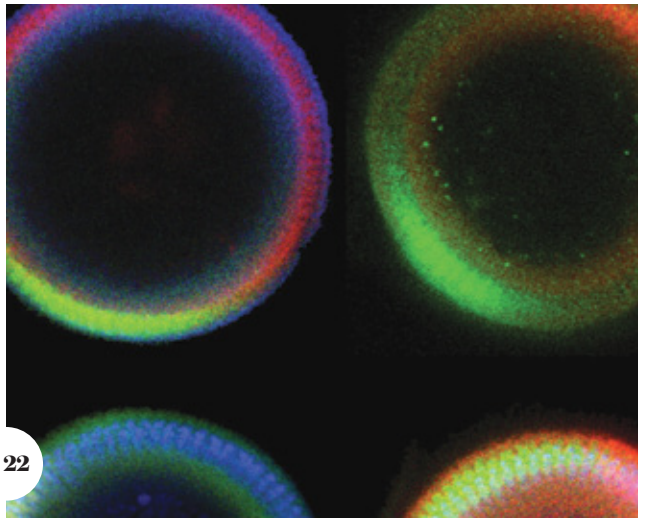

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# SCIENTIFIC AMERICAN

## DEPARTMENTS



### ON THE WEB

**Top 10 Science Stories of 2011**
A giant earthquake and tsunami devastated Japan, the space shuttle program completed its 30-year run and the tech world lost a titan of innovation. These are among the stories that shaped the science world in 2011.
*Go to www.ScientificAmerican.com/jan2012/top-stories*


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# A unique database of healthy-brain scans may help distinguish normal aging from dementia...


PET brain scan images (color) overlay MRI images (gray) to provide a comprehensive view of the brain's health. The upper row shows brain changes associated with normal aging. The lower row shows the onset of dementia, one form of which is Alzheimer's disease. Orange-to-yellow coloring indicates regions with reduced glucose metabolism.

**Helping to make better diagnoses**

Positron Emission Tomography (PET) may become an even more powerful tool for distinguishing between normal aging and dementia, such as Alzheimer's disease—thanks to a unique database and analytics being developed by Hamamatsu.

For a number of years Hamamatsu has been building an unusual database. We now have PET brain scans from over 6,000 *normal, healthy individuals,* both men and women, in a wide range of ages. And our researchers have learned a lot about how healthy brains look and how they change over time.

So, in the future, doctors may be able to spot more subtle anomalies in brain health by comparing their patients' PET scans with Hamamatsu's database—specifically by sex and age!

Hamamatsu is opening the new frontiers of Light

Hamamatsu's aim is to provide clinicians with new tools, to help them distinguish more clearly between normal aging and the early stages of dementia. Because earlier diagnoses may give doctors more options for treatment.

And though there are no cures for Alzheimer's disease at present, starting treatment earlier may give patients and their caregivers precious extra time to enjoy their quality of life.

It's one more way Hamamatsu is opening the new frontiers of light to improve our world.

*http://jp.hamamatsu.com/en/rd/publication/*

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PHOTON IS OUR BUSINESS

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

# The Science of Staying Young

"AND IN THE END IT'S NOT THE YEARS IN YOUR life that count. It's the life in your years," as the quote attributed to Abraham Lincoln goes. Although we humans have never been satisfied with the biblical allotment of threescore and ten, neither do we want to extend our life span only to pass the time in a decrepit state. No, we want a longer *health* span.

Might we be on the trail of one? The cover story, "A New Path to Longevity," by David Stipp, describes intriguing research into a billion-year-old mechanism that slows aging and could postpone the diseases of old age, letting us live healthier lives for longer. The work centers on studies of a protein called mammalian TOR, or mTOR. Interference with mTOR in mice by a drug called rapamycin in three parallel experiments extended life for the rodents by 9 to 14 percent—showing that the molecule plays a central role in aging. Turn to page 32.

At the outset of his career, Ralph M. Steinman first described dendritic cells, later shown to play a crucial role in preventing disease. In "The Patient Scientist," by Katherine Harmon, starting on page 54, you'll learn how Steinman, diagnosed with pancreatic cancer in 2007, used his own research to extend his life—just long enough to win the Nobel Prize last fall. A lot of life in those years, indeed. SA

## MEET THE WHALES

**If you've been** following SCIENTIFIC AMERICAN's activities, you know we're excited about citizen science—the idea that people who are not working scientists can nonetheless actively contribute to research. The Citizen Science tab on our home page at www.ScientificAmerican.com links to lists of existing projects. Now we add an original of our own, produced in partnership with Zooniverse: the Whale Song Project at http://whale.fm.

Families of orcas (also known as killer whales) and pilot whales, both members of the dolphin family, have their own dialects. Orcas, for instance, have more than 150 types of calls. Scientists want to categorize these songs to try to understand what the animals are saying. You can help.

By clicking on a spectrogram, which shows the shape of a sound, you can listen to recordings made by underwater hydrophones and then decide what categories to assign them to. When you cast your vote that a given song clip sounds similar to another, that vote—along with those of other participants—will help scientists identify sound patterns and groupings, which will assist in understanding how whales communicate. Because whales can sing at frequencies higher than we humans can hear and some clips are short, the songs are slowed down to make it easier to listen to them.

So take a virtual adventure in interspecies communication—while you contribute to real science—at http://whale.fm. Stay tuned, too, to learn what citizens and scientists together find out; we'll report the results in due course. —*M.D.*





*Illustration by Nick Higgins*


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editors@sciam.com


*September 2011*

### WHY CITIES SUCCEED

In "Bigger Cities Do More with Less," Luís M. A. Bettencourt and Geoffrey B. West assert that a high-rent city allows only greatly value-adding activities to be profitable, which leads to a cycle in which more talent is attracted, "pushing rents higher still, fueling the need to find yet more productive activities." The serious downside of higher commercial property rents is that many small businesses, such as barbershops, dry cleaners and convenience stores, are forced out of residential neighborhoods. There are many services that cannot be acquired through the Internet.

Ronald Bourque
*Brooklyn*

Bettencourt and West seem perplexed that the San Francisco Bay Area and the Boston region outperform other, similar urban conglomerations. They attribute this to "certain intangible qualities of social dynamics—rather than the development of material infrastructure." I would suggest that although Harvard University, the Massachusetts Institute of Technology, Stanford University and the University of California, Berkeley, do instill certain intangible qualities in their students, these institutions are very much "material infrastructure" and probably explain a lot of the difference in economic development.

Lee Otterholt
*Laguna Beach, Calif.*

**"Preventing another 9/11 requires owning up to what uncontrolled fires can do to tall buildings."**
LUKE BISBY *UNIVERSITY OF EDINBURGH*

The correlation Bettencourt and West make between patents and population confuses cause and effect. Cities mostly grow because innovative companies are successful and attract employees from all over the world, not because an urban environment spurs innovation. Here in Silicon Valley most of the innovation comes from midpeninsula suburban cities between San Francisco and urban San Jose. And companies here and in Dallas strive for an informal campus style of construction with open spaces. Innovation comes from synergy among entrepreneurship, available venture capital, access to universities, a mobile and diverse workforce, and a place where people want to live.

Ben Roberts
*Sunnyvale, Calif.*

### SUPERTALL SCRUTINY

In presenting the changes that have occurred in the design of skyscrapers since September 11, 2001, in "Castles in the Air," Mark Lamster notes three threats: aircraft impact, earthquakes and wind. He correctly claims that structural engineers are now able to effectively design against them.

Unfortunately, the Twin Towers collapsed primarily because of fire, and nowhere in the article is fire explicitly mentioned as a structural threat. On 9/11 we clearly saw that fire can cause entire modern high-rise buildings to collapse. (Indeed, 7 World Trade Center, a steel-framed high-rise, was not struck by an aircraft but collapsed because of fire ignited by debris from the Twin Towers.) To ensure safety in ever taller buildings, the potential impacts of uncontrolled fire need to be explicitly considered during the structural design process with the same care as earthquakes and wind. While changes in escape-stair width, firefighter communications systems and the addition of sky bridges (all noted by Lamster) can only improve life safety in tall buildings, they do not prevent structural collapse resulting from fire.

Preventing another 9/11 requires that the structural engineering and architecture communities own up to the reality of what uncontrolled fire can do to tall buildings and take the necessary actions.

Luke Bisby
*Senior Research Fellow in Structures and Fire*
*University of Edinburgh*

Lamster mentions that the Bank of America Tower in New York City "creates two thirds of its own energy" with a gas generator. But it depletes our unquestionably finite supply of natural gas to generate that energy.

Bill Christian
*North Bennington, Vt.*

"Castles in the Air" left the false impression that high-rise buildings are inherently "green" and essential to making cities more sustainable. Compared with lower-rise construction, they require more energy, and their wind tunnels and long shadows diminish livability. Whereas cities do need minimum corridor and neighborhood densities to support their pedestrian and transit-based economies, an occasional high-rise barely makes a dent. Lacking definitive research on the optimal scale of a sustainable city, I've nonetheless made informal surveys of expert colleagues that suggest that four to 30 stories is the optimal range for buildings in a sustainable city.

Doug Farr
*President, Farr Associates*
*Chicago*

### SIMPLE SECURITY

David Pogue is correct in "Password Prevented" [TechnoFiles] that our current method of making passwords is the worst of all possible worlds; it creates passwords that are nearly impossible for a human to remember but still relatively easy for a computer to guess.

The true secret to security is the reverse: a password scheme that is easy for users to remember (so they don't write it

down) but close to impossible for a computer to guess. The method of picking a string of letters and numbers gives a result that could be beaten in about three days of determined effort and is pretty much impossible to remember. A phrase of four random words, however, can be easy to remember but can require more than 500 years to guess.

ANDREW BENNETT
*Belmont, Mass.*

## POVERTY PRIORITY

Edward Glaeser's point that education matters more to the health of a city than construction and transportation projects in "Brains over Buildings" is valid but superficial. For a poor, urban community of color to prosper—or, nowadays, survive—good education that's free and relevant is essential. But people need to eat, too.

The trouble with urban development is that the contractors and workers almost never come from the community being developed. And the article doesn't mention the barriers erected in the past few years to accessing the two things it touts: education and entrepreneurship. Even San Francisco City College is too expensive for most people in the city's neighborhood of Hunter's Point, and cutbacks to faculty and classes make it futile for many. We're all for entrepreneurship, but what about redlining, which has gotten worse and is augmented by predatory loans that are nothing but landgrabs? And try running a business without money.

Further, a metric Glaeser ignores is the rich, who have education and entrepreneurship in abundance, pushing the poor out of the cities altogether.

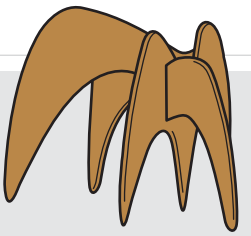
If the poor see that education will get them somewhere and help them feed their families, they and their kids will go for it. Otherwise, what's the point?

MARY RATCLIFF
*Editor,* San Francisco Bay View

## CLARIFICATION

In "The Best and Brightest" [Forum], New York City Mayor Michael R. Bloomberg refers to the University of Michigan as growing out of the land grant program that was created in 1862. The university was founded in 1817, although it did benefit from earlier land grants.





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# Read My E-mail? Get a Warrant

## As personal data move to the cloud, Congress needs to update privacy laws

**Last October** the well-known hacking group Chaos Computer Club revealed that the German state police had been monitoring the computers of ordinary citizens using specially designed surveillance software. This spyware could peek into users' files, record keystrokes, take screenshots of Web pages users happened to be visiting, and even commandeer Web cams and microphones, giving the cops an open window into the home. The revelations invited comparisons to the Stasi, the infamous police force that operated in the former East Germany.

It was a clear violation of citizens' rights—and about as quaint as a cold war spy movie. Nowadays governments have far more comprehensive ways of monitoring citizens than merely tapping computers on desktops or in briefcases. Hardly any of us still keep our private data solely in any one machine; instead it resides on corporate servers far from our homes. E-mail providers save messages in giant server farms distributed around the world. Online services such as Google Docs, Dropbox and iCloud store spreadsheets and word-processing files in the "cloud" so that we can work on critical documents wherever we happen to be. Wireless phone companies keep records of the individual towers our cell phones connect to as we move around our communities. We tend to assume that these data are ours to keep private, just as we expect that the data on our machines are private. But here the law fails us.

The last wholesale revision to U.S. electronic privacy law was the Electronic Communications Privacy Act of 1986 (ECPA), which prevented law enforcement from eavesdropping on digital files as they moved through the nascent Internet. (Before then, the Department of Justice had argued that monitoring anything that wasn't a voice call wasn't a wiretap and therefore didn't require a warrant.) Yet much has since changed. In 1986, when digital storage was expensive, an e-mail provider would send a file to the recipient's computer and delete the message from its own servers soon thereafter. Congress therefore let the protections of the act expire after a file had been stored for 180 days. In 1986 cell phones were still mostly called "car phones" because the briefcase-size boxes they required were usually kept in a vehicle. The first satellite that would make up the Global Positioning System was still three years away from launch, as was the World Wide Web. In 1986 Facebook genius Mark Zuckerberg was two.

Law-enforcement agencies have been making active use of all the new data these technologies generate. Google reports that U.S. government agencies send it nearly 1,000 requests for user information every month; the company complied with 93 percent of them between January and June of last year (the most recent period for which statistics are available). Verizon executives told Congress in 2007 that law-enforcement agencies send the company 90,000 requests for user details a year, including information on the specific locations of cell-phone customers.

In part because of this deluge, a broad coalition of technology companies, think tanks and privacy advocates called Digital Due Process has formed to ask Congress to update the ECPA for the modern age. Its demand is simple enough: if a law-enforcement agency wants to look at private user data—whether e-mails, documents or cell-phone location information—it needs a warrant. This reasonable demand for clarity is fully in keeping with the spirit of the original ECPA, as well as the Fourth Amendment of the Constitution's prohibition "against unreasonable searches and seizures." Indeed, the Digital Due Process coalition has brought together some uncommon allies—the American Civil Liberties Union, the Competitive Enterprise Institute, Amazon, Americans for Tax Reform and AT&T, to name just a few near the top of the alphabet. It deserves support from all members of Congress, too.

It is important to maintain a balance between the needs of security and the right of each citizen to lead a private life. Cops should be able to investigate a suspect's e-mail, location and other data. But first they should have to ask a judge. SA

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*Illustration by Post Typography*

Commentary on science in the news from the experts

**Peter H. Gleick** is president and **Matthew Heberger** is a research associate at the Pacific Institute in Oakland, Calif.

# The Coming Mega Drought

## The southwestern U.S. looks a lot like Australia before its nine-year dry spell

**Australia experienced the worst** and most consistent dry period in its recorded history over much of the past decade. The Murray River failed to reach the sea for the first time ever in 2002. Fires swept much of the country, and dust storms blanketed major cities for days. Australia's sheep population dropped by 50 percent, and rice and cotton production collapsed in some years. Tens of thousands of farm families gave up their livelihoods. The drought ended in 2010 with torrential rains and flooding.

Australia's Millennium Drought is a wake-up call for residents of the drought-plagued southwestern U.S. and for all of us. What happened in Australia could happen in the U.S., with devastating consequences to the region and to the nation. We can avert the worst, however, if we pay attention to Australia's experience and learn the right lessons.

**Drying out in the U.S.:** **The falling water level of Lake Mead near Las Vegas has left behind a white ring of mineral deposits.**

CHRISTOPHER J. MORRIS *Redux Pictures*

The southwestern U.S. bears some resemblance to parts of Australia before the drought. Both include arid regions where thirsty cities and irrigated agriculture are straining water supplies and damaging ecosystems. The Colorado River no longer flows to the sea in most years. Water levels in major reservoirs have steadily declined over the past decade; some analysts project that the largest may never refill. The U.S. and Australia also share a changing global climate that is increasing the risk of drought.

Evidence is mounting that climate change is playing a role in Australia's water woes. Since 1950 average rainfall has decreased 15 percent, and researchers found average temperatures over southeastern Australia from 1995 to 2006 were 0.3 to 0.6 degree Celsius higher than the long-term average. The combination of higher evaporation and lower precipitation depletes soil moisture and reduces runoff, making droughts more intense and more frequent. Australian scientists forecast a 35 to 50 percent decline in water availability in the Murray-Darling river basin and a drop in flows near the mouth of the Murray by up to 70 percent by 2030.

The Millennium Drought did have one benefit: it got people's attention. Australians responded to these extremes with a wide range of technical, economic, regulatory and educational policies. Urban water managers in Australia have been forced to put in place aggressive strategies to curb water use and to expand sources of new and unconventional supplies. They have subsidized efficient appliances and fixtures such as dual-flush toilets, launched public educational campaigns to save water, and more. Between 2002 and 2008 per capita urban water use—already low compared with the western U.S.—declined by 37 percent.

Other efforts focus on tapping unconventional supplies, such as systems that reuse gray water, cisterns to harvest rooftop runoff, and sewage treatment and reuse. The country's five largest cities are spending $13.2 billion to double the capacity of desalination, enough to meet 30 percent of current urban water needs.

Even in the midst of the drought, Australia moved forward with plans to restore water to severely degraded aquatic ecosystems. The government has continued with plans to restore rivers and wetlands by cutting withdrawals from the Murray-Darling river basin by 22 to 29 percent. It has committed $3 billion to purchase water from irrigators to restore ecosystems. Regulators introduced water markets in the hope of making farms more water-efficient and reducing waste. Despite efforts to phase out subsidies, the government announced more than $6 billion in aid to improve irrigation infrastructure and make it more productive.

The southwestern U.S. states would do well to push for these kinds of reforms before a similar disaster strikes. They need to tackle difficult policy issues, such as development of water markets and pricing, expansion of water efficiency and productivity programs, elimination of government subsidies that encourage inefficient or unproductive water use by cities and farms, and agricultural reform. As the climate continues to change, smart water planning may help ease the impacts of unexpected and severe shocks that now appear inevitable. SA

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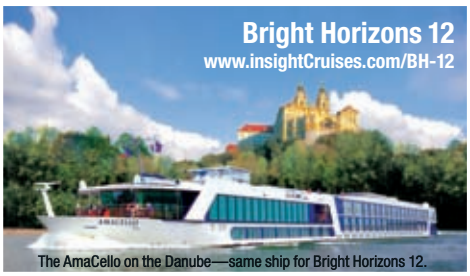

The AmaCello on the Danube—same ship for Bright Horizons 12.

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

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

**Sampling of Topics**

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

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

TECHNOLOGY

# Here Come the Drones

These popular, unmanned aircraft will eventually fall into the hands of hostile nations and terrorists

**Some are as large** and fast as commercial airplanes. Some are blimps that sit in the sky, surveying broad swaths of territory. Others flit around imperceptibly, like birds or insects, recording videos and landing themselves.

Unmanned aircraft have transformed the way the U.S. wages war, making it possible to gather unprecedented amounts of aerial imagery using nearly undetectable platforms and to strike at targets without putting pilots at risk. But it would be naive to assume drones will only be used to safeguard U.S. interests. As they continue to become smaller, cheaper and more numerous, drones will become easier for hostile nations, and perhaps even terrorists, to get their hands on. To think otherwise would be to disregard the history of military technology. Many countries, including Israel, China and Iran, are developing, using and selling drones, and global spending on drones is expected to approach $100 billion over the next 10 years.

Should a terrorist group deploy a drone in the U.S., it could be very hard to detect. Drones can fly right over fences and walls and are invisible to traditional radar systems. Because they can be transported in the trunk of a car or in a backpack, they can be launched from virtually any publicly accessible spot.

We might also be worried about our own government, or private companies, using drones to peer into our lives. In 1986 the U.S. Supreme Court ruled that law-enforcement agencies could use a private plane to view otherwise hidden marijuana plants because the police observations were made from "public navigable airspace." This may suggest that the government will enjoy broad latitude to use drones for surveillance.

Tightening access to drones is very difficult. The core information technologies used in small drones—extremely small video cameras, chips to process video and high-speed wireless communications systems—are routinely found in inexpensive consumer electronics.

This does not mean that there is nothing we can do. Drones could be equipped with kill switches and hidden tracking software that could help disable or trace them if they go missing. A combination of domestic regulation and international nonproliferation efforts could reduce the possibility that drones would fall into the wrong hands. It may be possible to equip sensitive government buildings or areas with new systems to detect and, if appropriate, electromagnetically or kinetically engage low-flying incoming drones. Yet despite these efforts, in the future we will no longer have the luxury of assuming that the skies above us are free of pilotless machines.

*—John Villasenor*

*Villasenor is a nonresident senior fellow at the Brookings Institution.*


CHRISTOPHER GRIFFITH *Trunk Archive*

SCIENTIFIC AMERICAN™ Travel

# BRIGHT HORIZONS™ 15

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

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

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

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

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




## NUCLEAR ASTROPHYSICS

**Speaker: David Lunney, Ph.D.**

### A Hitchhiker's Guide to the Universe

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

### Nuclear Cooking Class

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

### Weighing Single Atoms

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

### Panning the Seafloor for Plutonium: Attack of the Deathstar

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

## NEUROSCIENCE MEMORY

**Speaker: Jeanette Norden, Ph.D.**

### How the Brain Works

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

### Memory and All That Jazz

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

### Losing your Memory

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

### Use it or Lose it!

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

## COGNITIVE NEUROSCIENCE

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

### How the Brain Constructs the World We See

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

CONSERVATION

# Plight of the Condors

Once on the verge of extinction, North America's largest land birds have made a dramatic comeback. To ensure their continued survival, biologists are relying on high-tech gadgets and unusual interventions

**The first California** condors to enter the wild in five years took a few hesitant hops on a sandstone cliff, craned pinkish necks over the precipice and tentatively tested their nine-foot-plus wings. Since that landmark launch in 1992, wildlife biologists have released nearly 200 condors that were born and raised in captivity, and they've prospered. The world population has rebounded from 22 in 1987 to 396 birds, with wild populations concentrated in Baja California, Arizona, and southern and central California. As these giant scavengers move to reoccupy their full seven-million-square-mile range, scientists are using state-of-the-art technology to guide the Pleistocene-period survivors toward full self-sustainability. They are counting on this and other unusual inventions, such as swapping infertile for fertile eggs, to ensure their full recovery.

From his office in Ventura, Calif., Jesse Grantham, coordinator of the U.S. Fish and Wildlife Service's condor recovery program, can track each free-flying California condor to within a few feet of its location. He and his colleagues have fitted every 17-pound-plus bird with a radio transmitter and a solar-powered GPS device that sends more than 1,000 daily locator points per bird a day. Too many waypoints in one place for too long signal that a bird is in trouble. Crews then trek through remote canyons to check on the sick or dead condor and run tests on it and the carrion it was eating. The GPS data also help scientists find breeding caves, where they verify the viability of each egg and even switch infertile eggs laid in the wild with fertile ones laid by captive birds.

Scientists are finding that condors face many of the same dangers that stalked the birds 25 years ago, with the main one being lead bullet fragments that lodge in the flesh of carrion. Some nine out of 10 condors have elevated lead levels, a problem that persists despite a ban on the use of lead bullets within condor habitat in California. Bottle caps, DDT, high-voltage power lines and the occasional shooting also contribute, which means the environment still presents "all the mortality factors that nearly caused their extinction," Grantham says.

Using condor telemetry records, however, scientists are removing whatever dangers they can. Near Big Sur, Calif., GPS tracking documented a condor corridor from Anderson Peak to the Pacific Ocean in a canyon where Pacific Gas and Electric (PG&E) maintains a three-mile power line. After three condor electrocutions, flight data helped to convince PG&E to begin burying the power line in August. Elsewhere, scientists are working with solar- and wind-energy developers to avoid condor flight paths when they site projects. They have made headway on the lead issue, too, calling for extending the lead bullet ban and enforcing it more vigorously.

And there are more data to come. Plans include installing tiny digital devices to record condors' heart rate and wing-flapping intensity to learn how wind speed and direction affect their energy usage. By linking flight information to meteorological data, scientists are learning precisely how condors move across the landscape and what places are most important to protect, says Mike Wallace of the San Diego Zoo Institute for Conservation Research.

The $5-million-a-year condor recovery program has proved that California condors can be coaxed back into successfully reproducing and raising their young in the wild. Grantham and Wallace are optimistic that the telemetric information will help ensure that future populations become self-sufficient—if only something can be done about the lead.

*—Jane Braxton Little*

*California condor*

KONRAD WOTHE *Minden Pictures (condor)*; COURTESY OF TILBURG UNIVERSITY (*Stapel*)

## SUSPECT SCIENCE

***"Diagnose environmental disorder early and intervene immediately."***

—From a paper co-authored by prominent Dutch social psychologist Diederik A. Stapel purporting to link racial discrimination with messy environments. He was fired from his post at Tilburg University in the Netherlands in November after colleagues discovered he had faked data in this and other studies.

*Do you have a recent suspect science statement to submit? E-mail it, along with source material, to submit@sciam.com*

FURTHER READINGS AND CITATIONS ScientificAmerican.com/jan2012/advances

CAREERS

# No Spring Chickens

## Scientists are making Nobel-worthy discoveries at more advanced ages than in the past


TED SPIEGEL *Corbis*

**Albert Einstein** once commented that "a person who has not made his great contribution to science before the age of 30 will never do so." This may have been an accurate reflection of physics in his time, but it is no longer the case—for physics or any other field. Benjamin Jones, an expert in innovation at the Kellogg School of Management at Northwestern University, and Bruce Weinberg of Ohio State University analyzed 525 Nobel Prizes awarded in physics, chemistry and medicine between 1900 and 2008. With a few exceptions—notably quantum mechanics discoveries of the 1920s and 1930s—the trend across all fields is toward researchers being older when they produce their greatest work.

To explain the aging effect, Jones and Weinberg suggest a shift from theoretical work, in which youngsters do better, toward experimental work, which requires aggregation of knowledge. They also believe that as fields expand, it may take longer to accumulate the knowledge necessary to make a novel contribution.

Those younger than 30 need not despair, though. The anomaly of quantum physics suggests that, in the case of a scientific revolution where established knowledge can be a hindrance rather than a help, the trend might reverse. "If there are future revolutions out there, it may make people younger yet again," Jones remarks.

*—Zoë Corbyn,* Nature

DO THE MATH

# Weighing the Positives

## Breaking down the latest mammogram math

**It seems** like every few months a new study points out the inefficacy of yet another wide-scale cancer screening. In 2009 the U.S. Preventive Services Task Force suggested that many women undergo mammograms later and less frequently than had been recommended before because there seems to be little, if any, extra benefit from annual tests. This same group recently issued an even more pointed statement about the prostate-specific antigen test for prostate cancer: it blights many lives but overall doesn't save them.

More recently, researchers at the Dartmouth Institute for Health Policy and Clinical Practice announced that just because a mammogram (almost 40 million are taken every year in the U.S.) detects a cancer does not mean it saves a life. They found that of the estimated 138,000 breast cancers detected annually, the test did not help the vast majority of the 120,000 to 134,000 women afflicted. The cancers either were so slow-growing they did not pose a problem, or would have been treated successfully if later discovered clinically, or else were so aggressive that little could be done about them. Chest x-rays for lung cancer and Pap tests for cervical cancer have come under similar criticism.

Individual cases dictate what tests and treatment are best, of course, but one factor underlying all these tests is a bit of numerical wisdom that, though well known to mathematicians, bears repeating: when one is looking for something relatively rare (not just cancer but even for, say, terrorists), a positive result is very often false. Either the "detected" life-threatening cancer is not there, or it is of a sort that will not kill you.

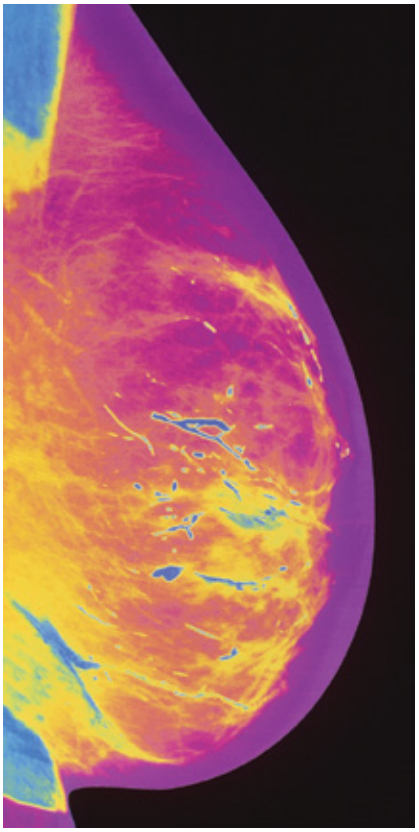
Rather than looking at the numbers for the prevalence of the above cancers and at the sensitivity and specificity of each of the tests mentioned, consider for illustration cancer X, which, let us assume, afflicts 0.4 percent of the people in a given population (two out of 500) at a certain time. Let us further assume that if you have this cancer, there is a 99.5 percent chance you will test positive. On the other hand, if you do not, we will assume a 1 percent chance you will test positive. We can plug these numbers into Bayes' theorem, an important result from probability theory, and get some insight, but working directly through the arithmetic is both more illustrative and fun.

Consider that tests for this cancer are administered to one million people. Because the prevalence is two out of 500, approximately 4,000 (1,000,000 × 2/500) people will have it. By assumption, 99.5 percent of these 4,000 people will test positive. That is 3,980 (4,000 × 0.995) positive tests. But 996,000 (1,000,000 – 4,000) of the people tested will be healthy. Yet by assumption, 1 percent of these 996,000 people will also test positive. That is, there will be about 9,960 (996,000 × 0.01) false positive tests. Thus, of the 13,940 positive tests (3,980 + 9,960), only 3,980/13,940, or 28.6 percent, will be true positives.

If the 9,960 healthy people are subjected to harmful treatments ranging from surgery to chemotherapy to radiation, the net benefit of the tests might very well be negative.

The numbers will vary with different cancers and tests, but this kind of trade-off will always arise in that nebulous region between psychology and mathematics. A life saved because of a test, though not that common, is a much more psychologically available outcome than the many substantial, yet relatively invisible, ill effects to which the test often leads. —*John Allen Paulos*

*Paulos is professor of mathematics at Temple University (www.temple.edu/paulos).*



MEHAU KULYK Photo Researchers, Inc.



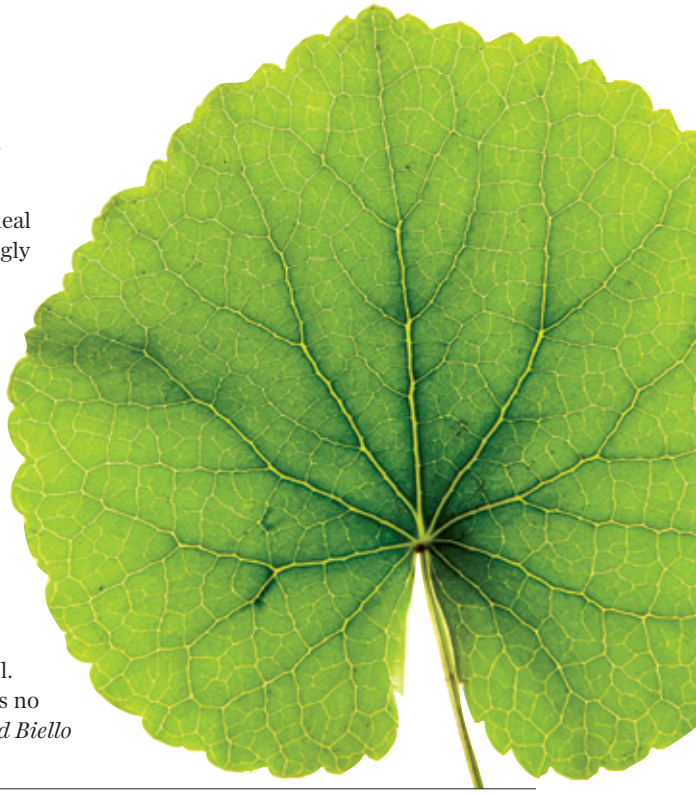


COMMENT AT ScientificAmerican.com/jan2012

ENVIRONMENT

# Tweaking Photosynthesis

By altering how plants turn sunlight into chemical energy, scientists hope to produce biofuels that make economic sense



CHRIS STEIN *Getty Images*

**For years researchers** have been trying to figure out the best ways of making plants produce biofuels. But there is a fundamental problem: photosynthesis, the process by which plants convert sunlight into stored chemical energy, is highly inefficient. Plants turn only 1 to 3 percent of sunlight into carbohydrates. That is one reason why so much land has to be devoted to growing corn for ethanol, among other bad biofuel ideas. And yet plants also have many advantages: they absorb carbon dioxide at low concentrations directly from the atmosphere, and each plant cell can repair itself when damaged.

Scientists have begun a new effort to soup up photosynthesis and help humans make greener fuel. The U.S. Advanced Research Projects Agency for Energy, known as ARPA-e, has funded 10 such projects so far, most of which use genetic engineering to tweak a plant's DNA-based instruction manual for growth, pigments, and the like. The largest grant—more than $6 million—has gone to the University of Florida to alter pine trees to make more turpentine, a potential fuel. Another project, led by Davis, Calif.–based Arcadia Biosciences, is aimed at inducing fast-growing grasses such as switchgrass to produce vegetable oil for the first time in history.

In the future, engineers might create a black plant that would absorb all incoming sunlight or a plant that uses different wavelengths of light to power the different steps of photosynthesis; plants now use the same wavelengths for everything. An engineered biofuel-producing plant might even have smaller leaves, reducing its own energy demands for growth, or it might no longer store energy as sugar but turn it directly into a hydrocarbon molecule for human use as fuel.

The scientists in the program, dubbed PETRO, for *p*lants *e*ngineered *to r*eplace *o*il, will also have to deal with the challenges of increasingly limited water supplies for crops and public skepticism of genetically modified organisms. And they will face competition from efforts to replace photosynthesis altogether, such as ARPA-e's own Electrofuels program, which aims to induce microbes to make hydrocarbons, or from efforts to build artificial leaves that use the electricity from solar cells to split water into oxygen and hydrogen for use as fuel. For plants, simply being green is no longer enough. —*David Biello*

SCIENTIST IN THE FIELD

# Pond Scum to the Rescue

The man who first sequenced the human genome and designed the first synthetic cell explains why simple algae—and some genetic engineering—may hold the key to our future

***Why algae?***

You look at the potential output from algae, and it's one to two orders of magnitude better than the best agricultural system. If we were trying to make liquid transportation fuels to replace all transportation fuels in the U.S., and you try and do that from corn, it would take a facility three times the size of the continental U.S. If you try to do it from algae, it's a facility roughly the size of the state of Maryland. One is doable, and the other's just absurd.

Everybody is looking for a naturally occurring alga that is going to be a miracle cell to save the world, and after a century of looking, people still haven't found it. We hope we're different. The [genetic] tools give us a new approach to being able to rewrite the genetic code and get cells to do what we want them to do.

***Why do this? What's the motivation?***

We all live on the same planet. The bad cliché is: we're all in the same lifeboat. If somebody takes a power drill and drills a hole in the bottom of the boat, we're all screwed. Sooner or later the oil and coal industries won't have any choice. The forward-looking companies are trying to get a real jump on that now. None of these solutions are things where you just pick up a book and find the solution. It is long-term research.

***What are the big hurdles?***

It's just the size, the expense—billion-dollar-plus facilities. Getting algae that are really robust and can withstand true industrial conditions on a commercial basis. The thing that will make the difference is the engineered cell, a cell that can produce 10 to 100 times as much.

***What about nutrients?***

We need three major ingredients: $CO_2$, sunlight and seawater, aside from having the facility and refinery to convert all those things. We're looking at sites around the world that have the major ingredients.

***How long will this take?***

To us, this is a long-term plan. It's a 10-year plan. We're not promising new fuel for your car in the next 18 months.

***What was the bigger challenge: the human genome or algae?***

I did [the human genome] in nine months. But there are 500 different parameters in the [algal] cells and in the systems. Absolutely, algae are the bigger challenge. It also has a lot bigger implications for the world if we're successful.

***Given algae's checkered past, what makes you confident of success?***

I like to win arguments by having the data. People making extraordinary claims have the obligation to provide extraordinary evidence that their claims are true. Right now nobody has the data in any of these fields. We have some new tools to approach these same problems. Algae have had a lousy history. There is no guarantee we will succeed, either. —*David Biello*

**PROFILE**

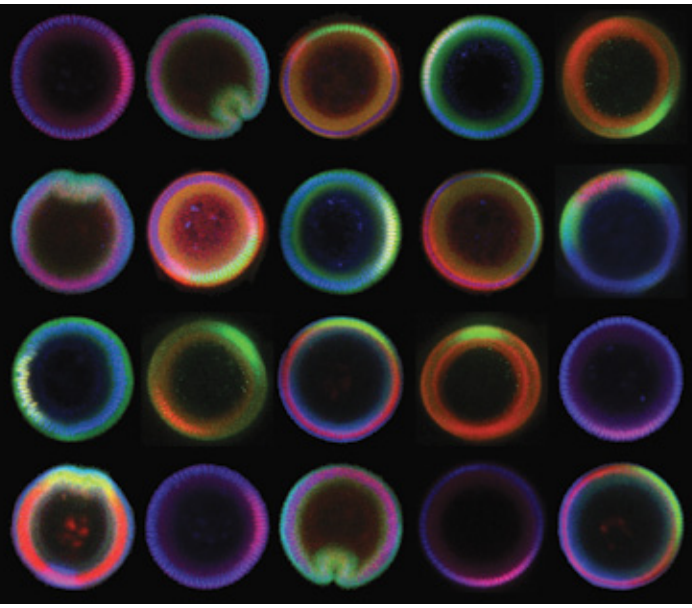
NAME
**J. Craig Venter**

TITLE
**CEO, Synthetic Genomics**

LOCATION
**La Jolla, Calif.**

**WHAT IS IT?**

***Small flies:*** For this Kandinsky-like image, researchers stained cross sections of 20 fruit fly embryos with antibodies to reveal three distinct tissue types: muscle, nerve and skin. Recently included in Princeton University's annual Art of Science exhibition, the image shows the progress made in this type of microscopy. The scientists, who come from Princeton and the Georgia Institute of Technology, developed a new microfluidic device that traps and vertically positions tiny objects faster than before. —*Ann Chin*



SANDY HUFFAKER *Redux Pictures (Venter)*; COURTESY OF YOOSIK KIM AND STANISLAV Y. SHVARTSMAN *Princeton University* AND KWANGHUN CHUNG AND HANG LU *Georgia Institute of Technology (embryos)*



COMMENT AT ScientificAmerican.com/jan2012

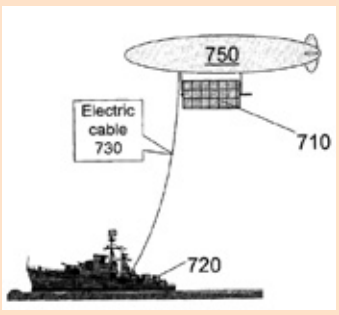
## PATENT WATCH

***Airborne power station:*** As a longtime resident of Seattle, Boeing engineer Brian J. Tillotson had often gazed up at the clouds and wondered how anyone living in such a sun-deprived place could ever hope to take advantage of solar power, the main offering of Boeing subsidiary Spectrolab. More than three years ago he came up with the answer: Why not build a power station above the clouds?

The idea, described in Patent No. 8,006,933 B2, has applications even in the brightest of locales. Between 20 to 30 percent of the sun's power is lost in the earth's lower atmosphere before you begin to account for unwanted haze or clouds. That is a technical challenge for Spectrolab, which makes efficient solar cells by using reflectors to amplify high concentrations of sunlight 400- to 800-fold. Spectrolab's cells are used most often to power satellites orbiting far above the atmosphere, which renders the problem moot. In 2008, however, Tillotson began looking for a way to adapt them for use by U.S. troops stationed in remote parts of Afghanistan, where security concerns requiring expensive convoys had driven the cost of delivering fuel to power diesel generators to as high as $700 a gallon.

A floating power station, he realized, could solve that problem—and bring solar power to downtown Seattle, too. "You would only have to go up a few thousand feet to get quite a bit of benefit," he notes. Tillotson envisions solar cells attached to an airship or dirigible, which would drop thousands of feet of lightweight transmission cable down to a mooring. The U.S. Army is already experimenting with battlefield-surveillance dirigibles that get their power from the ground via cables. Boeing's device would be similar, except power would move down.

Boeing has not yet built a prototype, Tillotson says, because engineers are "hoping to see some technological improvements that would make the floating power station a little more affordable." At the moment, dirigibles demand intensive upkeep. Helium must be replenished as often as once a week and repairs made regularly to their outer shell, which is battered by wind and weather. "It turns out, operationally, airships aren't as simple as I like to imagine—at least the ones being used by the army," he says. Over time, Tillotson observes, better sealant and material for the shell or hull will improve the economics by avoiding leaks when the dirigible gets knocked around. —*Adam Piore*

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NEUROSCIENCE

## Photographic Memory

A wearable video camera may be able to slow the ravages of Alzheimer's disease

**Hopes** for new drugs that would slow or stop the inexorable decline of Alzheimer's patients have repeatedly foundered in recent years. In one example, Eli Lilly had to halt the trial of a drug designed to prevent the production of toxic proteins in the brain because patients' cognition actually worsened while they were taking it.

Scientists are now looking to the computer industry for alternative ways to help patients. One approach is centered on a small camera called SenseCam, worn like a necklace, that snaps photographs automatically throughout the day. The idea is to use the images not to replace memory but to stimulate it. Each photograph can serve as a cue, like Marcel Proust's madeleine, tapping into the web of remembrances that collectively defines a person's identity.

SenseCam, developed by Microsoft and now marketed by a company called Vicon, uses a fish-eye lens to capture a wide-angle view. At regular intervals—say, every 30 seconds—a new image gets stored in the one-gigabyte solid-state memory. When the wearer moves from one room to another, a sensor that picks up the change in light triggers SenseCam to take a new photograph. Further, if a person walks by, an infrared sensor detects the body heat and signals that it is time for another photo. The result is a thumbnail chronology of the minutiae of the wearer's daily life. Later, patients or their caregivers pipe this electronic thumbnail record into a PC to display the images either individually or in chronological sequence.

Dozens of groups are now working on pilot tests of the device for memory impairments. The studies remain anecdotal but are still compelling. Steve Hodges of Microsoft Research Cambridge remembers an Alzheimer's patient who described a day trip with his spouse in Spain while wearing SenseCam, which produced images that the man could then "study." The patient, though, wondered aloud how the couple had arrived at their destination. His wife then interjected that he had taken the device off on the train because he was embarrassed to be sporting a funny-looking gizmo. Reviewing the pictures may be a form of brain calisthenics for enhancing the mental process known as autobiographical memory, recalling the time and place of past events. The ability to engage in this type of mental time travel is just what Alzheimer's obliterates.

Some people are skeptical about the device. "We have found that older individuals, particularly those with memory impairment, are often averse to technology," says Paul Aisen, a physician and researcher at the University of California, San Diego, who has assisted with the design of Alzheimer's drug trials. If the device works (and it is too early to tell if it does), SenseCam would merely slow deterioration. A delay of cognitive decline for only a few years could yield a major public health benefit by letting patients hold on to vestiges of memory. A picture might be worth more than 1,000 milligrams. —*Gary Stix*

NANOTECHNOLOGY

## The Little Engine That Could

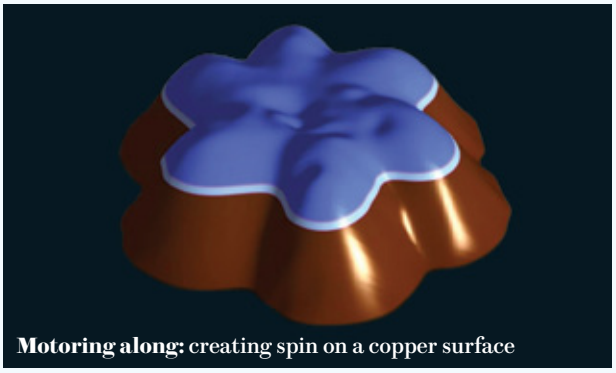
Researchers have built the world's tiniest motor

**For a long time** the smallest motor in the world was 200 nanometers across. That's really small, about one-fortieth the size of a red blood cell. Charles Sykes and his team at Tufts University have now crushed that record. Their motor is just a single molecule, one nanometer across. Unlike other, bigger motors, this one isn't driven by chemical reactions or light—it runs on electricity. "A lot of designs have been proposed," says Johannes Seldenthuis, a researcher at the Delft University of Technology in the Netherlands, "but this has really been the first one that's actually worked."

Here is how Sykes and his team did it: the motor—a single molecule of butyl methyl sulfide (BuSMe), which is made up of a sulfur atom with four carbon atoms on one side and one carbon atom on the other—was placed on a copper surface. The researchers then lowered a scanning electron microscope very close to that surface. The electrons flowed out of the tip of the microscope, exciting the electrons in the BuSMe molecule and causing it to rotate back and forth. But because the molecule is asymmetrical, it tended to spin in one direction slightly more than the other. Little by little, the excited molecule moved along the plate.

Although that might not sound like a motor, it resembles what is inside the human body. "If you watch biological motors, they don't look like they're doing anything useful—they just jitter around," Sykes says. Our bodies are populated with similar structures. The cell wall is littered with pumps that move ions into and out of the cell. Others move things from one place to another within the cell.

That is why this single-molecule motor is significant. Says Sykes: "If you can operate them in a controlled way, you have a whole host of things you can do." If researchers could reliably build replicas of the pumps in our cell walls, they could do experiments on those pumps extremely efficiently, shrinking their setups to fit onto small chips and reducing the amount of space, cost and time required for each test. —*Rose Eveleth*



**Motoring along:** creating spin on a copper surface

COURTESY OF MICROSOFT RESEARCH (*camera*); COURTESY OF SYKES LAB *Tufts University (molecular motor)*

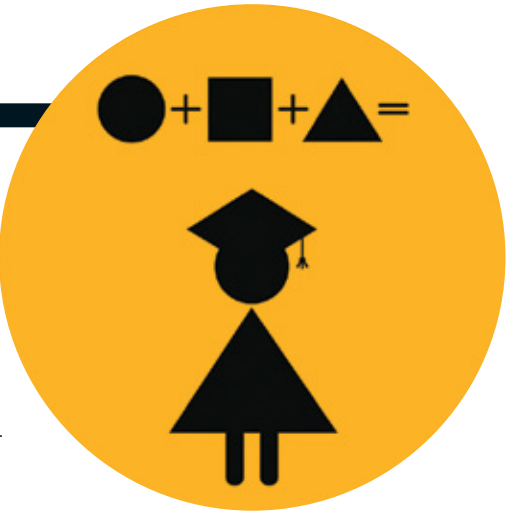


COMMENT AT ScientificAmerican.com/jan2012

EDUCATION

# Anything Boys Can Do …

## Biology may play only a minor role in the math gender gap



**When then** Harvard University president Lawrence Summers suggested in 2005 that innate differences between men and women may account for the lack of women in top science and engineering positions (and subsequently resigned), he was referring to the greater male variability hypothesis. Women, it holds, are on average as mathematically competent as men, but there is a greater innate *spread* in math ability among men. In other words, a higher proportion of men stumble mathematically, but an equally high proportion excel because of something in the way male brains develop. This supposedly explained why boys tend to dominate math competitions and why men far outnumber women in elite university math departments. Since then, scientists have put the variability hypothesis to the test, and it comes up short.

In the most ambitious study so far, mathematics professor Jonathan Kane of the University of Wisconsin–Whitewater and oncology professor Janet Mertz of the University of Wisconsin–Madison analyzed data on math performance from 52 countries, including scores from elite competitions such as the International Mathematical Olympiad. In particular, they examined variance—roughly, how spread out scores are. Two patterns emerged, they report in a paper in the January issue of the *Notices of the American Mathematical Society*. The first is that males' and females' variance is essentially equal in some countries. The other is that the ratio of males' to females' variance differs greatly from one country to another. These ranged from 0.91 to 1.52 (where a ratio of 1 means the two sexes' variance is equal, and a number greater than 1 means males' scores were more spread out than women's).

The finding that males' variance exceeds females' in some countries but is less than females' in others and that both range "all over the place suggests it can't be biologically innate, unless you want to say that human genetics is different in different countries," Mertz argues. "The vast majority of the differences between male and female performance must reflect social and cultural factors."

Such as? One clue comes from the finding that a widely used measure of a nation's gender equality, called the Global Gender Gap Index, correlates with the ratio of boys versus girls scoring in the top 5 percent on an international math competition called PISA. In some countries, such as the Czech Republic, the boys' and girls' distribution of math scores were nearly identical. Another clue that gender differences in math performance are not innate comes from the shrinking gender gap. In the U.S., the ratio of boys to girls scoring above 700 on the math SAT fell from 13:1 in the 1970s to 3:1 in the 1990s.

Psychology professor Stephen Ceci of Cornell University calls the new analysis "a very important argument" in the debate over the sources of sex differences in math careers. But, he adds, the findings do not mean that biology plays no role. Just because diet affects human height, for instance, does not mean "that nature is unimportant." Now that the greater male variability hypothesis has fallen short, nature is not looking as important as scientists once thought.

*—Sharon Begley*



*Illustration by Thomas Fuchs*

## *Best of the Blogs*

SPACE

# Why It's Raining Satellites

Orbital debris hits Earth daily, but NASA says not to worry

**Two well-publicized** satellite falls a month apart got me wondering: Is this the new normal? After all, there is plenty of junk in orbit, and it can't stay up there forever. And NASA, along with many other space agencies, now requires that satellites tumble back to Earth sooner rather than later once their useful lifetimes have ended so as to limit collisions in orbit. So how often are we going to be hearing about inbound satellites—and worrying about the ever so slim chance that they might kill us? A call to NASA's top orbital debris scientist clarified the issue and reassured me that we are not now witnessing the leading edge of a debris storm.

But first a brief recap. In September, NASA's defunct Upper Atmosphere Research Satellite, or UARS, came streaking back into Earth's atmosphere. UARS returned to Earth uncontrolled, meaning that NASA and the U.S. military could only guess where the pieces might land. Ultimately UARS did the world a favor and plunked itself down in the remote South Pacific, out of harm's way. Just a month later Germany's smaller ROSAT spacecraft followed suit, diving back to Earth over the Bay of Bengal. Again the fall proved benign.

Neither event, as it turns out, was all that rare. Pieces of space junk, whether derelict spacecraft, rocket bodies or other mission by-products, fall from orbit more or less daily. UARS turned so many heads because it "was the biggest NASA satellite to reenter uncontrolled in over 30 years," says Nicholas Johnson, NASA's chief scientist for orbital debris at the Johnson Space Center in Houston. And ROSAT came with a relatively high debris risk because of its construction.

But UARS-size objects belonging to other space-faring agencies fall from orbit roughly once a year; ROSAT-size junk is even more common. Humankind has survived decades of reentries without significant incident, thanks to the fact that most of Earth is ocean or sparsely populated land. "Reentries are very, very routine," Johnson says. And rules enacted since the launch of UARS are helping to ensure our safety. Engineers now "design for demise" when building spacecraft, swapping out materials that survive reentry.

Johnson and his colleagues keep a list of all NASA objects in orbit, including an estimate of when those objects will make the fiery plunge into the atmosphere. Two huge ones on the books are the Hubble Space Telescope and the International Space Station. The plan with both is to use thrusters to drive the craft into the ocean when their time comes. —*John Matson*

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

BEHAVIOR

# Your Birdsong Stays on My Mind

A new app may help birders identify species just by sound

**Birdsong—or, more technically, vocalization— is one way that die-hard bird-watchers identify different kinds of birds in the field, along with the more traditional visual markers. Yet how do you take written notes on the sounds that birds make? You could use conventional musical notation, but many bird-watchers aren't musicians. Field guides often resort to vague phrases such as "far-carrying melancholic song" or the mysterious "tee-do-do-eet." Also, how can birders identify strains of birdsong they may hear in the field?**

**Enter two enterprising Ecuadorian researchers who think they may have a solution to both problems. Hugo Jácome Andrade and David Parra Puente have developed software that "transforms sound into a sequence of numbers that can be readily converted and printed in a QR (Quick Response) bar code." They debuted a prototype version of the software last November at a meeting of the Acoustical Society of America, where attendees were able to see firsthand how the system imports recorded sounds and transposes them into a QR bar code and then "decodes" it using a conventional bar code scanner.**

**The next step for Jácome Andrade and Parra Puente is to adapt their software into an app for smartphones, a kind of mobile catalogue in a searchable e-book format. That would be the ultimate pocket field guide for bird-watchers, wouldn't it? Instead of lugging around lots of pricey and heavy equipment, enthusiasts could happily go about their bird-watching business armed with just a mobile phone with a built-in camera. If they heard a bit of birdsong, they could look it up on the smartphone app. Their phone, in turn, would display a picture of the bird (for visual identification) and a bar code that could be played so that watchers could verify the birdsong matches that they just heard. "No more confusing tweeting sound descriptions!" Jácome Andrade and Parra Puente declared in their lay-language summary. —*Jennifer Ouellette***

*Adapted from the Cocktail Party Physics blog at blogs.ScientificAmerican.com/cocktail-party-physics*

STEPHEN SCHWARTZ/iStockphoto



COMMENT AT ScientificAmerican.com/jan2012

# 自然出版集团上海公司 — 高薪诚聘中国业务主管

## Country Head — China, Nature Publishing Group
Shanghai

As part of a major strategic move by Nature Publishing Group (NPG) into China, NPG, publisher of the international science journal *Nature*, seeks a Country Head to lead the group's future business and editorial activities in China.

Based in new offices in Shanghai, the Country Head will be part of a broader initiative by the Macmillan Group (to which NPG belongs) that aims to establish a strong presence for Macmillan in China, with particular emphasis on science and education.

This is a senior appointment with a reporting line to the Regional Managing Director of NPG, currently based in Tokyo, and to the Managing Director of Greater China for the Macmillan Group of Companies, based in Shanghai.

The Country Head will be responsible for leading NPG's activities on a broad range of fronts. Within the first half of 2012, four editors of the new online multidisciplinary science journal *Nature Communications* will be based in Shanghai (see below). This is the first time manuscript editors of a *Nature* journal will be based in China. This initiative is in response to the rapidly growing output of high-quality research from China and to the growing number of research articles from China in *Nature* publications (see http://www.natureasia.com/en/publishing-index/china/). The Country Head will be responsible for making this move successful by working with the *Nature Communications* team and networking with leading Chinese scientists in the best research institutions and laboratories throughout China, encouraging high-quality submissions from China not only to *Nature Communications* but to *Nature* and NPG journals as a whole.

The Country Head will also work with colleagues in Tokyo and Melbourne to continue the rapid expansion of the Asian Academic Journal programme of NPG in China, which will have expanded to seven journals by July 2012 — many of them open-access publications. The Country Head will also be responsible for expanding and developing the NPG's open-access publishing of research from China, both in terms of the publication of open-access research articles within existing NPG journals but also in the development of new open-access titles.

On a related front, the Country Head will also be responsible for developing scientific communication services with colleagues from Macmillan Scientific Communications (MSC) in Tokyo and London, aiming not only to assist scientists in their writing and presentation of research articles but also to help institutions in China promote their best research to the world through the creation of custom publications such as websites, newsletters and annual reports.

Furthermore, the Country Head will be responsible, along with colleagues in Tokyo and Hong Kong, for ensuring that our existing business in site license sales, sponsorship and advertising continues to grow in China.

Candidates must have at least five years experience in the science publishing industry and some firsthand knowledge of science in China. A doctoral degree in science is highly desired and postdoctoral experience would be an additional advantage. Fluency in English is essential and a working knowledge of Mandarin would be a plus.

A keen understanding of the rapidly evolving research sector in China, including its goals and challenges, is essential. The successful candidate will be able to think strategically with the necessary hands-on business development skills to translate NPG's strategy and vision for China into initiatives, partnerships and business models. Day-to-day management capability, including financial management and team development skills, are essential, together with superb skills in communication — both internally, within NPG and Macmillan, and with the external world, in particular with the highest levels of the scientific community and government in China.

The Country Head will need a global mindset that can identify and develop both local and global opportunities involving China, will have the maturity, credibility and skills to work with scientific institutions, government agencies and other key players in China's research communities, and will exhibit a collaborative style that encourages cooperation, innovation and a positive work environment.

This is a challenging and demanding senior position with a competitive salary and employment terms. Any offer of employment will be contingent on the necessary work permit for China, as applicable, being granted (NPG will provide reasonable assistance with the necessary application process in this respect).

Applicants should send their CV, a covering letter explaining their interest in the position and their salary expectations to recruitment@macmillan.co.uk. They should also include a brief document (maximum two pages) outlining their vision of how NPG can best develop its business and editorial activities in China. Please quote reference number NPG/179/11 in the subject header.

**Closing Date: 6 January 2012**

## Editors of *Nature Communications* — China, Shanghai

NPG is also recruiting four Executive, Senior, Associate and Assistant Editor positions for *Nature Communications* to be based in Shanghai. For further details, please contact recruitment@macmillan.co.uk for further information.

**Closing Date: 6 January 2012**

nature publishing group npg

NPG/179/11

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

# Healing Kansas

## Better health requires improved education, more access to nutritious food and greater economic opportunities, new county rankings show

**As mayor of Kansas City, Kan.,** Joe Reardon is justifiably proud of the University of Kansas Medical Center, which has trained several generations of physicians and nurses for more than 100 years. After all, the medical center is consistently rated as the best hospital and treatment center in the state, according to a popular ranking of health institutions. So when Mayor Reardon—who heads the government of both the city and Wyandotte County, in which it sits—first learned that Wyandotte had come in dead last among the state's counties in a rigorous analysis of health measurements in 2009, he was shocked. "We have great access to excellent health care in a state where some counties have essentially no access," Mayor Reardon says. "And we're ranked last out of 105 counties? My first reaction was, 'How could this be?'"

The answer, Mayor Reardon discovered as he delved into the statistics behind the claim, is that proximity to fine hospitals and first-rate doctors is only one of many factors—and not always the most important—determining how long people live and how vulnerable they are to serious illness. Evidence collected by public health experts over the past few decades repeatedly shows that less obvious forces, including proper diet and exercise, higher levels of education, good jobs, greater neighborhood safety, and underlying support from family and friends, provide a powerful, and often unappreciated, boost to a community's health and well-being. By the same token, studies demonstrate, a poor showing in any of these areas can sink the health of individuals or of communities—even if they have access to topflight medical facilities.

The goal of the County Health Rankings project, which has given Wyandotte County low marks for health but high praise for its commitmennt to change, is to bring these hidden health factors to light and thereby help elected officials, civic leaders and community groups take concrete steps that can improve the health of local residents. The initiative originated at the University of Wisconsin–Madison, covering solely that state in 2003. A similar project began in Kansas in 2009, and in 2010 the Robert Wood Johnson Foundation in Princeton, N.J., provided funding so that the University of Wisconsin could expand its investigation to include within-state comparisons of counties in all 50 states.

Among the biggest lapses identified in Wyandotte County, for example, were much higher than average rates of smoking and obesity, lower than average rates of high school graduation, a distressing number of babies who weigh too little at birth, and a relative scarcity of fresh fruits and vegetables in grocery stores compared with the rest of the state. Mayor Reardon says these measurements have already transformed his approach to budget priorities. Changes include earmarking money for the addition of mentoring programs for high school students, new parks and sidewalks, and the opening of more and better supermarkets and community gardens in impoverished neighborhoods. And that is just the start, Mayor Reardon says. "The measure of our success as a city is not just how many jobs we create but also the health of our citizens." He believes that potential employers who want to stay competitive in today's global marketplace are more likely to settle in communities where workers are both highly skilled and relatively healthy.

### PUBLIC HEALTH STRATEGY HAS DEEP ROOTS

The notion that government officials can use public health statistics to improve policy decisions is not new. In 1854 physician John Snow, one of the founders of modern epidemiology, traced a cholera outbreak in the overcrowded London neighborhood of Soho to a contaminated public water pump by noting how many cases of illness clustered around the pump. (The pump was later found to be too close to a leaking cesspool.) Snow convinced officials to disable the pump, which helped to stop the spread of disease.

Today's health statisticians still search for instructive patterns of behavior and illness in communities, although they have moved beyond simply tracking infectious disease rates and deaths. Now-



*Illustration by Tim Bower*

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# CEITEC – a new multi-disciplinary research center in the Czech Republic

**CEITEC, the Central European Institute of Technology, is a new multi-disciplinary EU-funded center of scientific excellence in the fields of the life sciences and advanced materials. The center was approved by the European Commission on 6 June 2011, and has a planned budget of EUR 208 million. It will be based in the second largest city of the Czech Republic, Brno, and completed within the next three years. Chemistry dominates two of its seven research programs – Structural Biology and Advanced Materials.**

The research program **Structural Biology** is concerned with the structures of large macromolecules at several levels of resolution in order to understand vital processes at the cellular level. It aims to enhance European competitiveness, stimulate regional development, facilitate biomedical research and encourage biotechnology. When it comes to applications, it will help develop next-generation diagnostics and therapeutic strategies for the treatment of human diseases.

The research program **Advanced Materials** focuses on the synthesis of advanced materials – polymeric, ceramic, metallic and composite – and the analysis of their structures and properties. The aim of this research is to develop novel complex properties for use in various industrial sectors, as well as medicine. A parallel goal is setting up an equipment and human resources infrastructure to create excellence in the field.

**Funding for this center has been acquired by Brno universities and research institutes from the EU Research and Development for Innovation Operational Program. The center will employ up to 600 scientists that will supervise more than 1,200 students. It will also collaborate with Czech and foreign companies, and altogether help to push basic and applied research in the Czech Republic to achieve excellence.**

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adays, says Julie Willems Van Dijk, a researcher at the University of Wisconsin Population Health Institute who helps county leaders figure out what to do with the data, public health officials also monitor quality of life and trends in chronic, noncommunicative disorders, such as depression, diabetes and heart disease.

The trick for researchers, Willems Van Dijk says, is to sift information from broad studies of large populations to identify behaviors and other influences on health that can be modified. The next step is to see how those factors play out at the level of the city, county and town, where many of the policy decisions that most directly affect people's health are often made. Individual cities started enforcing smoking bans in restaurants, Willems Van Dijk notes, after studies showed that secondhand smoke increased the number of heart attacks and cases of asthma in nonsmokers. The County Health Rankings project, now updated annually, is an attempt to provide reliable health statistics on a scale and in a format that public officials can use to take action, such as altering zoning rules to allow for beneficial placement of grocery stores, bike paths and parks.

## FOUR BROAD CATEGORIES

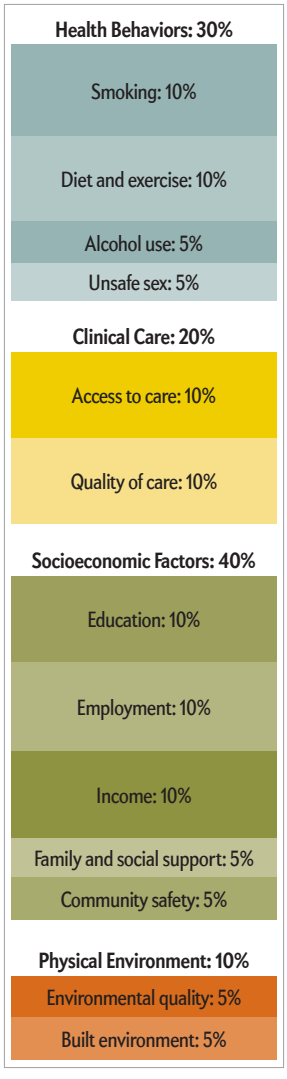
In comparing the counties within each state, Willem Van Dijk and her colleagues at the University of Wisconsin gather no new data. Instead they base their ratings on public information scoured nationwide from various sources, including the National Center for Health Statistics, the FBI and the U.S. Census. Their aim is to identify robust, reliable indicators that are measured the same way from county to county within each state for four broad categories—behavior, clinical care, socioeconomic status and physical environment—that research shows shape health.

Within these groupings, some of the most influential factors—such as smoking (behavior)—come as no surprise. Others include education level attained by most of the population (socioeconomic status), the relative number of sexually transmitted diseases diagnosed each year (behavior), and the number of car crashes related to drunk driving (behavior).

Researchers analyze a host of patterns in the data to help community leaders spot where improvements are most needed. For example, Wyandotte County scored particularly low on education in 2011. Part of the reason for that result is that just 60 percent of its ninth graders graduated from high school within four years, and only 42 percent of adult residents aged 25 to 44 had spent some time in college. Mayor Reardon hopes the high school internship and mentoring programs he has helped establish within the city government and within some of the county's high-technology firms will help turn around those low scores on education. Students need to see the link between college and a good job, he says, and to imagine themselves following that path.

**Scorecard:** Researchers rank U.S. counties according to how they measure up along the following behavioral, clinical, socioeconomic and environmental lines known to contribute to overall health.

### Health Checklist




## NOT EVERYONE BELIEVES

Not every Kansas official has responded as enthusiastically as Mayor Reardon has. At a 2009 public meeting in Shawnee County (home to the state capitol, Topeka), then County Commissioner Vic Miller dismissed Shawnee's low health ranking (78 out of 105) as misleading. "Frankly, I can't imagine what argument you're going to promote that dropout rates in schools relate to public health," Miller was quoted as saying in the *Topeka Capital-Journal*.

Willems Van Dijk says that Miller's skepticism is understandable, but the evidence that socioeconomic factors like education play a major role in health is solid and growing. For example, high school dropouts tend to die earlier than graduates. Further, their children are more likely to be born prematurely, robbing another generation of a healthy start. Every year of additional education improves those outcomes. "Research is now showing that many health effects once attributed to racial differences are actually tied to educational and economic disparities," she says.

## WHEN POLITICAL AND HEALTH PRIORITIES COLLIDE

No one expects a county's overall ranking to improve overnight. "Where you are on the curve isn't as important as which direction you're moving," Willems Van Dijk says. Wyandotte County was rated at or near the bottom of Kansas rankings for three years in a row and is likely to be there again when the state's latest numbers are released this spring. Yet Mayor Reardon is hopeful that the measures he is taking will ultimately shift the course. County planners must now consider the needs of pedestrians and bicyclists as well as drivers when designing road improvements, he notes. And a newly remodeled supermarket has doubled the amount of fresh fruits and vegetables that are available downtown. "There are a lot of polarizing issues in Kansas City," he says, "but I've been pleasantly surprised to see that doing all we can to improve the health of our community isn't one of them." That mapmaking visionary of epidemiology, John Snow, would be proud. SA

**SCIENTIFIC AMERICAN ONLINE**
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SOURCE: COUNTY HEALTH RANKINGS PROJECT, ROBERT WOOD JOHNSON FOUNDATION AND UNIVERSITY OF WISCONSIN POPULATION HEALTH INSTITUTE

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

# Silicon Superego

## How much personality do we want from our gadgets?

**The most buzzed-about** new feature in the latest iPhone is Siri, the virtual minion. You can give her an amazing range of spoken commands, without any training or special syntax, and marvel as she does your bidding.

You can say, "Call my assistant" or "Wake me up at eight" or "Make an appointment with Dr. Woodward for Friday at 2 P.M." You can say, "How do I get to the airport from here?" or "Play Taylor Swift" or "When I get to the office, remind me to file the Smithers report." You can ask her how many fluid ounces there are in a liter or the distance to Mars or when George Washington was born.

In each case, Siri briefly contacts Apple's servers and then responds in a calm female voice, simultaneously displaying the information you requested.

It didn't take long, though, for Internet wiseacres to start asking her questions with less concrete answers—and marveling at her witty, sometimes snarky replies.

You: "Siri, I love you." Siri: "That's sweet, David. Now can we get back to work?"

You: "What's the meaning of life?" Siri: "I can't answer that now, but give me some time to write a very long play in which nothing happens."

You: "Open the pod bay doors, Siri." Siri: "I'm sorry, David, I'm afraid I can't do that. [Pause] Are you happy now?"

Siri is a breakthrough in voice control, sure, but she's also a breakthrough in computerized personality. The question is: Do we *want* our gadgets to have personality?

Programmers and designers have always struggled with that question. The creators of every operating system have had to come up with a consistent syntax for communicating with people. Over the years various companies have flitted uncertainly from one philosophy to another.

Until Siri came along, Apple's software has always avoided personal pronouns such as "I" and "you." The result: some awkward passive-voice snarls like "The document could not be opened because it could not be found."

Microsoft's dialog-box English not only favors the passive voice, but it's usually aimed at programmers, not humans: "SL_E_CHREF_BINDING_0UT_0F_T0LERANCE: The activation server determined that the specified product key has exceeded its activation count." Ah, of course!

Citibank's automated-teller machines lie at the opposite end of the Emily Post spectrum. They take the "I"/"you" personal approach to an extreme. "Hello. How may I help you?" says the welcome screen. When you sign off, you get, "Thank you. It's always a pleasure to serve you." These machines even try to take the blame for your own dumb mistakes: "I'm sorry, I don't recognize that password."

Now, deep down—actually, not that far down—we all know that our computers are not really engaging us; every utterance they make was written by a programmer somewhere. So why do the software companies even bother? If everyone knows it's just a trick, should we even care how personable our machines are?

Yes, we should.

The designers' intention, no doubt, was to make their machines more user-friendly by simulating casual conversation with fellow humans. But there's a side effect of that intention: in trying to program machines that speak like people, the programmers are forced to *think* like people.

In Citibank's case, writing messages in that second-person conversational style forced the engineers to put themselves in the mind-set of real humans. You can't write an "I" statement for your ATM without also considering the logic, the terminology and the clarity of those messages. Someone writing in that frame of mind would never come up with "The activation server determined that the specified product key has exceeded its activation count."

The genius of Siri's "personality," meanwhile, is that she doesn't care if you say, "Will it rain?" or "Will I need an umbrella?" or "What's the forecast?" She is programmed to understand any wording. This time the payoff is more than user-friendliness; it's happiness. When Siri does what you want, the first time, when you haven't read any instructions or followed any rules, you feel a surge of pride at your instantaneous mastery.

So yes, of course, machines that converse like people are a total fake-out, and we know it. But psychology is a funny thing—as when we're watching a great magic show, we're delighted even when we know it's all a trick. SA

**SCIENTIFIC AMERICAN ONLINE**
The funniest things your computer says: ScientificAmerican.com/jan2012/pogue

*Illustration by Thomas Fuchs*

BIOLOGY

# A NEW PATH TO LONGEVITY

Researchers have uncovered an ancient mechanism that retards aging. Drugs that tweaked it could well postpone cancer, diabetes and other diseases of old age

*By David Stipp*

*Photographs by Evan Kafka*

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

# ON A CLEAR NOVEMBER MORNING IN 1964

the Royal Canadian Navy's *Cape Scott* embarked from Halifax, Nova Scotia, on a four-month expedition. Led by the late Stanley Skoryna, an enterprising McGill University professor, a team of 38 scientists onboard headed for Easter Island, a volcanic speck that juts out from the Pacific 2,200 miles west of Chile. Plans were afoot to build an airport on the remote island, famous for its mysterious sculptures of enormous heads, and the group wanted to study the people, flora and fauna while they remained largely untouched by modernity.

The islanders warmly welcomed Skoryna's team, which brought back hundreds of specimens of plants and animals, as well as blood and saliva from all 949 of the residents. But a test tube of dirt turned out to be the biggest prize: it contained a bacterium that made a defensive chemical with an amazing property—the ability to prolong life in diverse species.

Several research teams have now demonstrated that the chemical, named rapamycin, boosts the maximum life span of laboratory mice beyond that of untreated animals. Dubious anti-aging claims are sometimes made based on data showing increased average life span, which can be achieved by antibiotics or other drugs that reduce premature death yet have nothing to do with aging. In contrast, increased *maximum* life span (often measured as the mean life span of the longest-lived 10 percent of a population) is a hallmark of slowed aging. No other drug has convincingly extended maximum life span in any of our mammalian kin—gerontology's long-awaited version of breaking the sound barrier. The success in mice has therefore been a game changer for scientists who study aging and how to mitigate its effects. Gerontologists dearly want to find a simple intervention for slowing aging, not merely to increase longevity, but because putting a brake on aging would be a broad-brush way to delay or slow progression of so much of what goes wrong with us as we get old, from cataracts to cancer.

For years gerontologists' hopes of discovering antiaging compounds had been on a roller coaster. Optimism rose with the discovery of gene mutations that extend maximum life span in animals and with new insights into how calorie restriction produces the same effect in many species. Yet the advances, for all their promise, did not reveal any drugs that could stretch the outer limits of longevity in a mammal. Although calorie restriction, which involves nutritionally adequate near-starvation diets, can both do that and delay cancer, neurodegeneration, diabetes and other age-related disorders in mice, very stringent dieting is not a feasible option for slowing aging in most mortals.

In 2006 resveratrol, the famous ingredient in red wine that replicates some of calorie restriction's effects in mice, seemed likely to break through the barrier when it was shown to block the life-shortening consequences of high-fat diets in the rodents. But this substance, which is thought to act on enzymes known as sirtuins, later failed to extend maximum life span in mice fed normal diets. The disappointing picture suddenly brightened again when the rapamycin results were announced in mid-2009. A trio of labs jointly reported that rapamycin, by then known to inhibit cell growth, extended maximum life span by some 12 percent in mice in three parallel experiments sponsored by the National Institute on Aging. What is more, to gerontologists' amazement, the drug extended average survival by a third in old mice that were presumed to be too damaged by aging to respond.

Rapamycin's shattering of the life span barrier in mammals has riveted attention on a billion-year-old mechanism that appears to regulate aging in mice and other animals and may well

IN BRIEF

**In 2009** scientists discovered that a drug called rapamycin could significantly extend life span in mice, doing so by interfering with the activity of a protein called mammalian TOR, or mTOR.
**The finding** is the most compelling evidence to date that mammalian aging can be slowed pharmaceutically, and it galvanized interest in mTOR's role in the aging process.
**The result** also highlighted a mystery: Why would suppressing cellular growth and replication—one effect of interfering with mTOR—extend life span?
**Research** into that question could lead to medicines that postpone or mitigate aging-related disorders—from Alzheimer's disease to cancer to heart failure—and perhaps even extend how long humans can live.

PRECEDING PAGES: HAIR AND MAKEUP BY NIKKI WANG

do the same in humans. Its mainspring is a protein called TOR (*t*arget *o*f *r*apamycin) and the gene that serves as the protein's blueprint. TOR is now a subject of intense scrutiny in both gerontology and applied medicine because a growing number of animal and human studies suggest that suppressing the activity of the mammalian version (mTOR) in cells can lower the risk of major age-related diseases, including cancer, Alzheimer's, Parkinson's, heart muscle degeneration, type 2 diabetes, osteoporosis and macular degeneration. The remarkable diversity of potential benefits implies that if medicines able to target mTOR safely and reliably could be found, they might be used to slow the aging process in people, as rapamycin has in mice and other species—a possibility with profound implications for preventive medicine. (Rapamycin itself, unfortunately, has side effects that probably preclude testing whether it slows human aging.)

Similar predictions have been made for drugs that act on other molecules, notably the sirtuins. So what is different with mTOR? The finding that a drug has convincingly extended maximum life span in a mammal by acting on the molecule means that mTOR is central to mammalian aging and that researchers are now a lot closer than ever before to finding ways to brake the aging process. "It sure looks like [TOR] is the biggest game in town today and probably for the next decade," says Kevin Flurkey, a gerontologist at the Jackson Laboratory in Bar Harbor, Me., and a co-author of the rapamycin study in mice.

## TOR'S STORY

THE RESEARCH LEADING TO the discovery of TOR's influence on aging took shape when the Skoryna expedition turned over its soil samples to what was then Ayerst Laboratories in Montreal. Pharmaceutical researchers had been finding antibiotics in pinches of dirt since the 1940s, and so Ayerst's researchers screened the samples for antimicrobials.

In 1972 they sifted out a fungal inhibitor and named it rapamycin because Easter Island is also known locally as Rapa Nui. Ayerst initially hoped to use it to treat yeast infections. But then, scientists exploring its properties in cell-culture studies and on animals' immune systems found that it can hinder proliferation of immune cells, prompting its development instead to prevent immune rejection of transplanted organs. In 1999 rapamycin received U.S. Food and Drug Administration approval for patients who had received a kidney transplant. In the 1980s researchers also learned that the drug inhibits tumor growth, and since 2007 two derivatives of it—Pfizer's temsirolimus and Novartis's everolimus—have been approved to treat various kinds of cancer.

Biologists found rapamycin's ability to depress proliferation of both yeast and human cells highly intriguing—it suggested that the compound suppresses the actions of a growth-regulating gene conserved across the billion years of evolution between yeast and people. (Cells grow, expanding in size, when they are preparing to divide and proliferate.) In 1991 Michael N. Hall and his colleagues at the University of Basel in Switzerland identified the ancient target by discovering that rapamycin inhibits the effects of two growth-governing yeast genes, which they named *TOR1* and *TOR2*. Three years later a number of investigators, including Stuart Schreiber of Harvard University and David Sabatini, now at the Whitehead Institute for Biomedical Research in Cambridge, Mass., independently isolated the mammalian *TOR* gene. Many other species, including worms, insects and plants, are now known to possess *TOR* genes that govern cell growth.

Through the 1990s researchers learned much more about the gene's roles in cells and the body as a whole—many of which ultimately turned out to have a bearing on aging. They found, notably, that the gene encodes an enzyme, or catalytic protein, that combines in the cytoplasm with several other proteins to form a complex, called TORC1, which supervises a whole slew of growth-related activities in cells. Rapamycin mainly affects TORC1. A less well-understood, second complex, called TORC2, also incorporates the TOR enzyme.

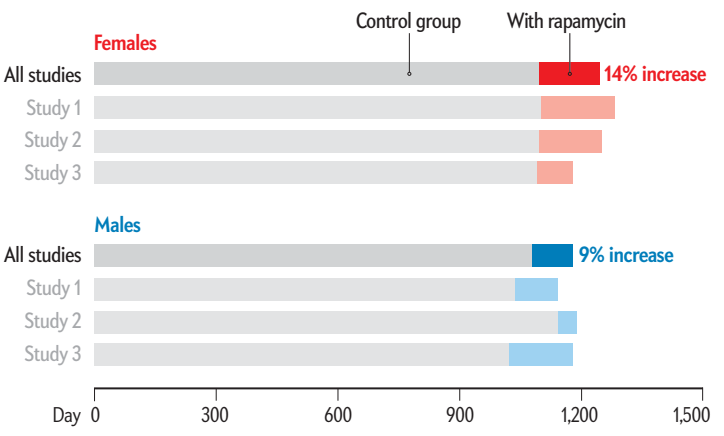
The teams further demonstrated that TOR is a nutrient sensor. When food is abundant, its activity rises, prompting cells to increase their overall production of proteins and to divide. When food is scarce, TOR settles down, and the resulting reduction in overall protein manufacture and cell division conserves resources. At the same time, a process called autophagy amps up: cells break down defective components such as misshapen proteins and dysfunctional mitochondria (the cell's energy powerhouses), generating by-products that can be exploited as fuel or building materials; newborn mice rely on autophagy to supply energy be-

TURNING POINT

# The Making of Supermice

**In 2009 three parallel experiments** in mice showed that a drug called rapamycin extended the animals' maximum life span by 9 to 14 percent. ("Maximum life span" was defined as the average longevity of the oldest 10 percent of a population.) It was the first time a drug had convincingly boosted maximum longevity in a mammal. The feat has raised new hope that, one day, a simple medicine might retard aging and protect late-life health in humans, although rapamycin's side effects probably bar it from serving as that drug.

**Longer Life for Mice**




SOURCE: "RAPAMYCIN FED LATE IN LIFE EXTENDS LIFESPAN IN GENETICALLY HETEROGENEOUS MICE," BY DAVID E. HARRISON ET AL., IN *NATURE*, VOL. 460; JULY 16, 2009

*Graphic by Jen Christiansen*

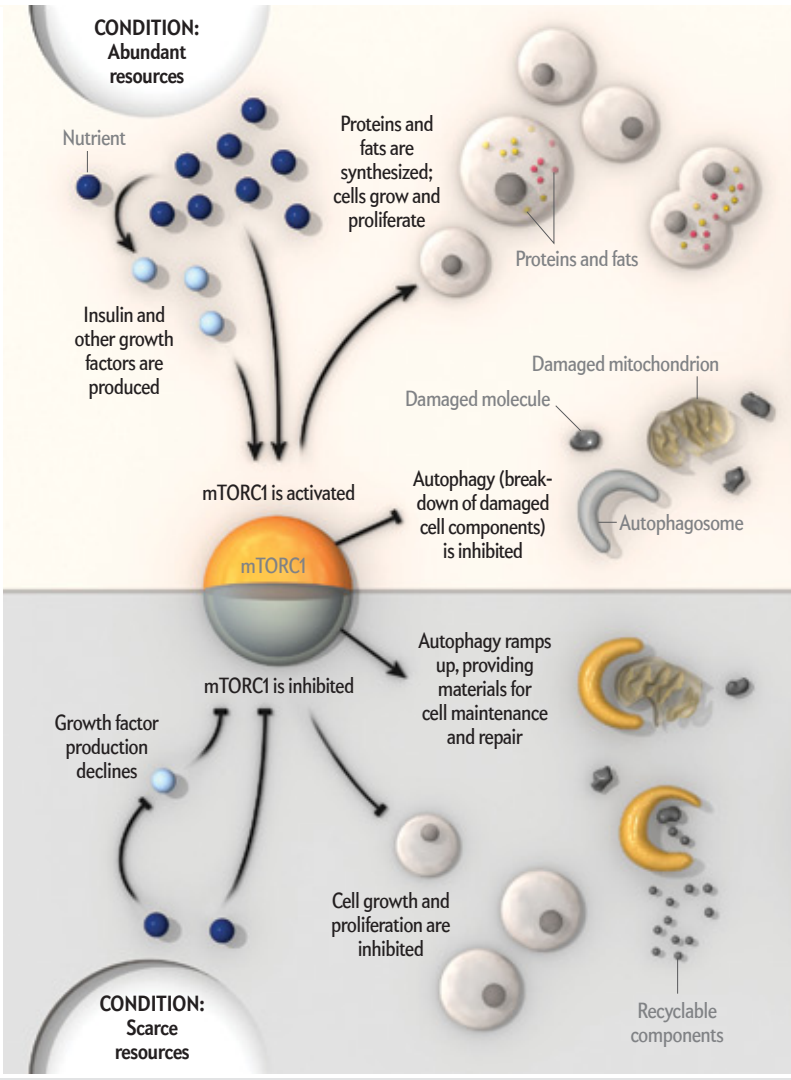
# TOR Story: A Jekyll and Hyde Molecule

**Rapamycin extends life** in yeast and animals by inhibiting a protein called TOR; calorie restriction, too, slows aging in part by acting on TOR. Research into how the protein functions in cells and into why its inhibition slows aging indicates that TOR is both angelic and diabolical. It is a nutrient sensor critical to organismal growth and development early in life (*near right*). Yet its continued activity after maturity can impair cell function (*far right*) and thus damage tissues. Investigators suspect that these late-life effects on TOR contribute to aging and its associated diseases in humans. The figures here, which focus on mammalian TOR (mTOR) are highly simplified; mTOR is affected by and affects a complex network of molecules in cells. (The pointed arrows represent stimulation; the others represent inhibition.)

## The Good Guy: A Key Nutrient Sensor Early in Life

Mammalian TOR exerts many of its effects as part of a complex called mTORC1. When food is plentiful (*top*), which evokes increased production of insulin and related proteins (known as growth factors), mTORC1 reacts to the nutrients and the growth factors by stimulating the synthesis of cellular components (especially proteins and fat) and prompting cell growth and division. At the same time, the complex instructs cells to pull back on autophagy—a process that degrades damaged mitochondria (the cell's energy factories) and molecules.

When food or other resources are scarce (*bottom*), mTORC1 quiets down, causing cells to focus on self-preservation over replication. Meanwhile autophagy increases to provide an emergency supply of raw materials for cellular repair and energy generation.




fore they start nursing. When food returns, the seesaw relation between TOR and autophagy swings back again: TOR activity rises, and autophagy slows.

Researchers also discovered that signaling pathways headed by TOR and insulin in animals are intertwined; signaling pathways are sequences of molecular interactions that control a cell's activities. Insulin is the hormone released by the pancreas after meals to signal muscle and other cells to absorb glucose from the blood for energy. But that is not all insulin does. It is a growth factor; both it and related proteins help to rev up the TOR pathway, a behavior that helps induce cells throughout the body to grow and proliferate in response to nutrient intake. In another feature important for health, the wiring between the TOR and insulin pathways includes a negative feedback loop: stimulating TOR makes cells less sensitive to insulin's signals. Chronic overeating, then, will activate TOR excessively and make cells increasingly deaf to insulin; this insulin "resistance," in turn, can lead to high blood sugar levels and diabetes and can also contribute to other age-related disorders, such as heart problems.

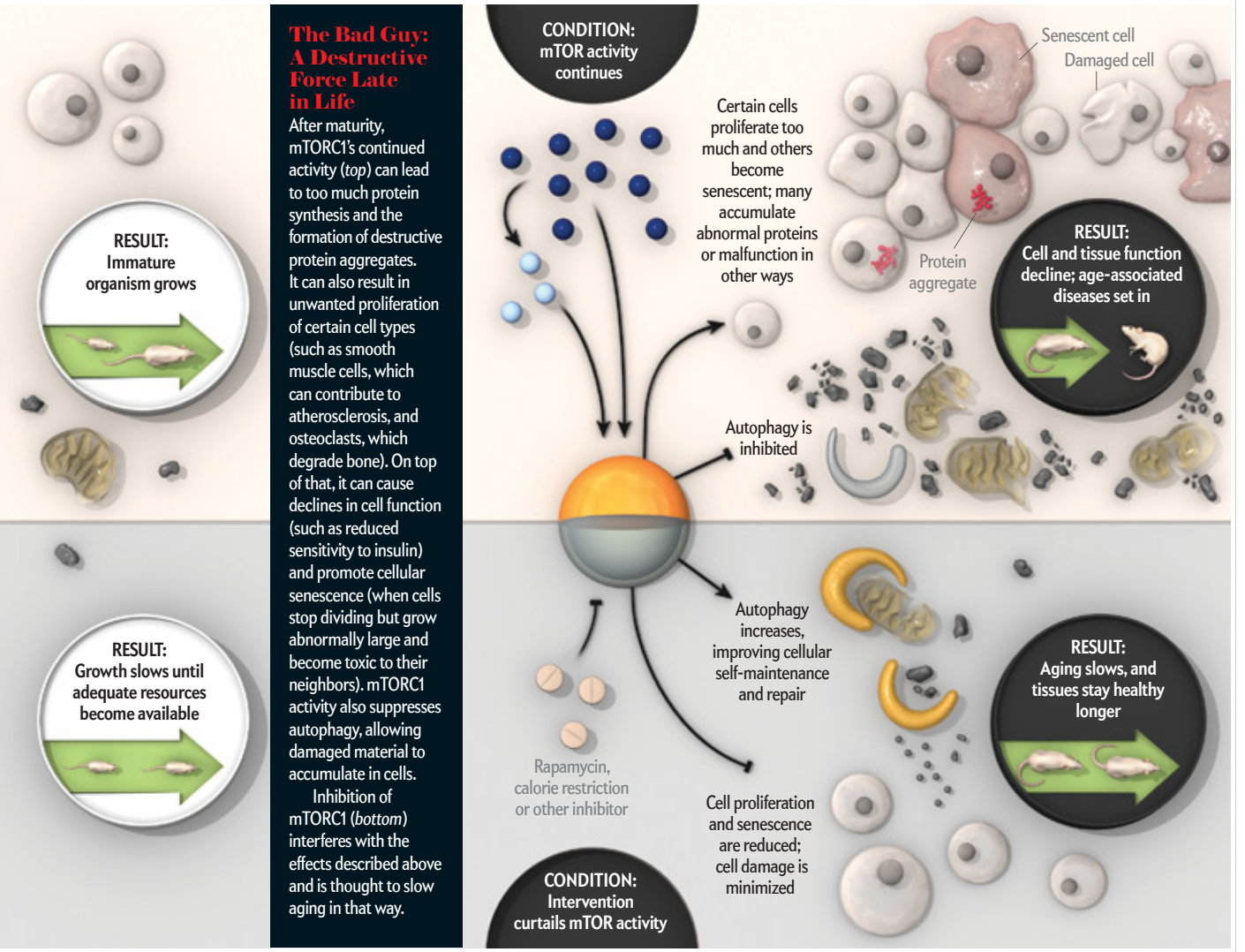
TOR also reacts to cellular stresses beyond nutrient shortages, including low oxygen levels and DNA damage. In general, when cells sense threats to survival, TOR activity dials back. The consequent slowing of protein production and cell proliferation frees up resources so that cells can channel them into DNA repair and other defensive measures. Studies in fruit flies indicate that as protein synthesis gets broadly curtailed in this red-alert mode, protein manufacturing also shifts in a way that leads to selective production of key mitochondrial components, perhaps helping cells rejuvenate their energy systems. No doubt this multifaceted "stress response" evolved to help cells cope with harsh conditions, but it may also inadvertently harden them against the ravages of time.

### FINDING THE AGING LINK

THE IDEA THAT TOR influences aging dates from findings in the mid-1990s indicating that nutrient-starved cells curtail growth by reducing TOR activity. Gerontologists had seen something like this before: in 1935 Cornell University nutritionist Clive McCay showed that putting young rats on near-starvation diets made them slow-growing *and* extraordinarily long-lived. Calorie restriction has since been shown to extend maximum life span in species ranging



*Illustration by Emily Cooper*




from yeast to spiders to dogs; preliminary evidence suggests that it also does so in monkeys. Cutting normal calorie intake by about a third early in life generally boosts maximum life span by 30 to 40 percent, apparently by postponing the deterioration of aging; elderly rhesus monkeys in long-term studies of calorie restriction are extraordinarily healthy and youthful-looking for their ages.

The approach does not always work—in some strains of lab mice, it actually shortens life—but mounting evidence implies that calorie restriction can promote healthy aging in people just as it does in monkeys. Thus, identifying compounds that evoke calorie restriction's effects without inducing hunger is a grail for scientists who study aging.

By the early 2000s researchers knew enough about TOR's functions to suspect that blocking its influence in cells might mimic calorie restriction. In 2003 Tibor Vellai, a Hungarian researcher visiting at the University of Fribourg in Switzerland, led a roundworm study offering the first evidence that inhibiting TOR may oppose aging: by genetically suppressing TOR synthesis in worms, he and his colleagues more than doubled the worms' average life span. A year later a study at the California Institute of Technology led by Pankaj Kapahi, now at the Buck Institute for Research on Aging in Novato, Calif., demonstrated that quelling TOR activity in fruit flies extended their average life span, too, and protected them from the consequences of rich diets, just as calorie restriction does. And in 2005 Brian Kennedy, then at the University of Washington, and his colleagues hammered home the link between TOR and aging by showing that disabling various TOR pathway genes in yeast cells increased longevity.

These studies, along with others on TOR, were especially intriguing because they suggested that inhibition of TOR mimics not only calorie restriction but also mutant genes known to extend life span. The first such "gerontogenes" had been discovered about a decade earlier in roundworms whose mean and maximum life spans were doubled by mutations later shown to interrupt their species' version of insulin signaling. The discovery that aging, previously thought to be intractably complex, could be dramatically slowed by altering a single gene had helped make gerontology a hot topic; among other things, it suggested that human aging might be retarded with drugs. That idea was reinforced by the discovery of various mouse gerontogenes in the late

1990s and early 2000s that block growth signals, including ones conveyed into cells by insulin and a closely related hormone called insulinlike growth factor 1. In 2003 a mouse with one such mutation set the record for its species' longevity: nearly five years. Lab mice generally live less than 30 months.

You might think the connections between TOR, calorie restriction and gerontogenes would have inspired a heated race to test rapamycin's life-extending effect in mammals. Yet experts on mammalian aging "didn't really take TOR seriously" before the late 2000s, says Steven Austad, a gerontologist at the Barshop Institute for Longevity and Aging Studies at the University of Texas Health Science Center at San Antonio. The reason is that rapamycin was known as an immunosuppressant; hence, long-term administration, it was widely assumed, would be toxic to mammals. Still, Zelton Dave Sharp, one of Austad's independent-minded colleagues at the Barshop Institute, concluded otherwise after studying the TOR literature. In 2004 he instigated a major study on life span in mice that were chronically dosed with rapamycin.

Funded by the National Institute on Aging, the study seemed to go badly at first—trouble formulating the drug in mouse chow delayed the initiation of doses until the study's rodents were 20 months old, the human equivalent of 60 years. At that point, Austad says, "no one—and I mean no one—really expected it to work." Indeed, not even calorie restriction reliably extends life span in such old animals. But in 2009 three gerontology labs that jointly conducted the study—Randy Strong's at the Barshop Institute, David E. Harrison's at the Jackson Laboratory and Richard A. Miller's at the University of Michigan at Ann Arbor—made history by reporting that the drug had upped life expectancy by an astounding 28 percent in the aged male rodents and 38 percent in the females versus control animals. Maximum life span was increased by 14 percent in females and 9 percent in males.

The galvanizing mouse results were quickly followed by others highlighting TOR's importance in aging. Researchers at University College London reported that disabling a gene called *S6K1,* which gives rise to an enzyme that mediates mTOR's control of protein manufacturing, makes female mice resistant to age-related diseases and extends their maximum life span. (Mysteriously, males showed scant benefit.) And the three U.S. labs that first tested rapamycin in mice reported that initiating doses in the rodents at nine months of age extended their life spans by about the same amount that starting them at 20 months did—suggesting that rapamycin mainly confers benefits after midlife, possibly because that is when the deterioration it opposes mostly occurs.

The fact that inhibiting TOR prolongs life across species now stands out like a beacon in the molecular murk surrounding aging. That prominence does not mean, however, that other aging-related pathways are unimportant for longevity. Indeed, gerontologists increasingly picture the pathways that calorie restriction affect as belonging to a complex, many-pronged network that can be tweaked in various ways to promote healthy aging. The network's components include insulin-related enzymes and proteins called FoxOs that activate stress responses in cells. Considerable evidence also indicates that sirtuins help to induce calorie restriction's benefits in mammals and may, in some circumstances, participate in TOR inhibition. At this point, though, TOR appears to be the closest thing to the network's central processing unit, integrating various inputs to control the rate of aging, at least in various animal species and perhaps humans, too.

## AN ENIGMA UNRAVELS

IN TRYING TO BETTER understand how TOR inhibition and calorie restriction extend life span in so many species, researchers have come up against a long-standing mystery: Why would any mechanism evolve to retard aging?

The issue has evolutionary biologists scratching their heads because natural selection works to foster successful reproduction, not to enable organisms to go into overtime in the game of life by remaining vibrant at ages when members of their species have typically been wiped out by predators, infections, accidents, and the like. Because of such "extrinsic" risks to survival, evolution effectively equips creatures to live long enough to reproduce before the environment does them in; then, as their odds of continued survival decline, they deteriorate like abandoned houses. Yet calorie restriction retards late-life decline in widely differing species, which implies that it evokes an ancient, conserved mechanism that has been shaped by natural selection to slow aging under some circumstances.

A frequently cited solution to the puzzle holds that calorie restriction taps an evolved starvation response that brakes organisms' aging during lean times so they can last long enough to reproduce when conditions improve. Skeptics, such as the Barshop Institute's Austad, counter that there is no evidence that low-calorie diets make animals in the wild live longer; calorie restriction has been observed to extend life span only in pampered lab animals. Already lean wild animals weakened by hunger may have little chance of surviving long enough to benefit from, and pass on, genes that slow aging and thus give rise to an evolved starvation response.

Some gerontologists think another solution to the conundrum makes more sense: calorie restriction extends life span as a side effect of responses evolved for purposes unrelated to aging. Austad, for example, theorizes that during lean times, animals branch out and eat unfamiliar things in the wild, exposing themselves to toxic substances not present in their regular food. Such "hard foraging" might have selected for a tendency to rev up inner defens-

es against poisons as hunger sets in, activating the cellular stress-response and repair processes that accompany it and thereby inadvertently slowing aging.

A few years ago Mikhail V. Blagosklonny, a cancer researcher at the Roswell Park Cancer Institute in Buffalo, N.Y., seized on discoveries about TOR to propose another theory that explains calorie restriction's magic as a kind of accident. A native of Russia whose work has ranged widely across cancer research and cell biology, he was inspired by an unorthodox idea: the capacity for growth, which seems the very essence of youthfulness, drives us into the grave later in life. Calorie restriction prolongs life, he posits, by interfering with the untoward, late-life effects of growth pathways, TOR's most important among them.

Blagosklonny's theory holds that TOR, which is essential for development and reproduction, becomes the engine of aging after maturity is reached. Because of its progrowth signaling, it abets proliferation of smooth muscle cells in arteries (a key step in atherosclerosis), accumulation of fat (which helps to spur body-wide inflammation), development of insulin resistance, multiplication of cells called osteoclasts that break down bones, and growth of tumors. Further, by diminishing autophagy, TOR favors the buildup of aggregation-prone proteins and of dysfunctional mitochondria, which spew DNA-damaging free radicals and hurt cells' energy metabolism. It also contributes to the accumulation of degradation-resistant proteins in neurons, a process that plays a part in Alzheimer's and other forms of neurodegeneration. Blagosklonny has shown that, late in life, TOR's signals can also help trigger cell senescence, a kind of night-of-the-living-dead state that damages nearby cells and saps tissues' regenerative capacity.

All this shows, Blagosklonny argues, that evolution has not built a mechanism designed to slow aging. Rather the life-extending effects of rapamycin, calorie restriction and gene mutations that block progrowth hormones are merely accidents of nature—ones that happen to interfere with what he calls the "twisted growth" of aging, causing it to play out more slowly than usual. In effect, the TOR pathway behaves very much like an aging program even though it was built to aid early development.

Although Blagosklonny's theory is novel, one of its key inspirations was a well-regarded hypothesis proposed in 1957 by the late evolutionary biologist George Williams. He theorized that aging is caused by two-faced genes that are beneficial early in life but harmful later on. Such "antagonistic pleiotropic genes" are favored by evolution because, as Williams put it, natural selection is "biased in favor of youth over old age whenever a conflict of interest arises." Blagosklonny sees *TOR* as the quintessential example of such genes.

Like many novel theories, Blagosklonny's is controversial. It strikes certain scientists as putting too much weight on TOR, whereas others see aspects of TOR distinct from growth promotion as the key thing—for instance, some regard TOR's inhibition of autophagy, which renews cellular components, as its dominant influence on aging. Still, some TOR experts find the theory plausible, and Basel's Hall gives Blagosklonny credit for "connecting dots that others don't even see"—adding, "and I am inclined to think he is right."

## TOR AND MEDICINE'S FUTURE

IF TOR IS A KEY DRIVER of aging, what are the options for defanging it? Rapamycin's side effects may rule it out as a candidate antiaging drug in people because, among other things, it can increase blood cholesterol, cause anemia and interfere with wound healing.

Another drug, metformin, might be an alternative, although much testing would be needed to evaluate the idea. Metformin is the most widely prescribed diabetes treatment—millions have safely taken it for long periods to lower blood glucose. Its mechanism of action is not well understood, but it is known to inhibit the TOR pathway and to activate another aging-related enzyme called AMPK, which is likewise stimulated by calorie restriction and promotes the stress response in cells. Metformin also has been shown to emulate calorie restriction's effect on gene activity levels in mice, and some evidence indicates that it may increase maximum life span in the rodents. We are still years away from knowing whether metformin can mimic calorie restriction in people, although rigorous tests of its ability to extend life span in mice are now under way.

Boosting human longevity proportional to rapamycin's enhancement of mouse life span could potentially add, on average, five to 10 years to a human life. That would be huge. Indeed, life expectancy in the developed world has risen so much over the past century that when it comes to aging, we are like Olympic athletes trying to eke out ever smaller incremental gains—average life span in the U.S. rose by more than 50 percent during the 20th century; over the past decade it rose by less than 2 percent.

Because we have cut early-life mortality about as low as it can go, boosting life expectancy much at this point will require pushing back diseases of aging. The exploding costs of geriatric medicine suggest this is a very tall order. But drugs that slowed aging could affordably manage it. In effect, they would serve as preventive medicines that could postpone or retard our late-life ills—dementia, osteoporosis, cataracts, cancer, loss of muscle mass and strength, deafness, even wrinkles—just as medicines that cut blood pressure and cholesterol now help to push off middle-age heart attacks. And they would buy us quality time, extending our period of vibrancy before we become frail and die.

Developing such drugs would not be easy. One obstacle is the lack of a reliable way to measure the rate of human aging; a good yardstick would enable researchers to test efficacy without having to run untenably long trials. Yet finding safe antiaging medicines would be worth the effort, if only to promote healthy aging irrespective of increasing longevity. Who would have thought that a vial of dirt scooped up almost five decades ago would become such fertile soil for research that could lead to more years of quality life? SA


MORE TO EXPLORE

**TOR Signaling in Growth and Metabolism.** Stephan Wullschleger et al. in *Cell,* Vol. 124, No. 3, pages 471–484; February 10, 2006. www.ncbi.nlm.nih.gov/pubmed/16469695

**Growth and Aging: A Common Molecular Mechanism.** Mikhail V. Blagosklonny and Michael N. Hall in *Aging,* Vol. 1, No. 4, pages 357–362; April 20, 2009. www.ncbi.nlm.nih.gov/pubmed/20157523

**Rapamycin Fed Late in Life Extends Lifespan in Genetically Heterogeneous Mice.** David E. Harrison et al. in *Nature,* Vol. 460, pages 392–395; July 16, 2009.

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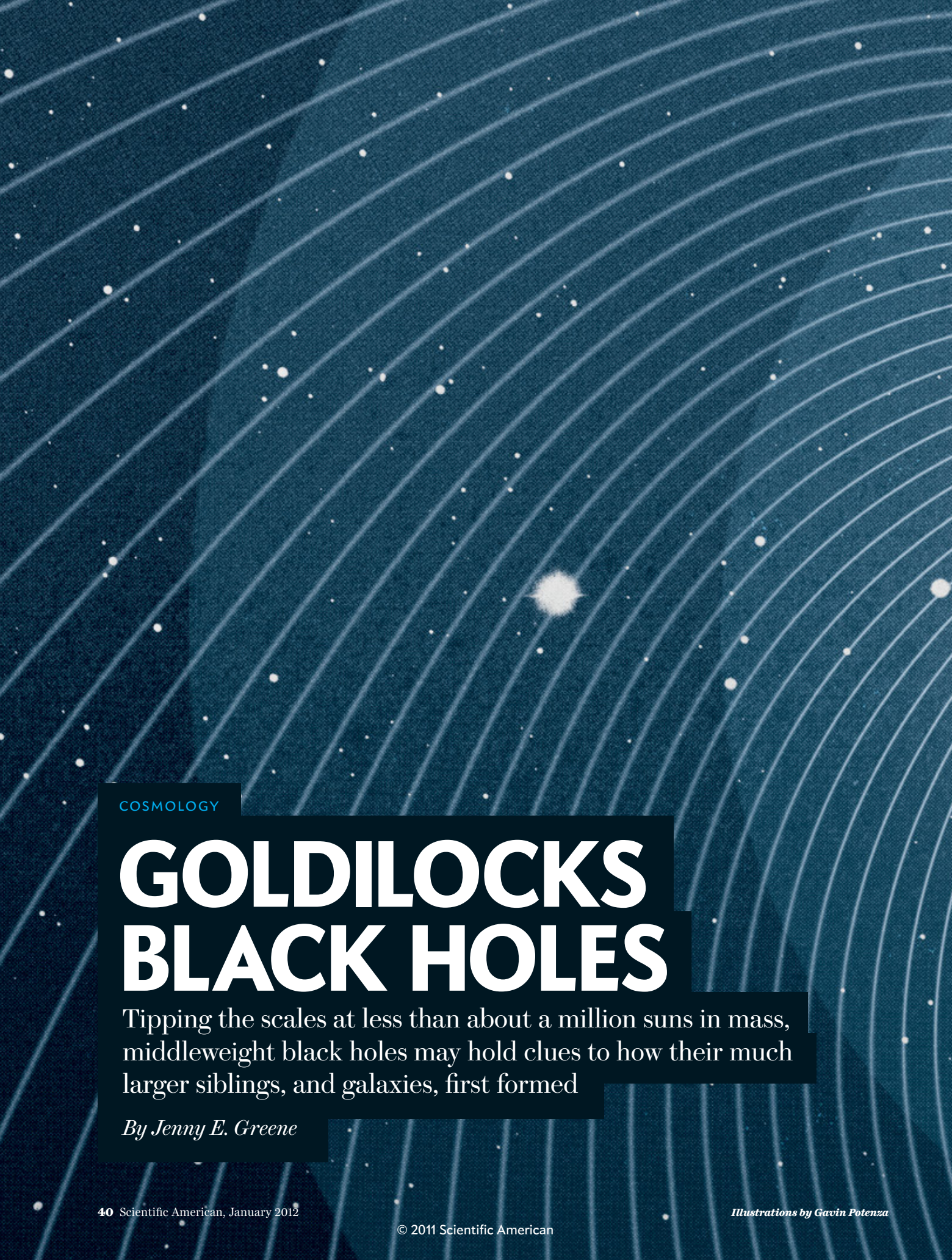


COSMOLOGY

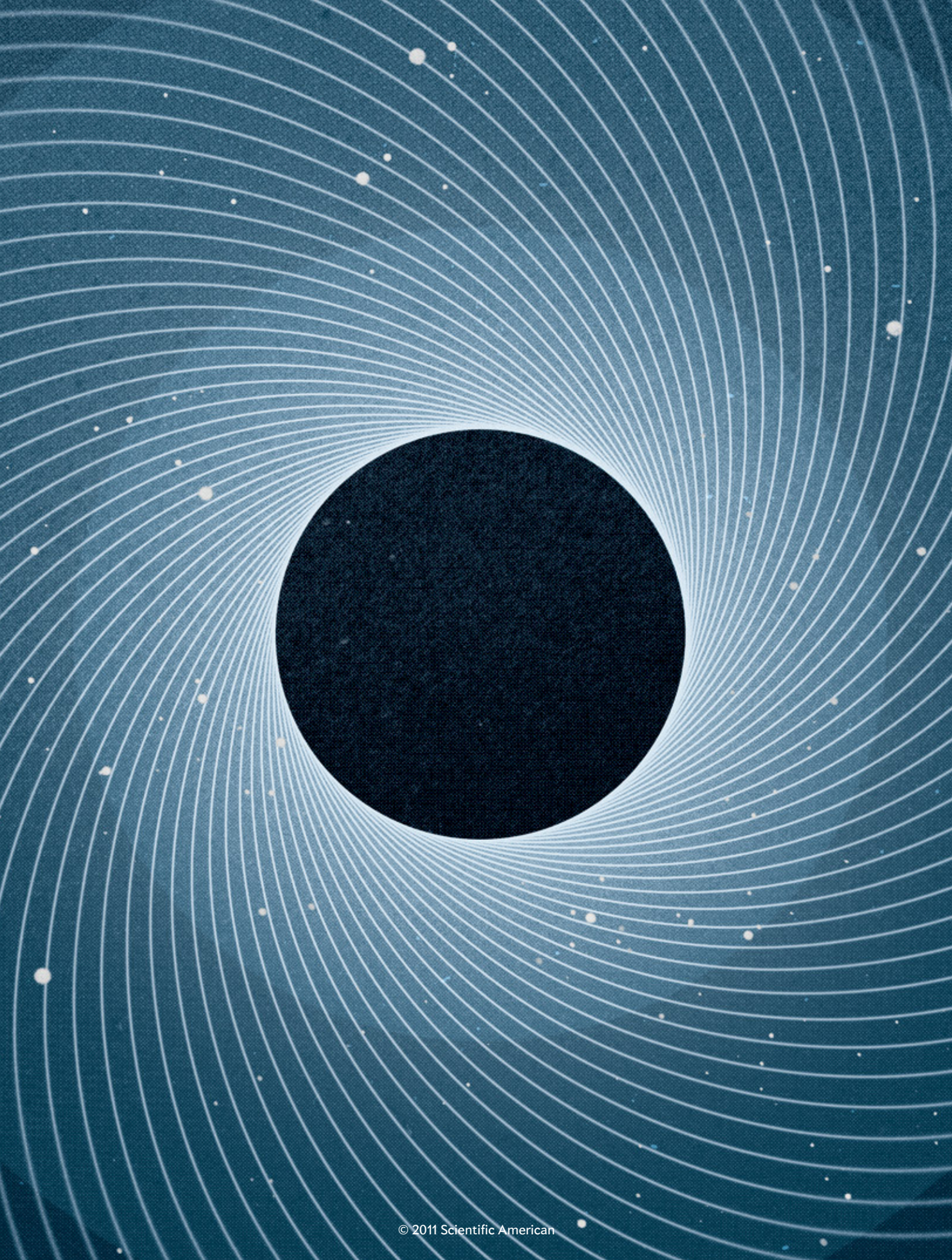
# GOLDILOCKS BLACK HOLES

Tipping the scales at less than about a million suns in mass, middleweight black holes may hold clues to how their much larger siblings, and galaxies, first formed

*By Jenny E. Greene*



*Illustrations by Gavin Potenza*



**Jenny E. Greene** pioneered the study of lower-mass black holes in galaxy centers as a part of her Ph.D. thesis at Harvard University. Now an assistant professor in astronomy at Princeton University, she investigates the evolution of galaxy structure more generally. She also teaches algebra to inmates in New Jersey prisons.

ASTRONOMERS HAVE KNOWN FOR SOME 10 YEARS that nearly every large galaxy contains at its core an immense black hole—an object having such intense gravity that even light cannot escape. The death of stars can produce small black holes—with masses ranging from about three to 100 times the mass of the sun—but such stellar-mass black holes are tiny compared with the behemoths at the centers of galaxies, measuring millions to billions of solar masses.

These supermassive black holes pose major puzzles: Why are they so common in galaxies? Which came first—the galaxy or the hole? And how did they form in the first place?

The mystery is intensified because supermassive black holes were already in place when the universe was very young. Last June, for instance, astronomers reported the earliest example detected so far—a hole of about two billion solar masses that existed 13 billion years ago, a mere 770 million years after the big bang. How could black holes get so big so quickly?

Such rapid formation is perplexing because although black holes have a reputation as mighty vacuum cleaners, they can also act like immense leaf blowers. Gas falling toward a black hole ends up swirling around the hole in a huge disk, the so-called accretion disk. The material heats up and emits radiation, particularly as it approaches the point of no return at the inner margins of the disk. The radiation pushes away other infalling material, limiting how fast the hole can ordinarily grow by accretion. Physicists calculate that a black hole sucking in surrounding matter continuously at its maximal rate would double its mass every 50 million years. That is too slow for a "seed" black hole of stellar mass to grow into a billion-sun monster in less than a billion years.

Astrophysicists have proposed two general ways for seed black holes to form. The first, considered for many years, assumes that the earliest huge black holes were indeed the remnants of stars. The first stars ever to have taken shape in the universe were likely to have been extremely massive compared with those that came later, such as our sun, because the primordial gas clouds were free of elements that help the gas to cool and form smaller clumps. These big stars would have burned out fast and produced black holes of perhaps 100 times the mass of the sun. Some process must then bulk up these holes faster than ordinary accretion. For example, if a big hole formed in a dense cluster of stars, it would end up near the cluster center, with other massive stars and black holes. It could then quickly grow to 10,000 solar masses by swallowing other holes and thereby beating the usual feeding limits. Further growth to supermassive scale could be by more ordinary accretion, perhaps with other largish holes on the menu as well.

Once astronomers knew that large supermassive black holes existed very early on, though, they began to wonder if stellar-mass holes could become supermassive quickly enough, even beginning life with this kind of accelerated growth. People started to look for alternative ways to produce seed black holes, routes that would generate bigger holes than those that could form in the death throes of stars.

Researchers proposed models that made bigger seeds by skipping the middlemen (stars). Rather a large cloud of gas would collapse to create a black hole directly, one larger than the product of a dead star. By making seeds with masses of 10,000 to 100,000 suns, this process somewhat alleviates the time crunch to form supermassive black holes at early times. This kind of direct collapse does not happen in our universe today, but conditions were different when the universe was young.

IN BRIEF

**Black holes** with a billion times the sun's mass already existed early in the universe. How did these behemoths grow so big, so fast? What process formed the "seed" black holes from which they grew?

**Did the death throes** of the first stars provide numerous small seeds that then merged together, or did vast primordial gas clouds bypass the star stage and collapse to form larger seeds directly?

**Astronomers** are trying to solve this mystery by finding and analyzing leftover seeds—"middleweight" black holes. Early indications suggest that middleweights formed by direct collapse.

Unfortunately, it is hard to figure out which of these two scenarios took place—whether seed black holes started off small, as the products of dying stars, or on the contrary, started off larger, as the products of gas implosions. Although astronomers can peer far back in time by looking out to vast distances with telescopes, they cannot yet hope to detect seed holes in the act of forming; even the biggest seeds would be too small to be seen so far away. (The James Webb Space Telescope could reveal them, but it is not due for launch until 2018 and must survive political battles over its funding.) So my colleagues and I have been pursuing another strategy: looking for leftover seeds that have, for whatever reason, survived to the present day without growing supermassive.

If seed black holes started off as stars, we would expect to find many leftover seeds, in both the centers and outskirts of galaxies, because primordial stars could have died anywhere in the galaxy. We would also expect to find a continuous range of masses from 100 to 100,000 suns because their growth could get interrupted for lack of food at any stage along the way to supermassive status. In contrast, if seeds formed mainly by direct gas collapse, then the leftovers should be pretty rare; the direct collapse process, if it happened at all, would have occurred less often than ordinary star death. Instead of a wide range of masses, we would find most leftover seed black holes to be heavier than 100,000 suns (the theoretical models indicate that is likely the typical mass of the seeds that would form by direct gas collapse).

Other astronomers and I have therefore been scouring the skies for a new type of black hole, neither stellar in mass nor supermassive but somewhere in between: the so-called intermediate-mass, or middleweight, black hole. Our aim is to see if their prevalence and range of sizes are more consistent with the star collapse or gas collapse models. When we began this effort about a decade ago, it did not look promising. Astronomers knew of only one middleweight hole and considered it to be a fluke. Since then, though, we have found hundreds.

What counts as a "middleweight"? Here I will take it to mean a black hole with an estimated mass between 1,000 and two million suns. That upper limit is somewhat arbitrary, but it excludes the smallest well-known supermassives, such as the Milky Way's four-million-sun hole. In any case, the boundary is inherently fuzzy. In practice, measurements of a hole's mass often start out very uncertain—for instance, the masses of our first batch of middleweights all shifted up by about a factor of two a few years ago when we improved our measurement technique. The precise boundary does not matter as long as we study the entire population of holes extending down from the low supermassive range. What we have learned so far has already provided us a new view of the interactions between black holes and the galaxies that they live in.

## ELUSIVE MIDDLEWEIGHTS

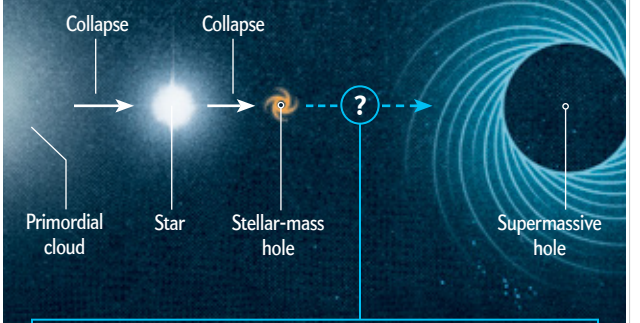
BLACK HOLES can reveal themselves in a number of ways. For instance, stars whipping around orbits at the very center of a galaxy are a telltale sign of a lurking supermassive black hole. Middleweight holes, however, are too puny to give away their presence by their gravity in this way. Instead we focus on "active" black holes—ones that happen to be eating stuff—because the hot infalling material emits a tremendous amount of light.

Over decades of studies astronomers found that active black holes usually live in big galaxies of a certain kind. Galaxies, par-

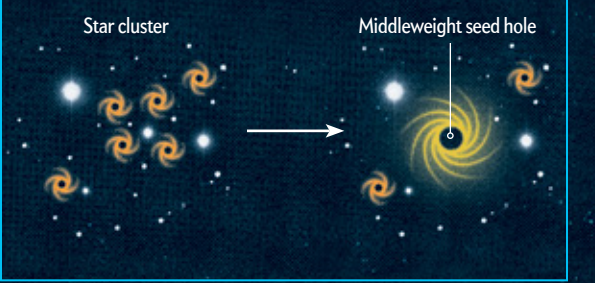
THE UNDERLYING QUESTION

# What Were the Seeds of Supermassive Black Holes?

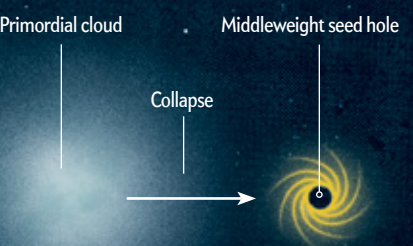
Immense black holes with masses greater than that of a billion suns already existed very early in the universe. The classic view of hole formation assumes that these giants began as "seed" holes created by the collapse of a primordial star. But such a small hole could not ordinarily grow quickly enough to become supermassive so early (*top*). A key question, then, is, How could larger seeds have formed (*center and bottom*)?




One explanation is that a big stellar-mass hole in a star cluster might quickly grow to 10,000 solar masses by swallowing other holes. This middleweight seed could then grow supermassive by eating gas.




Alternatively, a primordial gas cloud might collapse to form a middleweight seed hole directly. This hole, too, could then grow by eating gas.




The search for middleweight black holes seeks to determine which scenario took place.

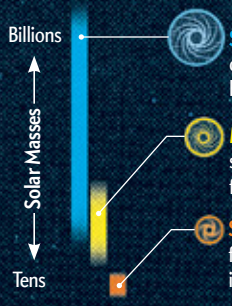
# Where Different Kinds of Black Holes Live

Galaxies come in many types, some of which routinely contain supermassive black holes. Our galaxy, the Milky Way (*left*), is a disk, or spiral, galaxy with a bulge (a large, dense collection of stars) and has a supermassive black hole of four million solar masses at its core (*blue*). Many stellar-mass black holes (*orange*) have also been detected in the Milky Way.

Bulged galaxies and large elliptical galaxies (*center*) all seem to harbor a supermassive hole at their core. In contrast, middleweight black holes (*right*, *yellow*) are more common in galaxies without a large bulge, such as bulgeless disks. Stellar-mass black holes occur throughout galaxies of all types.

## Classes of Black Hole

Known black holes fall into three classes, based on their mass, which is usually given in terms of solar masses, or "suns."

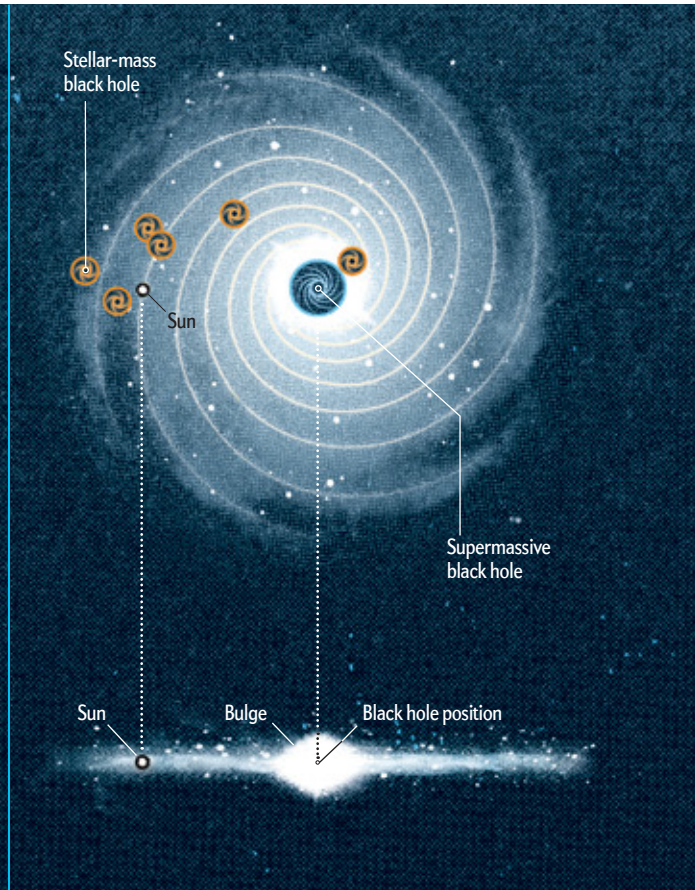



**SUPERMASSIVE BLACK HOLES:** Millions to billions of suns. Found in the cores of all big elliptical or bulged galaxies.

**MIDDLEWEIGHT BLACK HOLES:** 1,000 to two million suns. Suspected of being "leftover" seed holes that never finished growing to full supermassive size.

**STELLAR-MASS BLACK HOLES:** Known examples range from four to 30 suns. Formed when large stars collapse, which in theory can produce a hole of three to 100 solar masses.

*Black holes are not drawn to scale*




Disk galaxy with bulge (such as the Milky Way) and supermassive black hole

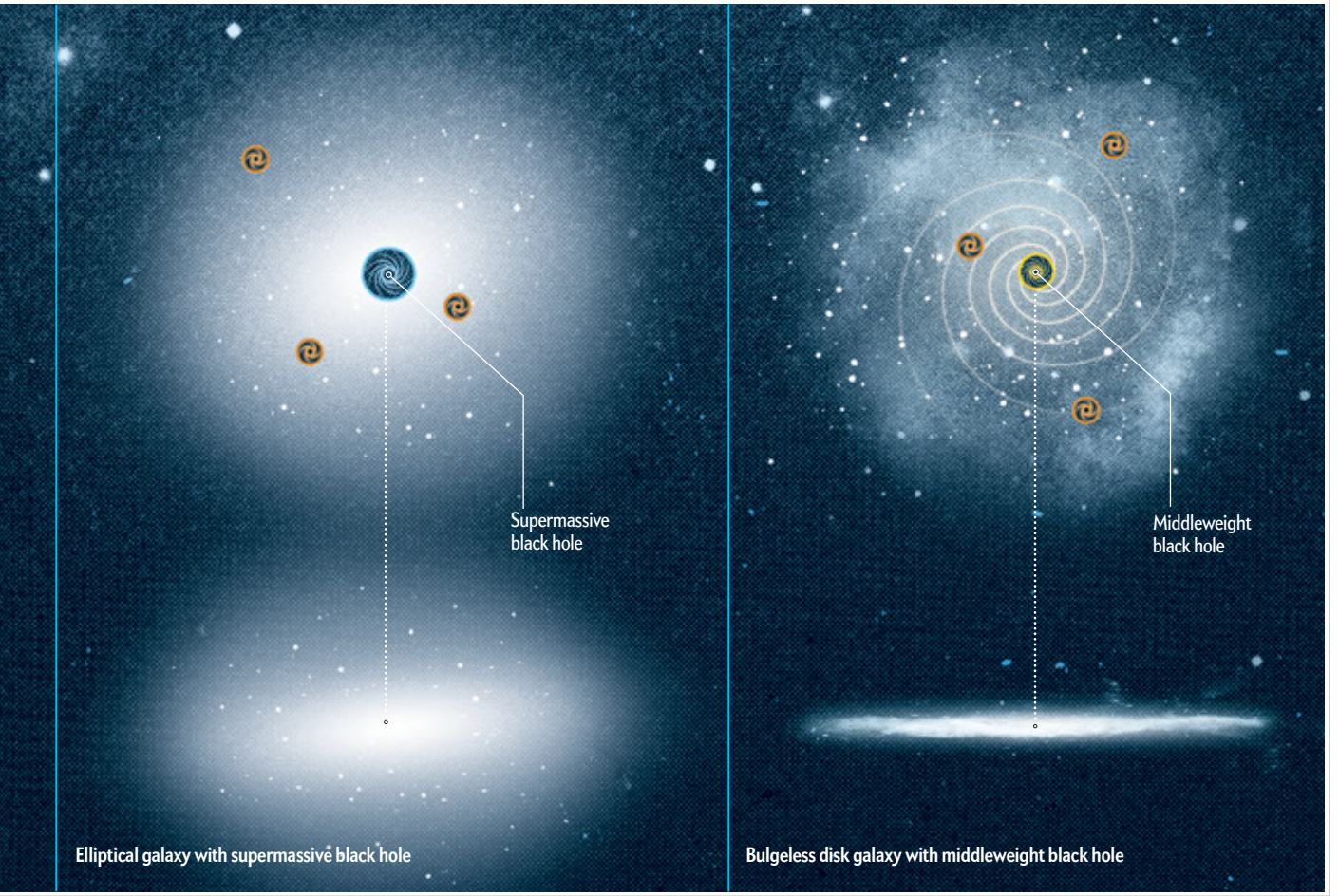
ticularly massive ones, come in two general types. Some, like our own, have a large, rotating disk of stars. These disk galaxies look like dinner plates when seen edge-on. The other kind, elliptical galaxies, are basically balls of stars. Some disk galaxies actually have small elliptical galaxies at their centers, known as bulges. Active black holes are most commonly found in large elliptical galaxies and disk galaxies with healthy bulges. Nearly every bulge astronomers look at that is close enough to tell turns out to harbor a black hole of millions to billions of solar masses. Furthermore, bigger bulges have bigger holes—the black hole's mass is usually about 1,000th of the bulge's mass. This surprising correlation is a mystery in its own right, implying that galaxies and supermassive black holes evolve together in ways that astrophysicists have not yet fathomed. More prosaically, this pattern suggested where to look for middleweight holes: in the smallest galaxies. But which ones?

A very puzzling little galaxy offered one idea. My thesis adviser, Luis C. Ho of the Carnegie Observatories, studied about 500 of the nearest bright galaxies for his own thesis in 1995. He found that while most of the galaxies with big bulges contain active black holes, galaxies without bulges do not—with one interesting exception. NGC 4395 is a disk galaxy with an active black hole and no bulge at all. Ho's own thesis advisers had noted this oddity as long ago as 1989, but most researchers considered it an anomaly. Except for NGC 4395, Ho's survey confirmed the broader rule: black holes are not found in bulgeless galaxies.

Accurately estimating the mass of the hole in NGC 4395 is a challenge. The most direct mass measurements in astronomy involve measuring orbital motion. For instance, the speed of a planet and the size of its orbit around the sun let us calculate the sun's mass. Similarly, the orbits of stars in a galaxy can reveal a black hole's mass but only if it is large enough for the effects of its gravity to be discernible in astronomers' observations of the star motions. The hole in NGC 4395 is too small.

Astronomers must therefore rely on less direct clues. For instance, x-rays coming from active black holes change in intensity over time, and the larger the black hole, the more slowly these variations occur. In 2003 David C. Shih and his colleagues, then at the University of Cambridge, found that the intensity of x-rays coming from NGC 4395 varies so quickly that it must be relatively small—most likely 10,000 to 100,000 solar masses. Ho arrived at the same rough mass range based on other evidence, also in 2003.

A slightly more direct measurement of the mass came in 2005, from Bradley M. Peterson of Ohio State University and his co-workers. They used the Hubble Space Telescope and a technique called reverberation mapping, which relies on gas clouds orbiting the hole similar to using planets orbiting the sun. The timing of echoes of light from the clouds provides the size of the orbits. Peterson and company concluded that the black hole is about 360,000 solar masses. Even with this technique, however,




the mass has a large uncertainty—as much as a factor of three—because of assumptions that feed into the number crunching.

The bulgeless galaxy NGC 4395 appears to host just the kind of intermediate-mass black hole we were looking for. Yet of the 500 galaxies examined by Ho, it was the only bulgeless one with clear evidence for an active black hole. The second was found in 2002. Aaron J. Barth, then at the California Institute of Technology, used the Keck II telescope in Hawaii to take a spectrum of a peculiar but little-studied galaxy called POX 52. Like NGC 4395, this galaxy had shown some signs of an active hole even though it is not one of the usual suspects for harboring a supermassive black hole (it is a rare type known as a spheroidal, which is distinct from the bulged disk and elliptical galaxies).

Barth sent the new POX 52 spectrum to Ho, who took one look at it and immediately asked Barth, "Where did you find such a beautiful spectrum of NGC 4395?" The two objects' spectra looked so similar that Ho could not tell them apart. (Features in the spectrum are what indicate the presence of a black hole.)

Because POX 52 is 300 million light-years distant (20 times farther away than NGC 4395), astronomers' mass estimates for its black hole are considerably less direct. Still, a variety of evidence all indicates that the galaxy harbors a black hole of around 100,000 suns. Middleweight black holes in bulgeless galaxies now formed a class of two.

Of course, to solve the bigger problem of how the seeds of supermassive black holes formed, we needed more middleweight specimens to answer a lot of basic questions: How common are middleweight black holes? Does every bulgeless galaxy contain one, or are most such galaxies holeless? Do these middleweight holes occur anywhere else? And are there specimens even smaller than these first two waiting to be found? Only by answering these questions could we learn about how seed black holes formed and what role they played in the early universe.

## COMBING FOR HOLES

UNFORTUNATELY, astronomers' standard techniques are biased against finding active middleweight black holes. The larger the black hole, the more it can eat and the brighter it can shine. Smallish black holes are faint and therefore harder to find. But it gets worse. The elliptical galaxies where large black holes tend to occur are extremely well behaved. These galaxies do not have much gas and are not making new stars, leaving a clean and unobstructed view of the galaxy center. In contrast, disk-dominated galaxies (like where we suspected middleweight black holes might commonly lurk) are often forming stars, and the young starlight and associated gas and dust can hide the active hole.

To overcome these obstacles, in 2004 Ho and I turned to an invaluable library of data designed for finding needles in the cosmic haystack—the Sloan Digital Sky Survey. Since 2000 this project's dedicated telescope in New Mexico has snapped imag-

es across more than a quarter of the sky and has recorded the spectra of millions of individual stars and galaxies.

We combed through 200,000 galaxy spectra and found 19 new candidates similar to NGC 4395—small galaxies that contained active black holes with masses we estimated at less than a million suns. Similar searches over the past few years, using more recent Sloan survey data, have expanded the total to about three dozen holes with masses under a million suns and more than 100 just over the million-sun threshold.

The method used to estimate these masses is relatively indirect. The Sloan light spectra tell us the speed of hot gas orbiting a hole. That is only half the information needed to compute the hole's mass directly (the other half is orbit-size). Still, astronomers know from observing active holes in the million- to billion-sun range how the gas speed usually trends with the hole's mass (smaller hole means slower gas). Extrapolating to somewhat lower-mass holes lets us pick out our little guys from the Sloan data.

These searches confirmed what we expected based on NGC 4395 and POX 52: a wider population of intermediate-mass black holes exists. Also in line with expectations, they are found preferentially in galaxies without bulges. Yet these holes still seem to be very rare. Only one in every 2,000 of the galaxies bright enough to study in the Sloan survey shows evidence for an active intermediate-mass black hole.

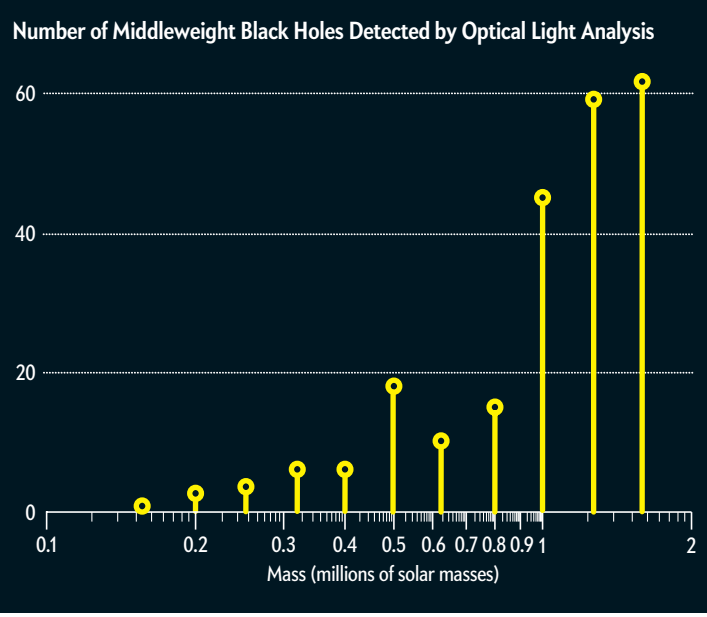
The Sloan searches, however, could be missing many black holes. They rely exclusively on optical light (the range of wavelengths our eyes can see), and dust clouds could well be hiding many black holes from sight. To get around this, astronomers are using wavelengths of light that can pass right through dust, such as x-ray, radio and midinfrared. Shobita Satyapal of George Mason University and her collaborators have been using midinfrared light to look for signs of hidden active black holes in bulgeless galaxies. Extreme ultraviolet light coming from material plunging into an active hole would wreak havoc in the surrounding gas, creating unusual species, such as excited states of highly ionized neon. Emissions from these ions would leave characteristic fingerprints in the midinfrared spectra. Relatively few galaxies are amenable to this kind of search, and Satyapal's team has found only a couple of new active middleweight black holes. Astronomers have also seen signs of possible middleweight or smallish supermassive black holes at x-ray and radio wavelengths, and follow-up observations to confirm these candidates continue.

These results indicate that the optical searches are indeed overlooking numerous bulgeless galaxies that hide their middleweight holes behind dust—but not enough to make middleweight holes common. The verdict is still out, but perhaps only 5 to 25 percent of bulgeless galaxies harbor a middleweight hole big enough to detect.

MIDDLEWEIGHTS FOUND SO FAR

## Early Evidence Favors Gas Collapse over Star Mergers

Analysis of optical light recorded from 500,000 galaxies has turned up more than 100 black holes with masses estimated to be under two million suns (*graph*). Other searches, using midinfrared light, x-rays and radio wavelengths, have detected additional candidate holes. So far it seems that most bulgeless galaxies do not have a middleweight at their core. These observations lend support to the direct collapse scenario of seed formation. If star collapse accounted for the earliest seeds, scientists would expect to have found many more smaller holes in the 10,000- to million-sun range.




### GROWING GALAXIES AND HOLES

THE OBSERVATIONS of middleweight holes in bulgeless galaxies may help explain the connection between larger holes and big bulges. As I mentioned earlier, supermassive holes in massive bulged galaxies tend to be about 1,000th of the mass of the bulge. The growth of a supermassive black hole appears to be intimately linked with the growth of the surrounding bulge. If the correlations between black holes and galaxies are established during the formation of the bulge, then there should be no correlations between the properties of bulgeless galaxies and their middleweight black holes.

A leading theory to explain how this tight correlation comes about in bulged galaxies goes like this: Elliptical galaxies and large bulges form when disk galaxies merge. During the merger, gravitational forces stir up the disks, so the stars no longer orbit in a disk but move around randomly in a ball (the new elliptical or bulge shape). Gas clouds collide during the merger and are funneled toward the center of the bulge, triggering a major burst of star formation, which increases the total mass of stars

SOURCE: "A NEW SAMPLE OF LOW-MASS BLACK HOLES IN ACTIVE GALAXIES," BY JENNY E. GREENE AND LUIS C. HO, IN *ASTROPHYSICAL JOURNAL*, VOL. 670, NO. 1; NOVEMBER 20, 2007



*Graphic by Jen Christiansen*

in the bulge. At the same time, the black holes from each galaxy merge together and eat some of the new gas in the galaxy center. In this way, large bulges and supermassive black holes can grow and evolve together through these large-scale processes that occur in galaxy mergers. By the time the hole reaches about 1,000th of the bulge mass, its leaf-blower aspect comes to the fore, pushing the remaining gas out of the galaxy center and ending the growth spurt.

Middleweights in bulgeless galaxies, such as NGC 4395, would never have had the benefit of these organized feasts. Instead they would be leftover seeds that have grown only by more happenstance meals of gas at the galaxy center—snacks that are not connected with events shaping the overall evolution of the galaxy. Some galaxies without bulges may not grow a black hole at all. That is the case for the pure disk galaxy M33 (a galaxy much like NGC 4395 in physical appearance), which very clearly contains no black hole more massive than 1,500 suns. Evidence is mounting for this picture, linking black hole growth with bulge formation, but many details remain to be worked out, and the case is not completely settled.

**Galaxy NGC 4395, a bulgeless disk galaxy, was the first to show signs of having a middleweight black hole at its core.**

COURTESY OF BOB FRANKE *Focal Ponte Observatory*

On the question of how black hole seeds formed in the first place, the rarity of middleweight holes lends weight to the theory of direct collapse of gas clouds in the early universe. If star collapse accounted for the earliest seeds, we would expect almost all those galaxies to contain a black hole of at least 10,000 suns at their center. It seems, however, that most small bulgeless galaxies do not contain such a hole at their center.

Other evidence also points toward the direct collapse scenario. In particular, the weak correlation of the middleweights' masses with their host galaxy masses more closely resembles that scenario's predictions. And it is much easier to make a billion-sun hole in a few hundred million years if the seeds start out heavy.

Of course, as more data come in, the conclusions drawn so far could change. For instance, if astronomers were to look at galaxies slightly fainter than those with spectra in the Sloan survey, the fraction of galaxies with middleweight holes might rise or fall. And it is possible that some galaxies contain middleweight black holes outside of galactic centers. Indeed, the search for middleweight holes is continuing on many fronts, as is described in detail at www.ScientificAmerican.com/jan2012/black-holes.

For now, many critical questions about middleweight black holes remain open. Are middleweight holes more common in specific types of small galaxies? (Such correlations might suggest new ways that holes and their host galaxies interact even before the merges that generate bulges and supermassive holes.) Do most bulgeless galaxies completely lack a middleweight hole, or do they have holes just slightly too small to be detected so far—perhaps in the range of 1,000 solar masses? (Such holes would surely have grown from remnants of dead stars and *not* formed by direct gas collapse.) Or do all bulgeless galaxies have hefty 10,000- to 100,000-sun holes, although most of them do not happen to be eating and spewing out x-rays and light? (That would change the conclusion that middleweights are rare.) The answers could push astrophysicists' theories of how galaxies and black hole seeds first formed in radically different directions. SA

## MORE TO EXPLORE


**A Low-Mass Central Black Hole in the Bulgeless Seyfert 1 Galaxy NGC 4395.** Alexei V. Filippenko and Luis C. Ho in *Astrophysical Journal,* Vol. 588, No. 1, pages L13–L16; May 1, 2003.

**Active Galactic Nuclei with Candidate Intermediate-Mass Black Holes.** Jenny E. Greene and Luis C. Ho in *Astrophysical Journal,* Vol. 610, No. 2, pages 722–736; August 1, 2004.

**Nuclear Activity in Nearby Galaxies.** Luis C. Ho in *Annual Review of Astronomy and Astrophysics*, Vol. 46, pages 475–539; September 2008. http://arxiv.org/abs/0803.2268

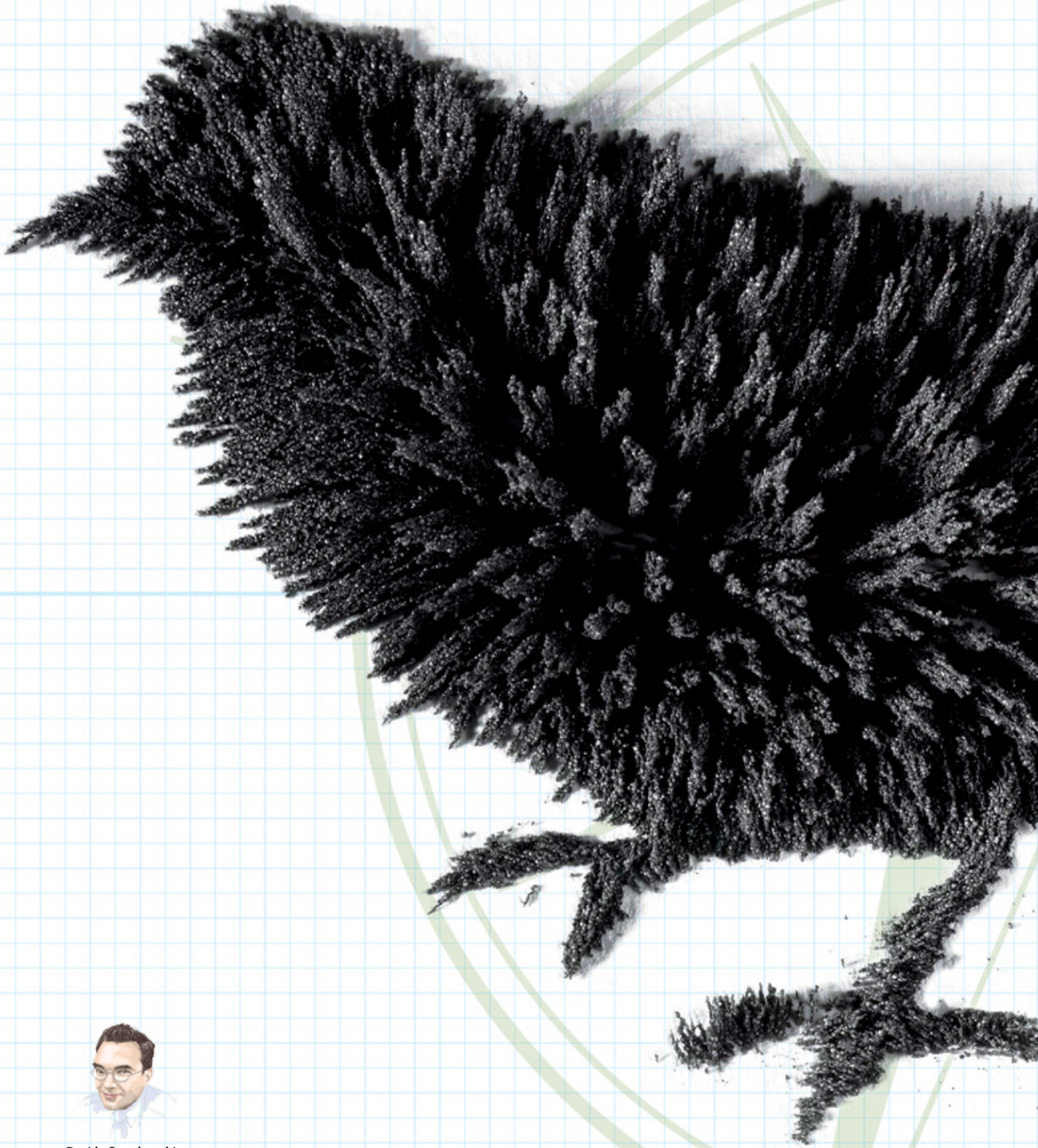
**Formation of Supermassive Black Holes.** Marta Volonteri in *Astronomy and Astrophysics Review,* Vol. 18, No. 3, pages 279–315; July 2010. http://arxiv.org/abs/1003.4404

**Supermassive Black Holes Do Not Correlate with Galaxy Disks or Pseudobulges.** John Kormendy, R. Bender and M. E. Cornell in *Nature,* Vol. 469, pages 374–376; January 20, 2011.

**Big Black Hole Found in Tiny Galaxy.** Jenny E. Greene in *Nature,* Vol. 470, pages 45–46; February 3, 2011.


**SCIENTIFIC AMERICAN ONLINE**

Learn more about the search for middleweights at ScientificAmerican.com/jan2012/black-holes



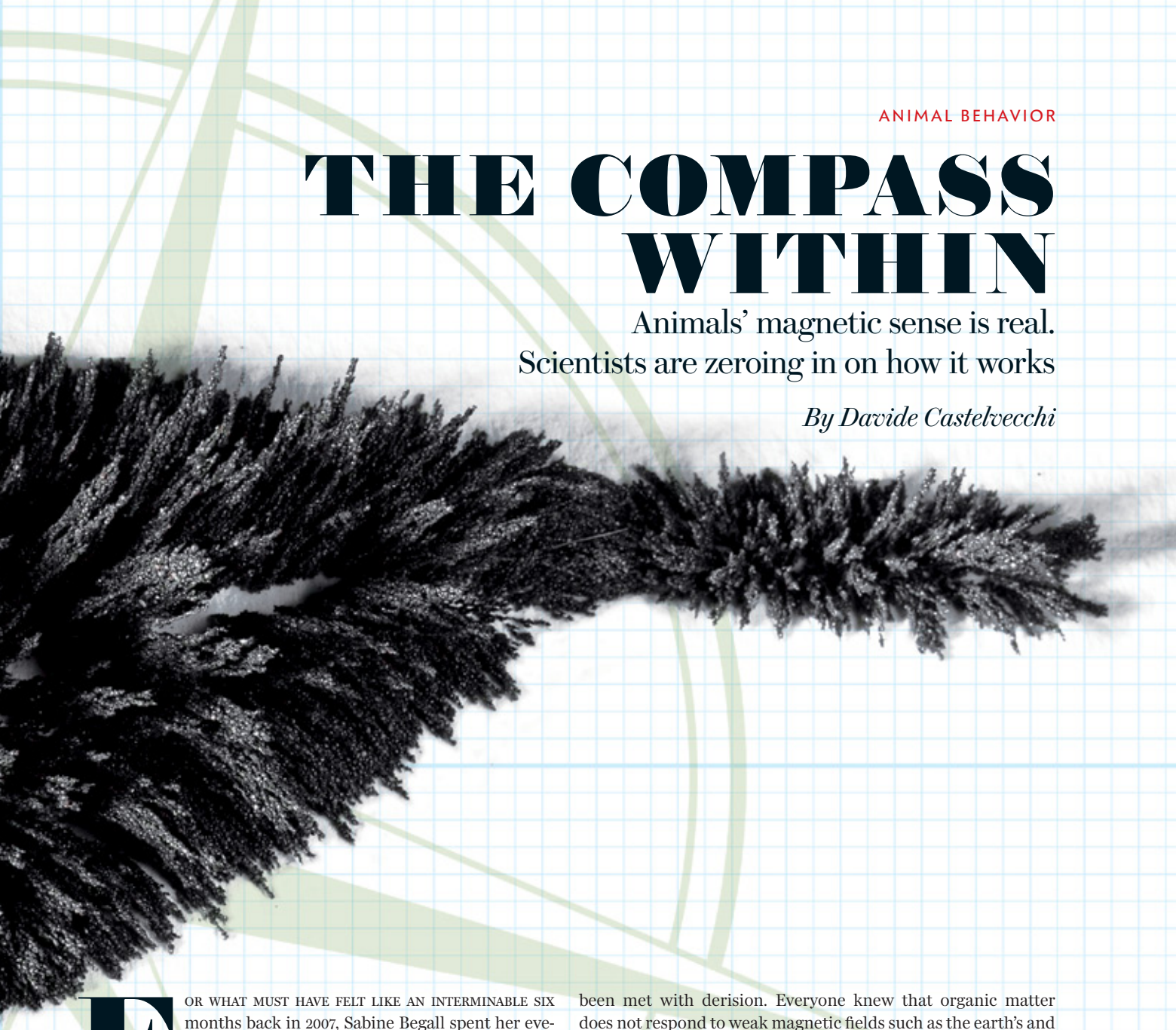


**Davide Castelvecchi**, a science writer based in Rome, is a contributing editor for *Scientific American*.

# THE COMPASS WITHIN

## Animals' magnetic sense is real. Scientists are zeroing in on how it works

*By Davide Castelvecchi*



FOR WHAT MUST HAVE FELT LIKE AN INTERMINABLE SIX months back in 2007, Sabine Begall spent her evenings at her computer, staring at photographs of grazing cattle. She would download a satellite image of a cattle range from Google Earth, tag the cows one by one, then pull up the next image. With the help of her collaborators, Begall, a zoologist at the University of Duisburg-Essen in Germany, ultimately found that the unassuming ruminants were on to something. On average, they appeared to align their bodies with a slight preference toward the north-south axis. But they were not pointing to true north, which they could have located using the sun as reference. Instead they somehow knew how to orient themselves toward the magnetic north pole, which is hundreds of kilometers south of the geographic pole, in northern Canada.

A follow-up study found more evidence that animals as large as cows can react to the earth's magnetic field: the aligning behavior vanished in the vicinity of high-voltage power lines that drowned out the relatively subtle signals coming from the planet.

Until a few decades ago studies such as Begall's would have been met with derision. Everyone knew that organic matter does not respond to weak magnetic fields such as the earth's and that animals do not come equipped with bar magnets to use as compasses. Franz Anton Mesmer's 18th-century belief in "animal magnetism"—the notion that breathing creatures harbor magnetic fluids in their bodies—had long been relegated to the annals of charlatanism.

Today the scientific community accepts that certain animals do read and respond to magnetic fields and that, for many of them, being able to do so should be helpful to survival—although why cattle would want to align magnetically is still mysterious. A magnetic sense has, in fact, been well documented in dozens of species—from seasonal migrants such as robins and monarch butterflies to expert navigators such as homing pigeons and sea turtles; from invertebrates such as lobsters, honeybees and ants to mammals such as mole rats and elephant seals; and from tiny bacteria to humongous whales.

What no one knows for sure yet is exactly how creatures other than bacteria do it. Magnetism is "the one sense that we know the least about," notes Steven M. Reppert, a neurobiologist at

*Photograph by Christopher Griffith*

the University of Massachusetts Medical School in Worcester.

In the past decade or so, however, collaborations of biologists, earth scientists and physicists have begun to propose plausible mechanisms and to pinpoint candidate anatomical structures where those mechanisms may be at play. None of these ideas has yet gained the acceptance of the full scientific community, but the experimental evidence found so far is truly mesmerizing. Some animals may even harbor more than one type of magnetic organ. And whereas certain biological magnetic field sensors seem to behave much like ordinary bar magnet compasses, others may well be rooted in subtle quantum effects.

The subject continues to have its share of controversy. But increased interest in magnetic reception and rapid improvements in experimental techniques could lead investigators to solve the mystery of this unusual sense in the next few years.

## THE URGE TO MIGRATE

THE FIRST MODERN HINTS that animals sometimes use magnetic fields to guide their behavior emerged about half a century ago. Researchers had noticed since the 1950s that in autumn caged European robins seemed to want to escape toward the south—where they would usually migrate—even if they had no visual cues as to where south was. Then, in the mid-1960s, Wolfgang Wiltschko, a student in biology at Goethe University in Frankfurt, demonstrated that electromagnetic coils wrapped around the birds' cage could trick them into trying to flee in the wrong direction. His was probably the first evidence of a magnetic sense, and the reaction was predictably skeptical. "When I found that the magnetic field plays a role in the orientation of robins, more or less nobody believed that," says Wiltschko, who recently retired from his professorship at Goethe.

Shortly after the discovery, Wiltschko met his future wife and lifelong scientific collaborator, Roswitha. The couple has studied avian magnetic detection ever since, working mostly with robins they capture with nets near their laboratories. The Wiltschkos began to publish the results of their joint investigations in 1972, when they revealed that robins are sensitive not only to the geographic direction of the magnetic north but also to the inclination of the earth's magnetic field relative to a horizontal plane.

The geomagnetic field's inclination varies continuously from pole to pole. At the magnetic south pole it points straight up, whereas at the magnetic north pole it points straight down; roughly halfway, along a "magnetic equator," it is horizontal. An ordinary compass needs to balance its needle horizontally, and thus it cannot measure the field's inclination, responding only to its side-to-side component. Birds—and, it turns out, other animals—can do better and probably use inclination to roughly estimate their distance from the magnetic poles.

Variations in the earth's field are not limited to inclination changes from one pole to the other. Magnetic minerals in the earth's crust produce local anomalies in both direction and strength. Some animals—notably, sea turtles—seem to have a mental map of those anomalies that helps them know not just where north is but what their position is relative to their destination. Kenneth J. Lohmann of the University of North Carolina at Chapel Hill and his collaborators have found that captured sea turtles tend to respond to artificial magnetic fields that simulate conditions at various locations along their migrating routes. The turtles attempt to swim in the direction that would lead them to their destination starting from those locations. To have such a magnetic map sense, an animal probably needs to detect not only the inclination anomalies of the field but also its varying strength.

Some researchers believe that birds also have a magnetic map sense in addition to plain magnetic orientation, but Anna Gagliardo, an avian olfaction expert at the University of Pisa in Italy, says the evidence for such a map sense is weak. And birds seem to find their way just fine using other senses. "Forty years of experiments," she says, "and no amount of magnetic manipulation has ever stopped homing pigeons from coming home." But she notes that the birds get lost if they have been deprived of their sense of smell by surgically cutting the nerves of their noses. Moreover, she adds, homing pigeons raised in aviaries that only open upward—so that the birds cannot tell which direction environmental scents are coming from—are unable to navigate. So whereas the evidence that birds can tell magnetic north from south is pretty solid, Gagliardo says, she doubts their magnetic sense can do much more than that.

Many other experts, however, now believe that birds have two distinct magnetic senses, each optimized for different uses—a compass sense for the field's direction and a separate "magnetometer" sense for its strength. Others argue that various lines of evidence suggest the existence of one sense or the other but not both in a species. One reason for the discord is that pinpointing the behavioral effects of magnetism is devilishly difficult, in part because birds and other animals exploit a number of different cues for orientation and navigation—they use the sun, the stars and the moon; they can recognize landmarks on the ground and the prevailing direction of the waves at sea; and they remember smells. Animals always navigate using multiple senses, notes Michael Winklhofer, a geophysicist at Ludwig Maximilian University in Munich. "They use whatever cue is available. Whenever one is dodgy, they use a more reliable one."

Unfortunately, even the strongest results from well-designed experiments often lend themselves to multiple interpretations. One of the Wiltschkos' main observations was that robins' compass sense does not work in the dark: it needs light with a blue, or short-wavelength, component. Their findings were obtained in lab conditions, which help to isolate cues from one another but are also somewhat artificial. Yet in a landmark study in 2004 Henrik Mouritsen of the University of Oldenburg in Germany and his collaborators found compelling evidence of light-compass interaction in the wild. They showed that night-flying thrushes recalibrate their magnetic sense every day at sunset.

For the experiment, Mouritsen's team captured dozens of

### IN BRIEF

**Dozens of animal species**, from ants to whales, have well-documented abilities to detect the geomagnetic field and use it for orientation and navigation.

**After some false starts**, researchers may have now located the organs for this magnetic sense, and they are finally understanding the physics that underpins it.

**Some animals** may use microscopic magnetic particles to detect magnetic fields; others might harness quantum effects on certain pigments in the eye.

PRECEDING PAGES: PROP STYLING BY MEGAN CAPONETTO

thrushes in central Illinois and outfitted them with radio transmitters. At sunset, the researchers exposed 18 of the birds to a magnetic field that simulated the earth's but pointed east instead of north. After dark, they opened the cages and let the birds go. As the birds flew away, members of the team chased them in a 1982 Oldsmobile with a large antenna sticking out of the roof—which often got them pulled over by the police. While the control group resumed their migration north toward Wisconsin, the 18 birds that had been exposed to the fake geomagnetic field headed west toward Iowa or Missouri. On subsequent nights, however, even those birds corrected their path and headed north again.

Although the results indicated that the birds reset their magnetic north at dusk, interpretations varied on the role of light in that process. One possibility is that the birds have an internal compass that works only in the presence of light, as the Wiltschkos had concluded. Another explanation seems equally plausible: the birds used the sun just as a point of reference for calibrating a compass that did not physically need light to work. In fact, they might have kept using their compass all night.

Clearly, behavioral experiments alone are unlikely to settle such issues one way or another. Eventually one needs to locate and study the sensory organs more directly.

## RUSTY CLUES

SEARCHING FOR magnetically sensitive organs is an anatomist's worst nightmare. The sensors could be single, isolated cells, located anywhere inside the body. They could contain microscopic magnetic particles—serving as the equivalent of a compass needle—that, when analyzed, would be difficult to distinguish from contaminants in tissue specimens. A candidate mechanism also has to meet stringent requirements; in particular, it must be sensitive to fields as weak as the earth's, and it must separate the magnetic signal from the noise of natural molecular vibrations—something that is especially hard for a microscopic structure to do. So far the only mechanism that has been identified and explained unequivocally occurs in bacteria.

At latitudes where the geomagnetic field's inclination is sufficiently steep, certain bacteria use it as a proxy for gravity to "know" which way is down so that they can swim toward muddy seafloors—their preferred habitat. In the 1970s researchers demonstrated that these bacteria contain strings of microscopic particles of magnetite—a strongly magnetic form of iron oxide—that align with one another and with the field and in the process orient the entire organisms in the right direction.

The bacteria offered a natural paradigm for trying to understand magnetic reception in general. In the 1980s geobiologist Joseph L. Kirschvink, now at the California Institute of Technology, and others proposed that similar magnetite-based structures might exist across the animal kingdom. Scientists began searching for these particles in magnetically sensitive animals.

In the early 2000s a team that included Winklhofer, Wolfgang Wiltschko, and Gerta and Günther Fleissner—another married-couple team at Goethe—used advanced imaging techniques to reveal intriguing structures lined with magnetite nanoparticles in homing pigeons. They found these structures in the skin of the birds' upper beaks. The magnetic particles were very small—a few nanometers—and thus their random motion would have been substantial compared with their size. That noise would have been too loud for the particles to read the magnetic field's strength, but in principle, they could have detected its direction, Winklhofer says: "You wouldn't have a very strong response, but it would have worked at least as a compass." Intriguingly, the structures were in regions dense with nerve endings, which is what one would expect of putative detectors because they would need to be integrated into the nervous system.

Only a few of the particles appeared to be magnetite, though; the others were a closely related material called maghemite, which is not as strongly magnetic. Still, researchers thought they might have the smoking gun.

In a follow-up paper, the Fleissners and their co-workers proposed a model for how even a structure composed mainly of maghemite could function as a compass. They suggested that the maghemite structures could temporarily magnetize and thus amplify the geomagnetic field in their vicinity, funneling it into the magnetite particles.

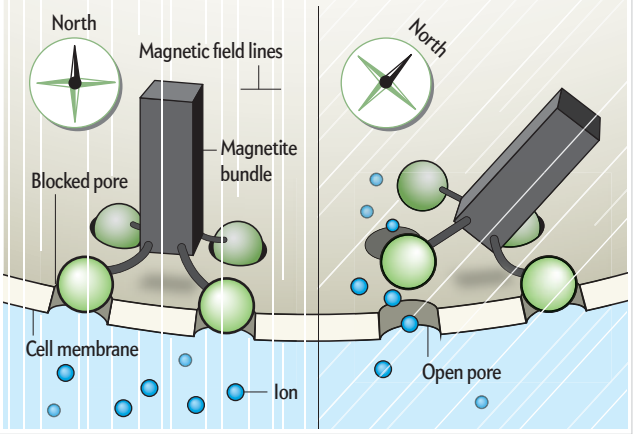
Winklhofer, however, parted ways from his former collaborators and, with Kirschvink, issued a rebuttal. The two researchers cited evidence that the maghemite in the study was "amorphous," meaning that it lacked a crystal ordering; such amorphous materials make very weak magnets, Winklhofer points out—too weak to do the job being attributed to the particles seen in birds. Others note that whether the nerve endings are located precisely at the magnetic particles is unclear. The candidate structures in homing pigeon beaks may have nothing to do with magnetic reception after all, Winklhofer concludes.

One more reason to be cautious is that magnetite and other magnetic particles are ubiquitous in the environment. "Even dust from the lab contains magnetic materials," Winklhofer says. Anatomists must use ceramic scalpels to try to avoid introducing

FIRST HYPOTHESIS

# Fish Do It, Birds Maybe

**Some researchers suspect** that the magnetic sense in animals is most often like that in the snouts of rainbow trout. In the fish, bundles of particles of magnetite, a form of iron oxide, in sensory cells respond to a change in the direction of the geomagnetic field (relative to the fish's head) by opening channels in the cell membrane (*right panel*). The subsequent passage of ions across the membrane initiates a signal that would carry information along a nerve and to the brain.




SOURCE: "THE MAGNETIC SENSE AND ITS USE IN LONG-DISTANCE NAVIGATION BY ANIMALS," BY MICHAEL M. WALKER, TODD E. DENNIS AND JOSEPH L. KIRSCHVINK, IN *CURRENT OPINION IN NEUROBIOLOGY*, VOL. 12, NO. 6; DECEMBER 2002

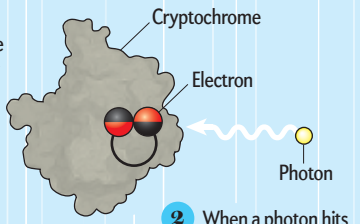
*Illustrations by Jen Christiansen*

SECOND HYPOTHESIS

## Magnetic Eyes

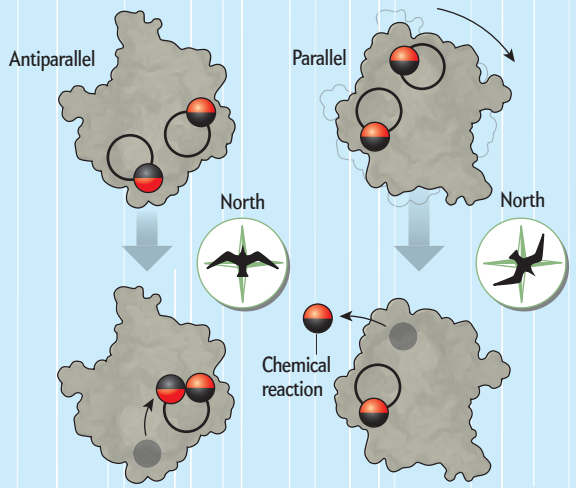
**Some scientists consider** the protein cryptochrome, present in the retina, to be the key to birds' magnetic sense. Certain eye cells would detect which way is north because a chemical reaction would speed up or slow down depending on the direction of the earth's magnetic field. The reaction would start when a photon of light hits a cryptochrome molecule, separating two electrons that would normally orbit as a pair. Eventually it would lead to the cell firing a signal to the brain, making the animal aware of the field's direction.

**1** Electrons in the stable cryptochrome molecule orbit as pairs, with their spins—the quantum physics equivalent of the south-north axis of a bar magnet—aligned in opposite, or anti-parallel, directions. (Just two of the molecule's many electrons are pictured here.)




**2** When a photon hits the molecule, it kicks one of the electrons in this pair off to another site within the molecule.

**3** The two electrons can now be in one of two states: parallel and antiparallel, and they actually spend some time in either state. But depending on which way the geomagnetic field points relative to the bird's eyes, they may spend more time in one state than in the other.




**4** Here the bird is flying toward magnetic north, which makes the electrons spend more time in the antiparallel state. No chemical reaction occurs. The displaced electron can then go back to its stable state (until the next photon hits).

**5** If the bird strays from that course, the electrons spend more time in the parallel state. A chemical reaction can then occur that carries away the displaced electron. This reaction would alert the animal that it is no longer pointing north.

Many of these details, including how the bird translates the chemical reaction into a signal to the brain or even what exactly the chemical reaction would be, are unknown.

metal fragments into tissues they extract from animals. But if the particles enter the body as contaminants, they may get scooped up by white blood cells, which would then show up in the microscope looking like possible sensory cells.

Despite the particular difficulties posed by the putative magnetic receptor in homing pigeons, Winklhofer and Kirschvink remain staunch proponents of the magnetite hypothesis. They point to what they say is the best evidence so far of such an organ: cells lining the nasal opening of rainbow trout. Michael M. Walker of the University of Auckland in New Zealand and his collaborators have been studying the cells since 1997, when they first found them. The researchers were able to demonstrate an electrophysiological response to magnetic fields: the cells actually sent a signal to the brain.

Kirschvink is now leading a multiyear, multilab effort to characterize the structure and behavior of these putative magnetic sensors. He says he suspects that the magnetite particles are contained in organelles that stick directly to the membranes of specialized neurons. Each such cell would constitute a microscopic magnetic-sensing organ. When a magnetic field causes the organelles to spin to a new orientation, they trigger the release of ions that prompt the neurons to fire and thereby "tell" the brain which way the fish should swim [*see illustration on preceding page*]. Perhaps, Kirschvink says, researchers who have been looking at pigeons' beak skin should take guidance from the fish and instead search inside the birds' snout.

### CRYPTIC SIGNS

MAGNETITE IS NOT the only leading contender in the race: a quantum physics–based mechanism also seems plausible to many researchers. Klaus Schulten, a theoretical biophysicist now at the University of Illinois at Urbana-Champaign, observed in the 1970s that chemical reactions affected by magnetic fields could provide the physical basis for a magnetic sense. The reactions involved would initiate when photons hit suitable pigment molecules, causing the formation of so-called free radicals. The need for photons would explain the apparent sunlight-compass connection observed by biologists. In those days, however, it just sounded like a wild idea, and Schulten did not explain how the signal would be conveyed to the brain.

Then, in the late 1990s, biochemists discovered a pigment protein called cryptochrome, first in plants and later in the retinas of mammals—including humans—where it was found to occur in several variants and to help the animals adjust their day-night cycles. Schulten, together with his colleagues Salih Adem and Thorsten Ritz, a biophysicist now at the University of California, Irvine, suggested that cryptochrome had just the right properties for a compass sense and that certain cells in the retina might be able to make use of the formation of free radical pairs in it to detect the direction of the earth's magnetic field.

Lab experiments had shown that when cryptochrome absorbs a photon in the blue part of the spectrum, the energy of the photon kicks an electron from one part of the molecule to another. For a molecule to be chemically stable, its electrons need to share orbits in pairs, but in cryptochrome the displacement leads to two electrons each flying solo. Now the two electrons, termed a radical pair, engage in an elaborate pas de deux dictated by their spins. Spin is the quantum-physics analogue of the magnetic axis of a bar magnet. Every electron's spin interacts

with the geomagnetic field and with the spins of atomic nuclei, and collectively the interactions make the electron's spin axis precess like that of a spinning top. In a radical pair, the spin of each electron is also influenced by that of its counterpart.

During parts of the paired electrons' performance, their spins point in roughly the same direction; at other times they point in opposite directions. Crucially, an external magnetic field, such as the earth's, changes the relative amount of time that the electrons spend in each alignment. That is how an external field can affect cryptochrome's chemistry: certain chemical reactions can take place only when the spins are parallel. Thus, if a field keeps the spins parallel for a longer time, the reactions will accelerate.

The speed of a spin-sensitive reaction could be the chemical signal for a sensory neuron to fire and thus send a message down a nerve to the brain center in charge of a magnetism-mediated behavior. Unfortunately, although the general principle is well known, in the case of cryptochrome no one knows what the relevant chemical reaction could be, nor how variations in its rate would induce a neuron to fire. Still, in the past decade several lines of circumstantial evidence have appeared.

Spin precession is sensitive not only to static fields such as the geomagnetic one but also to those that change rapidly in time, as in radio waves. In 2004 Ritz teamed up with the Wiltschkos and showed that radio waves disrupt the internal compasses of birds. The disruption occurred only at precise wavelengths, as would be the case if the waves were interfering with the dance of radical pairs. "From a physics perspective, so far that's the best evidence for the radical pair mechanism," Ritz says.

Then, in 2009, a team led by Mouritsen found that birds with lesions in a brain center that is related to vision have a hard time with magnetic orientation. And in 2010 a study of European robins and chickens led by Christine Niessner of Goethe found that cryptochrome is copiously produced not just in the birds' retina but more specifically in their ultraviolet-light-sensitive cone cells—that is, precisely where biologists would expect it to reside, given that radical pair formation requires light.

The case is not closed, however. Most results have yet to be independently replicated. As with the magnetite candidate, some of the evidence seen to date may not be as clear-cut as it sounds. Ritz himself, for instance, cautions that radio waves induce electric fields that could disrupt biological processes in unpredictable ways. For example, the waves are known to interfere with the neurotransmitter receptors that are active in pleasure centers, and thus they could indirectly disorient the animals rather than making them lose the ability to sense magnetic fields.

University of Oxford physicist Peter J. Hore adds that the sensitivity of birds to radio waves seems too good to be true: a field just 1/2,000th the strength of the geomagnetic field is enough to disrupt their magnetic sense.

Similar confusion surrounds cryptochrome studies in fruit flies. In 2008 Reppert and his collaborators showed that fruit flies could be trained to follow magnetic fields to a sugary reward but that mutant flies missing the gene for cryptochrome, and thus unable to produce the protein, could not.

The insects, however, were exposed to fields 10 times stronger than the geomagnetic field. And because the experimenters knew when the artificial fields were turned on or off, they might have cued the insects inadvertently, Kirschvink cautions.

Overall, Hore says, although evidence has been accumulating to support the radical pair idea, "we are not there yet." Several pieces of the puzzle are missing, starting with the particulars of the mechanism. "I find it very frustrating," he adds. Ultimately researchers will need to demonstrate an electrophysiological response—neurons firing in response to magnetic fields—to claim they have found the seat of the new sense. Electrophysiology is the golden standard of sensory biology, Ritz notes: "That's how we learned how vision works."

Intriguingly, in June 2011 Reppert and his colleagues showed that fruit flies that had their gene for cryptochrome replaced with the one from the human genome still retained the ability to orient magnetically. The discovery rekindled speculation that humans may have the magnetic sense, too, although evidence in that respect is scant. Experiments that Robin R. Baker of the University of Manchester in England conducted in the late 1970s purportedly showed that people have some magnetic homing abilities, but attempts to replicate those results gave negative outcomes.

## PUTTING IT ALL TOGETHER

FOR THE MOST PART, experts have abandoned alternative explanations for the magnetic sense, finding at least one of the two leading hypotheses plausible. A possible exception is the magnetic sense of manta rays and sharks, which some say could be a bonus of the animals' uncanny sensitivity to electric fields. These fishes have microscopic, electrically conducting canals in their skin that they use to sense voltages as weak as five billionths of a volt [see "The Shark's Electric Sense," by R. Douglas Fields; SCIENTIFIC AMERICAN, August 2007]. Because magnetic fields induce a voltage on conductors in motion, a fish could pick up the geomagnetic field just by moving left and right as it swims.

Even after the controversies are finally settled, feats of navigation by migratory animals such as humpback whales, which can swim for hundreds of kilometers at a time in the open ocean without deviating by more than one degree from the course they initially set, may still remain unexplained.

Yet many researchers are hopeful that the mechanisms of magnetic reception will soon be revealed. Experimental techniques have advanced dramatically: technology now enables researchers to track even small birds, methods for imaging microscopic anatomical structure have become more precise, and scientists from multiple disciplines have joined the effort. Once the mystery is solved, some will look back to these years with longing, Ritz says: "You don't often have the chance to discover a new sense." SA

### MORE TO EXPLORE


**Structure and Function of the Vertebrate Magnetic Sense.** Michael M. Walker et al. in *Nature*, Vol. 390, pages 371–376; November 27, 1997.

**A Model for Photoreceptor-Based Magnetoreception in Birds.** Thorsten Ritz, Salih Adem and Klaus Schulten in *Biophysical Journal*, Vol. 78, No. 2, pages 707–718; February 2000.

**Migrating Songbirds Recalibrate Their Magnetic Compass Daily from Twilight Cues.** William W. Cochran, Henrik Mouritsen and Martin Wikelski in *Science*, Vol. 304, pages 405–408; April 16, 2004.

**Magnetic Alignment in Grazing and Resting Cattle and Deer.** Sabine Begall, Jaroslav Červený, Julia Neef, Oldřich Vojtěch and Hynek Burda in *Proceedings of the National Academy of Sciences USA*, Vol. 105, No. 36, pages 13451–13455; September 9, 2008.

**Magnetoreception.** Single-theme supplement of *Interface Focus: Journal of the Royal Society Interface*, Vol. 7, No. 2; April 6, 2010.


**SCIENTIFIC AMERICAN ONLINE**

Read a blog post about this topic at ScientificAmerican.com/jan2012/magnetic-sense

IMMUNOLOGY

# The Patient Scientist

When Ralph M. Steinman developed pancreatic cancer, he put his own theories about cancer and the immune system to the test. They kept him alive longer than expected—but three days short of learning he had won the Nobel Prize

*By Katherine Harmon*



*Illustration by Roberto Parada*

PEERING THROUGH A MICROSCOPE AT A PLATE OF CELLS one day, Ralph M. Steinman spied something no one had ever seen before. It was the early 1970s, and he was a researcher at the Rockefeller University on Manhattan's Upper East Side. At the time, scientists were still piecing together the basic building blocks of the immune system. They had figured out that there are B cells, white blood cells that help to identify foreign invaders, and T cells, another type of white blood cell that attacks those invaders. What puzzled them, however, was what triggered those T cells and B cells to go to work in the first place. Steinman glimpsed what he thought might be the missing piece: strange, spindly-armed cells unlike any he had ever noticed.

His intuition turned out to be correct. These dendritic cells, as Steinman named them, are now thought to play a crucial role in detecting invaders in the body and initiating an immune response against them. They snag interlopers with their arms, ingest them and carry them back to other types of immune cells—in effect, "teaching" them what to attack. It was a landmark discovery that explained in unprecedented detail how vaccines worked, and it propelled Steinman into the top tiers of his profession.

In many ways, Steinman's story is typical: brilliant scientist makes major discovery that inspires a new generation of researchers. Indeed, his insight was remarkable for its implications, both for science and for him personally.

Over the years Steinman came to believe that dendritic cells were a crucial weapon for tackling some of the most loathed diseases, from cancer to HIV. He and his global network of colleagues seemed to be well on the way to proving him correct when Steinman's story took an unusual turn.

In 2007 he was diagnosed with pancreatic cancer, an unforgiving disease that kills four out of five patients within a year. In the end, the cells he discovered at the start of his career, and the friends he made along the way, would not only help him fight his cancer but would extend his life just long enough for him to earn the Nobel Prize. He died this past September, three days before a flashing light on his cell phone alerted his family that he had won.

## A PREPARED MIND

STEINMAN DID NOT encounter serious biology until he arrived as a student at McGill University. As soon as he did, though, he was hooked, and it was his fascination with the minuscule world of the immune cell that would bring him to the lab of Zanvil A. Cohn at Rockefeller. In his office Steinman would later display a quote from the famous 19th-century microbiologist and vaccinologist Louis Pasteur: *Le hazard ne favorise que les esprits préparés,* which is often translated as "Chance favors the prepared mind." Says Sarah Schlesinger, a longtime colleague and friend of Steinman, "Ralph was exceedingly well prepared, so he was poised to make a discovery. But with that said, he intuited that these were important," she says of the cells. It was that intuition and a confidence in observation that enabled him to make his seminal discovery—and eventually win the admiration of colleagues.

After he first spotted dendritic cells, Steinman spent the next two decades convincing the scientific community of their significance, defining how they worked and how researchers could work with them. "He *fought*—there's really no other word for it—to convince people that they were a distinct entity," says Schlesinger, who came to work at Steinman's lab in 1977, when she was still in high school. Even then, she says, people in the same lab were not convinced that these dendritic cells existed because they were difficult to enrich into larger batches. At the time, Steinman was still working at the bench, and Schlesinger recalls sitting with him at a two-headed microscope, examining the cells. "He just loved to look at them," she says, smiling at the memory. "There was such a joy in all of the little discoveries that he made."

By the 1980s Steinman, who had trained as a physician, started to look for ways his dendritic cell discovery could be applied more directly to help people. Over the next few decades, as the cells became more widely accepted, his lab expanded its focus to include research into dendritic cell–based vaccines for HIV and tuberculosis, as well as research into cancer treatment. For illnesses such as influenza or smallpox that could already be prevented with vaccines, those who survive natural

### IN BRIEF

**Ralph M. Steinman** was the first person to describe dendritic cells, which play a key role in initiating immune responses. He named them for their treelike limbs.

**Dendritic cells**, which "teach" other immune cells what to attack, now make up the core of many experimental vaccines against cancer and HIV.

**When Steinman** was diagnosed with pancreatic cancer in 2007, he and a network of colleagues turned to these new vaccines to treat his disease.

**His colleagues** believe the vaccines helped to extend his life well beyond the norm. He died just three days before winning the Nobel Prize.

exposure may develop a lifelong immunity. HIV, TB and cancer presented a greater challenge because they seemed to be better at overcoming the immune system—even, in the case of HIV, hijacking dendritic cells to do its dirty work. "Ralph would say, 'We have to be smarter than nature,'" Schlesinger says. That meant helping the dendritic cells by giving them more targeted information about the virus or tumor against which the immune system needed to form an attack.

In the 1990s, working with Madhav Dhodapkar, now at Yale University, and Nina Bhardwaj, now at New York University, Steinman created a process for extracting dendritic cells from the blood and priming them with antigens—telltale protein fragments—from infections, such as influenza and tetanus, and then placing them back in the body to create a stronger immunity. This technology served as the basis for a prostate cancer vaccine called Provenge that was approved in 2010 and has been shown to extend the life of terminally ill patients—if only by a few months.

### THE FINAL EXPERIMENT

IN EARLY 2007 Steinman was away in Colorado at a scientific meeting, a trip that he had turned into a family ski vacation, when he and his twin daughters all had what seemed like a stomach bug. His daughters recovered quickly, but his illness lingered. Soon after he returned home, he developed jaundice. In the third week of March he went in for a CT scan, and radiologists found a tumor in his pancreas. By then, it had already spread to his lymph nodes. He knew his odds of survival were slim: about 80 percent of pancreatic cancer patients die within a year.

"When he first told us, he said, 'Do not Google this—just listen to me,'" his daughter Alexis recalls. She felt like someone had punched her. "He really expressed to the family that while it was a very drastic disease, he was in a very good position," she says. Unlike the average cancer patient, Steinman had access to many of the top immunologists and oncologists on the planet—and, perhaps even more important, to their most promising therapies.

When Schlesinger heard the news, she was devastated. And she quickly rallied to her mentor's side. She, Steinman and their close Rockefeller colleague Michel Nussenzweig began making phone calls, sharing the news with colleagues across the globe. Steinman was convinced that the surest way to be cured of any tumor was to develop immunity against it through his own dendritic cells. They had a limited amount of time to prove him right.

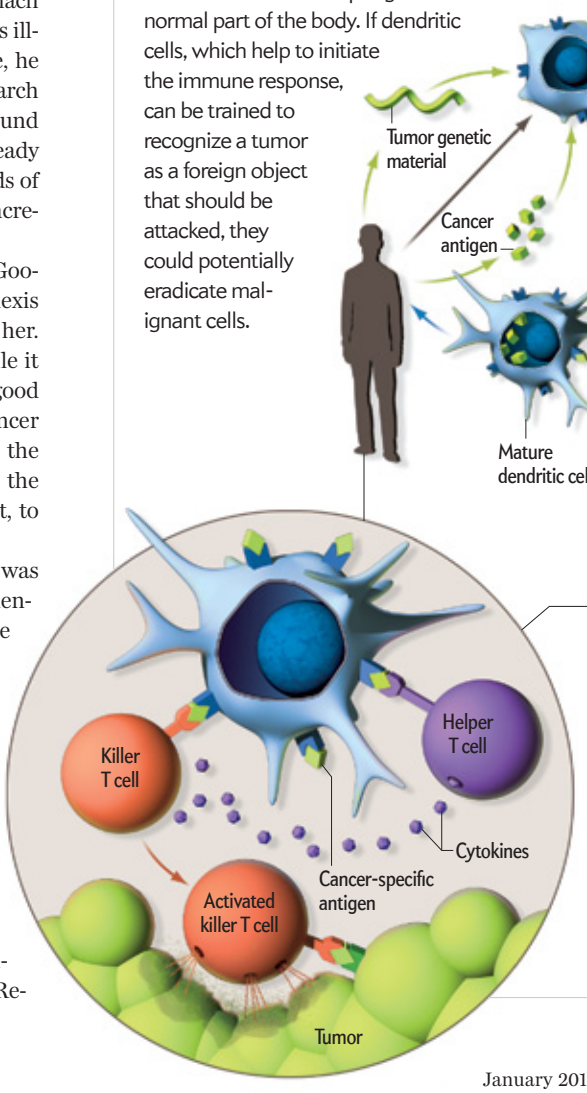
One of the early calls Steinman made after his diagnosis was to his longtime collaborator Jacques Banchereau, who now directs the Baylor Institute for Immunology Research in Dallas. Banchereau then picked up the phone to call Baylor researcher Anna Karolina Palucka, who had known Steinman since the 1990s. Although she had an experimental vaccine in the works that she thought could help Steinman, she struggled with the personal challenge of trying "to compartmentalize the friend, the patient and scientist."

For her part, Schlesinger called Charles Nicolette, a friend and collaborator of many years and chief scientific officer of Argos Therapeutics, an RNA-based drug company in Durham, N.C., that

BASICS

## A Dose of His Own Medicine

**Several experimental cancer treatments** that Steinman received made use of the very cells that he helped to discover—and that would earn him a Nobel Prize. The immune system constantly kills off cancerous cells. But when enough slip through the body's natural defenses, tumors can take hold and trick immune cells into accepting them as a normal part of the body. If dendritic cells, which help to initiate the immune response, can be trained to recognize a tumor as a foreign object that should be attacked, they could potentially eradicate malignant cells.




1. Dendritic cells are extracted from a patient's blood and exposed directly to either a protein from that type of cancer (also known as an antigen, which elicits an immune response) or genetic material extracted from the patient's own tumor (which in turn generates a personalized antigen). The cells take up the material, just as they do in the body when they encounter and absorb pathogens.

2. To prepare the antigen-infused dendritic cells to kick off a tumor-targeted immune response, stimulatory compounds are added to increase the number of these cells and to force them into their mature, antigen-presenting state before they are injected back into the patient.

3. In the body the programmed dendritic cells proceed—as they would in a natural immune response—to display the antigen to other immune cells, such as helper and killer T cells. If all goes well, the T cells will take the tumor-specific instructions and coordinate among one another, via cytokine-signaling proteins, to seek and destroy tumor cells.

CONSULTANT: ERIC VON HOFE

*Illustration by Tami Tolpa*

Steinman had co-founded. Nicolette, reeling from the news, mobilized his own colleagues within minutes of hanging up the phone.

Nicolette's group had developed a dendritic cell vaccine that was in a phase II (intermediate-stage) clinical trial to treat advanced kidney cancer. Argos's therapy endeavors to enlist a patient's own dendritic cells against a cancer by exposing them to genetic material, from the tumor, which induces them to rally T cells to mount a proper attack.

Steinman was scheduled to have part of his pancreas removed the first week of April 2007—a surgery known as a Whipple procedure, which is part of more traditional treatment for his prognosis. Nicolette would need part of that tumor to draw up his vaccine, which left him just days to get the U.S. Food and Drug Administration to approve Steinman's entry into his trial, permission the team was able to secure just in time.

With the tumor cells secured and while the Argos treatment was brewing, a process that would take months, Steinman started in on other therapies. Soon after his surgery, he went on standard Gemcitibine-based chemotherapy, and then, in the late summer, he enrolled in a trial of GVAX, a dendritic cell–based vaccine that was being tested to treat pancreatic cancer. Co-developed by Elizabeth Jaffee of Johns Hopkins University and administered at the Dana-Farber/Harvard Cancer Center, the vaccine uses a generic tumor antigen, as the Provenge prostate cancer vaccine does. In an earlier phase II trial, pancreatic cancer patients who had received the vaccine lived an average of four months longer than those who had not, and some ended up living for years. So for two months, starting in the late summer, Schlesinger traveled with him to Boston almost every week. "I remember walking in Boston on a day like this," she says, looking out of her corner office window into the clear, paling blue October afternoon sky, "thinking, 'He's not going to see another fall,' and I was so sad."

But fall came and went, and Steinman remained in relatively good health. In September 2007 he received the Albert Lasker Award for Basic Medical Research, considered by many to be a precursor to the Nobel, and he sat for a series of video interviews. In them, he elaborated on the promise of dendritic cells to fight cancer, noting that an immune attack is highly directed, highly specific and, unlike chemotherapy, nontoxic. "I think this provides the potential for a whole new type of therapy in cancer," he said. "But we need research and patience to discover the rules, to discover the principles."

At times, Steinman showed more patience than his colleagues would have liked. He had initially argued for a very slow course of treatment for himself so that his team could monitor his immune response after each therapy before beginning the next. But Schlesinger and Nussenzweig eventually convinced him that they simply did not have the time. If he died, the experiment and data collection were over.

By November 2007 the Argos vaccine, made by infusing cells taken from Steinman's blood with genetic material extracted from his tumor, was ready and waiting. Steinman had just finished with a chemo treatment, and he enrolled in Argos's renal cell carcinoma trial under a single-patient study protocol.

In early 2008 Steinman followed up with Palucka's vaccine, which was being developed for melanoma. It incorporated a selection of tumor-specific peptides (protein fragments), so she suspected it could be repurposed to target Steinman's cancer by using peptides from his tumor in place of antigens from melanoma.



## A Grand (Self-)Experiment

**After his cancer diagnosis,** Steinman received a flood of offers from friends and colleagues to try various experimental treatments. Based on his assessment of the data and discussion of options with his co-workers, Steinman settled on several new immunotherapies that were being evaluated in clinical trials he could enter as a special single patient, rather than enrolling according to the experimenters' original designs. These vaccines, some of which were tailored to his particular cancer, were interspersed with traditional and experimental chemotherapy sessions.

**Summer and Fall 2007**
GVAX dendritic cell vaccine for pancreatic cancer developed at Johns Hopkins and administered at the Dana-Farber/Harvard Cancer Center.

**Late 2007**
Cell-signaling inhibitor therapy in trials from Genentech; attempts to rein in abnormal cellular communication that can fuel tumor growth.

**Winter 2007 through Spring 2008**
Argos dendritic cell–based vaccine under development for kidney cancer.

**2008 through 2010**
Dendritic cell vaccine for melanoma; developed at Baylor University.

**Mid-2010**
A boost of peptides from the Baylor vaccine in combination with Oncovir's experimental immune stimulant Hiltonol, which activates the immune system in part by prompting release of the signaling molecule interferon.

**Winter and Summer 2010**
Ipilimumab from Bristol-Myers Squibb, a monoclonal antibody (a molecule made to attach to a specific target); approved for melanoma treatment by the FDA.

Other offers for experimental treatments poured in from all over the world. "Everybody who could brought the best they could," Palucka says. Steinman's decades of collegial work had united the field, and now that network of scientists turned to help one of their own. "People think of science as a solitary process. In fact, it's an extremely social process," Schlesinger says. The "social nature of our work facilitated the forthcoming of these tremendous intellectual resources."

In addition to standard treatment, Steinman ended up enrolled—under a special patient provision—in four ongoing clinical trials of various dendritic cell–based cancer treatments, most of which were not even being tested for pancreatic cancer, along with several other experimental immunotherapy and chemo treatments. Schlesinger, a member of the Rockefeller Institutional Review Board (IRB), steered his treatment through all the necessary IRB and FDA channels, making sure the standard protocols were followed. She also personally gave Steinman his vaccines whenever they could be administered at Rockefeller.

Steinman ran his own grand experiment like he ran others in the lab—always carefully collecting data, evaluating the evidence and doling out instructions. Schlesinger still has e-mail chains from the period, Steinman's messages coming back in all capital letters per his style. He kept particularly close tabs on how his own body was responding to treatment. In 2008, during his time on Palucka's therapy, she came for a visit to New York City. After

Schlesinger had given Steinman his dose of the vaccine, the three of them went out to dinner. On finishing their meal, Steinman insisted they stop by Palucka's hotel so that he could show them the welt developing on his leg around the injection site. "He was so enthused about it," Schlesinger says. "He said, 'Those are T cells' "—indicating that his body was having an immune response to the vaccine—"'that's great!' "

The local swelling showed that Steinman's body was reacting to the vaccine, although, Palucka says, she cannot be certain it was tumor-specific T cells that had been mobilized. As she points out, all vaccines work through dendritic cells, but the difference with her therapy and the others that Steinman tried was that rather than leaving exposure up to chance, researchers manipulated the dendritic cells outside of the body to improve the odds they would train T cells to attack the tumor. When Schlesinger was not on hand to see the evidence for herself, she says, "he would send me these descriptions of the vaccination sites with great enthusiasm," including information about the appearance and size of the sites—and even how each one felt.

His tumor marker, the level of a protein that indicates the progress of a cancer (which fluctuated throughout the course of his treatment), became a barometer for his attitude. The second time the marker went down, he sent an e-mail out with the subject line "We've repeated the experiment," the glee of which was apparent to those who knew his joy in a scientific triumph.

But the good news that satisfied Steinman the patient was never good enough to satisfy Steinman the scientist. The knowledge that his one-person experiment was hardly a scientific one frustrated him to no end. With the experimental treatments administered so close to one another—and interspersed with traditional chemotherapy—it was impossible to know what sent his tumor biomarker downward.

Nevertheless, Steinman generated some interesting data points along the way. During one of Palucka's immune-monitoring tests during his treatment, she found that some 8 percent of cells known as CD8 T cells (also called killer T cells) were specifically targeted to his tumor. That might not sound like a lot, but given all the potential pathogens that the body can encounter and mount an attack against, 8 percent "is a huge number," Schlesinger says. "So something immunized him—or some combination of things immunized him."

## A DEATH, DAYS TOO SOON

STEINMAN AND HIS WIFE, Claudia, traveled to Italy to celebrate their 40th wedding anniversary in June 2011—just two months after what he referred to as his fourth "Whipple-versary," in honor of his April 2007 surgery. Already he had far surpassed the average survival of a person with his type of cancer.

In mid-September 2011 Steinman was still working at the lab, and arrangements had been made for him to restart the Argos treatment. Then Steinman fell ill with pneumonia. "When he was admitted to the hospital, he said, 'I might not make it out of here,' " Alexis recalls. But after her father's four and a half years of good health, she found it hard to believe she would have only days left with him. He was still reviewing data from Rockefeller as late as September 24. On Friday, September 30, he died at the age of 68 from respiratory failure caused by pneumonia, which his cancer-weakened body could no longer fend off.

His family struggled with how to even begin to tell his vast network of friends and colleagues around the globe. They planned to visit his old lab—where he had been working until so recently—to tell those there on Monday, October 3. But early that morning, before any of them were awake, Stockholm called. Steinman's BlackBerry, on silent, was with his wife. In a fitful, early-morning sleep, she glanced over to see a new-message light blinking. Just then an e-mail popped up, politely informing Steinman that he had won the 2011 Nobel Prize in Physiology or Medicine.

The first response was that "we all collectively screamed the 'f' word," Alexis says. Her next thought was, "Let's go wake up Dad."

But for the rest of the world, nothing about the Nobel committee's announcement seemed amiss—articles were written, statements were issued about Steinman and the two other recipients, Bruce Beutler of the Scripps Research Institute and Jules Hoffmann of the French National Center for Scientific Research—until a few hours later, when news of Steinman's death surfaced. The prize rules state that it cannot be given posthumously, but if a laureate dies between the October announcement and the award ceremony in December, he or she can remain on the list. This odd timing threw the committee into a closely followed deliberation before it announced, late in the day, that he would remain a prize recipient.

Just days after Steinman's Nobel was announced and news of his death hit the media, pancreatic cancer also claimed the life of Apple co-founder and CEO Steve Jobs. Jobs, ill with a rare, slower-growing form of the disease—a neuroendocrine tumor—lived for eight years after his diagnosis, more of an average survival time for a patient with his form of the disease. Steinman's survival, though, far surpassed what was expected. "There's no question something extended his life," Schlesinger says.

Now researchers are working to figure out what it was. In early 2012 Baylor will be dedicating the Ralph Steinman Center for Cancer Vaccines, and Palucka is developing a clinical trial to treat pancreatic cancer patients with the same vaccine that she helped create for Steinman. At Argos, Nicolette is pursuing their kidney cancer vaccine full steam ahead: "There's a sense of duty to Ralph to see this through." This month they plan to launch a phase III clinical trial of the renal cancer vaccine Steinman tried.

For her part, Schlesinger believes her colleagues' interventions made a contribution in the end. "The scientific message is: immunity makes a difference," she says. But the final lesson is one Steinman liked to preach. "He used to tell people, 'There are so many other things left to discover,' " she recalls. "And there are." SA

***Katherine Harmon*** *is an associate editor at* Scientific American.

MORE TO EXPLORE

**Identification of a Novel Cell Type in Peripheral Lymphoid Organs of Mice, Vol. 1: Morphology, Quantitation, Tissue Distribution.** Ralph M. Steinman and Zanvil A. Cohn in *Journal of Experimental Medicine,* Vol. 137, No. 5, pages 1142–1162; May 1973. www.ncbi.nlm.nih.gov/pmc/articles/PMC2139237

**Taming Cancer by Inducing Immunity via Dendritic Cells.** Anna Karolina Palucka et al. in *Immunological Reviews,* Vol. 220, No. 1, pages 129–150; December 2007. http://onlinelibrary.wiley.com/doi/10.1111/j.1600-065X.2007.00575.x/full

**Dendritic Cell–Based Vaccination of Patients with Advanced Pancreatic Carcinoma: Results of a Pilot Study.** Christian Bauer et al. in *Cancer Immunology, Immunotherapy,* Vol. 60, No. 8, pages 1097–1107; August 2011. www.springerlink.com/content/t56q865742198411

**SCIENTIFIC AMERICAN ONLINE**

Watch Ralph M. Steinman explain more about the cells he discovered and enlisted to help fight his cancer at ScientificAmerican.com/jan2012/steinman-cancer

HEALTH

# FIVE HIDDEN DANGERS OF ... OBESITY

## Excess weight can harm health in ways that may come as a surprise

*By Christine Gorman*

BY NOW IT IS COMMON KNOWLEDGE THAT BEING severely overweight puts people at increased risk of suffering from heart disease, stroke and diabetes and that obesity—defined as weighing at least 20 percent more than the high side of normal—is on the rise. According to one estimate, the U.S. will be home to 65 million more obese people in 2030 than it is today, leading to an additional six million or more cases of heart disease and stroke and another eight million cases of type 2 diabetes. Many clinicians have already begun seeing families in which the grandparents are healthier and living longer than their children and grandchildren.

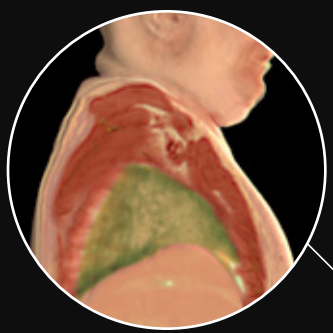
As if these alarming figures were not bad enough, studies over the past few years have shown that the obesity epidemic's true costs extend even further. Research now confirms that excess weight can impinge on mental well-being (exacerbating both depression and Alzheimer's disease), sexual and reproductive health, and the quality of everyday living—especially as we get older. Scientists believe that perhaps 25 percent of several types of malignancies—including cancer of the colon, kidney and esophagus—are triggered by increasing rates of obesity and physical inactivity.

The consequences, as documented in the images at the right, created by TheVisualMD.com and based on the latest related anatomical data, offer a sobering "anatomical travelogue" of just how far-ranging obesity's toll on the body can be. SA

***Christine Gorman*** *is the health and medical editor for* Scientific American.

**SCIENTIFIC AMERICAN ONLINE**
More images and links at ScientificAmerican.com/jan2012/obesity

**Heartburn:** **A 2005 study of 450 individuals found that obese adults are two and a half times more likely to experience heartburn compared with people of normal weight. One possible cause: visceral fat may push the stomach higher into the chest.**

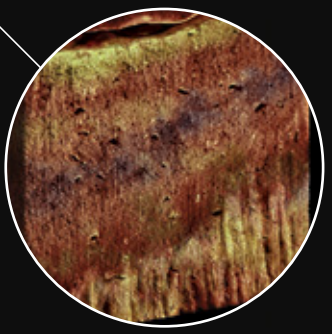


**Labored breathing:** **Visceral fat, which surrounds internal organs, is more dangerous than subcutaneous fat, which lies under the skin. In this side view, visceral fat presses on the diaphragm from below, which limits breathing by making it harder for the lungs (*here shown in green*) to expand.**

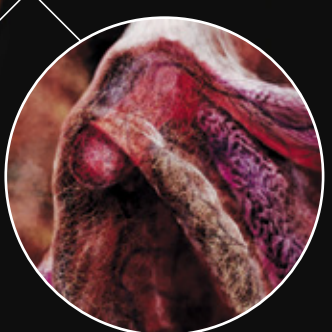
**Painful joints:** **The additional weight of excess pounds places a particular burden on the knees. In this image the arthritic damage (*white*) triggers pain and a decrease in the knee's range of motion.**

VISUALIZATIONS COURTESY OF THEVISUALMD.COM

**Torso:** A cross-sectional view of an obese woman.



**Depression:** A dozen studies suggest that obesity can be an important cause of depression, possibly because of a combination of physiological factors and social stigma. These neurons, from the cortex of the brain, have shrunk and are misshapen.



**Sexual dysfunction:** Inflammatory chemicals released by fat cells may damage the branchlike nerves in the penis (*above*) and attack blood vessels in the clitoris (*below*), leading to an inability to enjoy sex.

**James Vlahos** writes about science, technology and travel. He was a founding editor of *National Geographic Adventure* and is a regular contributor to the *New York Times Magazine, National Geographic Traveler, Popular Science* and *Popular Mechanics*.

TECHNOLOGY

# THE DEPARTMENT OF PRE-CRIME

In cities across the U.S. data-rich computer technology is telling cops where crimes are about to happen. Crime is down, and the technology is spreading. But does it really work?

*By James Vlahos*

PATROLMAN JOSEPH CUNNINGHAM AND I ARE HUNTING FOR CRIMINALS. NOT JUST ANY CROOKS but home burglars. And not just anywhere: although the city of Memphis covers 315 square miles, our search area has been narrowed to just a few square blocks of low brick apartment buildings in a crime-plagued part of town. The search date and time, too, have been tightly defined—Thursday, between 4 P.M. and 10 P.M. The shift begins now. "I don't anticipate any car chases tonight, but if one happens, be sure to put your seat belt on," Cunningham says as we pull out from the station.

In squad car number 6540, Cunningham and I reach the area that his report has flagged. We are scouting for would-be burglars in general—"I'm looking for people who look like they don't have a place to go," Cunningham explains—and one suspect in particular: a man named Devin who may be behind a recent spate of break-ins in the area. Cunningham pulls up Devin's picture on a dashboard-mounted touch screen.

We roll slowly into the parking lot of one of the buildings. A



*Illustration by Harry Campbell*

man walking by looks up, notices us and hurriedly ducks into an interior courtyard. Cunningham stomps on the gas, and we whip around three sides of the complex, screeching to a halt just in time to intercept the man walking out from the other side. Cunningham hops out of the car and runs up to the man. "Hold on," he says.

Any good cop knows his precinct's honeypots, the places where crime is most common and arrests easiest to make. But Cunningham's street savvy is being aided tonight by a crime forecast made by sociologists, investigators, mathematicians and a roomful of computers. The partnership between the Memphis Police Department (MPD) and the University of Memphis is called Blue CRUSH (for Crime Reduction Utilizing Statistical History), and the campaign is credited with helping to slash the numbers of major property and violent offenses by 26 percent citywide since the initiative was launched in 2006. Car break-ins, muggings and murders have plunged by 40 percent.

Number crunching is nothing new in police work—witness the New York City Police Department's widely imitated CompStat program, which provided officials with frequently updated maps of high-crime areas when it launched in the mid-1990s. In the past few years, though, so-called predictive policing has grown ever more sophisticated. The most ambitious criminologists are no longer content to analyze data from the past—they are trying to predict the future.

Predictive policing is one of the hottest topics in law enforcement today, with more than a dozen experimental efforts under way in the U.S. and Europe. The dirty secret of the futuristic approach, though, is that nobody knows for certain that it works. The causes of crime are multifactorial and complex, making it difficult to pinpoint which strategies are best to combat it. Criminologists are only beginning to separate the effects of predictive police work from the myriad other factors that lower crime, such as the aging of the American population. All the experts know for certain is that police are doing something right. Across the U.S., crime is down to its lowest levels in four decades.

When Cunningham returns with the man's driver's license, the picture looks virtually identical to the one of Devin on the touch screen. But his name does not match—a case of mistaken identity—so Cunningham steps out of the car again to go send the man on his way. "It's his lucky day," he says.

## THE SCENE OF THE CRIME

PREDICTIVE POLICING sounds like it belongs to the ominous future as imagined by writer Philip K. Dick, and indeed his 1956 short story "The Minority Report" (later adapted into a Steven Spielberg film) describes a future in which the police department intercepts criminals before they strike. In real life, the approach relies on crime analysts and computer software rather than the visions of mutants who sit in a darkened room. It also does not tell you who is likely to commit a crime. Instead it produces best guesses for everything else: what type of crime and where and when it will happen. "Some people say you can't predict what is going to happen in the future," says John Williams, crime-analysis manager for the MPD. "Well, we say, 'Yes, you can.'"

Dystopian overtones aside, though, the practice is merely a dramatic example of a field called predictive analytics, which, unlike the jet packs and rocket cars also envisioned in the Eisenhower era, is commonplace today.

When Amazon recommends books using taste-guessing algorithms, that is predictive analytics. Credit-card companies use soothsaying computer programs to flag restless customers and offer them better rates before they jump ship to another card, whereas Blue Cross hopes to predict what medical services individual policyholders will need years down the road.

Humanity has traditionally relied on expertise and instinct to divine the future. People can be good at these intuitive forecasts, too, as Malcolm Gladwell illustrated in his popular 2007 book *Blink*. But advocates of predictive analytics say that the volume of information we generate every day with our cameras, computers and smartphones has grown incomprehensibly large. "Business and government datasets are being measured not in mega- or gigabytes but in tera- and even petabytes (1,000 terabytes)," writes Ian Ayres in his influential 2008 analytics book *Super Crunchers*. The anti-*Blink* hypothesis, then, is that we are adrift in a sea of information too vast for any human mind to intelligently navigate. Enter the visionary machines.

In police work, every call for service, traffic stop, sidewalk interview and arrest generates data that tantalize analysts with the promise of actionable leads—if only they could be mined from a mountain of informational rubble. Investigators historically have read the statistical tea leaves by hand, pulling batches of dusty records from file storage or simply by sensing that something suspicious is happening. CompStat introduced regular, semiautomated data analysis to policing, but what has changed since the early days is not only the amount of information being recorded but also the computer-aided swiftness with which it can be analyzed. "We used to look at our crime statistics every year and say, 'Wow, look what happened,'" says Captain Sean Malinowski, who leads analytics efforts for the Los Angeles Police Department (LAPD). "Then we started looking monthly, weekly, daily and now in real time."

The headquarters for predictive policing in Memphis is the Real Time Crime Center, which, in suitable fashion for a crime fighter's redoubt, is hidden on the fourth floor of an unassuming office building downtown. Williams walks me past a dozen analysts sitting in stadium-style tiers and tapping away at computers. Projection screens showing icon-dotted maps of the city and the feeds from surveillance cameras cover the front and side walls. A news ticker runs across the top of one screen with the latest reported crimes, such as "Theft from Motor Vehicle, 12:30:46 P.M."

### IN BRIEF

**Predictive policing** techniques combine traditional criminal data with unorthodox information such as upcoming paydays to generate predictions about where crime is likely to happen in the future.

**Memphis** has been using a predictive policing system called Blue CRUSH to lower crime rates there. Since the system was instituted citywide in 2006, violent and major property crimes are down 26 percent.

**Predictive policing** techniques raise questions about whether they might be used to deem individuals guilty before they commit a crime. In addition, criminologists do not know how well they truly work.

In a conference room Williams introduces me to W. Richard Janikowski, a University of Memphis criminologist who was one of the original visionaries of Blue CRUSH. The seeds of the project were planted when police sought his help in battling the city's sexual assault rate, which for two decades had ranked first or second highest in the nation. Janikowski convened victim focus groups and personally visited assault locations. But the most powerful insights came from the reams of police report data—times, locations, descriptions of the assaults—from some 5,000 rapes. The analysis revealed that many victims were being assaulted under similar circumstances: when they left their homes to use pay phones mounted outside convenience stores at night. The police told convenience store owners to move their pay phones indoors, and sure enough, the rape level in Memphis soon dropped.

This was essentially an example of Predictive Policing 1.0. Using analytical software to gain insights about what had happened in the recent past, Janikowski and company rightly assumed that similar crimes would happen again in the near future. Since then, forecasting techniques have grown even more powerful, allowing police to divine the patterns hiding in much larger data sets—up to hundreds of thousands of records—a process of separating the signal from the surrounding noise that would overwhelm the typical human investigator.

The methodology has also become more sophisticated. The future does not always mirror the past, so criminologists must identify individual factors and tease out their influences alone and in combination. P. Jeffrey Brantingham, an expert in predictive policing at the University of California, Los Angeles, explains the fundamental challenge: "Given a cluster of crimes today, can we build a mathematical model and say what, in a probabilistic sense, the crime pattern is likely to look like tomorrow?" he asks.

Predictive Policing 2.0 thus looks like what happens in Richmond, Va., which, as is the case in Memphis, uses analytical software developed by IBM. Police computers analyze each crime by time of day, day of the week and day of the month. Offense locations are parsed by street address, as well as proximity to places such as ATMs, parks and bars. The computers are supplied with the paydays of major local employers such as Phillip Morris and the schedules at local concert and sports venues. Everything from the timing of gun shows to the weather and phase of the moon is deemed potentially important.

Evaluating how all these factors might influence future crime requires a partnership between people and machines, with each bringing different strengths to the table. Computers are better at flagging statistical trends, but cops still have to interpret them, says Lt. Col. Howell Starnes of the MPD. "Until you get that street officer who knows his ward, you won't know what's *causing* the crime," he says. "That's what you've got to look at. Not that you've got a problem—what's causing the problem."

The process of predictive policing often starts with a cop's hunch, such as that muggings tend to rise near ATMs around paydays. Computer analysis can ascertain whether that hunch is valid and add nuance to the theory. For example, it might turn out that muggings around a particular subset of ATMs go up the most on paydays, so that is where officers should preferentially be stationed. In Richmond the police had a feeling that violent crime went up after there had been a gun show in town. The computer analysis proved them mostly right—violent crime risk peaked not the weekend after the show as expected but two weeks later.

Computers, though, far outstrip humans working alone because of their phenomenal processing power and their advantage of not being blinded by human preconceptions. In the 2007 book *Data Mining and Predictive Analysis,* author and former police officer Colleen McCue describes a counterintuitive discovery made by criminologists in Virginia who were crunching the numbers on what types of people become rapists. "Not surprisingly, prior offense history reliably emerged as the most predictive variable," McCue writes. "What was a shock, however, was that a prior property crime actually was a better predictor for a stranger rapist than a prior sex offense." In particular, it was criminals who had broken into homes before but had stolen little to nothing who were likeliest to later rape. They were probably scouting for a victim, not looking to steal. So in the future, when computers flagged a rash of home break-ins in which nothing was taken, residents needed to be alerted to watch out for a rapist in their midst.

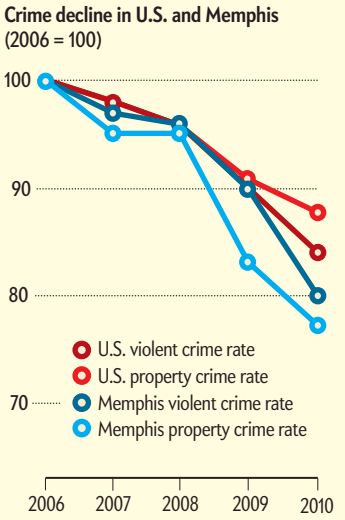
Predictive software does not even need to start with a theory from human overseers, although that can be helpful; the computers can instead troll an ocean of data and devise predictive algorithms automatically, a process known as rule induction. Feed the computer a set of data, and the software will trace combinations of factors that lead to crime, prompting guesses about how novel combinations influence overall future risk. For example, what might happen when there is a gun show scheduled on the same weekend that the weather forecast calls for a heat wave or when there will be a full moon the night of an upcoming payday?

The police in Richmond can essentially throw predictive

DOES IT WORK?

## Down Years

**The factors** that lead to crime are multifarious and complex; tracking crime rates back to primary causes remains notoriously difficult. Still, evidence exists that predictive strategies such as Memphis's Blue CRUSH system have helped staunch crime. Since 2006, when Blue CRUSH was instituted, Memphis has shown much sharper drops in the rates of violent and major property crimes than has the rest of the U.S.

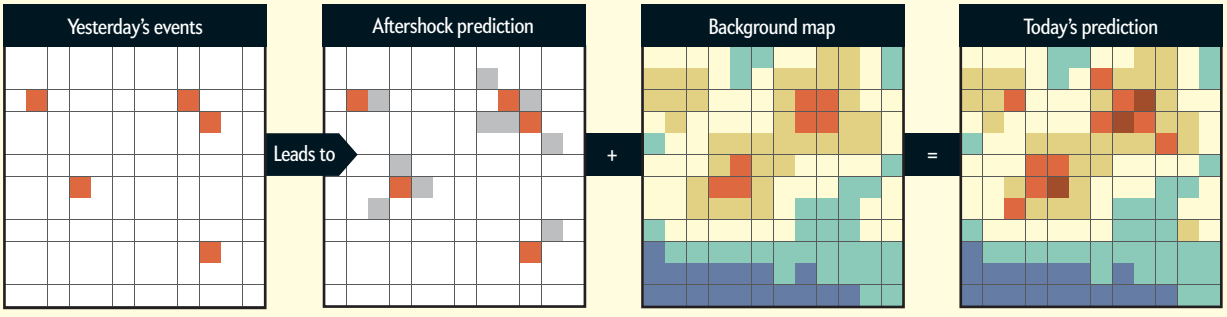



SOURCES: FBI UNIFORM CRIME REPORTS AND U.S. CENSUS BUREAU

*Graphic by Jen Christiansen*

# Criminal Aftershocks

**Recent work** in criminology has shown that crime shares much in common with earthquakes. Certain areas—be they tough neighborhoods or fault lines—are more likely to suffer. And in the same way that earthquakes spawn aftershocks, a crime will tend to be followed by a temporary uptick in crime rates in nearby areas. Researchers have used this insight to create maps of where crime is likely to happen in the coming days and weeks. They take yesterday's crime reports, build aftershock maps that reflect the increased likelihood of criminal activity in areas close by, and add these aftershock spikes to a background map of typical criminal activity. The police then use the resulting map to dispatch officers to the locations most likely to rumble.




ideas against the wall, however wacky, and see what sticks. Each time they introduce a new candidate factor, like the schedule of PTA school meetings, they reevaluate the model after the predicted future has come to pass. How good was the model at foreseeing the crimes that actually wound up happening? "In the end, the model might utilize only a subset of the candidate factors," explains IBM software engineer Bill Hafey, "but it is this subset that constituted the most accurate model."

## SOOTHSAYER DETECTIVES

THE LATE JACK MAPLE, then a New York City transit police officer, launched modern data-driven policing in the 1980s by plotting violent subway crimes with crayons and pushpins on maps. He called them "Charts of the Future." It was a catchy name, redolent with Disneyesque visions of a brighter tomorrow, and a prescient one, too; today, nearly two decades later, maps are still the key tool of predictive policing even if the analysis they reflect has grown far more sophisticated.

In Memphis I attended a weekly Blue CRUSH TRAC—that is, Tracking for Responsibility, Accountability and Credibility—meeting. In a large conference room, the city's eight precinct commanders took the podium in turn to discuss the latest crime in their areas. The projection screen behind them displayed maps marked with crime-symbolizing icons—fists, broken windows and little thieving men—each one representing a single offense in the past week.

Predictive-policing methods make use of far more variables than the times and locations of recent crimes, however. In Memphis an analyst might first pull up a map showing recent burglaries. He could then display the home addresses of all the students that the school district had reported as being recently absent. A third layer of data would indicate which of the truants had past convictions for burglary. When everything lines up—burglaries near the home of a truant student with a criminal record—it is time to hit the street and try to catch the thief in the act. Or show up at the truant's house. "You go to do a knock and talk, and, lo and behold, you find stolen stuff stacked all around the building," says John Harvey, manager of the Real Time Crime Center.

These algorithms have also begun to integrate the latest theories of criminologists. For example, conventional wisdom holds that savvy criminals do not return to the scenes of their crimes. But successful burglars do exactly that, according to U.C.L.A.'s Brantingham and George O. Mohler, a mathematician at Santa Clara University, who analyzed thousands of burglary incident and arrest reports from the LAPD to arrive at their findings. "From the offender's point of view, going back to the house you broke into yesterday is a good strategy," Brantingham says. "You know what's in the house. You know how to get in and out quickly." What is more, they found, the burglary risk also goes up considerably for other neighborhood houses because they often have similar layouts and types of possessions, making them attractive targets.

Brantingham and Mohler have since discovered a repeat-victimization effect for muggings, gang violence and grand theft auto. They determined how far the effect extended—about two miles in the case of burglary—and how the risk levels changed over the days and weeks following the original offense. They then developed predictive algorithms that include these findings, creating a predictive model that has been shown to be 10 to 20 percent more accurate at forecasting future crimes than a classic model that assumes the future will look exactly like the past.

At the Blue CRUSH TRAC meeting in Memphis, each of the precinct maps is marked with two to three "focus areas" where crime is expected to be heaviest in the coming week. Bullet points list what particular crimes to watch out for and when. That is how patrolman Cunningham and I were tipped off to be on the lookout for burglars in the Greer Street area that afternoon between 4 P.M. and 10 P.M.

The forecast is also how we know to be cruising later that



*Graphic by Joshua Korenblat*

night in another high-risk zone, the Orange Mound neighborhood, when we get a call for assistance. Two other squad cars, roof lights whirling, hem a black Nissan into the curb when we arrive. The man sitting in the backseat has nearly two ounces of marijuana on him, a few hundred bucks and a scale cleverly disguised as an iPhone. When one of the officers asks him what the scale is for, the suspect is helpfully open about his trade as a drug dealer, if not respectful of his own Fifth Amendment rights. "Sometimes my customers think I'm trying to cheat them, so I have to weigh the product," he says.

## GUILTY OF PRE-MURDER

THE POT DEALER is cuffed and quiet in the back of the car. We are transporting him to the county jail when a call crackles over the police radio: "6011 Apartments, Ridgeway and Hickory Hill. Report of a shooting." The next morning I go online and read about the incident. The victim's name is Claude Brake, a 56-year-old army veteran now working for Papa John's Pizza. He had just made a delivery when two teenagers approached him and demanded money. He refused. One of the teenagers shot him. He died.

Murder is infrequent, even in a big city like Memphis. The city had 25,324 reported thefts in 2010 but only 90 murders, enough of a statistical rarity to make it impossible to generate an algorithm reliable enough to catch killers before they strike. Brake's murder had happened outside the focus areas that Cunningham was policing, and the weekly report made no attempt to predict such a violent crime. Even a believer like Janikowski is quick to point out that guesswork, however high tech and well educated, can take you only so far. "I prefer to describe what we do as 'crime forecasting' rather than 'crime prediction,'" he says. The science is imperfect.

Yet even if the cops cannot predict where a murder is likely to happen, some researchers believe we can do a better job establishing who is likely to commit a murder. Richard Berk, a professor of criminology at the University of Pennsylvania, has developed an algorithm that estimates the probabilities that someone on parole or probation will kill. The algorithm is based on a review of tens of thousands of cases and includes variables such as age, gender, type of offense and date of first offense. "Of the people who will shoot, the algorithm correctly forecasts those outcomes about 75 out of 100 times," Berk says.

Such powerful crime-prediction techniques raise a troubling question: Are we judging people guilty before they ever commit a crime? Researchers such as Brantingham say that is not the case with programs like Blue CRUSH. "This is not about predicting the behavior of a specific individual," he says. "It's about predicting the risk of certain types of crimes in time and space." The police forces employing his analytical tools are not locking up free citizens before they commit a crime; instead they steer extra patrols to the areas where the most potentially dangerous people are.

Berk's work, meanwhile, would seem to skate closer to the ethical line. Parole boards are being influenced by Berk's findings about which prisoners are too potentially dangerous to release. Yet making judgments about future criminality is exactly what parole boards are supposed to do, Berk says. The only difference is that they are now using computer analysis to augment what they formerly did almost solely from the gut.

## BEYOND A REASONABLE DOUBT

IN THE FIVE YEARS since the MPD began to augment its gut instincts with computer analysis, serious property and violent crimes have dropped an impressive 26 percent. Yet despite all the apparent evidence in favor of predictive policing, it is hard to know just how much of the drop in crime seen in Memphis and elsewhere is a result of the software. Most other American cities around Memphis's size have also reported significant drops in crime, and not all of them have implemented campaigns similar to Blue CRUSH.

Also, as any crime statistician knows, the year you select for your baseline—the one all future gains will be measured against—plays a critical role in how impressive your results look. For Memphis, comparing back to 2006 makes sense because that was when Blue CRUSH was rolled out citywide. But 2006, as it happens, was the highest crime year for the entire decade, which had the effect of making all the years that followed look good by comparison. An alternative way to look at the stats would be to compare the average crime rate for the five Blue CRUSH years from 2006 to 2010 with that for the five previous ones, from 2001 to 2005. Viewed that way, what happened in Memphis is not nearly so miraculous: property crime went down a modest 8 percent in the second half of the decade, whereas violent crimes were actually up by 14 percent.

It is no coincidence, nor attempt at statistical trickery, that Blue CRUSH was launched when crime was peaking, Janikowski says. "[In 2006] we knew that crime had been going up for the past two years and that nothing we were doing was working," he says. "We had to try something new." He points out that many of the methods that were part of the Blue CRUSH campaign, such as hotspot policing, have, in fact, been validated in rigorous, large-scale studies and that crime went down in each of the years since 2006. But "is the predictive stuff all by itself yet scientifically proven?" he asks. "That, you can legitimately raise questions about."

With people throughout law enforcement looking for answers, the National Institute of Justice has gotten into the act. It recently issued grants to seven American city police departments, including those in Boston, Chicago, New York, Los Angeles, and Washington, D.C., to evaluate the effectiveness of predictive policing in carefully controlled tests. The LAPD and Brantingham, for instance, will compare the crime rates in areas of the city that use his repeat-victimization models with areas that do not. To bolster impartiality, the results from all the cities' studies will be additionally reviewed by Rand Corporation. Brantingham is cautiously optimistic: "We're on the cusp of a new era of policing," he says. Soon he will get to prove it. SA

### MORE TO EXPLORE


**Self-Exciting Point Processes Modeling of Crime.** G. O. Mohler, M. B. Short, P. J. Brantingham, F. P. Schoenberg and G. E. Tita in *Journal of the American Statistical Association,* Vol. 106, No. 493, pages 100–108; 2011.

**How New York Beat Crime.** Franklin E. Zimring in *Scientific American,* Vol. 305, No. 2, pages 74–79; August 2011.

Federal Bureau of Investigation Uniform Crime Reports: www.fbi.gov/about-us/cjis/ucr


**SCIENTIFIC AMERICAN ONLINE**

Ride along with the Memphis Police Department as computers predict the next crime at ScientificAmerican.com/jan2012/precrime

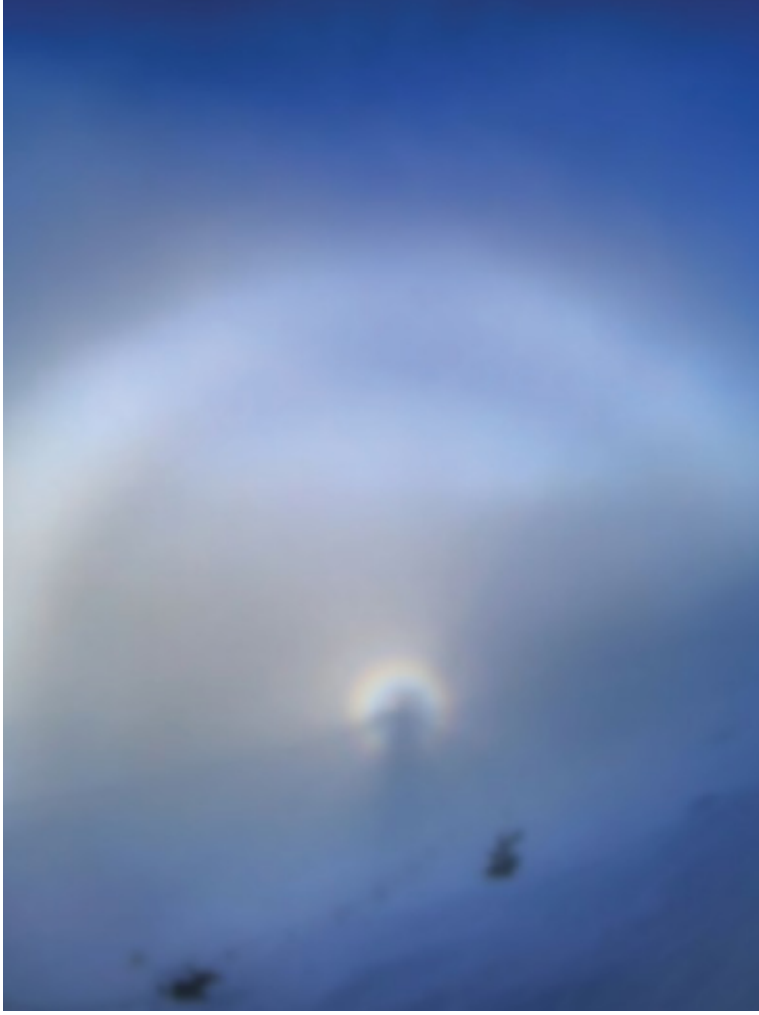
PHYSICS

# THE SCIENCE OF THE GLORY

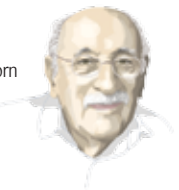
One of the most beautiful phenomena in meteorology has a surprisingly subtle explanation. Its study also helps to predict the role that clouds will play in climate change

*By H. Moysés Nussenzveig*

CLOCKWISE FROM TOP LEFT: STEVE JURVETSON; CLAUDIA HINZ; BARBARA LAUGHON; CLAUDIA HINZ



**H. Moysés Nussenzveig** is an emeritus professor of physics at the Federal University of Rio de Janeiro and a winner of the Max Born Award of the Optical Society of America. He has developed novel theoretical approaches to a broad range of optical phenomena and is currently directing research in cell biophysics.



ON A DAYTIME FLIGHT PICK A WINDOW SEAT THAT WILL allow you to locate the shadow of the airplane on the clouds; this requires figuring out the direction of travel relative to the position of the sun. If you are lucky, you may be rewarded with one of the most beautiful of all meteorological sights: a multicolored-light halo surrounding the shadow. Its iridescent rings are not those of a rainbow but of a different and more subtle effect called a glory. It is most striking when the clouds are closest because then it dominates the whole horizon.

If you are a mountain climber, you may also see a glory soon after sunrise, around the shadow your own head casts on nearby clouds. Here is how it was described in the first reported observation, published in 1748 and made a decade earlier by members of a French scientific expedition to the top of Pambamarca in what is now Ecuador: "A cloud that covered us dissolved itself and let through the rays of the rising sun.... Then each of us saw his shadow projected upon the cloud.... What seemed most remarkable to us was the appearance of a halo or glory around the head, consisting of three or four small concentric circles, very brightly colored.... The most surprising thing was that, of the six or seven people who were present, each of them saw the phenomenon only around the shadow of his own head, and saw nothing around other people's heads."

Scholars have often suggested that the halo around the heads of deities and emperors in eastern and western iconography may have been a representation of a glory. Samuel Taylor Coleridge's celebrated poem "Constancy to an Ideal Object" is an allegorical tribute to it. In the late 19th century Scottish physicist C.T.R. Wilson invented the cloud chamber in an attempt to reproduce the phenomenon in the laboratory. (Wilson failed, but he quickly realized that he could use his cloud chamber to detect radiation and ultimately received a Nobel Prize for its invention.)

The shadow of the observer or the airplane plays no role in creating a glory. The only reason for their association is that shadows mark the direction exactly opposite to the sun in the sky, signifying that the glory is a backscattering effect, in which sunlight gets deviated by nearly 180 degrees.

You would think that such a well-known effect, involving optics, a venerable branch of physics, would surely have been explained long ago. Yet for scientists this "phenomenon which must be as old as the world," in the words of the 1748 report, remained a challenge for centuries. Rainbows are themselves far more complex than introductory physics textbooks would lead one to believe. Still, rainbows are considerably simpler than glories.

In principle, both glories and rainbows are explained using a standard optics theory that was already available early in the 20th century, when German physicist Gustav Mie wrote down an exact mathematical solution of how water droplets scatter light. The devil, however, is in the details. Mie's method involves the summation of terms called partial waves. The summation includes infinitely many such terms, and even though only a finite number matter in practice, Mie's method still requires evaluating hundreds to thousands of mathematical expressions, each of which is rather complicated. Put the formulas into a computer simulation, and they will give the correct result but will provide no insight into the physical effects that are responsible for the phenomenon: the Mie solution is just a mathematical "black box" that, given certain inputs, generates an output. A remark attributed to phys-

IN BRIEF

**Looking down on a cloud** from a mountain or an airplane, sometimes you can spot a glory: rings of colored light around your shadow or the plane's.
**As in a rainbow,** the colors are produced by the microscopic water droplets that compose clouds, but in the case of glories the physics is more subtle.
**The light energy** beamed back by a glory originates mostly from wave tunneling, which is when light rays that missed a droplet can still transfer energy into it.
**The understanding gained from glories** is helping climatologists to improve models of how cloud cover may contribute to or alleviate climate change.

ics Nobel laureate Eugene Wigner is apt: "It is very nice that the computer understands the problem. But I would like to understand it, too." Blind faith in brute-force number crunching can also lead to incorrect conclusions, as will be shown.

In 1965 I began to develop a research program to provide, among other things, a full physical explanation of the glory—a goal that, with the help of several collaborators along the way, was finally completed in 2003. The answer involves wave tunneling, one of the most mystifying effects in physics, which Isaac Newton first observed in 1675. Wave tunneling is the basis of one type of modern touch screen, employed in computers and cell phones. It is also important in the notoriously complicated—and still incompletely solved—problem of determining how atmospheric aerosols, which include clouds but also dust and soot, contribute to climate change.

## WAVES AND PARTICLES

OVER THE CENTURIES physicists have offered several explanations for glories that proved to be incorrect. At the beginning of the 19th century German physicist Joseph von Fraunhofer proposed that sunlight that is scattered—that is, reflected back—from droplets deep within a cloud would become diffracted by droplets at the outer layers. Diffraction is one of the wavelike features of light, enabling it to "go around corners," just as sea waves can negotiate an obstacle such as a vertical beam and proceed as if the obstacle had not been there at all.

Fraunhofer's idea was that such double scattering would produce colored diffraction rings like those of the corona seen on clouds surrounding the moon in the sky. In 1923, however, Indian physicist B. B. Ray refuted Fraunhofer's proposal. After experimenting with artificial clouds, Ray noted that glory rings have a distribution of brightness and colors very different from those in coronas and that they arise directly from the outer layers of a cloud, from single backscattering by individual water droplets.

Ray tried to account for that backscattering with the help of geometric optics, historically associated with the corpuscular theory of light, which models its propagation by means of rectilinear rays rather than waves. When light meets an interface between two different media, such as water and air, part of it is reflected and part of it is transmitted, or refracted (refraction is what makes a pencil half-dipped in water look like it is broken). Light entering a water droplet gets reflected one or more times at opposite droplet sides before exiting. Ray considered light that travels along the droplet axis and is reflected back as it enters and at the opposite side. Even considering multiple back-and-forth axial bounces, though, his result was far too weak to account for glories.

Thus, the theory of glories had to go beyond geometric optics and account for the wave nature of light as well—and in particular for wave effects such as diffraction. In contrast with refraction, diffraction gets stronger as the wavelength increases. That the glory is a diffraction effect can be seen from the fact that its inner rims are blue, whereas the outer rims are red, corresponding to shorter and longer wavelengths, respectively.

The mathematical theory of diffraction by a sphere such as a water droplet, known as Mie scattering, calculates the solution as an infinite sum of terms called partial waves. Each partial wave term is a complicated function of the droplet's size, of the refractive index—a measure of how strongly water bends light rays compared with other media—and of the distance of a light ray from the droplet's center, called the ray's impact parameter. The calculations involved in Mie scattering from droplets of a sufficiently broad range of sizes are forbiddingly complex without a high-speed computer, and it was not until the 1990s that supercomputers began to be fast enough to give realistic results over the broad range of droplet sizes found in clouds. Researchers needed better ways to grasp what was going on.

Hendrik C. van de Hulst, a pioneer of modern radio astronomy, provided the first significant insight into the physical explanation of glories in the middle of the 20th century. He pointed out that a light ray that entered a droplet very close to the droplet's edge might follow a V-shaped trajectory inside the droplet, bouncing off at the back, and return almost exactly in the same direction that it came from. Because droplets are symmetric, among the bundle of parallel rays coming from the sun the favorable impact parameter would occur not just for one ray but for a whole circle's worth of rays all at the same distance from the droplet's center—a focusing effect that would dramatically enhance the backscattering.

The explanation sounds clear-cut, but unfortunately it had a serious snag. As a ray entered and exited the droplet, it would bend via refraction. But the refractive index of water is not large enough to scatter a ray back in the same direction after just one internal reflection. The best that water can do is send

THE CONDITIONS FOR A GLORY

### Why Does It Always Surround Your Shadow?

**Because a glory** is made of light that bounced back nearly in the same direction that it came from, it requires a particular and serendipitous alignment of sun, observer and cloud. Consequently, it is always seen as a halo surrounding the observer's shadow on the cloud. Different colors of the spectrum come off at slightly different angles, producing an iridescent pattern.


*Illustrations by Alfred T. Kamajian*

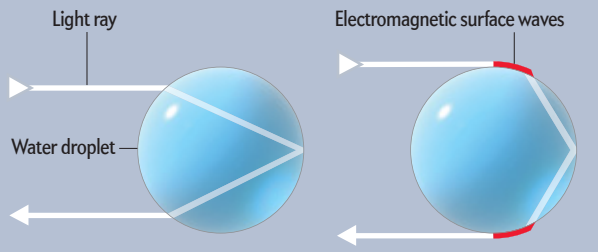
# Light at the End of a Tunnel

**Glories have been known for centuries,** but only in recent years (and after some false starts) have researchers gained real physics insight into them, based on a phenomenon called tunneling.

## A "Wrong" Attempt and a Better One

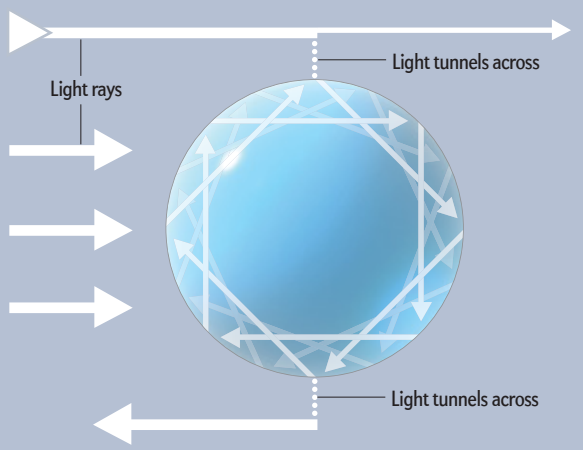
Researchers first tried to attribute the phenomenon simply to light bouncing back inside the microscopic water droplets that compose clouds. Light rays would bend (refract) as they entered a droplet and would get reflected inside. Then they would bend again as they exited, going back in the direction they came from (*below left*). But water does not bend light rays enough for rays to go back in the exact same direction.

A second theory posited that light rays grazing a droplet could temporarily turn into electromagnetic surface waves. By following the curved surface for small distances (*seen exaggerated, below right*) before entering and exiting from the droplet, the light could turn by just the angle needed to return in the same direction. This effect can take place, but it gives a relatively minor contribution to the overall energy seen in a glory.




## A Fuller Understanding

A mathematical theory of light scattering later explained glories through lengthy calculations but did not provide insight into the underlying physics. Instead the author demonstrated that most of the light seen in a glory is the result of energy "tunneling" into water droplets from light rays that would otherwise seem to miss the droplets altogether. Tunneling is a common feature of waves of all kinds, in both quantum and classical physics.




light backward in a direction within 14 degrees of the original ray.

Van de Hulst suggested in 1957 that this 14-degree gap could be bridged by extra paths in which the light travels as a surface wave along the droplet surface. Surface waves attached to an interface between two different media arise in a variety of situations. The idea was that a tangentially incident ray would graze the droplet, travel along its surface a short distance, then propagate through the droplet to its rear. There it would again travel along the surface and reflect back through the droplet. A final passage along the surface would send it on its way. The overall effect would be to scatter the ray back in the same direction that it came from.

One potential difficulty is that surface waves lose energy by shedding radiation tangentially, but van de Hulst conjectured that this damping would be more than compensated for by the axial-focusing enhancement. At the time when he proposed his conjecture, no quantitative procedure to evaluate the surface-wave contributions was available. Still, all the information about the physical origin of glories, including the role of surface waves, had to be implicitly contained within the Mie partial-wave series: the challenge was how to extract it.

### MIND BEATS COMPUTER

SURFACE WAVES are not the only potential solution to the riddle of glories. In 1987 Warren Wiscombe of the NASA Goddard Space Flight Center in Greenbelt, Md., and I came up with a new insight into diffraction: that light rays passing outside the sphere could make a significant contribution. At first glance, this seems absurd. How can a ray be affected by a droplet if it does not even pass through it? Waves, however—and light waves in particular—have the uncanny ability of "tunneling," or jumping through a barrier. For instance, light's energy can leak out in circumstances where it would be expected to stay within a medium, as is seen in the following situation.

Typically light propagating in a medium such as glass or water will be totally reflected at the separation with another medium of lower index of refraction, such as air, if it hits the surface of separation at a shallow enough angle. Such total internal reflection is what keeps signals within optical fibers, for instance. Even if all the light bounces back, however, the electric and magnetic fields that make up the light waves do not drop completely to zero at the interface. Instead the fields still extend for a short range beyond the surface, forming evanescent waves that do not propagate away from the immediate vicinity of the interface and do not carry any energy through the boundary. Evanescent waves make the electromagnetic field near the surface vibrate in place, like the strings of a guitar.

What I just described is a situation in which no tunneling occurs. If, however, a third medium is placed within a short distance of the boundary so that it overlaps with the evanescent waves, the waves can resume their outward propagation in the third medium and thus siphon energy away. As a result, the internal reflection in the original medium will weaken. The intermediate medium, which before acted as a barrier, has now been tunneled through.

Appreciable tunneling can take place only if the gap is not much greater than one wavelength across—about half a micron or less in the case of visible light. Yet Newton himself already observed the phenomenon as far back as 1675. He was investigating patterns of interference now known as Newton's rings by

laying a convex lens on a flat glass plate. The rings should appear only when light can directly propagate from the lens to the plate. What Newton found out was that even when an extremely narrow air gap separated the surface of the lens from the plate—so that the two surfaces were not quite in contact with each other—some light that should have undergone total internal reflection jumped across the gap instead.

Tunneling is highly counterintuitive. Russian-born physicist George Gamow was the first to employ it in quantum mechanics in 1928 to explain how certain radioactive isotopes can emit alpha particles. Gamow observed that alpha particles should not have enough energy to detach from a larger nucleus, just as a cannonball cannot reach escape velocity and leave the earth's gravitational field. He was able to demonstrate that because of their wavelike nature, alpha particles can still tunnel through this energy gap and escape.

Contrary to popular prejudice, however, tunneling is not an exclusively quantum effect: it also occurs with classical waves. Sunlight traveling well outside a water droplet in a cloud can, against intuitive expectations, penetrate within it by tunneling and, in this way, contribute to the production of a glory.

In our initial analysis in 1987 Wiscombe and I studied scattering by a totally reflecting sphere such as a silvered ball. We found that partial waves associated with above-edge rays can, if the rays pass close enough to the sphere, tunnel all the way to the surface and still give a sizable contribution to diffraction.

In the case of a transparent sphere such as a water droplet, after tunneling to the surface the wave can propagate inside. Once there the wave hits the internal surface at a shallow enough angle to be totally reflected, thus staying trapped inside. A similar situation occurs with sound waves: at the celebrated whispering gallery under the dome of St. Paul's Cathedral in London, a person who whispers facing the wall at one side can be heard far away at the other side because the sound undergoes multiple reflections, bouncing around the curved walls.

For light waves, however, light that has tunneled in can also tunnel back out. For certain wavelengths, after multiple internal reflections the wave reinforces itself by constructive interference and produces what is known as a Mie resonance. This effect may be compared with pushing a swing just in time with the rhythm of its natural pendulum oscillations, driving it higher and higher. Because of the acoustic analogy, these resonances are also known as whispering gallery modes. A tiny change in wavelength suffices to detune the resonance so that Mie resonances are extremely sharp and concentrated and yield large intensity enhancements.

To summarize, three potential effects contend for primary contributors to the glory phenomenon: rays that hit the sphere, including Ray's geometric-optic axial backscattering; edge rays, which involve the van de Hulst surface waves; and contributions from Mie resonances, arising from the tunneling of light. In 1977 Vijay Khare, then at the University of Rochester, and I evaluated the contribution from near-edge rays, including van de Hulst's term, and resonances were treated by Luiz Gallisa Guimarães of the Federal University of Rio de Janeiro and me in 1994. In 2002 I made a detailed analysis to determine which of these effects is the most important. As it turns out, axial backscattering is negligible; the main contributions arise from the above-edge tunneling resonances. The inescapable conclusion is that glories are a macroscopic light-tunneling effect.

## GLORIES AND CLIMATE

BESIDES AFFORDING US the intellectual satisfaction of finally understanding the origin of glories, light-tunneling effects also have practical applications. Whispering gallery modes have been employed to build lasers, using water microdroplets and solid microspheres, as well as other geometries such as microscopic disks. A recent application of light tunneling is used in multitouch screens. The approach of a finger to the screen plays the role of Newton's convex lens, enabling light to tunnel through, get backscattered and provide a signal. Evanescent light waves produced by tunneling also have many important applications in a technology called near-field microscopy because they can resolve details smaller than the wavelength—beating the notorious diffraction limit below which ordinary microscopes give blurry images.

Perhaps most crucially, understanding droplet scattering is necessary for estimating the role that clouds will have in climate change. Water is highly transparent in the visible spectrum, but—like carbon dioxide and other greenhouse gases—it absorbs certain bands of the infrared. Because Mie resonances usually involve long paths with huge numbers of internal reflections, a small droplet may end up absorbing a significant amount of radiation, especially if the water contains contaminants. As the average cloud cover changes, will it help keep the planet cool by reflecting more sunlight back into space, or will it contribute to heating by acting as an additional blanket to trap infrared radiation?

Until a decade or so ago simulations of light scattering from clouds performed Mie computations for relatively few droplet diameters that were thought to be representative for typical clouds. This rule of thumb reduced the need for machine time on supercomputers—but with an unexpected snag. As I demonstrated in 2003 using the methods I had developed for the analysis of rainbows and glories, the standard simulation methods could produce errors of up to 30 percent over narrow bands of the spectrum. Those brute-force techniques could calculate the scattering from droplets by sampling selected sizes but miss important contributions from many narrow resonances that fall in between—for example, if they performed calculations for sizes of one micron, two microns, three microns, and so on, they could miss a very sharp resonance at 2.4 microns. My prediction was confirmed in 2006 by a study that took into account droplet-size distribution in the atmosphere; in recent years models have been updated to include droplet sizes with much finer increments.

As Wigner had warned, even results from state-of-the-art supercomputers, if employed without physical insight, can be untrustworthy. Something to ponder, perhaps, next time you have a window seat. SA

### MORE TO EXPLORE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SUSTAINABILITY

# MORE FOOD, LESS ENERGY

Changes in agriculture, policy and personal behaviors can reduce the energy a nation uses to feed itself and the greenhouse gases it emits

*By Michael E. Webber*



*Photograph by Dan Saelinger*

**Michael E. Webber** is associate director of the Center for International Energy and Environmental Policy and assistant professor of mechanical engineering at the University of Texas at Austin.

FOR MORE THAN 50 YEARS FOSSIL FUELS AND FERTILizers have been the key ingredients in much greater global food production and distribution. The food-energy relationship has been a good one, but it is now entering a new era. Food production is rising sharply, requiring more carbon-based fuels and nitrogen-based fertilizers, both of which exacerbate global warming, river and ocean pollution, and a host of other ills. At the same time, many nations are grappling with how to reduce energy demand, especially demand for fossil fuels.

Although transportation, power plants and buildings receive a lot of policy attention as targets for reducing energy consumption, our food supply is often overlooked. In the U.S., about 10 percent of the energy budget goes to producing, distributing, processing, preparing and preserving the plant and animal matter we consume. That is a considerable wedge of the energy pie.

Examining our food supply through the lens of energy use reveals opportunities for smart policies, innovative technologies and new dietary choices that can potentially solve food and energy problems together. The same steps would also make our bodies, and our ecosystems, healthier.

## FARM TO FORK IS HIGHLY INEFFICIENT

SIMPLE MATH shows that food production is an inefficient process. Plant growth is not energy-efficient: photosynthesis typically converts less than 2 percent of incoming solar energy into stored energy. That low rate is worsened when animals convert plant matter into beef (5 to 10 percent efficiency) or chicken (10 to 15 percent). We then ingest that food and convert it into human energy stored as glycogen in muscles and as fats—notably around our midsection.

Given the abundance of photons striking the earth every day, low efficiencies hardly seem to matter. But when faced with limits on land, freshwater, fertilizer runoff, and fossil-fuel affordability and emissions, the inefficiencies can be daunting. The energy used to make food is vastly greater than the amount of energy we get out of it. The U.S. expends roughly 10 units of fossil energy to produce one unit of food energy.

The magnitude of consumption is remarkable when one considers the entire population. A healthy, active adult male's nominal instantaneous power consumption is approximately 125 watts. That equates to roughly 2,500 nutritional calories per day, or about 10,000 British thermal units (Btu). Thus, the 312 million people in the U.S. need about one quadrillion Btu (one quad) of food energy every year. Because we use 10 units of fossil energy to produce one unit of food energy, feeding the population requires 10 quads—which is 10 percent of the total annual U.S. energy consumption of 100 quads. If we as a society wish to reduce our food-energy consumption, we need to find ways to reduce the 10:1 ratio of energy input to food output.

The food energy needed to feed the world's seven billion people is about 25 quads a year, which is only about 5 percent of the world's 500 quads of annual consumption. It is not that the rest of the world is more efficient than the U.S. Rather one billion people are hungry, another billion are at risk of hunger and many more simply do not consume much.

Extensive energy use has dramatically increased food production through innovations such as diesel-powered tractors, electric irrigation pumps, and fertilizers and pesticides made from natural gas and petroleum. Since the mid-20th century crop yields from this green revolution have gone through the

### IN BRIEF

**About 10 percent** of U.S. energy consumption is for raising, distributing, processing, preparing and preserving the plant and animal matter Americans eat.
**Energy use** can be cut by converting agricultural waste such as manure into power; implementing new, pilot-level farming techniques such as drip irrigation, no-till planting, laser-leveling of fields and GPS-driven machinery; reducing spoiled and wasted food, which amounts to 25 to 30 percent of all food produced; and eating less meat, which is energy-intensive to create.
**The same steps** would make our bodies, and our ecosystems, healthier.

PRECEDING PAGES: PROP STYLING BY LAURIE RAAB

roof, and we have transformed deserts such as the Central Valley of California into the world's fruit baskets. At the same time, the percentage of workers needed for agriculture has plummeted.

Cheap energy, primarily petroleum, has also created transportation networks that have improved food distribution significantly, bringing us unexpected fare such as salads and fresh oranges in the middle of winter from far-flung corners of the globe. We expend more energy still to preserve and prepare our food.

When fossil-fuel prices were low and we did not care much about pollution or emissions, we did not worry about the energy waste. Now that prices are higher and we care more about environmental impacts, we have to improve that 10:1 ratio. The inefficiency could get even worse in the U.S. as more people, powered by cheap air conditioning, move into areas where local food production can support a mere fraction of the growing population (think Phoenix). In these cases, even more energy is used either to bring inferior lands into production through energy-intensive fertilizers and irrigation or to move food from remote markets.

Global trends will aggravate the challenge. World population is projected to grow to more than nine billion by 2050. Per capita energy and food consumption will rise, too: notably, as people get richer, they consume more meat, which is much more energy-intensive than other foods. And climate change implies that food production will be hurt by crop losses from droughts and floods, saltwater intrusion into aquifers, higher temperatures (which will decrease the effectiveness of photosynthesis in many places) and competition from biofuels for farmland. As a consequence, experts predict that food production will have to double by 2050.

## LOCAL FARMING MIGHT NOT HELP

UNFORTUNATELY, thinking about some popular food production "solutions" through the lens of energy shows that they do not always help. For example, many people have latched onto the local-food movement, billing themselves "locavores," as an antidote to the energy used to transport food long distances and the energy intensity of large-scale industrialized agriculture. "Eat local" campaigns encourage residents to shop for local food from farmer's markets or nearby community-supported farms.

Spending our money in the local community rather than sending it far away can be economically valuable, and having a vibrant local-food system creates resiliency in the event of unexpected occurrences such as war or drought. Local farms, however, sometimes use marginal lands to produce nonnative crops that require more chemicals and more energy for irrigation, and they still get low yields. Strangely enough, shipping food thousands of miles can sometimes require less energy, emit less carbon dioxide and do less environmental damage.

For example, it is typically less energy-intensive to grow lamb in New Zealand, where the animals graze on rain-fed grass that grows mostly without fertilizer or irrigation, and ship it to the U.K. than it is to grow lamb in the U.K. using energy-intensive inputs. Further, large industrialized farms, outfitted with laser-leveled fields (to minimize water losses and fertilizer runoff) and GPS-equipped tractors (to optimize fuel use and crop density) and planted with genetically modified crops designed to use minimal water can be surprisingly resource-efficient when compared with a bunch of distributed farms that inefficiently use energy and water but are closer to home. A Stanford University study concluded that Big Agriculture has spared a lot of carbon emissions because of its yield improvements and economies of scale.

Vertical, urban farms or algae production for feed, now in prototype stages, also has the potential for even greater biomass production per square foot of land than local farms.

Some popular solutions for renewable energy actually complicate the food-energy system. Food-based feedstocks—corn, soy, sugar and palm—dominate the world markets for biofuels and create unhealthy competition for farmland and freshwater. In 2010 in the U.S., about 30 million acres—more than one fourth of overall corn production—were used to produce 12.7 billion gallons of ethanol. That share will rise significantly as the U.S. tries to meet the federal mandate that 20 percent of all liquid transportation fuel come from biofuels by 2022.

## EXPLOIT THE WASTE

DESPITE ALL THE CONCERNS of the food-energy nexus, there is some cause for optimism. With different innovations, policies, markets and cultural choices that focus on reducing waste and inefficiencies, we can reduce the 10:1 ratio of energy used to energy eaten, as well as mitigate environmental damage.

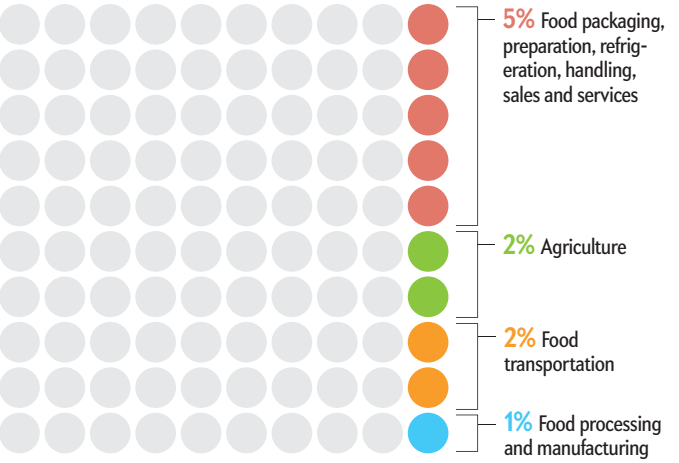
A first step is to stop using corn kernels for starch-based ethanol, which is the current U.S. practice. Let us use the kernels to feed people and livestock and use only the cellulosic stover (the

WEIGHTY CHALLENGE

# A Big Bite of the Energy Pie

A surprising 10 percent of the U.S. energy budget is used to produce food for 312 million Americans. Greater efficiency in farming, transport, processing and storage could reduce the demand, especially for fossil fuels.

**U.S. Energy Budget Spent on Food**




SOURCE: UNIVERSITY OF TEXAS AT AUSTIN

*Graphics by Jen Christiansen*

stalk and leaves of the plant) to make ethanol or synthetic fuels. U.S. energy policy already includes a push for this solution. The Energy Independence and Security Act of 2007 has a renewable fuels standard that mandates that we consume 36 billion gallons of biofuels per year by 2022 and that 16 billion of those gallons come from cellulosic sources. The latter requirement is a rare acknowledgment by politicians in Washington, D.C., that corn might not solve all our energy problems; experts predict we can produce only up to 15 billion gallons a year from corn-based feedstocks grown on available farmland without undercutting our ability to feed ourselves.

The aggressive biofuels rollout, however, pushes the food-based forms online the quickest, with cellulosic forms many years behind because they are more difficult to produce. Nature has designed cellulosic materials over many millennia to *not* break down. Breaking them down for ethanol means we have to reverse nature, which requires enzymes—code for money; producing enzymes at industrial scales is expensive. Nevertheless, we can overcome the technical hurdles and move more strongly in that direction. Using cellulosic sources instead of food-based sources can help the U.S. energy supply and also free up tens of millions of acres for other food production.

Another step to improve the food-energy equation is to convert agricultural waste products into power. Livestock manure is one rich resource. In the old days, small farms had a mix of animals and a variety of crops in one location; farmers spread manure instead of chemical fertilizer on fields of crops. Today, with large farms that grow just a handful of mega crops and with concentrated animal-feeding operations, that closed-loop practice has been lost. The massive amounts of manure created by large animal operations far exceed any local demand, and it is too expensive to ship cross-country to big farms. The system also creates environmental hotspots such as manure lagoons, which are significant emitters of greenhouse gases and sources of toxic waste. The lagoons are remarkably energy dense, however, and there are many of them; U.S. farms generate more than one billion tons of manure annually.

Anaerobic digesters and micro turbines could convert that manure into enough renewable, low-carbon biogas-fired electricity to displace 2.5 percent of the nation's power generation while reducing greenhouse gas emissions. This approach would also yield another revenue stream for farmers. Researchers at leading agricultural institutions such as Texas A&M University and Cornell University College of Agricultural and Life Sciences are looking at new ways to incorporate anaerobic digestion of manure into farm operations. Juehnde, a small German village working with Frank Mitloehner of the University of California, Davis, is generating so much biogas for heating and cooking that the town has become independent from the national gas grid. Policy makers could encourage the installation of more digesters and turbines by giving farmers access to low-cost capital, creating incentives such as property-tax breaks for the equipment, offering information and training sessions so that potential users know how to operate the systems, and establishing net metering—a system allowing any electricity generated on-site to reduce farmers' utility bills.

Another waste stream that can save food energy is carbon dioxide from smokestacks at coal plants. It can be used to grow algae for human food, animal feed and fuel, thereby avoiding some traditional energy inputs for agricultural production. Some people already eat algae directly for nutritional reasons, and some national restaurant chains use them as a stiffening ingredient. Algal lipids can also be converted into biodiesel, providing a low-carbon, domestic, renewable fuel that is made from something other than food-based feedstock. The remainder of the algal biomass is typically made up of proteins and carbohydrates, which might displace corn-based feed for animals, making more corn available for food and thereby contributing positively to the food-energy nexus. Some algae grow well in brackish water or saltwater, too, eliminating demand for freshwater. Private industry (through a variety of start-ups such as Solazyme), national labs such as the National Renewable Energy Laboratory, and universities such as the University of Texas at Austin and the University of California, San Diego, all have active testing and pilot programs. Although algal solutions seem to be decades away from large-scale implementation, their promise warrants additional research, so policy makers should continue funding development.

## MORE CROP PER DROP

SIMPLY IMPLEMENTING innovative agricultural techniques that have already been perfected in pilot programs on a much wider scale could significantly reduce the 10:1 energy-food ratio. For example, drip irrigation provides more crop per drop, sparing freshwater and the energy needed to pump it. The conventional approach—the center-pivot sprinklers that create alienlike green crop circles in the middle of brown deserts (easily visible when flying overhead)—is extremely wasteful, spraying water into the air where a major fraction evaporates. Droplets that do land on crops are likely to hit the leaves and stalks instead of the roots, causing more evaporation loss. In a typical drip-irrigation setup, long sections of narrow tubing laid at the bottom of plants sown in a row deliver water directly to the roots. Researchers at Iowa State University estimate that corn farmers in that state would use 40 percent less water and lower their energy bills by 15 percent with drip irrigation. Half a dozen large farm suppliers now offer the systems, which, if used widely, could save thousands of megawatt-hours of electricity nationwide every year. Incentives to switch to drip irrigation, combined with penalties for wasted water, might hasten adoption.

No-till agriculture is another promising approach. It reduces the disturbance of soils by using special planting equipment that places seeds into untilled soil through narrow surface slots rather than the blunt approach of turning the soil. Disturbing the soil less reduces labor, irrigation, energy, erosion and carbon emissions. Argentina is the world leader; more than half the farms there deploy this advanced technique. Training for farmers about the advantages of no-till can be implemented through agricultural extension services nationwide.

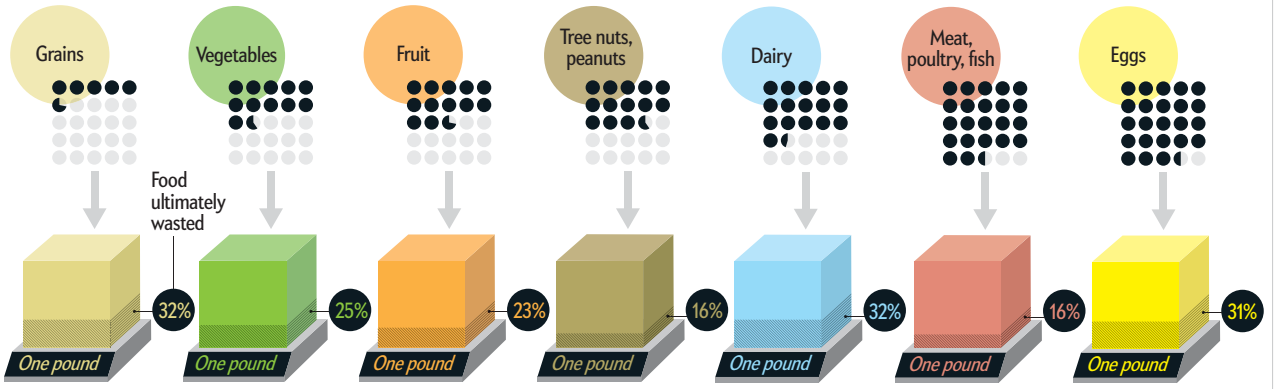
Laser-leveled fields can minimize erosion, irrigation and fertilizer runoff. Most fields have a gradual slope, which causes unequal water distribution and uneven collection of runoff. Rather than risking one portion getting less water than it needs, farmers often overfill the entire field, with the excess spilling over into local waterways. By making fields level, farmers waste less energy pumping water, and less fertilizer is needed because less runs off.

The advent of GPS-enabled tractors, combines and other machinery—today a standard feature offered by manufacturers such as John Deere—has introduced the concept of "precision

# More Efficient Foods, Less Waste

**Different foods** require vastly different amounts of energy to produce. Meat is four times as demanding as grains are. If consumers would gravitate toward less intensive foods, energy use would drop. Reducing the enormous amount of food that is wasted would save energy as well.

**Energy Required to Produce Food** British thermal units (Btu) of energy inputs per pound of food produced (● = 1,000 Btu)




SOURCE: UNIVERSITY OF TEXAS AT AUSTIN

farming," which drives up productivity and drives down energy use. GPS guidance allows farmers to tend fields and plant crops literally to the inch, reducing wasted space, time and fuel, without even needing to steer machines with their hands. Although the upgrades for a moderately sized farm might cost $10,000, researchers at Purdue University have shown that the benefits outweigh the cost. For one thing, fuel use decreases. Incorporating GPS with field diagnostics allows farmers to map out soil conditions and fine-tune the application of chemicals, which can vary from one end of a field to the other, ultimately requiring less. Fields can also be worked at night and during fog and rain, when human visibility is limited, pushing productivity up.

## BETTER BEHAVIOR

REDUCING WASTED FOOD can also lower the 10:1 ratio of energy used to food eaten. An egregious 25 percent or more of the food grown is wasted annually. That massive amount represents 2.5 percent of annual U.S. energy consumption—more energy than all the ethanol produced in 2011 in the U.S. and more than the energy that will be produced in 2030 from lifting drilling restrictions today on the outer continental shelf. Simply decreasing the amount of food we throw away might reduce energy consumption and greenhouse gas emissions more over the next decade or two than many of the expensive or controversial energy supply policies that have been proposed.

Many methods of reducing food waste can begin tomorrow. We can invest in diagnostics that monitor food spoilage instead of using the crude date-based labeling system that has been in place for several decades. One example is temperature- and time-sensitive inks on food packaging that cause labels to change color if the food has been exposed to the wrong temperature for too long. Start-up companies produce these labels, which could spare a lot of food that is unnecessarily thrown away by stores that are worried about making their customers sick. The labels could indeed also prevent a lot of illnesses induced by spoiled food. Requiring companies to keep track of the temperatures that food has been exposed to—in addition to how long the food has been packaged—might give retailers and consumers better information about the risks of spoilage.

Different attitudes and dietary choices can help, too. Restaurants can stop serving mammoth portions, and consumers can stop bragging about their conquests at all-you-can-eat buffets. More extra food can be kept and eaten as leftovers. We can shift our diets to replace at least some of our energy-intensive meats with less energy-intensive fruits, nuts, vegetables, beans and grains. These behaviors do not require invention; they just require new thinking. Many of them end up saving consumers money as well. Having meatless Fridays or veggie Mondays might start to get us there.

As the original green revolution showed, large-scale changes can be implemented relatively quickly over just a few decades. The changes can be dramatic, achieving outcomes far better than anticipated. Yet surprises can arise, too: years of abundant food production have increased the incidence of obesity and aggravated climate change. Technology alone is not enough; even with the original green revolution, hunger has not been solved. A global approach to reducing the energy waste in food that incorporates new behaviors, attitudes and policies will be critical to widespread success. There is no reason to think this new green revolution will be any different. SA

MORE TO EXPLORE

**Wasted Food, Wasted Energy.** Amanda D. Cuéllar and Michael E. Webber in *Environmental Science and Technology*, Vol. 44, No. 16, pages 6464–6469; July 21, 2010.

BP Foreseer project, a tool to predict trade-offs among energy, water and land use: http://bit.ly/rCqkNL

**SCIENTIFIC AMERICAN ONLINE**

For an interactive graphic revealing how much energy is required to produce various foods, see ScientificAmerican.com/jan2012/webber

ENVIRONMENT

# Dust Up

## Biologist Jayne Belnap warns of the consequences for the American West if we don't preserve a home for the minute organisms that live in desert topsoil

*Interview by Brendan Borrell*

**IN BRIEF**

WHO
**JAYNE BELNAP**

VOCATION | AVOCATION
**Research ecologist**

WHERE
**U.S. Geological Survey**

RESEARCH FOCUS
**Study of the biological crusts that hold in place desert dust and their ecological impact on human activities**

BIG PICTURE
**"We just need to start putting dust into the equation."**

One fine afternoon last May, Jayne Belnap drove north out of Moab, Utah, in her beige Lexus SUV when the highway vanished. In an instant, a 100-foot-tall cloud of dust had swallowed up her vehicle. She wanted to brake, but she worried about another car slamming into her from behind. She tried to pull over, but she couldn't see the shoulder. So Belnap split the difference: "I figured if I just crept slowly enough that I'd eventually get out of there or fall off the road."

Luckily, the dust storm passed after a few minutes. But Belnap, who works at the U.S. Geological Survey and is the world's foremost expert on the biological crusts that lock in desert dust, is well aware of the risks these tiny particles pose to people. In the 1990s a ranger at Canyonlands National Park in Moab, where she conducts fieldwork, broke her knee and two vertebrae in a collision caused by a dust storm. Dust affects denizens of the western U.S. in less dramatic ways as well. In the air, it can lead to respiratory problems, whereas dust settling on snowy mountaintops causes spring melts earlier in the season, harming agriculture in dry valleys.

Dust is poised to become an even bigger problem. Belnap has found that the total dust deposited in mountain lakes has increased sixfold since the early 1800s because of the livestock that stomp on and break the fragile crust. Today ever more off-road vehicles used for recreational fun and resource exploration comb through our deserts and tear up these top layers. Meanwhile the onslaught of climate change in the dry western states will reduce the formation of crusts and the growth of grasses, which also hold soil together.

Belnap, a laid-back former Olympic ski hopeful, recently spoke with Scientific

*Photographs by Jamie Kripke*

American about her interest in desert crusts and how climate change and dust will affect the lives of Westerners. Excerpts follow.

***Scientific American: What was your first introduction to the world of desert crust?***

Belnap: One day a professor I knew from college showed me these organisms growing on the ground. They were all these different lichens and mosses: pink and yellow and green. They were just gorgeous, and I said, "Wow, what is this stuff?!" And he said, "Well, ya know, I can tell you their names, but we don't know anything at all about what they do." That's when I got really interested for the first time, but then I didn't do anything about it. I kept goofing off.

***Kept goofing off?***

Well, I was a hippie.

***You were a hippie? What do you mean by that?***

Yeah! I hitchhiked from Alaska to Tierra del Fuego, I lived in a ski resort in Alta, Utah, for several years, and I surfed in Santa Cruz. I was a good, solid hippie. I didn't do drugs, but I have wanderlust of the feet. I always had my plant book and my bird guide. So even though I didn't have a formal education until many years later, I was always driven to know the system.

***The system you decided to focus on was desert crust. Why is it so important?***

I realized that few other things fix nitrogen in the desert and stabilize soils. Nitrogen, as it occurs in the atmosphere, is not in a form usable by vascular plants or animals, so it has to be converted, and that can only be done by cyanobacteria and a few other bacteria. When people talk about "nitrogen-fixing plants," they are not really talking about the plants, they are talking about the bacteria that live in nodules on the roots of the plants. In deserts, the soil is covered by cyanobacteria that occur free-living or that partner with fungi as lichens on the soil surface. The only other way to fix nitrogen is lightning, but we don't have a lot of that in the desert. And because plants grow very far apart in deserts, there is not much holding the soil in place other than soil crusts.

***How thick is the desert crust?***

It depends on the soil because these cyanobacteria have to photosynthesize to pull carbon dioxide out of the air and fix it as carbon for themselves. If you have a thick, heavy, clay soil where the light doesn't get through, they're going to be right at the surface. If you've got a nice sandy, fluffy soil where you've got a lot of quartz, then light can get down quite a ways—they'll go down half a centimeter or even a centimeter.

***How do cyanobacteria, whether free-living or in lichens, hold the sand together?***

They put out this sticky, gooey stuff made of polysaccharide starch. It holds water, so it allows them to dry more slowly. It also holds on to nutrients and keeps them from leeching out. Because it's very, very sticky when it's wet, these guys can cruise around the soil, and they leave this stuff behind that links the sand grains together.

***What is the most significant cause of damage to these crusts?***

The human footprint! I mean that in the broad sense. The biggest problem is compressional disturbance, and that can be vehicles, it can be animals, it can be those seismic trucks exploring for oil. Or off-road vehicles, livestock, or people hiking or biking. The filaments between the sand grains are easily crushed when they're dry. Nitrogen fixation needs to happen in an anaerobic environment, and when you break the crust up, you aerate it. They're also photosynthetic, so they have to be on or near the surface, and if the soil gets churned and they get buried, then they die. Surface disturbances are expanding ever more as we look for energy supplies, and as we recreate more, and as the population increases and gets pushed into places where the soil crusts are needed to hold the dust down.

***How long does it take them to recover from damage?***

They need rain to recover, but these are deserts, and rain doesn't happen very often. For a cool, high desert like the Colorado Desert, getting that good, solid cyanobacterial crust that will resist wind and water erosion probably takes 10 to 15 years. For the lichens, you're probably talking about 40 or 50 years. To climb down in the Mojave, where it's really, really hot, then it's in the hundreds of years to get the lichens back.

***How does climate change affect that process?***

Less rainfall is going to mean less activity time for cyanobacteria and lichens, which means recovery will be slower, nitrogen fixation will be less and carbon fixation will be less. We have lichen species that appear to be at their physiological tolerance limits for temperature, and so we'll probably be losing them and getting other ones coming up from the South that may or may not serve the same role as the ones we're losing. In particular, we seem to be losing our biggest nitrogen fixer, the jelly lichen *Collema*. It's gone from about 20 percent cover to about 5 percent cover in our long-term plots in national parks over the past 20 years, during which time we have had some very hot periods.

***In what ways does the loss of crust feed back into the climate system?***

One of the biggest effects for regional weather patterns is the albedo of surfaces. By trampling on lichens and mosses, we've gone from a very dark surface to a very light surface over much of the western U.S., which means we have a surface that reflects more heat, which can lead to reduced cloud cover and rain. Dust in the atmosphere both reflects and absorbs heat and is also important in atmospheric processes.

There are huge implications for dust loading in the mountains. One of them is that when you have dust deposited on the snow, it darkens the snow and makes it melt a lot faster. As the snow melts from under the dust layers, the dust layers pile up on one another through the

**Dust cover:** Desert crust includes lichens (*white, brown and raised black areas*), mosses (*rust patches*) and cyanobacteria (*black and sandy regions in background*).

season, making the snow surface darker and darker. Earlier melting means water enters streams and rivers sooner than normal, leaving less late-season water. In 2009 we had a very dusty year, and we had a 48-day earlier snow melt because of dust. Our models show dust can annually decrease water in the Colorado River by 2 to 7 percent. So if you own a ski resort, you're not going to be a very happy person; if you're a water user in the valley, like a farmer, you're also going to have big problems.

***Have there been more dust storms out West in recent years?***

In Phoenix and Texas during the past couple of years, we have had these big, giant haboobs: dust storms that are literally 5,000 feet high. It seems that the answer is yes, but we're also getting much better at observing and recording dust storms. We have had a series of very dry years, so it's really hard to tell. Now we've got dust-monitoring stations, but there are only a few, and they've only been around since 2006.

***Over a longer time scale, you have found that there's been more dust in the air?***

That's right. Dust cores extracted in mountain lakes show that the input of dust increased radically around 1850, when the large livestock herds hit the West. In one core, dust inputs went up from about 100 grams per meter squared per year to 800 grams per meter squared per year. Around 1900 we had a massive die-off of the livestock herds in the West, and in 1934 the government passed the Taylor Grazing Act to rein in overgrazing. The dust dropped to about 600 grams per meter squared per year. We don't have enough resolution to see how energy exploration and off-road vehicles have affected it over the past 20 years, but inputs are holding steady at about 600 grams per meter squared per year.

***Are native grasses also being affected by climate change?***

They are shallow-rooted, and with less water and hotter temperatures, they are not going to do well. In our long-term study plots, we have seen Indian ricegrass go from 40 percent cover down to about 4 percent during hot and dry years. They come back with wetness, but if it is dry year after year after year, then they are not going to. So overall, they are going down. This is the grass that is important for the base of the food chain, including mice and rabbits. It is also the most important grass for livestock in this region.

***It sounds like ranchers will be facing a lot of changes.***

I truly do not believe ranching in the West is going to be economically viable in even as short as 20 years where I live. We're going to have a vacuum in all these western lands, and if we don't come up with something, there are lots of things that can fill this vacuum in ways many of us won't like. Ranchettes and developments for rich people with jetports, antler hunters with ATVs driving everywhere and just a million different things could fill these voids in a way that is far more destructive than cattle ranching. So I really think we've got to think hard about what we're going to do when ranching is no longer economically viable.

***What types of actions could help rangelands?***

Several things. We could get much better at how we explore for oil and minerals. Right now we just have these trucks driving across soils, disrupting the surfaces. We do this over and over again because the information is proprietary, and so each company has to do its own exploration. We could certainly do much better at planning things such as solar and wind farms, including where they are placed and how we should share roads and power lines going to and from them. And we need to think about the effects of these actions on land albedo. Revegetating disturbed areas and abandoned croplands would help prevent dust storms.

We could be much better at how we deal with livestock grazing and recreation, where we think they should take place and at what time of year. We just need to start putting dust into the equation, and I think that dust credits are one option. Seriously. Ranchers could sell their grazing rights and receive money for keeping the dust down, just like industry can buy or sell carbon credits. As water supplies, especially the Colorado River, begin getting more and more scarce, people will be getting seriously creative about how to keep the dust down. SA

**Brendan Borrell** *is based in New York City and frequently writes about science and the environment for* Scientific American *and* Nature.

MORE TO EXPLORE

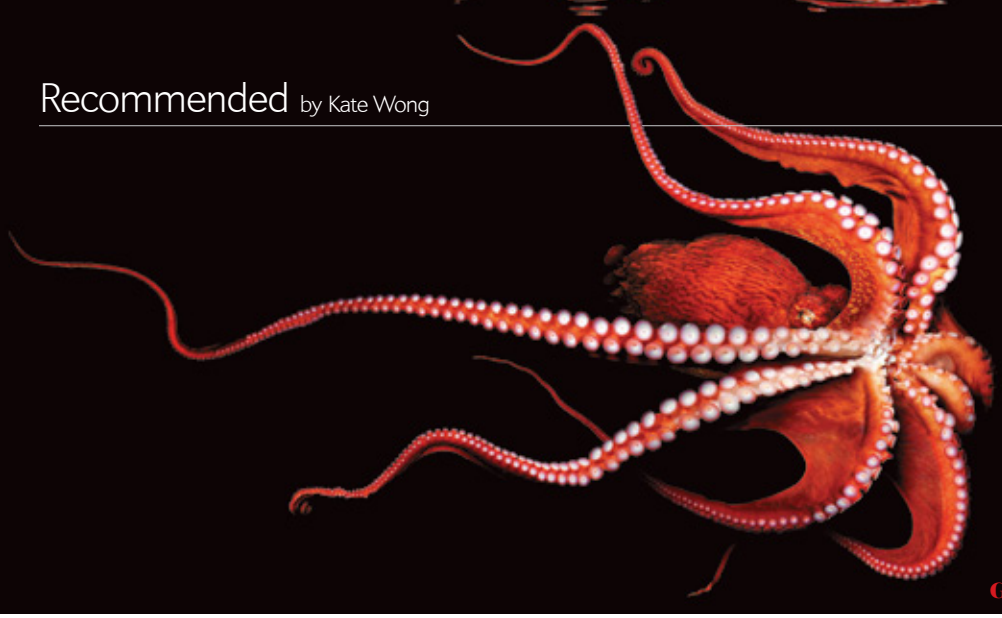
**Prioritizing Conservation Effort through the Use of Biological Soil Crusts as Ecosystem Function Indicators in an Arid Region.** Matthew A. Bowker, Mark E. Bowler, Jayne Belnap, Thomas D. Sisk and Nancy C. Johnson in *Conservation Biology*, Vol. 22, No. 6, pages 1533–1543; December 2008.

**Responses of Wind Erosion to Climate-Induced Vegetation Changes on the Colorado Plateau.** Seth M. Munson, Jayne Belnap and Gregory S. Okin in *Proceedings of the National Academy of Sciences USA*, Vol. 108, No. 10, pages 3854–3859; March 8, 2011.

SCIENTIFIC AMERICAN ONLINE

Read more from Jayne Belnap at ScientificAmerican.com/jan2012/belnap

# Recommended by Kate Wong



**Giant octopus** of the North Pacific


## Sea

by Mark Laita. Abrams, 2011 ($50)

**See sea horses**, stingrays, octopuses, nudibranchs and other marine creatures as you have never seen them before. Photographer Mark Laita borrowed a veritable ark of specimens to shoot in the black aquarium he built in his studio in Los Angeles. The result is a mesmerizing series of portraits of those enigmatic denizens of the deep.

## The Wandering Gene and the Indian Princess

by Jeff Wheelwright. W. W. Norton, 2012 ($26.95)

**In 1999 a Hispano woman** named Shonnie Medina died at the age of 28 after refusing surgery for breast cancer. Medina had been found to carry a dangerous breast cancer mutation called *BRCA1* 185delAG that is associated with Jewish ancestry. Journalist Jeff Wheelwright tells the story of this gene and how the Medinas—previously unaware of their background—came to inherit it.


## A Universe from Nothing: Why There Is Something Rather Than Nothing

by Lawrence M. Krauss. Free Press, 2012 ($24.99)

**Theoretical physicist** Lawrence M. Krauss skewers the notion that creation requires a creator. Mounting evidence from cosmology, particle theory and gravitation, he asserts, indicates that not only could our universe have arisen from nothing but that nothingness might have been required for its origin. Krauss discusses the possible implications of these findings for predicting what the future holds.


## Dirty Minds: How Our Brains Influence Love, Sex and Relationships

by Kayt Sukel. Free Press, 2012 ($25)

**Journalist Kayt Sukel** delves into the latest neurobiological research to explore what, exactly, love is and why it makes us do crazy things. This is no self-help book, however. In exploring such topics as monogamy, the parent-child bond, pheromones, and male and female responses to pornography, Sukel reveals just how complex and mysterious our brains really are.

### ALSO NOTABLE

#### BOOKS

**The Sounding of the Whale,** by D. Graham Burnett. University of Chicago Press, 2012 ($45)

**The Infinity Puzzle: Quantum Field Theory and the Hunt for an Orderly Universe,** by Frank Close. Basic Books, 2011 ($28.99)

**Memory: Fragments of a Modern History,** by Alison Winter. University of Chicago Press, 2011 ($30)

**The Life of Super-Earths: How the Hunt for Alien Worlds and Artificial Cells Will Revolutionize Life on Our Planet,** by Dimitar Sasselov. Basic Books, 2012 ($25.99)

**Evolution's Witness: How Eyes Evolved,** by Ivan R. Schwab. Oxford University Press, 2011 ($75)

**Time Travel and Warp Drives,** by Allen Everett and Thomas Roman. University of Chicago Press, 2011 ($30)

**Deep History: The Architecture of Past and Present,** by Andrew Shryock and Daniel Lord Smail. University of California Press, 2011 ($29.95)

**Incomplete Nature: How Mind Emerged from Matter,** by Terrence W. Deacon. W. W. Norton, 2011 ($29.95)

#### APPS

**Swift Explorer.** NASA's Swift mission team, 2011 (gratis). For iPad/iPhone

**Mammals of North America.** Princeton University Press, 2011 ($19.99). For iPhone/iPad/Android

COURTESY OF *SEA*, BY MARK LAITA, ABRAMS, 2011



COMMENT AT ScientificAmerican.com/jan2012

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

# In the Year 9595

## Why the singularity is not near, but hope springs eternal

**Watson is the IBM computer** built by David Ferrucci and his team of 25 research scientists tasked with designing an artificial-intelligence (AI) system that can rival human champions at the game of *Jeopardy*. After beating the greatest *Jeopardy* champions, Ken Jennings and Brad Rutter, in February 2011, the computer is now being employed in more practical tasks such as answering diagnostic medical questions.

I have a question: Does Watson know that it won *Jeopardy?* Did it think, "Oh, yeah! I beat the great Ken Jen!"? In other words, did Watson feel flushed with pride after its victory? This has been my standard response when someone asks me about the great human-versus-machine *Jeopardy* shoot-out; people always respond in the negative, understanding that such self-awareness is not yet the province of computers. So I put the line of inquiry to none other than Ferrucci at a recent conference. His answer surprised me: "Yes, Watson knows it won *Jeopardy.*" I was skeptical: How can that be, since such self-awareness is not yet possible in computers? "Because I told it that it won," he replied with a wry smile.

Of course. You could even program Watson to vocalize a Howard Dean–like victory scream, but that is still a far cry from its *feeling* triumphant. That level of self-awareness in computers, and the time when it might be achieved, was a common theme at the Singularity Summit held in New York City on the weekend of October 15–16, 2011. There hundreds of singularitarians gathered to be apprised of our progress toward the date of 2045, set by visionary computer scientist Ray Kurzweil as being when computer intelligence will exceed that of all humanity by one billion times, humans will realize immortality, and technological change will be so rapid and profound that we will witness an intellectual event horizon beyond which, like its astronomical black hole namesake, life is not the same.

I was at once both inspired and skeptical. When asked my position on immortality, for example, I replied, "I'm for it!" But wishing for eternal life—and being offered unprovable ways of achieving it—has been a theme for billions of people throughout history. My baloney-detection alarm goes off whenever a soothsayer writes himself and his generation into the forecast, proclaiming that the Biggest Thing to Happen to Humanity Ever will occur in the prophet's own lifetime. I abide by the Copernican principle that we are not special. For once, I would like to hear a futurist or religious diviner predict that "it" is going to happen in, say, the year 2525 or 7510. But where's the hope in that? Herein lies the appeal of Kurzweil and his band of singularity hopefuls. No matter how distressing it may be when the bad news daily assaults our senses, our eyes should be on the prize just over the horizon. Be patient.

Patience is what we are going to need because, in my opinion, we are centuries away from AI matching human intelligence. As California Institute of Technology neuroscientist Christof Koch noted in narrating the wiring diagram of the entire nervous system of *Caenorhabditis elegans,* we are clueless in understanding how this simple roundworm "thinks," much less in explicating (and reproducing in a computer) a human mind billions of times more complex. We don't even know how our brain produces conscious thoughts or where the "self" is located (if it can be found anywhere at all), much less how to program a machine to do the same. Pop rock duo Zager and Evans were probably closer in their 1969 hit song *In the Year 2525*'s prediction that the biggest milestones would happen between the years 2525 and 9595, their exordium and terminus.

An irony: amid all this highfalutin braggadocio of how close we are to computers taking over the world and emulating human thought, I had to give my talk on the "social singularity" (progress in political, economic and social systems over the past 10,000 years) early because Rice University computer scientist James McLurkin could not get his small swarm of robots to work. Either someone's wireless mic or the room's wireless network was interfering with the tiny robots' communications system, and no one could figure out how to solve the problem. My prediction for the Singularity: we are 10 years away … and always will be. SA

**SCIENTIFIC AMERICAN ONLINE**
Comment on this article at ScientificAmerican.com/jan2012

*Illustration by Daniel Hertzberg*

The ongoing search for fundamental farces

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

# Physics Uncowed

## You don't have to say cheese to get the picture

**Sean M. Carroll does not mince words.** On October 17 he also did not cube them, dice them or thinly slice them, even when he was seriously discussing the theory that the moon is made of green cheese. Just to be clear, the discussion was serious, not the theory, when Carroll spoke at the ScienceWriters2011 conference in Flagstaff, Ariz.

A noted theoretical physicist, Carroll is not to be confused with noted evolutionary biologist Sean B. Carroll. The Sean Carroll duality may be one reason that the physicist version often muses about the multiverse.

"How do you know the moon is not made of green cheese?" asked Carroll, a senior research associate at the California Institute of Technology, author of the entropy examination *From Eternity to Here* and blogger for another publication you can sometimes *Discover* at magazine stands. "People will say, 'Well, we've landed on the moon, we've picked it up, we've brought pieces of it back.'" Such people might think that as late as 1969 there was still widespread uncertainty about the moon's curd content.

"But that's just the surface," Carroll Havartily argued. "Of course, there's a layer of moon dust a few meters thick that sits on top of the green cheese. How do you know that most of the moon, 99 percent, is not really green cheese? And they will say, 'Well, we know the mass of the moon, the density, and so forth.' But don't think that you fully understand the properties of lunar green cheese. This is very dense cheese."

The physicist yet again posed his provolone problem: "How do you know it's not made of green cheese?" He then cut the Goudaian knot. "The answer is that it's absurd to think the moon is made of green cheese." (If you were hoping for an explanatory equation, mull over the fact that a cylinder of mozzarella of radius $z$ and height $a$ has a volume equal to $pi\,z\,z\,a$.)

Carroll allowed his reasoning to ripen. "The formalization of that absurdity," he said, "is that we are allowed to use other things we know about the universe when judging the plausibility of a hypothesis. The real reason the moon isn't made of green cheese is not because we've gone there and brought pieces of it back. It's because cheese comes out of cows, ultimately, or sheep or goats."

Ah, but what about any influence from the cow that jumped over the moon? Frankly, I find the story of a cow that reaches escape velocity without the aid of a powerful multistage rocket far-fetched. And I think the absurdity argument can be applied here as well.

"Cheese," Carroll continued, "was not part of the primordial solar system. We have a theoretical understanding of how the solar system works and how planets are formed that precludes the possibility that the moon is made of green cheese. Just like the reason why we know you can't bend spoons with your mind is not because we've caught people on *The Tonight Show* faking it. It's because it would violate the laws of physics. The moon being made of green cheese would violate how the solar system works." I'll go further than Carroll. I contend that the moon being made of cheese *of any color* is impermissible.

"That the moon is not made of green cheese," Carroll said of his Gorgonzolic gripe, "is not a proof, the way you can prove a statement in logic or math. But science nevertheless passes judgments on claims based on how well they fit in with the rest of our theoretical understanding."

Despite the existence of well-established and powerful theoretical frameworks, some individuals may still hold an Edelpilz epistemological notion that only the samples brought back by astronauts were truly decisive. Or even that a deep moon core sample is still necessary to settle the lunar Limburger. But such people have truly lost their whey. SA

**SCIENTIFIC AMERICAN ONLINE**
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*Illustration by Matt Collins*


## January 1962

### Nuclear Genie

"As the nuclear powers resumed their deadlock at the Geneva test-ban conference, most of the nations of the world were maneuvering to keep themselves clear of the atomic incubus. Acting through the United Nations, these countries passed a quick succession of anti-atom resolutions. First, the General Assembly voted 71 to 20 to request all powers to stop nuclear testing immediately and permanently. Voting against the measure were the nuclear powers—the U.S., Great Britain, France and the U.S.S.R.—who also declared that they would not be bound by the resolution."

### Sonic Boom

"Last year Congress appropriated $11 million for the Federal Aviation Agency to begin the development of a prototype supersonic transport, with technical support from the National Aeronautics and Space Administration. Among the large questions of design, construction and operation that remain to be solved before airliners travel faster than sound, one of the most difficult is the problem of sonic boom: the explosive sounds generated when an object moves through the air at supersonic speed. Sonic booms have caused alarm and damage when they have been produced in isolated cases by supersonic military jets flying over thinly populated areas; to allow a new fleet of booming supersonic transports to pass over cities at low altitudes during operations near metropolitan airports is clearly impossible."


## January 1912

### The Business of Flying

"The third International Aviation Salon was held in Paris from December 16th to January 2nd. It was noteworthy that, as compared with the exhibitions of previous years, the collection of exhibits on view was more or less international in character. Besides great structural changes, improvements have been made looking to the comfort of pilots and passengers; and given the Deutsch 'taxicab' to begin with, the coach builders will soon be called upon to make closed bodies for aeroplanes the same as they do for automobiles. —Stanley Yale Beach"

*For a slideshow on new airplanes for 1912, see www.ScientificAmerican.com/jan2012/aviation*

### Concrete Solutions

"Mr. Thomas A. Edison has conceived the idea of building furniture of concrete, for use in his concrete houses, the advantage of concrete furniture lying in its cheapness. He has already built a sample piece of furniture. The cost of this cabinet is but $10. Mr. Edison explains that this will not be the selling price, and he does not venture to name the store price of the cabinet, as he has no idea how much the middle man may require for his share of the profits. In order to test the ability of this piece of furniture to stand the rough handling of freight men, he recently sent the furniture to Chicago and back."

## January 1862

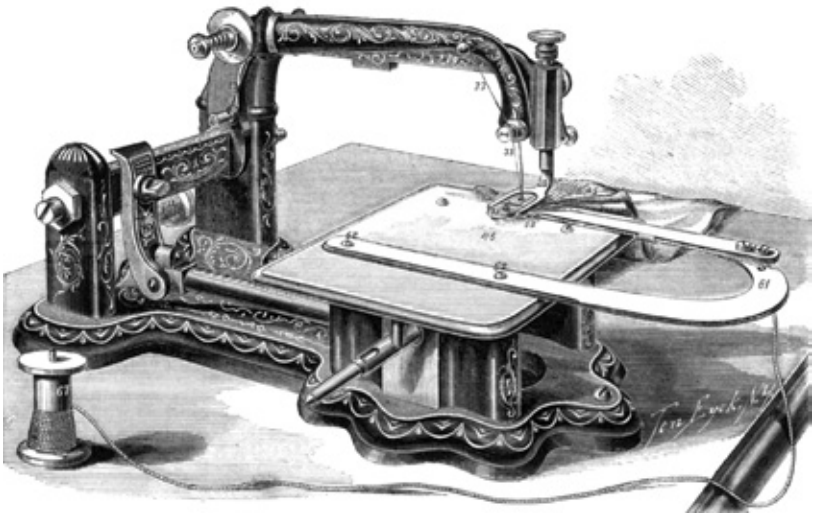
### Sewing Machines

"We give herewith an illustration of some important improvements added to the Wheeler & Wilson sewing machine. Though the radical operation of this machine has not been changed since its first introduction to the public, now nearly ten years, valuable attachments have from time to time been added. One of the more recent is the Corder, a simple attachment for laying cord on shirt bosoms, collars or on gentlemen's vests and coats and on ladies' clothing."

*Wheeler & Wilson was at the time the biggest manufacturer of sewing machines in the U.S. By 1907 Singer had acquired all of their manufacturing and retail operations.*

### Noble Hearth, Wretched Stove

"How vividly the picture of one of those spacious kitchens of the olden times comes to our mind. The crowning glory of that kitchen was the old-fashioned fireplace, with its blazing embers, huge backlogs and iron fire-dogs, that shed a glory over the whole room, and gilded the plain and homely furniture with its bright light. How pure was the air in those days! The huge fire-place, with its brisk draught, carried off the impurities of the atmosphere, and left the air pure, life-giving and healthful. Now, we crouch around hot cooking stoves, and think it strange that we feel so stupid and drowsy of an evening; or we huddle about air-tight stoves, and wonder that the air seems burned and impure."



**A new sewing machine from Wheeler &Wilson, the leading supplier to a burgeoning industry, 1862**

SCIENTIFIC AMERICAN, VOL VI, NO. 1, JANUARY 4, 1862

SCIENTIFIC AMERICAN™ Travel

# BRIGHT HORIZONS™ 15

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

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

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

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## NUCLEAR ASTROPHYSICS

**Speaker: David Lunney, Ph.D.**

### A Hitchhiker's Guide to the Universe

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

### Nuclear Cooking Class

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

### Weighing Single Atoms

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

### Panning the Seafloor for Plutonium: Attack of the Deathstar

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

## NEUROSCIENCE MEMORY

**Speaker: Jeanette Norden, Ph.D.**

### How the Brain Works

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

### Memory and All That Jazz

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

### Losing your Memory

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

### Use it or Lose it!

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

## COGNITIVE NEUROSCIENCE

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

### How the Brain Constructs the World We See

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

## Cognitive Neuroscience, cont.

### Windows on the Mind

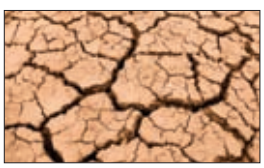
What's the connection behind eye movements and subliminal thought? Join Dr. Macknik and Dr. Martinez-Conde in a look at the latest neurobiology behind microsaccades, the involuntary eye movements that relate to perception and cognition. Learn how microsaccades suggest bias toward certain objects, their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

### Champions of Illusion

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

### Sleights of Mind

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



## CLIMATOLOGY

**Speaker: Yohay Carmel, Ph.D.**

### Prioritizing Land for Nature Conservation: Theory and Practice

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

### Facing a New Mega-Fire Reality

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

## HUMAN EVOLUTION

**Speaker: Chris Stringer, Ph.D.**

### Human Evolution: the Big Picture

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

### The First Humans

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

### The Neanderthals: Another Kind of Human

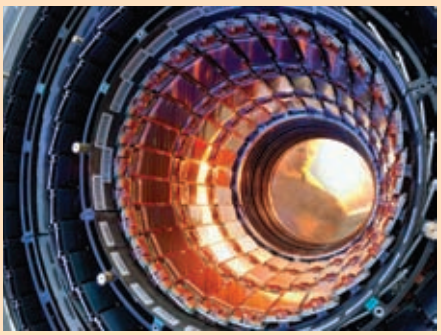
Our close relatives, the Neanderthals, evolved in parallel with *Homo sapiens.* Often depicted as bestial ape-men, in reality they walked upright as well as we do, and their brains were as large as ours. So how much like us were they? What was their fate? Track the evolution of the Neanderthals in light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

### The Rise of *Homo Sapiens*

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

# SCIENTIFIC AMERICAN Travel HIGHLIGHTS

## INSIDER'S TOUR OF CERN



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

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

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

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

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

## EPHESUS

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

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

## ATHENS

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

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

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The U.S. Money Reserve Vault Facility today announces the final release of 5,000 U.S. Gov't Issued Gold Coins previously held in The West Point Depository/U.S. Mint. U.S. citizens will be able to buy 2011 Gov't Issued $5 Gold Coins at an incredible no mark-up price of only $189.93 each. An amazing price because these U.S. Gov't Issued Gold Coins are completely free of dealer mark-up. That's correct, our cost. This is an incredible opportunity to buy U.S. Gov't Issued Gold Coins at cost. The Gold market recently skyrocketed past $1,900 per ounce and is predicted by experts to have the explosive upside potential of reaching up to $5,000 an ounce. A limit of ten U.S. Gov't Issued Gold Coins per customer will be strictly adhered to. Orders that are not immediately reserved with our order center could be subject to cancellation and your checks returned uncashed. Order immediately to avoid disappointment. Coins from other years will be shipped if oversold. Call Toll-Free 1-800-455-8461.

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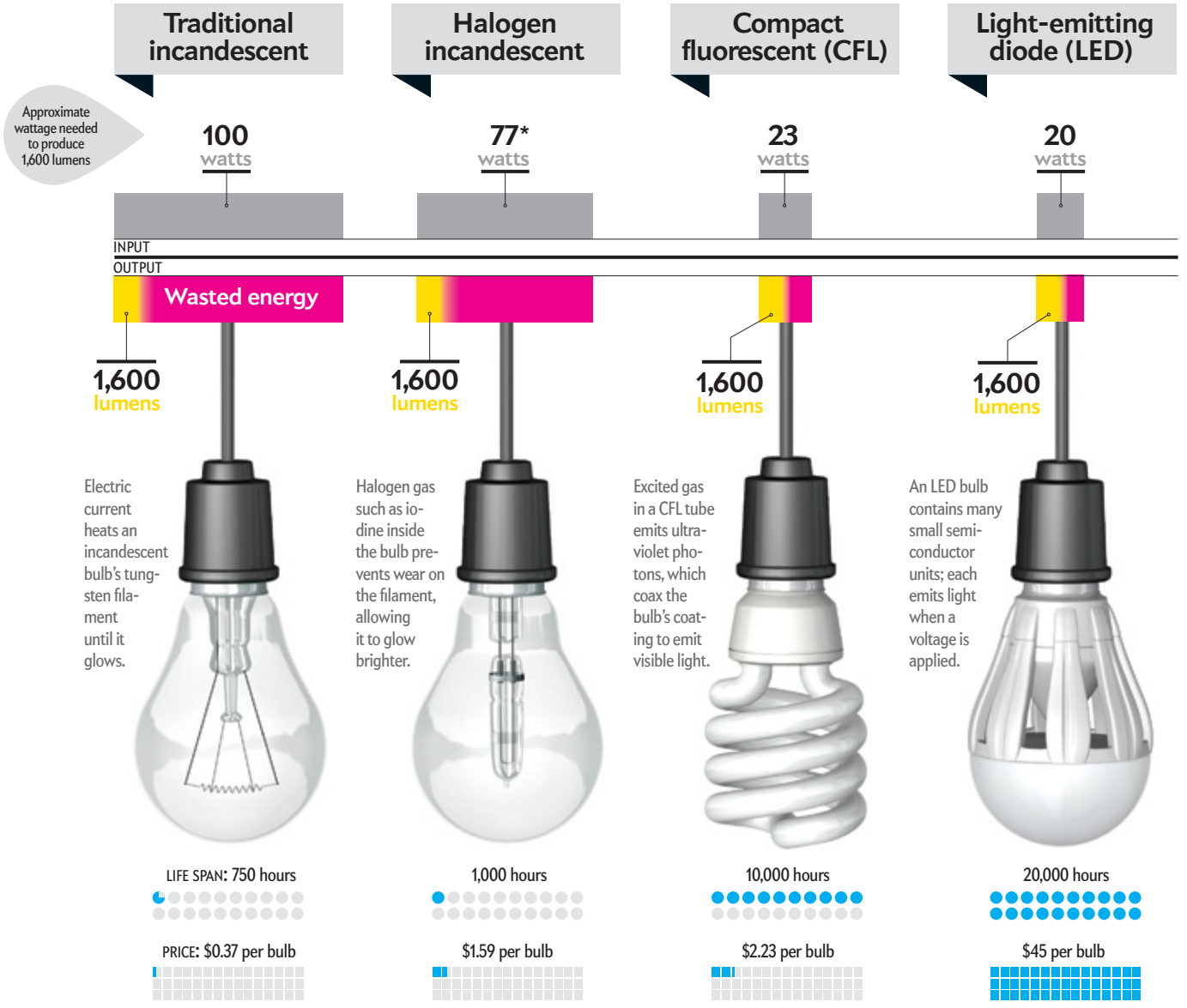


# Buying a Better Bulb

## The U.S. is phasing out energy-hog lightbulbs in January. How do the alternatives stack up?

**Contrary to rumor**, the incandescent lightbulb is not going away—at least not right away. New U.S. regulations, starting January 1, cap energy consumption of a roughly 1,600-lumen bulb (equivalent to a standard 100-watt incandescent bulb) at 72 watts—which means the workhorse of home lighting will have to become about 30 percent more efficient overnight. The law will expand in the next two years to cover 75-, 60- and 40-watt bulbs. There is room for improvement: incandescent bulbs currently waste 90 percent of their energy as heat. Halogen incandescents provide a more efficient, if pricier, alternative and will give compact fluorescents a run for their money. A light-emitting-diode replacement for 100-watt bulbs is expected to reach market this year; dimmer LEDs are already available. Consumers will be able to check federally mandated labels that give performance specs, similar to nutrition labels on food, but here we illuminate the essentials facts.—*John Matson*

**SCIENTIFIC AMERICAN ONLINE**
More data in an interactive graphic at ScientificAmerican.com/jan2012/graphic-science

**Under the new law, bulbs need produce only 1,490 lumens from 72 watts, which halogens do.*

SOURCES: U.S. DEPARTMENT OF ENERGY AND EFFICACY CALCULATIONS BASED ON CURRENTLY AVAILABLE BULBS (*traditional, halogen and compact fluorescent*); SWITCH LIGHTING (*LED*)



*Graphic by George Retseck and Jen Christiansen*


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